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55 Graphical interpolation

90 " method

148 "Diagram" with curves +156 +175

336 Smoked glass for seismology

342 Graphic records

Freeman

Official Copy.

Published by
Authority of the Lords Commissioners of the Admiralty.

A MANUAL OF SCIENTIFIC ENQUIRY;

PREPARED FOR THE USE OF

OFFICERS IN HER MAJESTY'S NAVY, AND TRAVELLERS IN GENERAL.

ORIGINALLY EDITED

BY SIR JOHN F. W. HERSCHEL, BART.

Fifth Edition.

EDITED

BY SIR ROBERT S. BALL, LL.D., F.R.S.,

ROYAL ASTRONOMER OF IRELAND.

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MEMORANDUM

By the Lords Commissioners of the Admiralty,

Relative to the Compilation of a Manual of Scientific Enquiry for the use of Her Majesty's Navy.

(Prefixed to the First Edition of 1849.)

It is the opinion of the Lords Commissioners of the Admiralty that it would be to the honour and advantage of the Navy, and conduce to the general interests of Science, if new facilities and encouragement were given to the collection of information upon scientific subjects by the officers, and more particularly by the medical officers, of Her Majesty's Navy, when upon foreign service; and their Lordships are desirous that for this purpose a Manual be compiled, giving general instructions for observation and for record in various branches of science. Their Lordships do not consider it necessary that this Manual should be one of very deep and abstruse research. Its directions should not require the use of nice apparatus and instruments: they should be generally plain, so that men merely of good intelligence and fair acquirement may be able to act upon them; yet, in pointing out objects, and methods of observation and record, they might still serve as a guide to officers of high attainment; and it will be for their Lordships to consider whether some pecuniary reward or promotion may not be given to those who succeed in producing eminently useful results.

Their Lordships are aware that in the instructions prepared under the directions of the Royal Society for the Antarctic expedition; in the hints for collecting information given to officers on the expedition to China; in the excellent book by A. Jackson, entitled 'What to Observe'; and in other documents and publications—the fullest directions are to be found; but they are either more voluminous or more closely confined to objects which regard particular localities than is to be desired for a general Manual. Their Lordships are, therefore, desirous that a new compilation should be made, and are satisfied that their wishes would be best met if they could obtain the assistance of some of our most eminent men of science in the composing, by each, of a plain and concise chapter upon the head of inquiry with which he might be most conversant; and they have been readily and kindly promised the advice and labour of Sir John Herschel in revising the whole and preparing it for publication. The several heads of inquiry are as follows:—

Astronomy.	Magnetism.
Botany.	Meteorology.
Geography and Hydrography.	Statistics.
Geology.	Tides.
Mineralogy.	Zoology.

Independently of matters of exact science, their Lordships would look in many instances for Reports upon National Character and Customs, Religious Ceremonies, Agriculture and Mechanical Arts, Language, Navigation, Medicine, Tokens of value, and other subjects; but for these only very general instructions can be given, though valuable Reports may be expected from men of observation and intelligence acting under the encouragement which the notice of whatever is well and usefully done is certain of affording.

It would give additional value to each chapter if the name of him by whom it might be composed should be affixed to it; and their Lordships are anxious that no time be lost in the preparation of this work. They are sending a surveying vessel to New Zealand, and have others in the Torres Straits and in other parts of the world. A new establishment is contemplated at Borneo. Expeditions are proposed in search of Sir John Franklin. They have cruisers in every sea; and where the ships of the navy are not present, it sometimes happens that the vessels of the merchant are conducted with much intelligence and enterprise: and for all of these the work proposed would be valuable.

PREFACE TO THE FIFTH EDITION.

THE arrangement of the present edition is substantially the same as in the earlier editions, but about half of the work has been entirely re-written.

The Editor has to express his thanks to the eminent men of science who by their various contributions have adapted the work to the present state of knowledge.

First, he must mention Sir G. B. Airy, Dr. W. Aitken, Sir J. D. Hooker, and Mr. E. B. Tylor, who have revised or re-written their articles in the earlier editions.

In defect of the original authors ten articles had to be placed in other hands. Aid was kindly rendered by Captain W. J. L. Wharton, R.N., Hydrographer of the Admiralty, Professor G. H. Darwin, Professor G. F. Fitzgerald, Mr. Robert H. Scott, General Sir Henry Lefroy, Professor C. F. Bastable, Professor A. Geikie, Professor W. J. Sollas, Mr. Thomas Gray, and Professor H. N. Moseley.

Contributions have also been made by Professor Pritchard, Mr. W. F. Denning, Mr. J. E. Gore, Professor Russell, Staff-Commander Creak, R.N., and Mr. G. M. Whipple. The Editor is also indebted to Rev. M. H. Close for many suggestions.

ROBERT S. BALL.

Observatory, Dublin,
6th July 1886.

LIST OF ARTICLES,

WITH

NAMES OF THE AUTHORS OR REVISERS.

CONTENTS.

The figures refer to the pages.

I.—ASTRONOMY.

II.—HYDROGRAPHY.

III.—TIDES.

IV.—TERRESTRIAL MAGNETISM.

V.—METEOROLOGY.

VI.—GEOGRAPHY.

VII.—ANTHROPOLOGY.

VIII.—STATISTICS.

IX.—MEDICINE AND MEDICAL STATISTICS.

X.—GEOLOGY.

XI.—MINERALOGY.

XII.—SEISMOLOGY.

XIII.—ZOOLOGY.

XIV.—BOTANY.

A

MANUAL OF SCIENTIFIC INQUIRY.

ARTICLE I.

ASTRONOMY.

By Sir GEORGE B. AIRY, K.C.B., F.R.S.

(*Revised by the Author for this edition.*)

The science of Astronomy may occasionally derive benefit from the observations of navigators, in the following respects :—

By contributions to Astronomy in general.
By improvement of the methods of Nautical Astronomy.
By accurate attention to Astronomical Geography.

The remarks which follow will be arranged under these heads.

General Astronomy.

1. The first point which calls for attention is the observation of the places of *comets or other extraordinary bodies*, especially those which can be seen only in low northern or in southern latitudes. In regard to these observations (and indeed to almost all others), one remark cannot be too strongly impressed on the observers—that a bad observation, or an observation which is given without the means of verification, is worse than no observation at all. In order

to make the observations good, the following cautions must be observed :—

The index-error of the sextant must be carefully ascertained. If it has not been found a short time before the observations, it must be found as soon as possible after them.

The distance of the comet from three conspicuous stars in different directions must be measured with the sextant. (*See* Appendix No. 3.) The point of the comet which is observed with the sextant should be precisely described. It is desirable that the navigator should be possessed of some star-maps or star-charts, by means of which he will be able at once to give the proper names to the stars, and much confusion and loss of time will be avoided.*

If the time at the ship and the latitude are very well known, there will be no occasion to make further observations; but if these are not well known, some attempt must be made (by the use of Becher's horizon, or by any equivalent method) to ascertain the altitude of the stars and the comet. The lower these objects are, the greater must be the care in the determination of their altitudes.

For affording means of verification, these rules should be followed :—

The observations of distance with the sextant should be entered in the book precisely in the manner in which they are made. The reading of the sextant, *uncorrected*, should be written down : in a column by the side of this should be written the correction for index-error, with a statement whether it is to be added to, or to be subtracted from, the sextant-reading : in the next column should be written a reference to the observations by which the index-error was determined : and in the last column should be written the distance as corrected. For the altitudes, the height of the eye, the depression of the horizon, and the altitude corrected for dperession, should also be stated. At some convenient place, either at the beginning or at the end of all, should be written out all the measures by which the index-error was ascertained, exactly in the manner in which they were made, and so that any other person can deduce from them the value of the index-error.

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* Keith Johnston's Atlas of Astronomy, edited by J. R. Hind, will suffice for most purposes, but Dien's Atlas Cèleste, Paris, 1877, contains a much more complete set of star-charts.—(R. S. B.)

The time of making every observation should be entered exactly as it is read from the chronometer or deck-watch. By the side of this should be placed the error of the chronometer of the deck-watch on Greenwich time, or on time at the ship (as may be most convenient): and, after this, the corrected time.

At some convenient place, either at the beginning or the end, must be written out all the observations by which the error of the chronometer is ascertained. If its error on Greenwich time is given, the longitude of the ship must also be given, and the means and observations by which that longitude has been determined must be stated at length.

If a deck-watch is used, the comparison of the deck-watch with the chronometer must be given.

The last observations by which the latitude was determined, and the course and rate of sailing of the ship must also be given.

All the observations must be sent in this detail to the Admiralty or other body appointed to receive them.

2. Opportunities will sometimes occur, when a ship is lying in a harbour of which the latitude and the longitude are well known, for observing *eclipses of the sun.* These observations are almost always valuable. It can seldom be expected that the time of the beginning of an eclipse can be observed accurately, but the time of the end of it can usually be observed with very great accuracy. And if the eclipse is total, the times of beginning and end of the totality can be observed accurately; if it is annular, the times of beginning and end of the annularity can be observed accurately. The observations should be made with the largest telescope which the navigator possesses; and any peculiarity of distortion of the sun's limb or the moon's limb, any light surrounding the moon, &c. should be carefully recorded. If the eclipse be total, attention should be paid to any coloured or other appendages projecting from the dark edge of the moon and to their changes, also to the luminous corona surrounding the moon.* While the eclipse

* For the details of the phenomena which have been observed in annular and total eclipses the *Memoirs* and *Notices* of the Royal Astronomical Society should be consulted beforehand, especially vol. xli. of the *Memoirs*, in which Mr. Ranyard has brought together all the available knowledge on the subject.—(R. S. B.)

is in progress, but especially near the beginning or the end, measures of the distance between the cusps or sharp points at which the moon's limb crosses the sun's limb may be repeatedly taken. In recording these observations, the observations by which the time is determined, and the observations by which the index-error of the sextant is determined, should be written down in the fullest detail; and the unreduced observations should be given as well as the reduced observations.

3. In similar circumstances *occultations of stars by the moon* may frequently be observed. *Eclipses of Jupiter's satellites* may also be seen; and (if the navigator have a telescope somewhat better than is usually carried in ships, and steadily mounted) the passage of Jupiter's satellites, either behind the planet or in front of the planet, may be seen, and the times at which the centres of the satellites just touch the edge of the planet may be observed. All these observations will be useful: the observations must be recorded with the same fulness which has been mentioned before.

4. It may chance that the navigator is in some climates where the air is much more damp, and in others where it is much more dry, than in Europe. It is possible that in these places he may be able to make observations which will throw some light upon the influence of moisture in atmospheric refraction. It is recommended that repeated observations of the altitude of the sun's upper and lower limb be taken when the sun is very near the horizon. It will be necessary that the time at the ship and the latitude be very well known. The thermometer must be read, as also some hygrometrical instrument, and the barometer, if there is one on board, during the observations. The observations of every kind must be recorded with the utmost fulness.

5. It is certain that some of the *stars* of the southern hemisphere are *variable* in magnitude; the most remarkable of these is η Argûs. It is desirable that, on favourable nights, the magnitude of this star should be observed and recorded. The best way of doing it will be, not to state that it looks like a star of the second magnitude, or of the third magnitude, &c., but to compare its brightness with that of some of the stars near it. Thus it will be easy to say that it appears pretty exactly as bright as one star, certainly

brighter than a second, and certainly not so bright as a third.* (*See* Appendix No. 1.)

6. Much attention has been excited by the appearance, in several years, of meteors in great numbers, especially on or about the 9th of August and the 12th and 27th of November. It is probable that these appearances may be seen by persons at sea, when, either from the hour at which they occur, or from other causes not yet understood, they cannot be seen in Europe. It is impossible to observe them with accuracy; but very valuable information will be given by counting repeatedly how many can be seen in some fixed interval of time, as five minutes; and by remarking whether they all come from, or go to, one part of the heavens; what is that part of the heavens; whether they usually leave trains behind them; what is their usual brightness (as compared with that of known stars); and by any other remarks which may be suggested by their appearance. A general comparative table of the radiant points from which meteor showers diverge as well as the dates of their occurrence will be found in the Reports of the British Association, Glasgow, 1876, p. 156. More than 200 showers visible in the Northern hemisphere are contained in this table. Additional information as to the showers in the Southern hemisphere is much desired. (*See* Appendix No. 4.)

7. Many opportunities will occur of observing the zodiacal light; more especially when the observer is near the equator, where probably it can be seen at all seasons, before sunrise and after sunset; or, if in northern latitudes, after sunset in February and March, and before sunrise in September and October; if in southern latitudes, before sunrise in March and April, and after sunset in August and September. The zodiacal light consists of a pyramid of faint light, whose base is somewhere near the place of the sun, and whose point is at a distance of perhaps 30° from the sun; the axis of the pyramid being usually inclined to the horizon, following nearly the direction of the ecliptic. Although it presents to the eye a considerable body of light, yet the light of any portion of it is so feeble, and the definition of its outline is so imperfect, that it cannot be observed with a telescope. The observer, therefore, should only attempt to observe it with the naked eye when the sky is very clear, and when the sun is so far below the horizon that no twilight is visible. He should then endeavour, with the assistance of a chart of the stars, to define as accurately as possible its boundary

with reference to the stars; remarking especially the place of the point of the pyramid, the width where it rises from the horizon, whether its sides are curved, and in what parts the light is brightest. It will be found that these observations are made most accurately by occasionally turning the eye a little obliquely from the zodiacal light. In registering the observation, in addition to the particulars to be recorded as prescribed above, there should be a statement of the latitude of the ship, the day, the time at the ship (or the Greenwich time and the longitude of the ship), the state of clearness of the sky, and the state of the weather for the day preceding the observation.* (See also *Meteorology*.)

Improvement of Nautical Astronomy.

8. So much attention has been given to every detail of Nautical Astronomy, that it is very difficult to fix upon any part of it to which the attention of navigators should be specially directed with a view to its improvement. Perhaps the principal deficiency at the present time is in the want of well understood methods of observing (with the sextant) the altitudes of stars at night, and of observing the altitudes of the sun and moon when the horizon is ill-defined. Every endeavour ought to be made to become familiar with the use of Becher's horizon, or some equivalent instrument, and to acquire a correct estimate of the degree of confidence which can be placed in the use of it.

9. It is likewise desirable that efforts should be made to facilitate the observation of *occultations of stars by the moon*, and the observation of *eclipses of Jupiter's satellites*

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* A valuable paper by Professor C. Piazzi Smyth on the Zodiaca Light, containing observations made by him near the Cape of Good Hope in the years 1843–5, will be found in the *Transactions of the Royal Society of Edinburgh*, vol. xx. The principal merit of this memoir consists in its supplementing the more numerous observations in the Northern hemisphere, at times when the light is not visible there. A far more elaborate series of observations of the general boundaries of the light is that made, and chiefly in the tropics, by the Rev. George Jones, between the years 1853 and 1855, while engaged with the United States Japan Expedition in the steam frigate Mississippi. The results of the observations are given in a series of charts drawn on Mercator's Projection, and form the 3rd volume of the "Results of the United States Japan Expedition."—(R. M.)

at sea. Occultations occur rarely, but the result which they give for longitude is usually so much more accurate than that given by lunar distances, that, in long voyages where little dependence can be placed on the chronometer, the observation of an occultation must be extremely valuable. The eclipses of Jupiter's satellites afford less accurate determinations of longitude, but they occur very much more frequently, and may be very useful where chronometers cannot be trusted.*

Astronomical Geography.

10. The intelligent navigator, on arriving at any port which has not before been visited, or whose position is not very well settled, ought to consider it his first duty to determine with all the accuracy in his power the *latitude and longitude* of the port. Supposing him to have determined by the usual nautical methods the approximate latitude, longitude, and error of chronometer, the best method of determining the latitude will be to find the chronometer-time at which the sun or any bright stars of the Nautical Almanac list will pass the meridian, and to observe the double altitude of any such object by reflexion in a mercurial horizon, several times, as near as possible to the time of the meridian passage. If the place is in the northern hemisphere, the observation of the double altitude of the pole-star may be made at any time when it is visible; convenient tables for the reduction are given in the Nautical Almanac. For these and other observations the navigator ought to be provided with a proper trough and a store of mercury.

For determining the longitude where telegraphic facilities are not available there is probably no method superior to that of lunar distances (the exactness of which will be increased

* Attempts may laudably be made to devise some available mode of suspending a chair, so as to afford a steady seat to the observer. Hitherto such attempts have failed of practical success, from setting out with the principle of perfectly free suspension, a principle which tends to prolong and perpetuate oscillations once impressed. It remains to be seen what *stiff* suspension, as, for example, by a rigid rope or cable, or by a Hooke's joint, purposely made to work stiffly (and that more or less at pleasure), by tightening collars—as also deadening and shortening oscillations, by lateral cords passing through *rings* to create friction—and other similar contrivances may do. In the suspension of a cot, at least, I have found this principle signally available.—(Ed. Sir J. H.)

if the sextant or reflecting circle be mounted on a stand), unless the stay at the port is so long that transits of the moon can be observed. In any case, if there be a transit instrument in the ship, it ought to be mounted on shore as soon as possible. The instrument ought, on the first evening, to be got very nearly into a meridional position, and then a mark should be set up, and the instrument should always be adjusted to that same mark (even though it be not exactly in the meridian), and should always be levelled, before commencing a series of observations. One or two stars at least, as near the pole as possible, should be observed every night, in addition to the Nautical Almanac stars necessary for chronometer error, and the moon-culminating stars which are observed with the moon. The instrument should be reversed on alternate nights; and, if possible, as many transits of the moon should be taken after the full moon as before the full moon. The extension of the electric telegraph is now so great that it may reasonably be expected that, at every port at which a British ship is likely to call a good telegraph office will be furnished with a clock of which the error is determined by telegraphic communication with the metropolitan office. Immediately on the ship's arrival, an officer is to carry two chronometers to the telegraph office, and (after severe inquiry into the nature of the communication with the metropolitan office, and into the origin of its time determinations) is to compare his chronometers with the telegraph clock. The information thus obtained may be most important for the further navigation of the British ship.

In the register of all these observations, the same rule should be followed which is laid down under the first suggestion; that every observation should be recorded *unreduced*, exactly in the state in which it is read from the sextant or chronometer; and that the unreduced observations should be accompanied with the elements of reduction of whatever kind; and that (if the navigator has had leisure to reduce them) the reduced results should also be given.

G. B. Airy.

APPENDIX No. 1.

A List of the most conspicuous Variable or periodic Stars of which observations would be desirable, with their periods of variation and changes of magnitude. Compiled by Mr. J. E. Gore to replace the similar list in former editions.

Star.	Period.	Change of Magnitude.
	D. H. M.	
δ Libræ	2 7 51	4·9 to 6·1
β Persei	2 20 49	2·2 to 3·7
λ Tauri	3 22 51	3·4 to 4·2
δ Cephei	5 8 47	3·7 to 4·9
X (3) Sagittarii	7 0 17	4 to 6
η Aquilæ	7 4 14	3·5 to 4·7
κ Pavonis	9 2 24	4 to 5·5
ζ Geminorum	10 3 43	3·7 to 4·5
β Ursæ Minoris	10 16 11 (?)	2·2 to 2·8
β Lyræ	12 21 47	3·4 to 4·5
l Carinæ	31 6	3·7 to 5·2
L_2 Puppis	135 days.	3·6 to 6·3
η Geminorum	229 "	3·2 to 4·2
o Ceti	331 "	2 to 9·5
χ Cygni	406 "	4 to 13
R (υ) Hydræ	436 "	4 to 10
α Herculis	Irregular	3·1 to 3·9
ε Aurigæ	Irregular	3 to 4·5 (?)
η Argûs	Irregular	1 to < 7
μ Cephei	Irregular	3·7 to 4·9
ρ Persei	Irregular	3·4 to 4·2

* Much has been done lately in the observation of known variable stars and the detection of new ones. A catalogue of 191 stars in both hemispheres, now known to be variable, by J. E. Gore, F.R.A.S., was published in 1884 in the "Proceedings of the Royal Irish Academy" (2nd series, vol. IV., No. 2, Science).

APPENDIX No. 2.

THE STAR LISTS HAVE BEEN KINDLY COMPILED BY PROFESSOR PRITCHARD, TO REPLACE THE SIMILAR LISTS IN THE FORMER EDITION.

List of Fixed Stars in either hemisphere, approximately arranged in order of brightness, down to the fourth magnitude, for the purpose of mutual comparison under favourable circumstances of altitude, and especially in equatorial and tropical voyages, or land stations, with a view to bringing the nomenclature and scale of magnitudes in the two hemispheres to agreement, and to the improvement of this branch of astronomical knowledge. The comparisons to be made by the naked eye among the stars of both lists not differing much (at the time of observation) in altitude, and in the absence of the moon and twilight, and the results arranged in sequences, beginning with the brightest and ending with the faintest star compared. In each sequence *stars of the two lists should alternate whenever circumstances will allow.*

a. NORTHERN STARS.

Arranged in order of brightness, with magnitudes determined by the Wedge Photometers at the Oxford University Observatory.

No.	Name of Star.	Oxford Mag.	No.	Name of Star.	Oxford Mag.
1	Capella - -	* + 0·92	25	γ Androm. -	2·14
2	α Lyræ - -	+ 0·86	26	β Ursæ Maj. -	2·17
3	Arcturus -	+ 0·69	27	γ Cassiop. -	2·19
4	Procyon -	+ 0·50	28	β Androm. -	2·21
5	α Orionis - -	+ 0·02	29	α Ophiuchi -	2·23
6	α Aquilæ -	1·04	30	α Coronæ -	2·23
7	Aldebaran -	1·12	31	γ Cygni - -	2·26
8	Regulus -	1·17	32	γ Ursæ Maj. -	2·30
9	α Cygni - -	1·32	33	β Cassiop. -	2·32
10	Pollux - -	1·36	34	α Pegasi - -	2·33
11	Castor - -	1·53	35	γ Draconis -	2·40
12	β Tauri - -	1·79	36	α Cassiop. -	2·41
13	γ Orionis - -	1·79	37	ε Pegasi - -	2·43
14	ε Ursæ Maj. -	1·80	38	ε Cygni - -	2·45
15	α Ursæ Maj. -	1·89	39	ε Boötis - -	2·47
16	α Persei - -	1·93	40	γ Pegasi - -	2·47
17	β Aurigæ -	1·94	41	β Pegasi - -	2·50
18	Polaris - -	2·05	42	δ Leonis - -	2·55
19	α Androm. -	2·05	43	α Cephei - -	2·57
20	β Leonis - -	2·07	44	ζ Herculis -	2·64
21	ζ Ursæ Maj. -	2·09	45	α Serpentis -	2·67
22	γ Leonis - -	2·12	46	β Herculis -	2·67
23	α Arietis - -	2·13	47	η Boötis - -	2·74
24	γ Geminor. -	2·13	48	β Arietis - -	2·75

* + 0·92 signifies that the star is 0·92 brighter than a star of the first magnitude.

No.	Name of Star.	Oxford Mag.	No.	Name of Star.	Oxford Mag.
49	η Draconis -	2·79	97	γ Cephei - -	3·51
50	δ Cygni - -	2·79	98	ε Cassiop. -	3·51
51	γ Aquilæ - -	2·81	99	θ Pegasi - -	3·53
52	δ Cassiop. -	2·89	100	η Cephei - -	3·53
53	β Ophiuchi -	2·92	101	β Delphini -	3·53
54	η Pegasi - -	2·95	102	γ Tauri - -	3·55
55	β Draconis -	2·96	103	α Draconis -	3·56
56	δ Draconis -	2·96	104	ο Tauri - -	3·56
57	ζ Tauri - -	3·00	105	41 Arietis	3·58
58	ε Virginis -	3·01	106	μ Pegasi - -	3·58
59	γ Ursæ Min. -	3·02	107	π Herculis -	3·60
60	β Cygni - -	3·02	108	θ Geminor. -	3·60
61	θ Aurigæ -	3·03	109	η Herculis -	3·60
62	γ Persei - -	3·06	110	ι Cephei - -	3·61
63	ζ Aquilæ - -	3·08	111	κ Ursæ Maj. -	3·62
64	ζ Persei - -	3·08	112	π[1] Orionis - -	3·62
65	ζ Cygni - -	3·09	113	κ Geminor. -	3·63
66	β Can. Min. -	3·11	114	ε Aurigæ - -	3·64
67	δ Persei - -	3·11	115	η Geminor. -	3·65
68	β Trianguli -	3·12	116	τ Cygni - -	3·65
69	η Tauri - -	3·12	117	ο Herculis -	3·67
70	θ Ursæ Maj. -	3·12	118	ε Tauri - -	3·69
71	ε Persei - -	3·13	119	α Piscium -	3·71
72	α Lyncis - -	3·16	120	η Piscium -	3·71
73	γ Lyræ - -	3·16	121	γ Sagittæ -	3·72
74	δ Androm. -	3·18	122	ξ Tauri - -	3·72
75	γ Boötis - -	3·21	123	λ Geminor. -	3·72
76	ι Ursæ Maj. -	3·23	124	ο Androm. -	3·74
77	δ Herculis -	3·25	125	ζ Cassiop. -	3·75
78	θ Aquilæ - -	3·26	126	ζ Aurigæ - -	3·80
79	ι Draconis -	3·26	127	γ Ophiuchi -	3·83
80	λ Aquilæ - -	3·27	128	ξ Geminor. -	3·84
81	ζ Pegasi - -	3·29	129	χ Draconis -	3·93
82	ζ Draconis -	3·29	130	α Delphini -	3·93
83	ε Geminor. -	3·29	131	ι Geminor. -	3·98
84	Cor Caroli -	3·32	132	δ Aurigæ -	3·98
85	δ Aquilæ - -	3·36	133	ξ Herculis -	3·99
86	ο Ursæ Maj. -	3·36	134	ζ Geminor. -	4·01
87	β Cephei - -	3·37	135	γ Delphini -	4·05
88	ζ Cephei - -	3·39	136	ρ Cygni - -	4·10
89	η Cassiop. -	3·41	137	ι Herculis -	4·11
90	λ Tauri - -	3·43	138	γ Arietis - -	4·11
91	δ Boötis - -	3·44	139	ξ Pegasi - -	4·16
92	μ Geminor. -	3·45	140	φ Draconis -	4·22
93	δ Geminor. -	3·48	141	ι Pegasi - -	4·24
94	η Aurigæ - -	3·49	142	γ Trianguli -	4·35
95	α Trianguli -	3·50	143	κ Aurigæ - -	4·81
96	μ Herculis -	3·50			

b. Southern Stars.

Arranged in order of brightness; the Magnitudes are taken from Gould's Uranometria Argentina, except that of Sirius, which is by Pritchard.

No.	Name of Star.	Mag.	No.	Name of Star.	Mag.
1	Sirius	+1·95	42	α Columbæ	2·5
2	Canopus	+0·6	43	λ Argûs	2·5
3	α Centauri	+0·3	44	ι Argûs	2·5
4	Rigel	1·0	45	ζ Argûs	2·5
5	α Eridani	1·0	46	η Centauri	2·5
6	β Centauri	1·2	47	β Corvi	2·6
7	α Crucis	1·3	48	α Lupi	2·6
8	Fomalhaut	1·4	49	ε Centauri	2·6
9	Antares	1·4	50	β Aquarii	2·6
10	Spica	1·5	51	ζ Ophiuchi	2 6
11	β Crucis	1·7	52	θ Eridani	2·6
12	ε Orionis	1·8	53	κ Argûs	2·7
13	ε Can. Maj.	1·8	54	δ Ophiuchi	2·7
14	ζ Orionis	1·8	55	ζ Centauri	2·7
15	α Gruis	1·9	56	α Leporis	2·7
16	β Argûs	2·0	57	β Hydri	2·7
17	γ Argûs	2·0	58	λ Sagittarii	2·7
18	λ Scorpii	2·0	59	α Aquarii	2·7
19	γ Crucis	2·0	60	π Argûs	2·7
20	δ Can. Maj.	2·1	61	γ Sagittarii	2·8
21	ε Argûs	2·1	62	β Eridani	2·8
22	α Pavonis	2·1	63	β Aræ	2·8
23	θ Scorpii	2·1	64	δ Sagittarii	2·8
24	α Hydræ	2·1	65	δ Centauri	2·8
25	β Gruis	2·2	66	δ Capricorni	2·8
26	δ Argûs	2·2	67	α Toucanæ	2·8
27	α Triang. Aust.	2·2	68	ι Orionis	2·8
28	ε Sagittarii	2·2	69	β Lupi	2·8
29	β Canis Maj.	2·2	70	β Columbæ	2·9
30	θ Centauri	2·2	71	η Can. Maj.	2·9
31	β Ceti	2·3	72	β Leporis	2·9
32	κ Orionis	2·3	73	α Aræ	2·9
33	δ Orionis	2·3	74	μ Argûs	2·9
34	ε Scorpii	2·3	75	θ Argûs	2·9
35	σ Sagittarii	2·4	76	α Muscæ	2·9
36	δ Scorpii	2·4	77	α Hydri	2·9
37	γ Centauri	2·4	78	υ Hydræ	3·0
38	α Phœnicis	2·4	79	δ Corvi	3·0
39	η Ophiuchi	2·4	80	ι Centauri	3·0
40	β Scorpii	2·5	81	π Sagittarii	3·0
41	γ Corvi	2·5	82	γ Gruis	3·0

No.	Name of Star.	Mag.	No.	Name of Star.	Mag.
83	α Libræ - -	3·1	106	β Phœnicis -	3·3
84	β Libræ - -	3·1	107	ε Hydræ - -	3·3
85	γ Virginis -	3·1	108	κ Centauri -	3·3
86	γ Triang. Aust.	3·1	109	π Scorpii - -	3·4
87	ζ Sagittarii -	3·1	110	σ Scorpii - -	3·4
88	β Capricorni -	3·1	111	γ Tubi - -	3·4
89	β Triang. Aust.	3·1	112	β Muscæ - -	3·4
90	α Indi - -	3·1	113	υ Argûs - -	3·4
91	α Doradûs -	3·1	114	λ Centauri -	3·4
92	υ Scorpii - -	3·2	115	υ Argûs - -	3·5
93	τ Scorpii - -	3·2	116	ξ Argûs - -	3·5
94	γ Hydræ - -	3·2	117	σ Argûs - -	3·5
95	ρ Argûs - -	3·2	118	α Pictoris -	3·5
96	γ Lupi - -	3·2	119	η Serpentis -	3·5
97	τ Argûs - -	3·2	120	η Circini -	3·5
98	δ Aquarii -	3·2	121	ζ Scorpii - -	3·6
99	γ Hydri - -	3·2	122	π Hydræ - -	3·6
100	ζ Can. Maj. -	3·2	123	ω Argûs - -	3·6
101	N Velorum -	3·2	124	φ Sagittarii -	3·7
102	ι Scorpii - -	3·3	125	o^2 Can. Maj. -	3·9
103	ε Corvi - -	3·3	126	ζ Hydræ - -	5·2
104	π Ophiuchi -	3·3	127	λ Crucis - -	5·6
105	β Tubi - -	3·3			

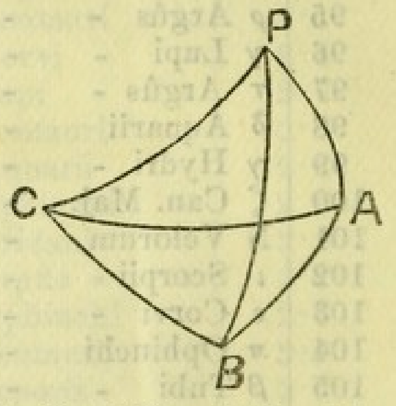
APPENDIX No. 3.

By the late REV. R. MAIN; revised by PROFESSOR S. M. RUSSELL.

On Comet Observations made with the Sextant.

As a proof that such observations are occasionally of very great service, the great comet of 1843 may be referred to. This comet, from its low southern position, could not be observed in Europe; and generally there was a great want of observations made with instruments in fixed observatories. But it was an object of great attention to the officers of ships on their passage from southern latitude towards England, and several extensive series of observations were sent to the Royal Astronomical Society, and accurately reduced at the expense of that body. The paper containing the results of the calculations is printed in the sixteenth volume of the *Memoirs* of the Society. The want of care of some of the observers in giving the requisite elements of reduction was exhibited in a very instructive manner, and may be useful to future observers. By the greater number of the observers neither the barometer nor the thermometer had been read at all, and it became necessary to supply the defect conjecturally, in the computation of refraction, by the average pressures and temperatures of the air as deduced from the general results of climatology. When taking the observations the time should be carefully noted. The observer should state what chronometer he used, whether sidereal or solar, also its correction and rate. The barometer and thermometer should be read after each observation. The index error of the sextant should be determined and applied to the measures.

The observations may be conducted in the following manner: Two stars are selected and the distances of the comet from each of the stars measured. Let A and B be the two stars, C the comet, and P the pole. The stars should be chosen so that the triangles C A B and C P B, or C P A, may be as nearly equilateral as possible. In the triangle B P A, the sides B P, P A, and the angle B P A are known, so that B A and the angle B A P may be calculated. In the triangle C A B the three sides are known, and the angle B A C can be calculated. The angle P A C and the sides P A and A C are known, hence P C and the angle C P A can be found. The right ascension and declination of the comet are now known, and with three such determinations the elements of the comet can be calculated.



C A and C B are the apparent distances of the comet and stars and should be corrected for parallax and refraction. The mode of doing this is described in works on practical astronomy.

APPENDIX No. 4.

TABLE of the Dates and Radiant Points of the Principal Meteor Showers, compiled for this edition by Mr. W. F. Denning.

Ref. No.	Date of Shower.	Radiant Point. RA. Dec.	Approximate bright Star.
1	January 1–3 - -	232° + 49°	β Boötis.
2	January 5–11 - -	145 + 5	o Leonis.
3	January 28 - -	236 + 25	α Coronæ Bor.
4	February 5–10 -	74 + 43	α Aurigæ.
5	February 15 - -	236 + 11	α Serpentis.
6	February 16 - -	167 + 5	τ Leonis.
7	February 20 - -	181 + 34	α Canum Ven.
8	March 4 - -	176 + 9	β Leonis.
9	April 9–12 - -	249 + 51	β Draconis.
10	April 18–20 - -	269 + 33	α Lyræ.
11	April 29–May 2 -	326 − 2	α Aquarii.
12	May 11 - - -	231 + 27	α Coronæ Bor.
13	May 30 - - -	330 + 28	ν Pegasi.
14	June 9–13 - -	261 + 5	η Cephei.
15	June 13 - - -	310 + 61	β Ophinchi.
16	June 25–30 - -	253 + 47	β Draconis.
17	July 23–25 - -	48 + 43	β Persei.
18	July 27–29 - -	341 − 13	δ Aquarii.
19	August 9–11 - -	45 + 57	η Persei.
20	August 21–25 -	291 + 60	o Draconis.
21	September 6–8 -	62 + 37	ε Persei.
22	September 21 - -	31 + 19	α Arietis.
23	September 21–22 -	74 + 44	α Aurigæ.
24	September 24–26 -	99 + 43	β Aurigæ.
25	October 15 - -	106 + 23	δ Geminorum.
26	October 17–20 -	90 + 15	υ Orionis.
27	Oct. 30–Nov. 4 -	43 + 22	ε Arietis.
28	November 12–14 -	149 + 23	γ Leonis.
29	November 13–18 -	155 + 40	μ Ursæ Maj.
30	November 19–23 -	62 + 21	ε Tauri.
31	November 26–28 -	25 + 43	γ Andromedæ.
32	Nov. 30–Dec. 4 -	194 + 43	α Canum Ven.
33	December 1–10 -	117 + 32	α Geminorum.
34	December 6 - -	80 + 23	ζ Tauri.
35	December 10–12 -	108 + 33	α Geminorum.

ARTICLE II.

HYDROGRAPHY.

Originally written by the late Rear-Admiral
F. W. BEECHEY.

(Revised for the Third Edition by the late Admiral Washington; for the Fourth Edition by Rear-Admiral Sir G. H. Richards; and re-written for the present or Fifth Edition by Captain Wharton, R.N., F.R.S.)

Hydrography is here taken to mean all such observations of the phenomena and characteristics of the sea as can increase our knowledge of it, whether for practical navigation, as its depths, boundaries, movements, both horizontal, as of currents or tidal streams, and vertical as of the rise and fall of the tide, or for more scientific purposes which eventually lead to practical uses, as its temperature, specific gravity.

It is proposed in this article to point out the ways in which seamen can contribute to our knowledge on these points.

The observations which an intelligent sailor can make are many and varied, but they must be made in such a manner as will ensure their acceptance at the hands of those who have to add them to and incorporate them with existing knowledge. This knowledge is now far more extended than in the days when the Admiralty Manual was first published; but much remains to be gathered even in well frequented parts of the globe, and more especially in other regions, which are either little traversed, or are often passed over without record.

The officers of Her Majesty's ships who are charged with keeping Remark Books have the recognised means of recording such observations at their hands, and from these books an

c. coarse, cl. clay, d. dark, f. fine, gy. gray.
g. gravel, m. mud, r. rock, st. stones.

Plate A. *To illustrate Hydrographic delineation.*

Buoys :— Can. Conical. with staff & ball. with bell or whistle. gaslight.

Figures underlined thus 2 show heights in feet above low water Springs, of banks which cover and uncover.

Tide arrows:— Flood ⟶, Ebb ⟵ ; dots on them thus the 2nd and 3rd hour of the tide. Current arrows thus

Figures on the land show heights in feet above high water Springs.

Edwd Weller

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immense amount of information has been gained, but looking at the numbers of them that are annually sent in to the Admiralty, it cannot be said that a due proportion of these contain many valuable facts.

The Meteorological Logs, now kept by many vessels, afford an even more extended means of recording observations of all kinds.

These Books are carefully studied and all useful information extracted. Let it not be thought that any such is lost. The ocean is vast, and it takes many observations in the same region to enable trustworthy generalisation to be made. The individual observations may apparently disappear, but they are all, nevertheless, included in the consideration of the facts that are given to the seaman whether in charts, sailing directions, meteorological or other publications.

It is difficult, in such matters, to separate hydrography from meteorology. The two subjects are frequently, as in the case of currents and winds, inextricably interwoven, and cannot be disentangled.

General Remarks during and after Passages.

General remarks on the correctness or otherwise of the data furnished by the wind and current charts, as ascertained during the passage, are very valuable, as they draw attention to the detailed observations in the tabular forms. Such remarks as the latitude and longitude where periodic winds, as monsoons or trades, were picked up and lost; the distance from the coast that sea and land breezes were experienced; the position where a well marked line of current was passed; are most useful.

Should another vessel happen to have made the same voyage at about the same time, it is always useful when the information can be obtained to compare the circumstances of the two passages, and to record the main points of difference.

The limits and localities within which ice is seen, the direction in which the bergs were travelling, frequently different to that of the surface drift, should be carefully noted. The size and shape of the bergs are also points of interest, as bearing on their origin; as is likewise stratification of the ice.

The heights of waves and their velocity are subjects on which observations are never amiss.

The former is most readily obtained by ascending the rigging, till, when the ship is in the trough, the eye is level with the advancing wave crest. The height of the eye can easily be found by remarking the angle of heel at the time.

To obtain an observation of velocity it is necessary to be in company with another vessel, and that her distance should be known, when the time taken for a wave to pass from one to the other will form the basis of a simple calculation.*

Currents, and Temperature of the Sea.

Temperature of the sea is now known to be closely connected with all great movements of the ocean. Observations on this point should, therefore, be frequently recorded.

When opportunities occur, the temperature at different depths, as well as of the surface, should be made. Little is yet known of the depths of the great currents of the ocean, and the requisite knowledge is, perhaps, more readily obtained by means of the thermometer than by any other method. A warm current is frequently well marked by a considerable difference of temperature from the nearly still and colder water on which it flows, and occasionally *vice versâ*.

Warm currents are often streaked with colder zones on the surface; observations on this are interesting and are only to be obtained by more frequent trials of the temperature than are generally taken.

The specific gravity of the water, recorded as frequently as possible, may also throw light on the currents.

Much has been already done, and the charts of the surface temperatures, recently published by the Meteorological Office, are the result of many thousands of observations.†

These show in a very marked manner that the regions of the ocean where gales most frequently originate, are those where the temperature of the sea varies most, either from the meeting of currents, or from cold strata of water coming to the surface in warmer areas.

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* *See also* p. 141.

† A reduced copy of these charts is given in the Admiralty Wind and Current Charts.

Increase of knowledge in this direction will thus clearly tend to elucidate the mystery of the origin of gales, a most important practical point to seamen, and much remains to be done in this direction. No matter how well known a region may seem to be, more observations are never amiss, as the greater the number of these, the truer will be the directions published for the use of the mariner. A moment's consideration will show how numerous the observations must be to enable monthly charts of the currents or of the temperature of the sea to be issued, and these it is hoped may some day be compiled when the data are forthcoming.

When approaching a coast, or any extensive banks in the ocean, the temperature of the surface of the sea should be more closely attended to, for it has been found in many instances that, after a certain shoaling of the water, the surface partakes of the temperature of the lower strata of the sea, which are in general colder than the upper. If such should be found to be the case always, and if from well authenticated facts it should become possible to fix zones of certain temperatures about particular localities, the result would be highly useful to the navigator when out in his reckoning and perplexed with thick and hazy weather.

To give instances ; the sea temperature along the northern part of the western shore of Africa is known to be extraordinarily low compared with that a few miles to seaward, a difference of 20 degrees existing between the water close in shore and in the offing.

It has been recently stated, that, the dangerous locality of Ras Asir (Cape Guardafui) may be avoided by attention to the temperature of the sea. A thick haze frequently covers the land, currents are strong and variable, and many a ship has been wrecked here before the sandy shore has been sighted. This statement requires confirmation.

In all such places an intimate knowledge of the thermometric condition of the sea could not fail to be immediately practically useful, besides the scientific light which is thrown on the circulation of the ocean.

The main runs of the principal currents of the ocean are now tolerably well known, but all observation tends to show that great variations occur even in the best established of these oceanic streams. Every seaman who has any experience in navigation knows how often he is disappointed in finding that an expected current is non-existent, or that its rate and direction are different to what he hoped from his current charts. These charts are but generalisations, and at present are only compiled for the whole year, and are, therefore, but rude approximations to the true course of the currents at any given season, and many more trustworthy observations must be made in many localities before the detailed charts just mentioned can be satisfactorily drawn up.

Let every navigator, therefore, bear this in mind, and remember that he can add to the sum of our knowledge every day that he is under weigh.

Direct observations on surface currents are, when out of sight of land, generally only to be obtained by means of the difference between the astronomical and dead reckonings. As these are both of them liable to considerable errors, any single determination must be only regarded as an approximation. By the multiplication of these, however, a mean, not far removed from a correct mean, can be calculated, and on such observations the majority of currents shown in the current charts are based.

If time and circumstances allow, the rate of the surface current, when out of soundings, may be obtained by lowering a light boat, and from it paying out a heavy lead to about 200 fathoms. If a framework of any kind which will increase the resistance is added just above the lead, the observation will be better; but even with a bare lead, the direction and rate of the current will be apparent, as the boat will be more or less anchored by the lead, being in a still stratum of water. An ordinary log-line paid out from a boat thus anchored, with several turns of the glass, will give the rate. Thus, if the two knot mark runs out after four turns of the glass, the current will be half a knot. If a larger log-ship than usual be made and employed, the observation will be more correct.

The rate deduced will be only the difference between the surface drift and that of the stratum of water in which the submerged lead or frame is, and will in all cases be less than that of the actual surface stream, on account of the friction caused by the drag of the boat, the lead not being actually fixed; still, except in channels, it is not believed that the under currents are of any considerable velocity compared with that of the surface streams, and a very fair approximation may be obtained.

In sight of land the best way is to drop a loose buoy or barricoe, which should be weighted so as to show little or no area above the surface for the wind to act upon. Fix its position when started by angles, so that its position can be plotted on the chart, and watch it for an hour, or any convenient time, when its position can be again fixed by angles, and its movements deduced from the distance and direction in which it has travelled.

Another way, when in soundings and the current is strong, is to heave the log as above from the ship or a boat at anchor, or to veer a heavy lead to the bottom and attach a buoy to the line when the bottom is reached, and veer away as the ship or boat drifts, taking the time and measuring the amount of line out after a certain interval, from which can be calculated the rate, and by a bearing of the buoy, the direction. This method is liable to error from the action of the wind causing the ship or boat to drift, and in soundings a direct observation by means of the log-line from the ship or boat at anchor, is much to be preferred.

The bottles containing current papers are of but little use to us in the present state of our knowledge. They give at best but a very general notion of the direction of the current, and it is impossible to say by what circuitous course they have reached the position at which they are eventually picked up. They were valuable aids when the general circulation of the ocean was yet a mystery; but now more detailed knowledge is wanted.

The occurrence of floating sea-weed in certain areas should be noted. The presence of this, except off the mouths of great rivers, is intimately connected with oceanic circulation.

In plate C* is given a reduction of the Admiralty Current Chart, which shows the mean direction of the circulation of the surface waters of the globe.

Tidal Streams.

Observations are much needed on these, and any ship at anchor may gather information on them.

The stream often varies much at different periods of the tides, and frequently turns before the high or low water by the shore.

Observations on these points will much amend the sailing directions in all parts of the world. Though it is a special object with surveying ships to gather such knowledge, it is often necessarily of a scanty nature in any locality, and all vessels may add to it by taking a little trouble. The ordinary log-ship hove when at anchor and permitted to run out during

* Plate C is at end of the book.

several turns of the glass, as mentioned on page 5, with the bearing of the log-ship when the line is checked, affords an easy means of determining the rate and direction of the tidal stream.

A page of the Remark Book devoted to the record of such observations, noting the age of the moon, time of tide, and the wind, would be well bestowed.

Upon an open coast one set of such observations, made here and there, well clear of the headlands, will be sufficient; but in channels and straits, in which the tide enters at both extremities, the tidal phenomena are so varied and full of interest, that it becomes highly important to spread the observations over as large an extent of the channel as possible, and to pursue a regular system of hourly observation throughout both the *ingoing* and *outgoing* streams.

It is desirable to know at each place the time of slack water, the direction in which the stream turns, and the rate and course at which it runs during its several stages. The stations should be numbered, and the times all referred to one meridian. In such channels there will probably be one or more places where the streams meet, and there, of course, observations will be made; and as one of these places will probably be the *virtual head of the tide wave*, it may so happen that the time of the high and low water there *by the shore* will govern the turn of the stream either along the whole channel or until it reaches a spot where another meeting of the streams occurs. In such a channel also it will probably be found (as in the Irish Channel) that the same stream makes high water at one end and low water at the other at *the same time;* so that the observer must entirely divest his mind of the too often mistaken notion of the turn of the stream being governed by the rise and fall of the water in its immediate locality. As our space does not admit of further detail, I shall leave the subject in the hands of the observer with a remark which, whilst it will put him in possession of what kind of observations are required, will at the same time, I think, insure his interest in the subject and his hearty desire to co-operate in the matter.

In the Philosophical Transactions, 1848, Part I.,* it has been shown that in such a channel as that above mentioned

* This valuable paper, by the late Rear-Admiral Beechey, as well as another on the Tides of the Channel and North Sea, is annexed to the Tide Tables published annually by the Admiralty, and supplied to all H.M. ships. (W.)

there have been discovered two remarkable spots, in one of which the stream runs with considerable velocity without there being any material rise or fall of the water by the shore, and in the other that the water rises and falls considerably without there being any apparent motion of the stream. Such phenomena are highly curious, and worthy of all the attention that can be bestowed upon the observations.*

The phenomenon known to seamen as tide and half tide, when the tidal stream in the centre of a channel runs for three hours after the high or low water by the shore, has been shown by Sir George Airy to be an effect of the motion of the particles of water in a wave.*

The complications in the tidal rise and fall, and the changes of the stream caused by the passage of the tidal wave into estuaries, round the two sides of interposing islands, as the Isle of Wight, demand much attention and many observations.

Improvements of Charts and Plans.

It will be a long time before the published charts are perfect, and many useful corrections and additions can be made by officers in Her Majesty's ships visiting places that are manifestly imperfectly surveyed.

Such corrections, however, must be forwarded with a sufficient amount of information as to how they were made, or confidence cannot be placed in them.

It is of no manner of use to state that a shoal is much more extended than shown on the chart, without forwarding evidence in the shape of angles to well-marked objects, by which the accuracy of the statement can be tested. Many alterations have been made in charts, on the faith of apparently trustworthy reports, which on future examination have proved to have been anything but improvements. The instrument used, whether sextant or compass, the objects utilised, the angles or bearings of them taken to fix the soundings, rocks, points of land, &c. reported on, should be in all cases given.

Extra soundings where the chart is bare are especially useful, and the nature of the bottom should always be mentioned. Angles taken by a sextant are always better than

* Airy. Tides and Waves. Encyclopædia Metropolitana, Art. 184, 361.

bearings. A compass is rarely used in regular surveys, as the degree of accuracy attainable is much greater with a sextant than with a compass. Especially when making a correction, three angles should be given, a third as a check on the two first. A position given by three angles to well-chosen objects is indisputable, if they intersect in one spot, otherwise there is always room for doubt.

If errors in a published plan are suspected, it is safest to begin by testing the charted positions of well-marked objects, such as sharp points, hill summits, houses, rocks, &c. This can be done in the first instance from the ship, by taking a good round of angles, measuring them all from one object in the centre so far as the range of the sextant will permit. Lay all these down with a protractor on tracing paper, and then, placing this on the plan, see if all the lines will pass through the several objects. In this way a general idea of the correctness of the foundation of the plan will be obtained, but it must be remembered that, if the chart be large, a certain amount of distortion always takes place from the unequal contraction of the paper after printing in a damp state. The mounting on holland, placed at the back to preserve the chart, often adds to this distortion.

If the objects, or any of them, are manifestly wrongly placed, go to them, and take angles at them to the other objects, and then by laying these angles down on the chart it will soon be ascertained which of them are wrong, and new and correct places can be sent in for them.

If the whole plan is so rough as not to stand this test, the only way is to make a new plan from the beginning.

This can often be done by taking the positions of two objects at the extremes of the plan as correct, and, using them as a base, laying down the angles taken from them, first, to other objects, and building the sketch of the new plan upon them in the usual manner.

This article is no place to describe the ordinary method of surveying. It must be assumed that officers know the general principles of constructing a plan. All that is attempted is to give hints on the readiest mode of making a rough plan of a small bay, and to point out the practical means at hand.

In making a survey for purposes of navigation, time is wasted on attempts at an accurate base. More especially, a more or less rough plan, as will generally be made by those not versed in all the details of surveying, nor supplied with all the appliances necessary, does not need it.

A ship is not navigated to yards, and extreme accuracy in the scale is therefore unnecessary. It will always, however, be well to test the distances, and this is most readily done by a masthead angle.

Fix the ship by means of horizontal angles to objects at the water level, and take elevations of the masthead from one or more of them. The distances resulting from these will be quite accurate enough for all ordinary purposes, and a mean may be taken if they do not quite agree. Should the ship be at some distance from the shore, or a plan of some inner bay be required, a base may be measured by one of the following methods.

By measuring the distance between two marks, either set up for the purpose, as extempore flagstaffs or cairns; or natural, as trees, buildings, &c., by means of a lead line or other measured rope.

By measuring with a sextant, on and off the arc, from one end of the base to be used, the angle subtended between the ends of a long pole held up at the other end. In this case it will be found useful to mark the ends of the pole, between which the angle is to be measured, by white paper.

Or two posts, boarding pikes, or boat hooks, can be set up in the ground at a known distance apart, and the angle measured between them from the chosen position, whose distance from one of the posts is to be used as the base. The advantage of this method is the larger base that can be obtained, than that from the angular measurement of a pole. Care must be taken that the pole, or the line joining the two poles, is at right angles to the position at which the angle is observed. The required distance is calculated by considering the pole as the perpendicular, and the distance from it as the base of a right-angled triangle.

The measurement of a base by sound may be had recourse to when the extent of the survey is considerable, and the ground unsuitable for other methods.

Unless it happens to be calm the distance should be measured in both directions.

Land a small gun at two stations, not less than two miles apart, and more, if possible; or the ship may be used as one end of the base.

Observers at either end note the time intervening between the flash and the report, the guns being fired alternately, a certain number of seconds after a preconcerted signal is made, to allow the eye and ear to rest.

When the signal is made, begin to note the beats with the watch to the ear, but not to count until the explosion is seen. Let the next beat be one, and so count until the report is heard. This should be repeated several times, and the number of beats noted at each observation meaned, and turned into seconds, by the number of beats the watch makes in a minute.

Then by the following formula, the mean interval can be calculated

$$T = \frac{2tt'}{t + t'}$$

When T is the mean interval required.
t the interval observed one way.
t' the interval the other way.

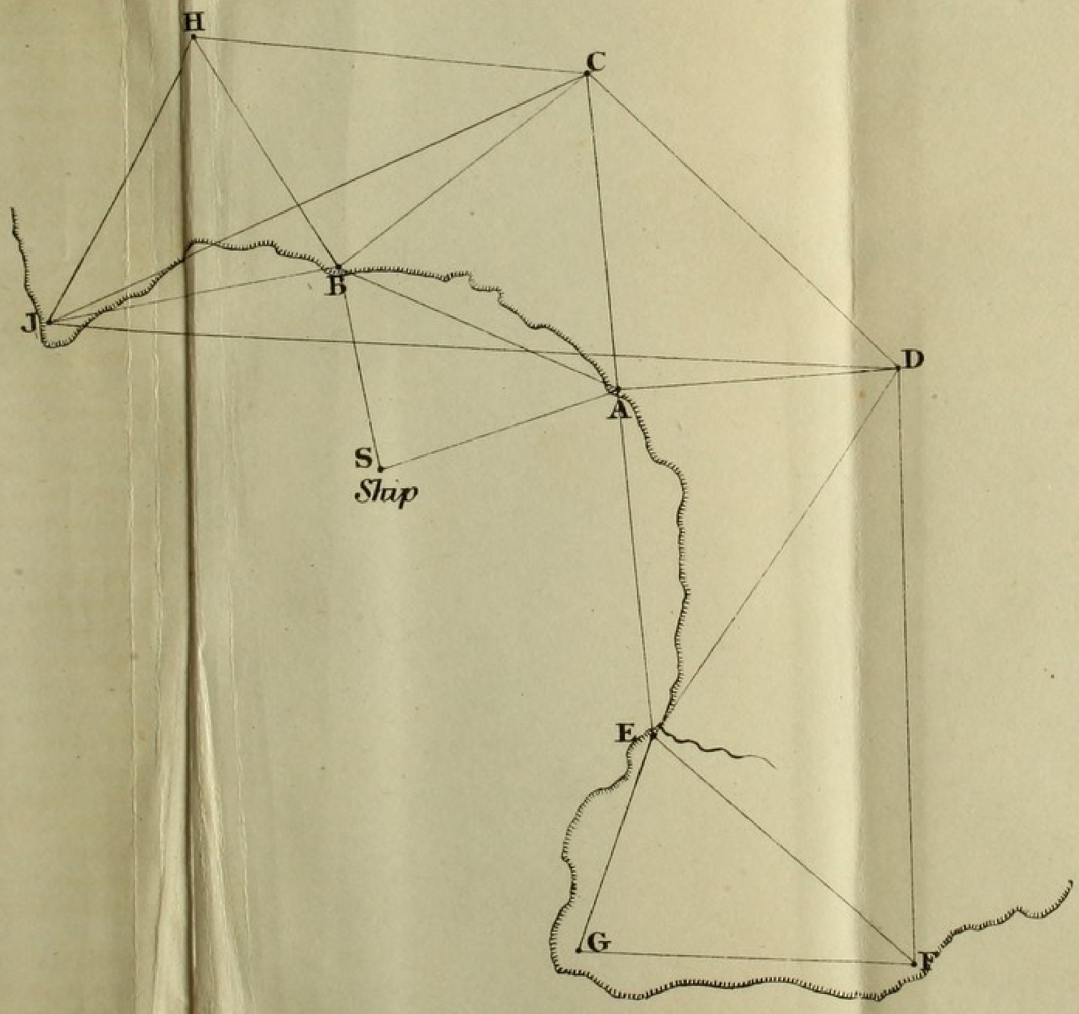
Multiply the number of seconds of this mean interval by the velocity of sound for the temperature at the time, and the result will give the base.

At a temperature of 32° F. sound travels 1,090 feet in a second, and the velocity increases at the rate of 1·15 feet for each degree of temperature above freezing point.

From each end of the base, however measured, take sextant angles between the other end of the base, and other objects, technically called afterwards "points." These angles must be measured in the plane of the horizon. Thus an angle between a tree and the summit of a hill, should be measured between the foot of the tree and a point directly under the summit, in the same plane as the foot of the tree. If the ship has been used as one end, as in the case of a survey based on a masthead angle, the angle from the ship to the "points" must be taken at the same moment as those from the shore end, otherwise the swinging of the ship may introduce unnecessary incorrectness. Angles will then be taken from the "points," between the base ends and other "points" until a skeleton framework is constructed on which to build the plan.

Thus in Plate B, supposing that we use the ship, an observer at A would, simultaneously with another on board, take angles to the other "points" previously settled upon, or set up if no natural marks exist. The observer from the

PLATE B.



DANGERFIELD. LITH. 22, BEDFORD ST. COVENT GARDEN. 11619. 3/86.

ship, who should stand at the foot of the mast, will take all the angles to A; and the observer at A, after carefully measuring the angle between the mast and B, would use B as the fixed point from which to measure all the angles within the limit of his sextant, taking at the same time the elevation of the mast. If another observer can be found for Station B at the same time, the accuracy of the plan will be increased.

In taking angles from the other points, the ship would only be used as a subsidiary object, as she is liable to move.

To plot this, it will be found best to work out by simple trigonometry a larger side than AB, on which to commence the plan. Thus in the triangle ABS, from the measured side AS, find AB. In triangle ABC find AC. In triangle ACD find CD. In triangle CDJ find DJ.

Take this distance DJ as the commencement of your plotted plan, and from the fact of all the other distances being shorter than it, the position of the other "points" will be more correct. C would be first laid down, by drawing by the protractor the observed angles from J and D, and then G from the three positions J, C, and D. The three lines thus drawn from the three "points" to G should intersect, in which case you may feel satisfied your ground work is correct. From these four points all the others may be plotted, using always three lines before you assume a "point" to be settled.

The "points" plotted as above should be marked by small circles on the paper.

These should be transferred to another piece of paper, pinned or pasted down on to a board, so that it can be taken away in the sounding boat, or on shore to put in the coast line, for all information should be put on paper on the spot if possible. Omissions and mistakes are avoided by this method, and the general correctness of the work is much enhanced by it.

The best method of transferring is to lay the original sheet over the other, and prick through the points with a fine needle. In every chart box in the service will be found a sheet showing the symbols and abbreviations adopted in the Admiralty charts. These should be strictly followed, and in plate A are given the usual hydrographic delineations of banks, cliffs, shoals, &c.

The coast line should be walked over, fixing all prominent points, and other positions here and there, by angles, and drawing in the intermediate shore by eye, assisted by angles to the corners and bends, from the fixed stations. Height of the land, rocks, and islets, should not be omitted, and are perhaps best obtained from the ship by sextant angles, measured from the summits to the water line, remembering that when this is nearer than the distance of the sea horizon due to the height of the eye, the dip from the *shore* horizon must be applied, and that therefore it is best to get the angles from a spot as near the water line as possible; as a boat alongside, or the lowest step of the accommodation ladder.

See page 36 for information on obtaining heights.

On the copy forwarded to the Admiralty, all the "points" should be shown, as well as all other information which may tend to show how the work has been done.

For a bearing, objects taken from the standard compass, at the same time that the ship is fixed by the shore objects, will be sufficiently correct, but a time bearing obtained by an angle from the sun when low, observed by the sextant to some other fixed object will give a more accurate result.

This is more likely to be correct if taken at the position of some shore object. The true bearing can be most readily obtained by noting the correct local time at the moment of taking the angle, and, by means of the Azimuth tables, ascertaining the corresponding true bearing of the sun.

Soundings should be fixed by sextant angles to shore objects if possible. If no station pointer is at hand, plot them on tracing paper, and lay them on the plan by its means. Lines of soundings run in all directions from the ship, and fixed by angles of the elevation of the masthead, are easily obtained, and form a good method of correcting a chart, when there is not time to make a regular plan. A bearing of the sounding boat should be taken from the standard compass, at every so many casts, by a preconcerted signal, as dipping a flag. As the position of such soundings depend entirely on that of the ship, her relative position with regard to the shore must be carefully fixed. In all cases lines of soundings should be straight, and, when not steering round the ship, at right angles to the shore.

The nature of the bottom must be carefully recorded every now and then, as the value of the anchorage much depends upon it. When the shape of the bottom is even, it will only be necessary to fix every fifth or sixth sounding, if these are taken regularly, placing the intermediate ones, or a selection of them, between those fixed.

The outermost casts that will be five and three fathoms when reduced to low water, should in all cases be carefully fixed, as they mark the limits of navigable water.

Draw a meridian line through the station from which the bearing was observed, and insert a scale. State in a corner of the plan the length of the base and the means by which it was obtained; the length of the longest calculated side; the nature of tidal observations and the datum to which the soundings were reduced; the means adopted to obtain the true bearing; and any other remarks tending to show how the plan has been generally constructed.

Tidal Observations.

Soundings must always be reduced to low water of ordinary spring tides. To do this it is necessary to know something of the tidal movement.

The scientific and accurate methods of discussing the tides is treated in the next article, but a few words here on the practical means used for observing them, are within the province of hydrography as here treated.

For the ordinary purposes of chart making, a very rough tide pole suffices. This should be marked in feet, and placed erect at some convenient spot just covered by the water at the lowest tide. Stays to keep it in position are indispensable. They may be made fast to boat's anchors, or heavy weights on the seaward side; and to rocks, stakes, or other fixed bodies to landward. Circumstances so differ that it is impossible to state fixed means, but any seaman can improvise methods of securing the pole.

The height of the water must be observed every hour. To get the level of low water springs it is of course best to observe it, but frequently when a small plan is made, the ship may not stay long enough to enable this to be done, and an approximation must be obtained by noting the high water springs mark on the shore, and measuring the height of this above the highest water mark on the day of sounding. Subtract the same amount from the low water shown by the pole on the same day, which will give the mark on the pole corresponding to low water springs.

Frequently the rise at springs will be already known and mentioned on the chart. In this case take the middle height between high and low water on any day on the temporary tide pole. This may be assumed to be the mean water level. From it subtract half the springs rise given on the chart, which will give the mark on the pole corresponding to low water springs, to which all soundings must be reduced.

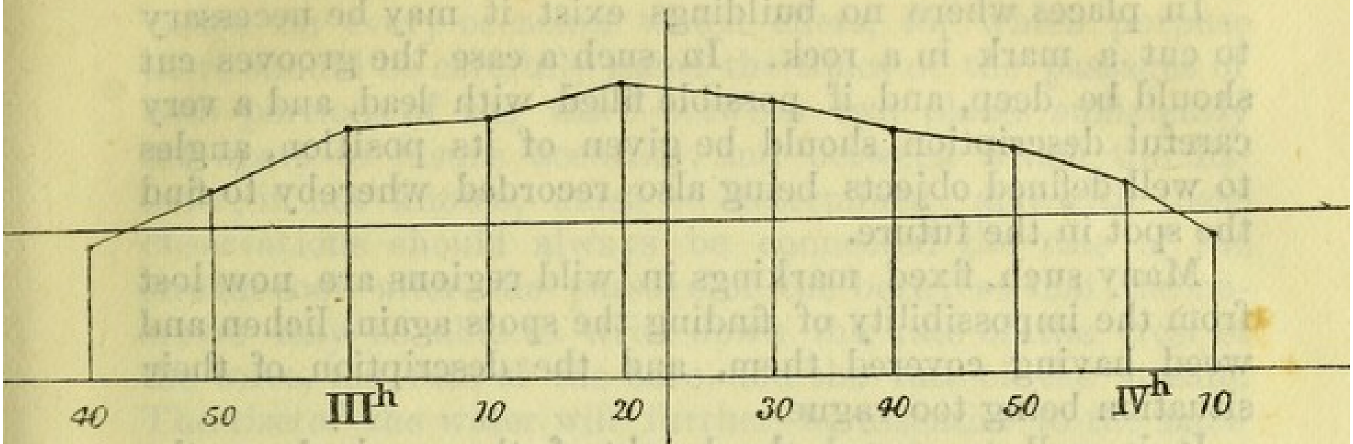
A more accurate method of measuring the height of the tide is to use a tube of some kind, as the wash of the waves is thereby got rid of. A square trunk of board may easily be knocked up, with holes in its lowest part to admit the water freely. A float, either of light wood or hollow metal, carrying a light rod, rises and falls with the water in the tube. This rod may itself be marked in feet painted on it, the numbers working downwards on the rod, so that 0 may be about level with the top of the tube when the tide is low.

In many places where the range of tide is great, it may be found impossible to obtain the observation with a single tide pole, either from the inconvenience of a long gauge, or from the shelving nature of the foreshore. Two poles must then be used, one some distance from the shore, for the lower half of the tide; the other nearer the high water mark.

They must overlap, so that the heights on them at half tide may be compared to carry on the continuous observation. On all occasions when accuracy is desired, it is necessary to observe at night as well as by day, as in many places the height of day and night tides vary, one being the highest at one season, and the other at another. This is known as the diurnal inequality. The watch used must be set to mean time. Equinoctial spring tides always range higher and lower than ordinary springs, and should opportunity have occurred to ascertain the difference, it should be recorded. Soundings should not, however, be reduced to the level of these exceptionally low waters, as they are comparatively rare.

The effect of winds from different directions in raising or lowering the mean level of the water should also be noted. In some places, as in the Rio de la Plata, the fluctuations from this cause are greater than those from the astronomical tides.

To deduce the level and time of high and low water accurately, the height must be observed every 10 minutes near the times of high and low tide. Project these on paper with the times as equal distances on the normal, and the heights, or a portion of the heights, as abscissæ, thus :—



Join the points thus obtained, which will form a rough curve.

Draw a line parallel to the normal cutting the curve. Bisect the distance included by the curve, and drop a perpendicular to the normal, which it will cut at the time of high water. This in the figure will be $3^h\ 23^m$.

The same perpendicular produced to the curve will serve to measure the height of the tide, this being the distance from the normal to the point where the perpendicular cuts the curve.

Wherever a tide pole is set up, a mark should be noted on some neighbouring rock, corresponding to some height on the pole, in order that should the pole be washed down or displaced, it may be again erected at the same level and the continuity of the observations be preserved.

The mean level of the sea is to be obtained by meaning the high and low water heights for each day, and meaning them again for the mean water level.

When a series of observations have been made, the low water datum is found by meaning three or four successive lowest waters of each spring tide, and meaning them again for a general mean.

This should be recorded as being so many feet below the mean water level, and is known as the low water standard of the port.

It should be referred to some fixed mark on the land, by which not only future surveys can be exactly reduced to the same level, but secular movements of the crust of the earth may be detected as years roll by.

This fixed mark should be the most permanent solid object handy, such as the sill of a main entrance to a public building, the coping of a quay wall, &c.

In places where no buildings exist it may be necessary to cut a mark in a rock. In such a case the grooves cut should be deep, and if possible filled with lead, and a very careful description should be given of its position, angles to well defined objects being also recorded whereby to find the spot in the future.

Many such fixed markings in wild regions are now lost from the impossibility of finding the spots again, lichen and weed having covered them, and the description of their situation being too vague.

It is well to record the height of the mark above the mean level of the sea as well as its height above the low water standard, and also the period of the year at which the tidal observations were made to determine such height, as the mean level varies in many places with the seasons.

In a country subject to earthquakes, carefully watch the tide pole during and after the shock, and if any undulations of the water are observed, note them, and the directions whence they proceed.

Be careful never to place the tide pole at the mouth of a river, and especially guard against having it within a bar, sandbank, or other impediment to the free action of the water.

The Bore.

If any place should be visited by that peculiar phenomenon, the bore, a wave which in some places comes rolling in with the first of the flood, with a crest foaming and rushing onward, threatening destruction to boats and even to shipping; note the time of the tide at which it begins, whether there be *one wave* only or more, the height to which it rises, and *where it first* appears with respect to its elevation above or below the mean water level of the ocean, and to any alteration in the feature of the river; and especially note the situation and extent of shoals at or below the spot.

It seems essential to the formation of the bore that there should be first a great rise of tide; hence the reason why this phenomenon is said to occur at spring tides only; and secondly, that there should be an obstruction to the advance of the foot of the tide wave, so that the crest of the wave is rapidly overtaking it. It is desirable, therefore, that we should determine these points by observation on every occasion which offers, for which purpose there should be carefully noted the times of the passages of both portions of the wave between two places sufficiently far apart to insure accuracy, and between which the distance, if not known, must be determined; and with these observations should always be connected the rate of the stream soon after the passage of the bore; so that the observer may be able to write down the rate of the crest of the wave, the rate of the bore, and the rate of the stream. The rise of the water will further be essential to the satisfactory completion of the observation.

Astronomical Observations.

The astronomical positions of many points on the earth's surface are still considerably in doubt, notably in the Pacific.

In obtaining such, it must always be remembered that every sextant has errors besides the index error; errors arising from bad graduation, imperfect centering, injuries by falls, or rough treatment, and from expansion of the metal frame under a hot sun.

These vary with the angles, and in some instruments may amount to as much as two minutes in some parts of the arc.

Unless these are known and attended to, no angle measured by a sextant can be considered as accurate, and hence the necessity, when any nicety is desired, of observing two different sides of the horizon; or otherwise by differential observations, eliminating these errors.

Thus a latitude obtained by a meridian altitude or circummeridian altitude of the sun, however carefully observed, whether in the artificial horizon or to the sea, is always doubtful. The only really correct method of obtaining a latitude is by pairs of stars observed in an artificial horizon, north and south of the zenith, and of nearly similar altitudes. The mean of the latitudes resulting from these are very exact, and the error of the sextant for the angle measured may be derived from such observations, being half the difference of the resulting latitudes by each star of a pair.

Curiously enough the longitude of many places is now more accurately known than the latitude, simply from ignorance of these facts, the sun alone having been observed, with the error of the sextant unknown.

Similarly an a.m. or p.m. altitude of the sun is of little value for obtaining the time, and the sole accurate determination is to be calculated from equal altitudes, or in a less degree from the mean of the errors obtained by a.m. and p.m. observations of nearly equal altitudes. If the existing error of the sextant is known, however, a very fair approximation to the truth can be obtained from single observations of any kind.

The Observatory at Kew is prepared, for a small fee, to test sextants, and to issue a certificate giving the errors at different points of the arc. Everyone who wishes to know the value of his sextant should avail himself of this facility, but it must be remembered that any shock may alter the value of these errors, and that the heat of the sun in tropical countries may introduce a variable error.

When measuring the difference of longitude between two places by means of chronometers, an important point is that the observation for obtaining the time at the two places must be similar, and the sextant and observer must be the same. Thus, though equal altitudes should always be taken, if possible, a meridian distance by a.m. sights at both places should give a good result; but it is useless to take a.m. sights at one end, and p.m. at the other, or equal altitudes at one position, and single sights either a.m. or p.m. at the other.

In such a case the instrumental error might vitiate the result, and no confidence can be placed in such a determination.

It need, perhaps, scarcely be stated, that observations to a sea horizon are all but useless for purposes of the accurate fixing of positions.

Chronometers should always be wound at the same hour and by the same person. The arrangement by which a watch goes while being wound, known as the maintaining power, is sometimes weak, and the watch will lose a certain amount during winding. So long as the same time is daily spent in winding, this does not much matter, as it is included in the regular daily rate, but if wound one day slowly and the next quickly, there may be a difference in the quantity lost, which will affect the rate. The same person will generally wind in the same manner, hence the advisability of one person undertaking this duty.

Rocks and Banks.

If the appearance of a rock, bank, or other danger unmarked on the charts should be encountered, time is never mispent in obtaining a verification of the supposition by closer examination or by soundings. The "vigias" or doubtful dangers which still appear on charts in many parts of the world, are most of them due to reports, which, though apparently circumstantial, and, therefore, not to be wholly disregarded, are not founded on indisputable observations. A very small proportion of them have been found to be correct, and it is much to be regretted that such vague reports still continue to be forwarded. Unless the state of the sea and weather is such as absolutely to forbid a closer examination, no seaman can be considered as having done his duty towards his brother mariners, who neglects to put his suspicions beyond a shadow of doubt.

The configuration of the bottom of the deep sea is an interesting subject, but it is not one that most ships have appliances by which to add to our knowledge of it. It is not, therefore, proposed to enter into the question, as vessels fitted with sounding apparatus have also special instructions on the mode of using it.

All of Her Majesty's ships, however, have sufficient line to enable them to ascertain if banks exist, and as numbers of these reported submarine mountains have been from time to time reported and are still unproved, opportunities may offer for additional evidence to be collected when in their vicinity. Within the last few years several banks have been discovered north of the Canary Islands and off the Strait of Gibraltar, and doubtless more exist. These seldom show any sign on the surface, but the currents are usually abnormal in the neighbourhood, any ripplings or other indications of a strong current may be taken as a token that banks may be near, and a cast of the deep-sea lead to 200 fathoms may be rewarded by striking bottom. It is important in such cases to use heavy leads, as a 28-pound lead with the large line supplied descends so slowly when 100 fathoms is out, that the stern of the ship dipping in the trough of the sea may cause the line to apparently stop, and unless care is taken an erroneous report may be made.

This is especially the case when hove to under sail, and instances have occurred where such false bottoms have been recorded. When lime is used to harden the tallow of the arming, as is frequently done in the tropics, the particles of lime on the surface of the arming, which generally comes up roughened, may easily be taken for evidence that the bottom has been reached.

The vexed question of the formation of coral atolls is one that calls for additional evidence as to the actual steepness of their outer edges.

Darwin's theory of the universal subsidence of the bottom around the coral atolls is now believed to have been founded on inaccurate reports of this steepness. A reef that appears to be, from a deep cast at what seems a very short distance, almost perpendicular, will often be found, where the depth and distance are drawn as a diagram on equal scales of distance and depth, to have no very extraordinary angle of slope.

Thus a sounding of 100 fathoms a cable from the edge of a reef, which will appear on board a ship to be a very short distance, only gives an angle of 45°, a slope not unknown on land.

Sectional lines at right angles to the coral wall, with soundings at every 10 yards or so, will throw much light on the subject, giving especially the nature of the bottom at each cast.

Obtaining Heights; and Distance from known Heights.

The height of a mountain above the sea cannot be obtained by simply calculating a right-angled triangle, as the true angle of elevation, being measured from a tangent to the earth's surface at the place of the observer, will only give the height above the spot where that tangent cuts the vertical line dropped from the summit of the mountain.

The portion of the vertical line between this spot and the surface of the earth must, therefore, be added to the perpendicular obtained from the solution of a right-angled triangle, where the base is the distance and the true angle of elevation the angle. The correction, known as the dip in feet, is calculated from the following formula :—

$$\text{Dip in feet} = 0{\cdot}8815\, d^2$$

d being the distance in sea miles.

A table of dip in feet is given in appendix.

To obtain the true angle of elevation, the observed altitude must be corrected for the ordinary angular dip for the height of eye, and also by subtracting a quantity of $\frac{1}{12}$ the distance in miles, to allow for refraction.

Thus, given the angle of elevation of a mountain whose distance is known to be 15 miles, measured by a sextant on and off the arc to the sea horizon, from a ship, height of eye being 18 feet = 0° 41′ 15″.

log 6075 (feet in a sea mile) - - -	3·783546
log 15 (distance in miles) - - -	1·176091
log tangent 0° 35′ 49″ (elevation $-$ dip $-\frac{\text{dist}}{12}$)	8·017220
	948 = 2·976857
Dip in feet for 15 miles + 198	
Height of mountain = 1146 feet.	

To obtain a distance from the angle of elevation of a mountain whose height is known, the simplest method is to utilise a table given in Raper's Navigation (Table 8).

The formula is—

Distance = $\sqrt{\text{True depression}^2 + \text{elevation in mins}^2} - \text{elevation in mins}$.

The altitude must be corrected for refraction, as above, for the estimated distance. Should this prove very erroneous the calculation must be repeated. The true depression squared is taken out directly from the table, which can also be utilised to obtain the square of the elevation, to save the trouble of multiplying.

Working out the same example as above, reversed :

True depression² for 1146 feet -	1296
Elevation ² = (35·8)² - .. -	1282
	2578
Square root -	50·8
Elevation -	35·8
Distance =	15·0 miles.

Works for reference on Nautical Surveying.

1. Practical Notes on Marine Surveying and Nautical Astronomy, by Captain R. C. Mayne, R.N., C.B.
   J. D. Potter, 31, Poultry. 1874.
2. An introduction to the practical and theoretical study of Nautical Surveying, by J. K. Laughton, M.A.
   London, Longmans, Green, & Co. 1872.
3. Practical Nautical Surveying, by Staff-Commander J. A. Hull, R.N.
   Lecture delivered at United Service Institution. 1872.
4. Hydrographical Surveying, a description of the means and methods employed in constructing marine charts, by Captain W. J. L. Wharton, R.N.
   London, John Murray. 1882.
5. Report of the scientifie results of the voyage of H.M.S. "Challenger" during the years 1873–76. Narration. Vol. I., First and Second Parts.
   H.M. Stationery Office.

American Works.

Nautical Surveying, by Commander W. N. Jeffers, U.S.N., Van Nostrard, New York.

Deep Sea Sounding and Dredging, by C. D. Sigsbee, Lieut.-Commander United States Navy.
Washington, Government Printing Office, 1882.

APPENDIX No. 1.

Coasts and Islands of which our Hydrographic Knowledge is imperfect.

Abstract from a Return made to the House of Commons, 10th February 1848, from the Hydrographic Department of the Admiralty.

"There is wanted a critical examination of the eastern islands of the Mediterranean, along with the coasts of Syria and Egypt, and as much of the northern shore of Africa as would meet the French survey, which, having commenced with Algiers and Morocco, will very probably be continued along Eastern Barbary and Tunis. (*a*)

"From the Strait of Gibraltar the western coast of Africa has been sufficiently surveyed and published as far as Cape Formosa, in the Bight of Benin; but as there is much legitimate traffic in the eastern part of that great Bight, as well as further to the southward, both it and many of the ports and anchorages on this side of the Cape of Good Hope require a more careful and connected examination.

"The charts of the whole of the Cape Colony are exceedingly defective, and from thence to the Portuguese settlements of Delagoa we know scarcely anything. (*b*)

"From Delagoa to the Red Sea and the whole contour of Madagascar are sufficiently represented on our charts for the general purposes of navigation, though many further researches along the former coast might still be profitably made. (*c*)

"The Red Sea, part of the coast of Arabia, the Gulf of Persia, and many detached portions of the East Indies, have been already executed by the Company's officers; and no doubt it is intended that the coasts of Malabar and Coromandel shall soon be undertaken by the same hands. The long Malay Peninsula and the Strait of Malacca will require much time and skill to complete, and to combine with each other those parts that have been surveyed. (*d*)

"With the China Sea we are daily becoming better acquainted, but much is still to be done there; for probably not one of the multitude of rocks and shoals with which it is almost covered is put exactly in its right position; and while some are repeated two or three times, others have been omitted. (*e*)

"On the coast of China the charts are excellent from Canton round to the mouth of the great river Yang-tse-Kiang; but of the Yellow Sea we know very little, and still less of the Korea, Japan, and the coast of Tartary, and up to the confines of the Russian empire. (*f*)

"The southern passages into the China seas have never been examined with the care they deserve; and all that is known of what are called the eastern passages through the great Malay Archipelago are only the results of the casual observations and sketches made years ago by industrious seamen. (*g*)

"The islands and surrounding shores of the Arafura Sea, if better known, would offer many ports of refuge, and probably an increased opening to commercial enterprise.

"The Strait of Torres has been satisfactorily surveyed; but before it becomes the great highway for steam vessels to and from Sydney, its approaches, and also its contiguous coasts of New Guinea, should be more intimately known. (*h*)

"The whole circuit of the great island of Australia has been well explored, and the general characteristics of its several shores are sufficiently known for all general purposes; but far more minute surveys of its immediate waters and maritime resources must precede their being inhabited, beginning with the eastern coast, along which the tide of colonisation seems to be already creeping.

"The shores of Tasmania, in like manner, are but very roughly laid down, and even to this day there is no chart of the harbour and entrance to Hobart Town, its capital and principal seat of trade.

"A full survey of New Zealand has just been commenced, and will no doubt answer all the wants of both the settler and navigator. (*i*)

"In advancing to the eastward across the Pacific Ocean, there are many groups of islands with which our merchant vessels have occasional traffic, or in which the whaling vessels refit, and which ought, therefore, to be more efficiently examined.

"On the opposite side of the Pacific some progress has been made in surveying the coast between the Russian territory and the Strait of Juan de Fuca; but with the long interval between the Oregon district and the entrance of the Gulf of California we are very superficially acquainted, and but little is known of the interior of that extensive Gulf. In the present state of those countries it does not appear necessary to push our survey into their inner waters; but there can be no doubt that the coasts of Mexico, Guatemala, and New Granada, which contain many valuable harbours and innumerable trading ports, ought to be minutely and connectedly surveyed. (*k*)

"From the Equator to Cape Horn, and from thence round to the river Plata, on the eastern side of America, all that is immediately wanted has been already achieved by the splendid survey of Captain (now Rear-Admiral) Robert FitzRoy.

"Some parts of the great empire of Brazil we owe to the labours of Baron de Roussin and of other French officers; but there is much yet to be done on that coast between the Plata and the Amazon rivers, and again along Guayana and Venezuela up to the mouth of the Orinoco.

"The shores of the mainland between Trinidad island and the Gulf of Mexico have been charted and published by the Admiralty; but many of the West India Islands are still wanting to complete a wholesome knowledge of those seas. (*l*)

"The United States are carrying on an elaborate survey of their own coasts; and to the northward of them a part of the Bay of Fundy has been done by ourselves, as well as all the shores of Nova Scotia, Canada, and Newfoundland; and when these surveys are finished, we shall only want to complete the eastern coast of America, those of Labrador and of Hudson Bay, which, being in our possession, ought to appear in our charts with some degree of truth." (*m*)

As it is impossible here to open the question of the positions of the multitude of islands, of the Pacific especially, the apparent number of which has been so greatly increased by the errors of observation of navigators who have reported them, we can only recommend to the observer the propriety of fixing astronomically every island which he may fall in with, and to note any peculiarity by which it may be identified hereafter.

F. Beaufort.

Supplement to the Appendix No. 1, by the late Admiral Washington. 1858.

Ten years having elapsed since the above Memoranda were written, a few corrections become necessary, without, however, entering into details.

a. In the Mediterranean all the eastern islands are surveyed, with the exception of Scarpantho and Caxo and the surrounding islets and rocks. The coast of Syria, with the exception of the Gulf of Iskanderún, is still unsurveyed. That of Egypt, from El Arish westward to Alexandria, has been mapped and published. The northern part of the Dardanelles, the Bosphorus, the islets west of Sicily, as Maritimo, &c., and the Balearic Isles, still require to be surveyed.

b. In the Cape Colony the coast from Table Bay to Cape Agulhas, with Algoa Bay and Port Natal, have been surveyed. The rest of the coast, as far as Delagoa Bay, remains as before.

c. The islets and dangers off the north-west, north, and north-east of Madagascar, from the Comoro Isles to Diego Garcia, require to be examined.

d. In the Gulf of Persia the longitudes are very vague. The east and south coasts of Ceylon require examination, as well as the Andaman and Nicobar Islands, and from St. Matthew Isle, in 10° N. lat., to Prince of Wales Island. The coasts of Malabar and Coromandel are all but completed by the officers of the Indian Navy. The Straits of Malacca and Singapore have also been surveyed, as well as those of Rhio and Durian. The east coast of Sumatra, from Malacca Strait to Sunda and Banca Straits, requires examination.

e. Java, and all the islands eastward, including Timor, with the Java Sea, Flores Sea, with the south coast of Borneo, Celebes, &c., and the islets and rocks in that region, have been partially examined by the Dutch, but no regular survey has been made. The west coast of Borneo, from Tanjong Api southwards to Sambar Point, has not been surveyed, nor have the islands and passages from the Strait of Gaspar to the Natunas. The west coast of Borneo, from Tanjong Api northwards, and Paláwan Island, have been surveyed, as well as the east coast of the Malay Peninsula and the Gulf of Siam. Cochin China with some trifling exceptions, a part of the coast of Haïnan, and the whole of the Gulf of Tonking, may be considered as unknown.

f. Some detached portions of the coasts of Korea and Tartary, and of Japan, and some few of their harbours, have recently been examined; but of the coast of China northward of the Yang-tse-Kiang, the gulfs of Pechili and Liatung, we still know very little.

g. The Spaniards have surveyed a portion of the Philippine Islands, and the Dutch have made some partial surveys; otherwise the eastern passages remain as before.

h. The outer dangers off the east coast of Australia, in what is termed the Coral Sea, require careful examination.

i. The survey of New Zealand has been completed, and charts of the coast and plans of all the ports, with ample sailing directions, are published.

k. The Strait of Juan de Fuca, and the channels between Vancouver Island and the mainland of British Columbia and Oregon, have been surveyed by England, and the coast thence to the Gulf of California by the United States.

l. The coast from the Gulf of Campeche to Texas has never been examined. Cuba, Jamaica, St. Domingo, and Puerto Rico have been partially examined, but are very far from being completely surveyed. The islands from Guadaloupe to Tobago, inclusive, with the exception of Martinique (which has been surveyed by France), require surveying.

m. The Bay of Fundy is all but completed, and the shores of Nova Scotia are in rapid progress. Newfoundland still remains only partially surveyed.

Second Supplement to the Appendix No. 1, by the Hydrographer, Rear-Admiral G. H. Richards, 1871.

During the 12 years which have elapsed since this work was last revised (1859), great advance has been made in maritime exploration; and the present condition of our Hydrographical knowledge may be briefly summed up as follows :—

In the Mediterranean, the coasts of Syria and the Eastern Archipelago have been completed; as also the shores of Tunis and Tripoli; and little is left to complete an accurate knowledge of this sea in as far as the wants of navigation are concerned.

But little has been added to our knowledge of the Western seaboard of Africa, with the exception of the approach to and bars of the principal oil rivers, and a reconnaissance of some of their upper waters by the annual naval expeditions which ascend these rivers for the protection of commerce.

The coasts of the Cape Colony, from Orange River on the West to Algoa Bay on the East, have been almost completed, and with an accuracy and minuteness which leaves nothing to be desired.

Of the Eastern coast of Africa, as far as the entrance of the Strait of Babelmandeb, and of the Island Madagascar, little has been added to our knowledge for the last 40 years; and the same may be said of most of the groups of islands between Madagascar and the Western coasts of Hindostan.

The Red Sea is very fairly known, but the more intricate portions of it are at present undergoing a minute examination, consequent on the opening of the Suez Canal and the stream of commerce which has set in that direction.

The coasts of Arabia, Hindostan, and Bay of Bengal, eastward to the Malay Peninsula, have been sufficiently surveyed for the purposes of navigation, and the positions of the Andaman and Nicobar Isles have been recently rectified.

Of Sumatra, with the exception of that portion of it which forms the Western side of Malacca Strait, we have but a general knowledge.

Java has been fairly surveyed by the Dutch, as also the chain of islands eastward to Timor, but a more correct knowledge of these islands, as well as the various groups which stud the Flores and Arafura Seas, is very desirable.

The coasts of China as far North as the Gulf of Pechili, the various passages leading into the China Sea by Sunda Strait and the Strait or Malacca, the Western coast of Borneo and Palawan, the Gulf of Siam, and especially the dangers which encumber this extensive sea itself, have engaged the attention of English surveyors consecutively for the last 30 years, and this vast work, with some few exceptions, has been sufficiently completed to provide for the safety of the world's commerce.

The French have also added to our knowledge of Cochin China, but the Gulf of Ton-King and the Island of Haïnan with portions of the coast between it and Hong Kong are still but partially explored.

The Korean Peninsula is almost unknown, but with the coast Northward in the Russian Territory as far as the Amur River, and the Western coasts of Saghalin, we have a better acquaintance.

Rapid strides have been made within the last few years in the examination of the coasts of Japan; the treaty ports have been surveyed, together with the more important portions of the great Inland Sea, and a survey under the conduct of English officers is being vigorously prosecuted at the special request of the Japanese Government, and with their co-operation.

The Eastern coasts of Borneo with the Northern shores of Celebes, the Sulu and Celebes seas, and the various channels leading from them into the China and Java seas, and Eastward into the Great Pacific, are but imperfectly known and are full of dangers. The Spaniards, however, are carrying on a systematic survey of their possessions among the Philippine Islands, and an English surveying vessel is employed in the Southern portion of these seas, and the time is probably not distant when these great highways will be free and open to the commerce of the world.

The great Island of New Guinea, with its surrounding groups, excepting in the neighbourhood of and eastern approach to Torres Strait, may be said to be a blank; we have, with the exception stated, scarcely anything beyond its general configuration depicted on our charts.

With the coasts of Australia we are rapidly becoming better acquainted; during the past 10 years systematical surveys have been in progress by officers of the Royal Navy. The coast of the colony of New South Wales has been completely and accurately surveyed; Queensland, from Cape York to its Southern boundary, is rapidly being completed with similar accuracy. The coasts of Victoria and South Australia are making fair progress.

On the North, between the Gulf of Carpentaria and Port Darwin, additions to our knowledge have been made by exploring parties undertaken for the purposes of settlement by the colony of South Australia; still we have but a very general knowledge of the Hydrography of this portion of Australia, and, indeed, with exceptional portions here and there which are colonized the same may be said of the whole of Western Australia. And in regard to the Great Australian Bight between Cape Leeuwin and Spencer Gulf, little has been added to the surveys since the time of Flinders.

The Coral Sea, or what is termed the outer passage between Australia and the Indian Ocean, has undergone examination, and most of its numerous and dangerous reefs which have proved fatal to so many ships have been correctly placed on the charts.

In Tasmania but little has been done in the way of accurate surveying, and, with the exception of the principal port and seat of government, the whole coasts of the island are as yet rudely laid down on the charts.

The Islands of New Zealand have been completely surveyed at a comparatively modern date, and are sufficiently known for all the requirements of navigation; though as the remoter portions of its extensive coasts become peopled and opened up to commerce it is possible that more minute and critical surveys of those parts may become necessary.

Of those vast groups of islands and coral reefs which cover the whole of the western portion of the Pacific Ocean between the parallels of 30° north and 30° south, with comparatively few exceptions, our acquaintance with them has been at a standstill for nearly half a century. England and America have mapped the Fiji group and made partial examinations of others. The French have explored great portions of New Caledonia, and passing ships of all the maritime nations have done something towards fixing the correct geographical positions of individual islands, but that of far the greater number are uncertain, and have, moreover, doubtless been increased in number by errors of observation.

A great work remains to be done here, which might well and profitably occupy the attention of more than one maritime country, now that a considerable and increasing commerce is opening up between the Australasian Colonies and many of these groups, and a line of powerful passenger steamers has been established between the former and the United States possessions in Western America.

Crossing over to that continent, we find that Vancouver Island has been accurately surveyed, and the whole of the coast line of British territory sufficiently examined for the purposes of navigation, while the same may be said of the coast of California as far as Cape St. Lucas, the southern termination of the peninsula.

Of the Gulf of California itself our knowledge is still very deficient.

Of the Western coasts of Mexico, Central America, and the various republics southward of the Equator, we possess a fair general knowledge, probably sufficient for the purposes of commerce and navigation; and an entirely new and accurate survey has just been completed by this country of the Strait of Magellan, and the inner channels as far north as the Gulf of *Peñas* on the West.

The Falkland Isles are well known, and the whole of the Eastern coasts of South America, as far as the Amazon, have been fairly mapped, principally through the labours of English and French explorers.

The coast of Guyana, however, with the shores extending Westward along Honduras, Campeche, and the Gulf of Mexico, would, with exceptional portions, bear a much closer examination.

The coasts of the United States and those of the British Possessions in Canada, including the Gulf of St. Lawrence to the Strait of Belle Isle, are all accurately and indeed minutely surveyed; to the Northward of this, though some examinations and rectifications have been made lately, the coasts are but imperfectly known.

The coasts of Newfoundland have been for some years and are still undergoing a strict examination by this country; and the French have also made some valuable surveys of portions of its Western shores.

In the West Indies, the Caribee or Windward Islands, from the Virgin Isles to Trinidad, including the Gulf of Paria, have been for the most part minutely surveyed by the English; Guadaloupe and Martinique by the French; but Porto Rico, St. Domingo, and Cuba are by no means so well known as they should be; while even our own Island of Jamaica is far from being as accurately surveyed as its importance demands.

Any outline of the progress of Hydrographical knowledge during the past few years would be incomplete without some brief allusion to the researches which have been made in the

Physical Geography of the bed of the ocean during the same period.

With the introduction of submarine telegraphy came the necessity for an accurate knowledge of the depth, character, and temperature of the bed of the sea.

The want of success, or the very partial success which had hitherto attended the many efforts of our best navigators to throw some light on these subjects, fraught with so much importance to many branches of scientific inquiry, may be said to have been entirely owing to want of means and appliances; but when the practical necessity for such information became apparent, the ingenuity of the mechanist and the skill of the seaman combined, aided by the all powerful application of steam, soon removed all difficulties, and at the present day it is not unusual to see our surveying vessels going forth armed with some hundred thousand fathoms of line manufactured expressly for the occasion, many tons of iron and lead to carry it swiftly to the bottom, there to be deposited, and above all the steam-engine, to recover, almost as rapidly as it descended, the line released from its ponderous weight, but bringing back with it undeniable evidence of the success of the operation in the shape of specimens of the bed of the ocean in sufficient quantities to satisfy even the investigations of the naturalist. In this manner the depth of the Atlantic has been accurately measured between Great Britain and the Continent of America by three different routes, as well as longitudinally from the Cape of Good Hope by St. Helena and Ascension to the British Channel, likewise the Mediterranean between Gibraltar and Alexandria, the Red Sea between Suez and Aden, thence across the Gulf of Arabia to Bombay, and from the Eastern shore of Hindostan to the Strait of Sunda. The greatest depth attained was in the South Atlantic, at two thousand nine hundred fathoms, or about three and a quarter statute miles; and although this is probably considerably under the extreme depth of the ocean, yet the comparative ease with which it has been reached, and the unfailing success which has attended all the recent operations, leave little room to doubt that the great Pacific and Indian Oceans will yield up their secrets, when the time arrives, with equal facility and the same satisfactory results.

The temperature of the ocean bed was found to be a point of scarcely less importance to submarine telegraphy than its exact depth and character, and some anomalies in former temperature experiments having led to the belief that the registration of the minimum thermometer was considerably affected by pressure at great depths, a series of experiments were made by means of a hydraulic apparatus, which confirmed this belief, and an ingenious invention to counteract the effects of pressure, by the late Professor W. A. Miller, was applied to all the thermometers used in subsequent experiments, with the most perfect success. The description of these experiments, as well as an account of the results of the expeditions undertaken in 1869–70 for the investigation of sea bed of the Atlantic and Mediterranean, will be found in the Proceedings of the Royal Society, 1870–71.

Third Supplement to Appendix No. 1, containing a Brief Statement of our Hydrographical Knowledge of the Coasts of the World in 1885.

Great as has been the advance in the publication of accurate charts of the globe made since the last revision of the Admiralty Manual in 1871, the needs of navigation have increased more rapidly.

Steam power, which renders it possible for vessels to approach coasts so much more closely than was deemed safe with sailing ships, is now becoming the means of communication with nearly all parts of the world. One immediate consequence has been that as steamers, in the race for time which has accompanied their multiplication, hug the shore, and habitually turn sharply round points which formerly were given a wide berth, the necessity for more detailed and minutely accurate charts has arisen, and many surveys which 30 years ago were deemed excellent are now inadequate.

Thus, though many shores are still but very vaguely charted, re-surveys of coasts already fairly known are proceeding everywhere, in the interests of vessels traversing the main lines of commerce.

The charts of many parts of the United Kingdom are thus now becoming obsolete, and it demands all the exertions of the naval staff available, added to local enterprise, to keep pace with the changes of depth and shifting of banks which are so continually taking place in many places.

The surveys of the coasts of Norway have been improved, but the labyrinth of rocky fiords is not yet delineated in full detail.

The same may be said of all the Baltic shores. The seaboards of Holland, Belgium, and France are well laid down, but they require and are more or less receiving constant correction.

The Spanish and Portuguese coasts cannot be called well surveyed.

In the Mediterranean the more minute character of the former surveys leave less to be desired than in most other seas. Sicily has been completed, and the Italians are re-surveying parts of Italy which require more detail. The Sea of Marmora and the Dardanelles have been re-surveyed, and the only portions more immediately requiring re-charting are the northern shore of the Ægean Sea, and the south coast of Asia Minor.

Little has been done on the West Coast of Africa, where the northern part, little frequented by ships, has not called for attention, though it is but roughly delineated.

The Cape Colony is well supplied with charts, and from the northern boundary of British territory in South-east Africa to the northward along the east coast surveying has been active. The Portuguese coast has been improved and the principal ports re-surveyed. The territories of Zanzibar have received much attention, though parts north of Pemba still remain to be more accurately done. Madagascar remains nearly as it was, and though most of the outlying islands in the Indian Ocean have been re-charted, a few, as the Seychelles group, with the large bank on which they lie, require further examination.

Much has been done in the Red Sea, all by English vessels, and as far as the main route of commerce is concerned, the charts can scarcely be improved. The intricate Gulf of Suez, the Musawwa Channel, the Southern portion of the Red Sea, and the principal harbours with their approaches, have all been re-surveyed in great detail during the past 15 years, but the shores of the centre portion with the outlying reefs are still insufficiently known for safe navigation.

The charts of our Indian possessions have received many improvements, but in many parts the shifting nature of the foreshore requires more re-charting, which is, however, rapidly proceeding.

Though much has been done in the Straits of Malacca, a re-survey of the whole is still wanted.

Hydrographic knowledge of the eastern shores of Asia and the China Sea has advanced considerably. Most of the dangerous banks are now known, and the Chinese coast has had British surveying ships continually upon it. Much, however, yet remains. Parts of the Tonquin coast have been re-surveyed by the French. The Dutch Archipelago is still imperfect, though many additions have been made, but these have not been of a detailed character. The Gaspar and Carimata Straits, through which much traffic passes, have, however, been fairly charted by the Dutch and ourselves.

Further eastward, on the route from Australia to Hongkong, many charts have been made, but this intricate region will demand many years work to complete.

Surveys of the Korean shores, especially on the western side, have been made, but not as yet in much detail; sufficient for present traffic has, however, been completed.

Japan is now as well charted as most parts of the world. Japanese surveyors are now constantly at work, and their surveys will compare favourably with any. Detailed surveys of the parts still imperfectly known are in rapid action.

Western New Guinea remains as it was, very imperfect. On the eastern and southern shores English surveys are in progress, and have already added much to our knowledge.

In Australia, the South Australian, Victorian, and New South Wales coasts may be considered good, but a re-survey of Bass Straits is now in progress. The inner route on the Queensland coast has been in many parts re-surveyed, and a vessel is now working at unfinished portions. The whole of the northern part of this now frequented route, however, still demands more minute charting. From Cape York westward to Cape Leeuwin our knowledge is very slight. A survey of the Western Australian shores has been, however, in progress for some years, and of the more frequented parts good charts are now in existence.

The Coral Sea is now demanding attention, as the trade rapidly springing up between Australia and the islands to the North-east requires in these days a more direct route than that known as the outer passage. This it is hoped will shortly be provided.

In Tasmania much still remains to be accomplished.

Nothing has been recently done to New Zealand, except some harbours, but the former surveys are still good for present requirements.

In the immense area of the Pacific the work that has been done is a mere drop in the ocean compared to that which is to come. Nevertheless, progress has been made. Fiji is accurately laid down. Parts of the Solomon Islands have been well done. Harbours and bays in many islands have been planned, and the position of many groups has been rectified. Many doubtful dangers still stud the charts, but it is believed that there are now few islands whose existence is uncertain, which is a great advance.

The British possessions in Western America are with few exceptions well charted, and the United States is doing much to improve the charts both of their own shores and those of Mexico.

Few of the harbours of Western South America can be considered as equal to modern requirements, and the shores are very imperfectly laid down. The work of the late Admiral FitzRoy still remains as the backbone, but wonderful as it was, considering his time and means, is not now sufficient.

The re-survey of the main Strait of Magellan is now completed, but the Patagonian Channels, though passed through by steamers continually, cannot, save in certain parts, be considered as well surveyed, though much has of late years been added.

The eastern shore of America to the Rio de la Plata has scarcely been touched since 1830, and are imperfect. The Rio de la Plata is, notwithstanding much recent work, not yet finished.

To the north the shores are probably sufficiently known for present needs, but are by no means accurately laid down, until the British Colony of Guiana is reached, and even here a re-survey is now proceeding.

The West Indies are probably as well charted as any part of the world, but in places, as parts of Cuba, St. Domingo, Porto Rico, Curaçoa, and parts of Venezuela, Honduras, and Central America generally, require more detail.

Jamaica and the northern Bahamas have been recently re-surveyed and are now well known.

The minute coast survey of the United States is still proceeding, and has produced admirable charts, but modern needs in many places have not yet been served.

The shores of British possessions in Eastern America are fairly well known, and Newfoundland is nearly complete except on the western coast. The much traversed St. Lawrence is now being minutely examined below Quebec.

Labrador has received many additions, but this rock-studded shore is still but badly laid down as a whole.

In the Arctic regions additions have been made by British and American expeditions in Smith's Sound and on the northern shores bounding the Arctic Sea.

Franz Josef land has been added to the charts, and the voyage of the "Eira" has improved the knowledge of northern Asia.

Our knowledge of the Antartic lands has not been increased.

The greatest advance made in any branch of hydrography during the past 15 years has been in our knowledge of the configuration of the deep sea bottom. The ships of several nations, notably of the United States and of England, have been employed in deep sea sounding in various parts of the world to such an extent that the general character of the shape of the great ocean basins is no longer conjectural.

The scientific voyage of the "Challenger" will always be notable, not only from the vast amount of information gathered in many branches of science, but as marking an epoch when the desirability of making such observations was first fully recognised by the State. It is not too much to say that there is no branch of physical science that was not the gainer by this voyage.

The necessity for the extension of submarine telegraphs has also added many deep sea soundings to our charts, and these, taken by the different telegraph companies, have always been accompanied by records of temperature, and character of the ocean bed.

All surveying vessels are continually adding to these observations, but the vastness of the field and the continual demand for more accurate knowledge still leaves much to be accomplished.

APPENDIX No. 2.

The number of Miles or Minutes of the Equator contained in a Degree of Longitude under each parallel of Latitude for the Spheroid, Compression $\frac{1}{304}$.

Lat.	Length of Degree.	Lat.	Length of Degree.	Lat.	Length of Degree.
°	′	°	′	°	′
0	60·000	31	51·475	61	29·161
1	59·991	32	50·930	62	28·240
2	59·964	33	50·370	63	27·310
3	59·918	34	49·793	64	26·372
4	59·854	35	49·202	65	25·426
5	59·773	36	48·596	66	24·471
6	59·673	37	47·975	67	23·509
7	59·556	38	47·339	68	22·540
8	59·419	39	46·688	69	21·564
9	59·266	40	46·021	70	20·581
10	59·094	41	45·346	71	19·592
11	58·905	42	44·654	72	18·596
12	58·697	43	43·948	73	17·595
13	58·472	44	43·229	74	16·588
14	58·229	45	42·495	75	15·577
15	57·968	46	41·750	76	14·560
16	57·690	47	40·992	77	13·539
17	57·394	48	40·220	78	12·514
18	57·081	49	39·437	79	11·485
19	56·751	50	38·642	80	10·452
20	56·403	51	37·834	81	9·416
21	56·038	52	37·015	82	8·377
22	55·657	53	36·185	83	7·336
23	55·258	54	35·343	84	6·292
24	54·842	55	34·400	85	5·246
25	54·410	56	33·627	86	4·199
26	53·962	57	32·754	87	3·150
27	53·496	58	31·870	88	2·101
28	53·015	59	30·977	89	1·050
29	52·518	60	30·074	90	0·000
30	52·004				

APPENDIX No. 3.

Table of Dip in Feet.

Calculated for length of mile=6,060 feet. Dip=d^2 0·8815; d=dist. in miles.

Distance.	Correction.	Distance.	Correction.	Distance.	Correction.	Distance.	Correction.
Miles.	Feet.	Miles.	Feet.	Miles.	Feet.	Miles.	Feet.
1	0	13½	160	20	352	29	741
1½	1	13¾	166	20¼	361	30	793
2	3	14	172	20½	370	31	847
2½	5	14¼	178	20¾	379	32	902
3	7	14½	185	21	388	33	959
3½	10	14¾	191	21¼	398	34	1,019
4	14	15	198	21½	407	35	1,080
4½	17	15¼	204	21¾	416	36	1,142
5	22	15½	211	22	426	37	1,206
5½	26	15¾	218	22¼	436	38	1,273
6	31	16	225	22½	446	39	1,340
6½	37	16¼	232	22¾	456	40	1,410
7	43	16½	240	23	466	41	1,482
7½	49	16¾	247	23¼	476	42	1,555
8	56	17	254	23½	486	43	1,629
8½	63	17¼	262	23¾	497	44	1,706
9	71	17½	269	24	507	45	1,784
9½	79	17¾	277	24¼	518	46	1,865
10	88	18	285	24½	529	47	1,947
10½	97	18¼	293	24¾	539	48	2,031
11	106	18½	301	25	550	49	2,116
11½	116	18¾	309	25¼	561	50	2,203
12	126	19	318	25½	573	51	2,292
12½	137	19¼	326	26	595	52	2,383
13	148	19½	335	27	642	53	2,476
13¼	154	19¾	343	28	691	54	2,570

ARTICLE III.

TIDES.

By G. H. DARWIN, LL.D., F.R.S.

Plumian Professor of Astronomy in the University of Cambridge.

I.—Introduction.

The object of the present article is to show how the best use may be made, for scientific purposes, of a short visit to any port.

We refer to the article "Hydrography" for an account of the method of observing the tides, and shall here assume that the height of the water above some zero mark may be measured, in feet and decimals of a foot, at any time, and that the zero of the tide gauge may be referred by levelling to a bench-mark ashore.

Something of the law of the tide might be discovered from hourly or half-hourly observations even through a single day and night, but to discover the law at all adequately it is necessary that the observations should embrace at least one spring tide and one neap tide. For the full use of the methods given below, the observations should be taken each hour for 360 hours, or 720 hours. A longer series must be regarded as a new set of observations, and the means of final results taken.

It has been usual to recommend observations of the times and heights of high and low water, but hourly observations are far preferable, the hours being reckoned according to mean time of the port.

We shall, however, begin by a sketch of the treatment of observations of high and low water, and shall then give more detailed instructions for hourly observations and the formation of a tide table.

The height of the water is subject to considerable perturbation from the weather, and the most perfect tide table is one which gives the height of the water, when abstraction is made of the disturbing causes. Such a table can only be made from observations of such extent as to eliminate irregularities by averages.

No general rule can be given for wind disturbance, but it is often considerable in bays and estuaries. The water stands higher with low, and lower with high, barometer; the amount of the effect appears to be very uncertain, the estimates varying from 7 inches to 20 inches rise of water for an inch fall of the mercury. It appears probable that the rule differs in different ports, and even in the same port with different winds. To make the most, however, of a short series of observations, it might perhaps be best to reduce each hourly tide height to a standard height of barometer at the rate of a foot of water to an inch of mercury, before undertaking the tidal reductions.

In order to discover the general run of the tide in any part of the world, observations should be taken at several stations separated by 50 to 100 miles; and this is the more important if some of the stations have to be chosen in estuaries, since the tide wave takes a considerable time to run up from the open sea and changes its form in doing so.

In estuaries and rivers it is important not to confuse flood and ebb with high and low water, for the water often still runs up-stream for long after the tide has turned and when the water-level is falling; and the converse is true of ebb and low water. We refer to "Hydrography" for remarks on tidal currents and streams.

II.—Tidal Observations of High and Low Water.*

The immediate object is to connect the times and heights of high and low water (H.W. and L.W.) with the time of the moon's transit. About high and low tide the water often rises and falls irregularly, and the critical moment cannot be found from a single observation. Obser-

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* Founded on Dr. Whewell's article in a former edition of this manual.

vations are, therefore, to be taken every 5 or 10 minutes for half-an-hour or an hour about H.W. and L.W. The time and height of H.W. or L.W. are then to be found by graphical interpolation, *i.e.*, take a straight line to represent time, and at the points corresponding to the observations erect perpendiculars or ordinates corresponding to the observed heights, draw a sweeping curve nearly through the tops of the ordinates, so as to obliterate minor irregularities and measure the height of the maximum or minimum ordinate, and note its incidence in the time scale.*

Dr. Whewell recommends that the observation should begin with half hourly observations during 24 hours, for if there should be found to be double H.W. or L.W., or only a single tide in the 24 hours, this method will fail; he also advises that tidal observations be referred to the moon's transit during their course, in order to detect irregularities in "the interval" from transit to H.W., which might cause the observations to prove useless.

The object of the observations is to find "the establishment," or time of high water, on days of full and change of moon, the heights of tide at spring and neap, and "the fortnightly or semi-mensual irregularity" in the time and height. The reference of the tide to the "establishment" is not, however, scientifically desirable, and it is better to determine the mean or corrected establishment, being the average interval from moon's transit to H.W. at spring tide, and "the age of the tide," being the average interval from full and change to spring tide. For these purposes the observations are conveniently treated graphically.†

An equally divided horizontal scale is taken to represent the 12 hours of the clock of civil time, regulated to the time of the port—or more accurately arranged always to show apparent time by being fast or slow by the equation of time; this time scale represents the time of the clock of the moon's transit, either upper or lower. The scale is perhaps most conveniently arranged in the order V, VI, ..., XII, I, ..., IIII. Then each "interval" of time

* A similar but less elaborate process would render hourly observations more perfect. The readings might be every $2\frac{1}{2}$ minutes, from five minutes before to five minutes after the hour.

† For numerical treatment, *see* "Directions for reducing Tidal Observations." By Staff Commander John Burdwood, R.N. London. 1876. J. D. Potter. Price 6*d*.

from transit to H.W. is set off as an ordinate above the corresponding time-of-clock of moon's transit. A sweeping curve is then drawn so as to pass nearly through the tops of the ordinates, cutting off minor irregularities. Next along the same ordinates are set off lengths corresponding to the height of water at each H.W.

A second similar figure may also be made for the interval and height at L.W.

In the curve of H.W. intervals the ordinate corresponding to XII is the vulgar "establishment," since it gives the time of H.W. at full and change of moon. That ordinate of H.W. intervals which is coincident with the greatest ordinate of H.W. heights gives the "mean establishment."*

Since the moon's transit falls about 50 minutes later on each day, in setting off a fortnight's observation there will be about five days for every four hours-of-clock of moon's upper transit. Hence in these figures we may regard each division of the time scale I to II, II to III, &c. as representing 25 hours instead of one hour. Then the distance from the maximum ordinate of H.W. heights to XII, each division being estimated as 25 hours, is called "the age of the tide."

From these two figures the times and heights of H.W. and L.W. may in general he predicted with fair approximation; we find the time-of-clock of moon's upper or lower transit on the day, correct by the equation of time, read off the corresponding heights of H.W. and L.W. from the figures; and the intervals to H.W. and L.W. being also read off are added to the time of moon's transit, and give the times of H.W. and L.W.

We shall show below how a tide table may be otherwise computed from establishment and spring rise and neap rise.

At all ports, however, there is an irregularity of intervals and heights between successive tides, and in consequence of this our curves will present more or less of a zig-zag appearance. Where the zig-zag is perceptible to the eye, the curves must be smoothed by drawing them so as to bisect the zig-zags, because these "diurnal inequalities" will not present themselves similarly in the future. When, as in some equatorial ports, the diurnal tides are large, this

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* *See* section IV. for the numerical computation of mean from vulgar establishment.

method of tidal prediction fails, but we shall show below how the observations may then be treated scientifically.

III.—Instructions for the Reduction of Hourly Tidal Observations, with an Example.

We now suppose that the observations of the tides are taken at each hour. If the observations are only taken every two hours, or if there are hiatuses in the series, the hourly numbers must be filled in as indicated below.

All the measurements should be positive, and if the zero of the tide gauge has been fixed too high it will be well to refer the measurement to an ideal zero 10 feet lower. The following instructions for reduction should be read along with the example.

Computation Forms.

Mark three large sheets of paper with the letters M, O, S ; divide them into squares, with 24 columns; head the columns, 0^h, 1^h, $2^h \cdots 23^h$ for the several hours. On the left margin write the numbers of the days, 0^d, 1^d, 2^d, &c. Each square may be specified by its day and hour.

M *Sheet.*

Place dots in the squares of each row, as follows: 0^d, 14^h; 1^d 18^h; 2^d, 23^h; 3^d, none; 4^d, 3^h; 5^d, 8^h; 6^d, 12^h; 7^d, 17^h; 8^d, 21^h; 9^d, none; 10^d, 2^h; 11^d, 7^h; 12^d, 11^h; 13^d, 16^h; (13^d is the last row required for a fortnight's observation); 14^d, 20^h; 15^d, none; 16^d, 1^h; 17^d, 5^h; 18^d, 10^h; 19^d, 14^h; 20^d, 19^h; 21^d, 23^h; 22^d, none; 23^d, 4^h; 24^d, 8^h; 25^d, 13^h; 26^d, 17^h; 27^d 22^h. (27^d is the last row required for a month's observation.)

O *Sheet.*

Place dots in the following squares: 0^d, 6^h and 19^h; 1^d, 8^h and 22^h; 2^d, 11^h; 3^d, 0^h and 13^h; 4^d, 2^h and 16^h; 5^d, 5^h and 18^h; 6^d, 7^h and 20^h; 7^d, 10^h and 23^h; 8^d, 12^h; 9^d, 1^h and 14^h; 10^d, 4^h and 17^h; 11^d 6^h and 19^h; 12^d, 8^h and 22^h (12^d is the last row required for a fortnight's observation); 13^d, 11^h; 14^d, 0^h and 13^h; 15^d, 2^h and 15^h; 16^d, 5^h and 18^h; 17^d, 7^h and 20^h; 18^d, 9^h and 23^h; 19^d, 12^h; 20^d, 1^h and 14^h; 21^d, 3^h and 17^h; 22^d, 6^h and 19^h; 23^d, 8^h and 21^h; 24^d, 11^h. (24^d is the last row required for a month's observation.)

S *Sheet.*

There are no dots. For a fortnight's observation, let row 13^d be the last; then leave three rows blank, and add another row numbered 14^d.

For a month's observation, let row 26^d be the last; then leave three rows blank, and add three more rows numbered 27^d, 28^d, 29^d.

The shorter series (13^d or 26^d) is for diurnal tides, the longer (14^d or 29^d) for semi-diurnal tides.

Entry in S.

The first hourly observation is supposed to be at noon or $0^d, 0^h$; enter it in that square; enter the second in $0^d, 1^h$; the third in $0^d, 2^h$, and so on.

The 0^h of the rows are the noons of each day; write the day of the month opposite each row.

If any hourly observations are wanting or obviously vitiated through accident or weather, fill in the blanks thus. Consider a column in which a blank occurs; take a number of equidistant points along a line, and let each point correspond to one of the days before and after the blank; then draw lines perpendicular to the first line proportional to the height of water on each of the days. Draw a sweeping curve through the extremities of the lines, and measure off the height of the curve where it passes above the blank. The resulting number is to be used for filling in the blank.

If the observations at night are taken at rarer intervals, say every two or three hours, the same process of filling in blanks must be employed, by considering the hourly observations before and after the blank.

Every deficiency of data of course weakens the strength of the result.

The entry of observations is to stop as indicated in the instructions for forming the S sheet.

Entry in M.

Copy the numbers on the S sheet; begin entering as in S, but when a dot is reached, enter two successive hourly values, the first above, the second below; then continue copying from S (the entries falling of course in a different hour column) until a second dot is reached, where again make a double entry; and so on.

The entries stop as indicated in the instructions for forming the M sheet.

For a fortnight's observation the last entry (which is in square $13^d\ 23^h$) is that which is copied from square $14^d\ 11^h$ of S.

For a month's observation the last entry (which is in square $27^d\ 23^h$) is that which is copied from square $28^d\ 23^h$ of S.

Entry in O.

Follow the same rules for entry as in M.

For a fortnight's observation the last entry (which is in square $12^d\ 23^h$) is that which is copied from square $13^d\ 23^h$ of S.

For a month's observation the last entry (which is in square $24^d\ 23^h$) is that which is copied from square $26^d\ 20^h$ of S.

Rules of reduction on all three Sheets.

Add up the numbers in each column (in S there will be two sums, one without rows 14^d or $27^d, 28^d, 29^d$, as the case may be, and the other with those additional rows). Divide the sum in each column by the number of entries of which it is the sum. In S the divisors for each of the two sets of sums are all the same, since there are not duplicate entries.

The results are 24 hourly mean values, and there are four of them, viz., two from S, one from M, one from O.

The set from M, and the second set (longer series) on S are to be harmonically analysed for semi-diurnal inequality ; the first set (shorter series) on S, and the set from O are to be harmonically analysed for diurnal inequality.

Thus where it is known that the diurnal tides are small, the O sheet and the shorter series on S may be omitted for rough results.

The height of mean water with reference to the zero of the tide gauge has also to be determined from the second set on S.

Harmonic Analysis.

If we have any quantity which is variable during the day and night, such as temperature or the height of the barometer, it is often desirable to express it by the formula—

$$A_0 + A_1 \cos\theta + B_1 \sin\theta + A_2 \cos 2\theta + B_2 \sin 2\theta + A_3 \cos 3\theta + B_3 \sin 3\theta + A_4 \cos 4\theta + B_4 \sin 4\theta,$$

where θ is an angle which increases at the rate of 15° per hour, and is zero at noon.

If we put $\tan\zeta_1 = \frac{B_1}{A_1}$, $\tan\zeta_2 = \frac{B_2}{A_2}$, $\tan\zeta_3 = \frac{B_3}{A_3}$, $\tan\zeta_4 = \frac{B_4}{A_4}$, and

$R_1 = A_1 \sec\zeta_1 = B_1 \operatorname{cosec}\zeta_1$, $R_2 = A_2 \sec\zeta_2 = B_2 \operatorname{cosec}\zeta_2$, and so on, the formula may be written—

$$A_0 + R_1 \cos(\theta - \zeta_1) + R_2 \cos(2\theta - \zeta_2) + R_3 \cos(3\theta - \zeta_3) + R_4 \cos(4\theta - \zeta_4).$$

The term in R_1 is diurnal, that in R_2 semi-diurnal, that in R_3 ter-diurnal, that in R_4 quater-diurnal; that is to say, they go through their changes once, twice, thrice, and four times a day.

The term A_0 gives the mean value for the day.

The A's and B's are the numbers which are derived from harmonic analysis, as explained below.

The same process is applicable to the tides, but with the difference that there are several kinds of days, viz.:—first, the ordinary or mean solar or S day ; second, the mean lunar or M day ; and a third kind—the O day—for which there is no name.

Thus in application to the tides there are to be four harmonic analyses, two performed on the means on the S sheet, one on the means on the M sheet, and one on the means on the O sheet. The matter is simplified, however, by the fact that from the first means on S we only want A_1, B_1 ; from the second means on S we only want A_2, B_2, and A_0 ; from the means on M we only want A_2, B_2 ; and from the means on O we only want A_1, B_1.

The following schedule gives General Strachey's rules for harmonic analysis. Columns I. and II. contain the 24 hourly values to be analysed, and the headings to each successive column give the rules for its derivation from the preceding ones.

If we only want A_1, B_1 the columns I. to VIII. inclusive are required ; if we only want A_2, B_2 the columns I., II., and IX. to XIV. inclusive are required, and for A_0 we require also column XV.

A comparison of this complete schedule with the numerical example below will render the process intelligible.

FORM FOR HARMONIC ANALYSIS.

Hours.	I. Hourly Values, 0 to 11.	Hours.	II. Hourly Values, 12 to 23.	III. I.−II.	IV. Middle 4 of III. with opp. sign.	V. Last 4 of III.	VI. III.+IV.+V.	VII. *See* III. and VI.	VIII. *See* III. and VI.	IX. I.+II.	X. Second half of IX.	XI. IX.−X.	XII. Second half of XI.	XIII. XI.−XII. omitting top entry of XII.	XIV. XI.+XII. omitting top entry of XI.	XV. IX.+X.	XVI. Second half of XV.	XVII. XV.−XVI.
0	.	12	.	(*a*) .	.	.	(*c*) .	M .	M .	.	.	.	.	.	.	.	.	(*g*) .
1	.	13	.	.	.	.	(*d*) .	−N.	N .	.	.	.	.	.	.	.	.	(*h*) .
2	.	14	.	sum .	.	.	(*e*) .	(*a*) .	(*b*) .	.	.	.	.	.	.	.	.	(*i*) .
3	.	15	.	.	.	.	(*f*) .	$\frac{1}{3}\alpha$.	$-\frac{1}{3}\beta$.	.	.	.				.		
4	.	16	.	.						.	.	.				.	$(g)+(h)-(i)$ = .	
5	.	17	.	.	$\alpha=(c)+(d)-(f)$ = . ×·0690 A_3=			Sum . ×·0658 A_1= .	Sum ×·0658 B_1= .	.	.	.				.	÷16 A_4= .	
				M = .														
6	.	18	.	(*b*) .						.	Sum of XIII.= . ×·067 A_2= .							
7	.	19	.	.						.								
8	.	20	.	.						.					Sum = . ÷24 A_0= .			
9	.	21	.	sum .	$\beta=(d)+(e)+(f)$ = . ×·0690 B_3=					.	Sum of XIV.= . ×·067 B_2= .						$(h)+(i)$= . ×·072 B_4= .	
10	.	22	.	.						.								
11	.	23	.	.						.								
				N = .														

General Rule for the Determination of ζ *and* R *from* A *and* B.

If A is + and B is +, ζ is less than 90°, or in 1st quadrant.

If A is − and B is +, ζ lies between 90° and 180°, in 2nd quadrant.

If A is − and B is −, ζ lies between 180° and 270°, in 3rd quadrant.

If A is + and B is −, ζ lies between 270° and 360°, in 4th quadrant.

If tan ζ is numerically less than 1, compute from $R = A \sec \zeta$; if greater than 1, compute from $R = B \operatorname{cosec} \zeta$.

In certain cases mentioned below, we shall have also to augment the result R by a factor which is nearly equal to unity, as there explained.

General Rule as to Angles.

All angles are to be written as positive angles less than 360°; if an angle is greater than 360°, subtract 360°.

Certain small angles, however, determined below are to be estimated as either positive or negative (*e.g.*, 355° will in this case be written as —5°), and do not fall under this rule. The occurrence of the exception will always be noted at the time.

It will often be convenient to write angles in degrees and decimals of a degree.

Harmonic analysis of M.

Analyse the hourly means for A_2, B_2.

Find ζ_m from $\tan \zeta_m = \frac{B_2}{A_2}$.

Find R_m from $R_m = A_2 \sec \zeta \times 1{\cdot}0115$ or $B_2 \operatorname{cosec} \zeta_m \times 1{\cdot}0115$, according as $\tan \zeta_m$ is numerically less or greater than 1.

N.B.—Log 1·0115 = ·0050.

Harmonic analysis of S.

Analyse the second hourly means (the longer series) for A_2, B_2, and for A_0.

Find ζ_s from $\tan \zeta_s = \frac{B_2}{A_2}$.

Find R_s from $R_s = A_2 \sec \zeta_s$ or $B_2 \operatorname{cosec} \zeta$, according as $\tan \zeta_s$ is numerically less or greater than 1.

Analyse the first hourly means (the shorter series) for A_1, B_1.

Find ζ' from $\tan \zeta' = \frac{B_1}{A_1}$.

Find R' from $R' = A_1 \sec \zeta'$, or $B_1 \operatorname{cosec} \zeta'$, according as $\tan \zeta'$ is numerically less or greater than 1.

Harmonic analysis of O.

Analyse the hourly means for A_1, B_1.

Find ζ_0 from $\tan \zeta_0 = \frac{B_1}{A_1}$.

Find R_0 from $R_0 = A_1 \sec \zeta_0 \times 1\cdot0029$ or $B_1 \operatorname{cosec} \zeta_0 \times 1\cdot0029$, according as $\tan \zeta_0$ is numerically less or greater than 1.

N.B.—Log $1\cdot0029 = \cdot0013$.

ANGLES AND FACTORS FOR REDUCTION.

N.A. stands for Nautical Almanac.

Call local mean noon of day 0 of the series of observations to be reduced, or of the tide table to be computed *the Epoch.* N.A., p. 1: Find ☊ the mean longitude of the ascending node of ☽'s orbit at epoch. Find sin ☊, cos ☊, sin 2☊, cos 2☊, and compute the following small angles (+ when ☊ lies between 0° and 180°, − when ☊ lies between 180° and 360°), and numerical factors—

Angles to be determined as + or −

$$\begin{cases} \nu = 12^\circ\cdot9 \sin ☊ - 1^\circ\cdot3 \sin 2☊ \\ \xi = 11^\circ\cdot8 \sin ☊ - 1^\circ\cdot3 \sin 2☊ \\ \nu' = 8^\circ\cdot8 \sin ☊ - 0^\circ\cdot6 \sin 2☊ \\ 2\nu'' = 17^\circ\cdot8 \sin ☊ - 0^\circ\cdot5 \sin 2☊ \end{cases}$$

Factors

$$\begin{cases} f = 1 - \cdot037 \cos ☊ \\ f' = 1\cdot006 + \cdot116 \cos ☊ - \cdot009 \cos 2☊ \\ f'' = 1\cdot024 + \cdot285 \cos ☊ + \cdot008 \cos 2☊ \\ f_\circ = 1\cdot009 + \cdot189 \cos ☊ - \cdot015 \cos 2☊ \end{cases}$$

In the N.A. find the ☉'s parx. at the middle of the fortnight or month of observation, subtract from it the ☉'s mean parx. (*see* Preface to N.A.). Multiply the result by $19\frac{1}{3}$, and considering the product as degrees, look out the sine of the angle and add 1, the result is $p_{,}$; *e.g.*, if ☉'s parx. be $8''\cdot85$, and if the mean parx. be $8''\cdot95$, we get diff. $-0''\cdot10$, and $-19\frac{1}{3} \times \cdot10 = -1^\circ\cdot93 = -1^\circ\ 56'$,

$$\sin(-1^\circ\ 56') = -\cdot034,\ p_{,} = 1 - \cdot034 = \cdot966.$$

This is a short way of finding the cube of the ratio of ☉'s parx. to ☉'s mean parx.

Arguments at Epoch.

From N.A. (Moon's Libration), find ☽, the moon's mean longitude at epoch. From N.A. find ☉, the sun's mean longitude at epoch, by converting sidereal time to angle at 15° per hour. The diurnal increase of ☽ = 13° 11′. The corrections for longitude of port are subtracted for E. long. and added for W. long. The correction to ☽ is $0^\circ\cdot549$ for each hour of longitude, and $0^\circ\cdot041$ to ☉ for each hour of longitude.

Find $-2($☽$-\xi)$, ☉$-\nu$, $2($☉$-\nu)$, ☉$-\nu'$, and compute the following "arguments at epoch," $V = 2($☉$-\nu) - 2($☽$-\xi)$; $V' =$ ☉$-\nu' + 270^\circ$; $V_\circ =$ ☉$-\nu - 2($☽$-\xi) + 90^\circ$.

Find a mean value for ☉ for the period under reduction, by adding to ☉ seven days' motion for a fortnight's observation, or 15 days' motion for a month's observation. The motion for a day may be taken as 1°, and thus we add 7° or 15°; with this mean ☉ compute, 2☉$-\nu'$; $V'' = 2$☉$-2\nu''$.

ADMIRALTY SCIENTIFIC MANUAL.

ARTICLE TIDES.

Erratum, to be inserted at page 63.

For the tide K_2

In the formula for tan ψ, in the denominator, for $3\cdot 67\ p_{\prime}$ read $3\cdot 71\ p_{\prime}$ for a fortnight's observation, and $3\cdot 84\ p_{\prime}$ for a month's observation.

In the formula for H_s wherever $3\cdot 67$ occurs read $3\cdot 71$ for a fortnight, and $3\cdot 84$ for a month's observation.

The formula $H'' = \frac{1}{3\cdot 67} H_s$ remains correct.

For the tides K_1 *and* P.

In the formula for H' the 3 in the numerator (but not that in the denominator) should be replaced by $3\cdot 007$ for a fortnight's observation, or by $3\cdot 027$ for a month's observation.

The formula $H_p = \frac{1}{3} H'$ remains correct.

For $\kappa' = \kappa_p = \zeta' + V' + \phi$ read

$\kappa' = \kappa_p = \zeta' + V' + \phi + 6°\cdot 88$ for a fortnight,

and $\kappa' = \kappa_p + \zeta' + V' + \phi + 13°\cdot 29$ for a month.

The succeeding numerical example must be corrected accordingly. The only sensible change is that $\kappa' = \kappa_p = 334°$ in place of $327°$.

G. H. D.

May 1906.

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FINAL REDUCTION.

Principal Lunar Tide called M_2.

Let mean semi-range $= H_m$, constant angle of retardation or lag $= \kappa_m$. The angle of retardation is hereafter called *the lag*.
Then from M sheet take R_m, ζ_m, and compute—

$$H_m = \frac{R_m}{f}, \quad \kappa_m = \zeta_m + V.$$

Principal Solar Tide called S_2, *and Lunisolar Semi-diurnal Tide called* K_2.

For S_2, let mean semi-range $= H_s$, lag $= \kappa_s$.
For K_2, let mean semi-range $= H''$, lag $= \kappa''$.
Find ψ, as a positive or negative angle, from—

$$\tan\psi = \frac{f''\sin V''}{3\cdot67p_{,} + f''\cos V''}.$$

Then from S sheet take R_s, ζ_s, and compute—

$$H_s = \frac{3\cdot67\cos\psi}{3\cdot67p_{,} + f''\cos V''} R_s, \; H'' = \frac{1}{3\cdot67} H_s, \; \kappa_s = \kappa'' = \zeta_s + \psi.$$

Lunisolar Diurnal Tide called K_1, *and Solar Diurnal Tide called* P.

For K_1, let mean semi-range $= H'$, lag $= \kappa'$.
For P, let mean semi-range $= H_p$, lag $= \kappa_p$.
Find ϕ, as a positive or negative angle, from—

$$\tan\phi = \frac{\sin(2\odot - \nu')}{3f' - \cos(2\odot - \nu')}.$$

Then from S sheet take R', ζ', and compute—

$$H' = \frac{3\cos\phi}{3f' - \cos(2\odot - \nu')} R', \; H_p = \frac{1}{3} H', \; \kappa' = \kappa_p = \zeta' + V' + \phi.$$

Lunar Diurnal Tide called O.

For O, let mean semi-range $= H_o$, lag $= \kappa_o$.
Then from O sheet take R_o, ζ_o, and compute—

$$H_o = \frac{R_o}{f_o}, \quad \kappa_o = \zeta_o + V.$$

For *rough* results all the diurnal tides may be omitted, unless the diurnal inequality is known to be large.

Collect Results.

These constants express six of the most important tides, and A_0 gives the height of mean water mark from the zero of the tide gauge.

Example of Reduction of a Fortnight's Observation at Port Blair, Andaman Islands.

(Portion of) S Sheet.

Date, 1880	Day.	0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.
April 19th -	0d.	4·4	4·7	5·1	5·4	5·7	5·8	5·7	5·4	4·8	4·2	3·7	3·4	3·3	3·5	4·0	4·5	5·0	5·4	5·6	5·5	5·2	4·7	4·2	3·9
" 20th -	1d.	3·7	3·9	4·3	4·9	5·5	6·0	6·2	6·1	5·7	4·9	4·1	3·4	2·9	2·9	3·2	3·9	4·7	5·4	6·1	6·3	6·1	5·6	4·9	4·1
" 21st -	2d.	3·5	3·3	3·5	4·1	4·8	5·7	6·3	6·6	6·4	5·8	4·9	3·8	2·9	2·4	2·5	3·1	4·0	5·1	6·1	6·8	6·9	6·5	5·6	4·6
" 22nd -	3d.	3·7	3·0	2·8	&c.	&c.																			
							*		*			*		*			*		*						
	&c.																					&c.	3·7	4·2	4·9
May 1st -	12d.	5·6	6·4	6·7	6·7	6·3	5·7	4·9	4·1	3·5	3·2	3·2	3·6	4·2	4·8	5·3	5·6	5·6	5·4	5·0	4·6	4·2	4·0	3·9	4·1
" 2nd -	13d.	4·6	5·2	5·8	6·2	6·4	6·2	5·7	5·1	4·5	3·8	3·4	3·3	3·5	3·9	4·6	5·2	5·6	5·8	5·7	5·4	5·0	4·5	4·1	4·0
Sum - -		78·7	74·0	67·0	61·0	57·1	57·4	59·6	64·2	68·5	71·9	72·5	70·3	65·8	60·4	55·0	52·3	50·5	53·4	59·4	67·3	74·9	80·6	83·2	82·4
	Divisor 14.																								
Mean for diurnal - -	}	5·62	5·29	4·79	4·36	4·08	4·10	4·26	4·59	4·89	5·14	5·18	5·02	4·70	4·31	3·93	3·74	3·61	3·81	4·24	4·81	5·35	5·76	5·94	5·89
May 3rd -	14d.	4·1	4·5	5·1	5·7	6·2	6·4	6·3	5·9	5·2	4·4	3·7	3·3	3·1	3·4	4·0	4·8	5·5	6·1	6·4	6·3	5·9	5·3	4·6	4·0
Sum - -		82·8	78·5	72·1	66·7	63·3	63·8	65·9	70·1	73·7	76·3	76·2	73·6	68·9	63·8	59·0	57·1	56·0	59·5	65·8	73·6	80·8	85·9	87·8	86·4
	Divisor 15.																								
Mean for semid.		5·52	5·23	4·81	4·45	4·22	4·25	4·39	4·67	4·91	5·09	5·08	4·91	4·59	4·25	3·93	3·81	3·73	3·97	4·39	4·91	5·39	5·73	5·85	5·76

Harmonic Analysis for Diurnal Component of Means from 14 Days on S Sheet.

I.		II.		III.	IV.	V.	VI.	VII.	VIII.
Hours.	Hourly Values, 0 to 11.	Hours.	Hourly Values, 12 to 23.	I.–II.	Middle Four of III. with opposite Sign.	Last Four of III.	III.+IV.+V.	*See* III., IV., and V.	*See* III., IV., and V.
0	5·62	12	4·70	(*a*) +·92	–·47	–·46	(*c*) –·01	M +3·22	M +3·22
1	5·29	13	4·31	+·98	–·29	–·62	(*d*) +·07	–N +2·93	N –2·93
2	4·79	14	3·93	+·86	–·02	–·76	(*e*) +·08	(*a*) +·92	(*b*) +·02
3	4·36	15	3·74	Sum +·62	+·22	–·87	(*f*) –·03	$\frac{1}{3}\alpha$ +·03	$-\frac{1}{3}\beta$ –·04
4	4·08	16	3·61	+·47				Sum +7·10	Sum +·27
5	4·10	17	3·81	+·29				×·0658	×·0658
				M=+3·22				A_1=+·4672	B_1=+·0178
6	4·26	18	4·24	(*b*) +·02					
7	4·59	19	4·81	–·22					
8	4·89	20	5·35	–·46					
9	5·14	21	5·76	Sum –·62					
10	5·18	22	5·94	–·76					
11	5·02	23	5·89	–·87					
				N=–2·93					

$\alpha=(c)+(d)-(f)=+·09$

$\beta=(d)+(e)+(f)=+·12$

A_1+, B_1+, ζ' lies in 1st quadrant.

log B_1=8·2504
colog A_1= ·3305

log tan ζ'=8·5809
$\zeta'=2°\ 11'=2°·2$

log sec ζ'= ·0003
log A_1=9·6695

log R'=9·6698
R'= ·468

Harmonic Analysis for Semi-Diurnal Component of Means from 15 Days on S Sheet.

I.		II.		IX.	X.	XI.	XII.	XIII.	XIV.	XV.
Hours.	Hourly Values, 0 to 11.	Hours.	Hourly Values, 12 to 23.	I.+II.	Second Half of IX.	IX.−X.	Second Half of XI.	XI.−XII. omitting top entry of XII.	XI.+XII. omitting top entry of XI.	IX.+X.
0	5·52	12	4·59	10·11	8·78	+1·33	−2·56	+1·33	−2·56	18·89
1	5·23	13	4·25	9·48	9·58	− ·10	−2·98	+2·88	−3·08	19·06
2	4·81	14	3·93	8·74	10·30	−1·56	−2·45	+ ·89	−4·01	19·04
3	4·45	15	3·81	8·26	10·82	−2·56		Sum=+5·10	Sum=−9·65	19·08
4	4·22	16	3·73	7·95	10·93	−2·98		×·067	×·067	18·88
5	4·25	17	3·97	8·22	10·67	−2·45		A_2=+·3417	B_2=−·6466	18·89
6	4·39	18	4·39	8·78						Sum 113·84
7	4·67	19	4·91	9·58						÷24
8	4·91	20	5·39	10·30						A_0=4·743
9	5·09	21	5·73	10·82						
10	5·08	22	5·85	10·93						
11	4·91	23	5·76	10·67						

A_2+, B_2-, ζ_s lies in 4th quadrant.

log B_2=9·8106
colog A_2= ·4664
log tan ζ_s= ·2770
ζ_s=360°−62° 9′
=297° 51′
=297°·9

log cosec ζ_s= ·0535
log B_2=9·8106
log R_s=9·8641
R_s= ·731

(Portion of) M Sheet.

(Decimal points omitted for brevity ; the dotted squares are those holding two entries.)

	0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.
0d.	44	47	51	54	57	58	57	54	48	42	37	34	33	35	40 45	50	54	56	55	52	47	42	39	37
1d.	39	43	49	55	60	62	61	57	49	41	34	29	29	32	39	47	54	61	63 61	56	49	41	35	33
2d.	35	41	48	57	63	66	64	58	49	38	29	24	25	31	40	51	61	68	69	65	56	46	37	30 28
3d.	31	39	49	60	67	&c.																		
	*			*			*			*			*			*			*			*		
																					&c.	45	38	34
13d.	33	35	39	46	52	56	58	57	54	50	45	41	40	41	45	51	57 62	64	63	59	52	44	37	33
Sums	407	505	691	845	886	912	872	817	667	469	376	393	438	548	748	862	1030	1091	1026	851	695	559	406	388
Divisors	14	14	15	15	14	14	14	15	15	14	14	15	15	14	15	14	15	15	15	14	14	15	14	15
Means	291	361	461	563	633	651	623	545	445	335	269	262	292	391	499	616	687	727	684	608	496	373	290	259

The harmonic analysis with columns I., II., IX., X., XI., XII., XIII., XIV. gives

$A_2 = -1 \cdot 8251$, $B_2 = +1 \cdot 1437$; ζ_m lies in 2nd quadrant.

$$\log B_2 = \cdot 0583$$
$$\text{colog } A_2 = 9 \cdot 7387$$
$$\log \tan \zeta_m = 9 \cdot 7970$$
$$\zeta_m = 180^\circ - 32^\circ\, 4' = 147^\circ\, 56' = 147^\circ \cdot 9$$

$$\log \sec \zeta_m = \cdot 0719$$
$$\log A_2 = \cdot 2613$$
$$\log 1 \cdot 0115 = \cdot 0050$$
$$\log R_m = \cdot 3382$$
$$R_m = 2 \cdot 178$$

(Portion of) O Sheet.

(Decimal points omitted for brevity.)

	0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.
0d.	44	47	51	54	57	58	57 54	48	42	37	34	33	35	40	45	50	54	56	55	52 47	42	39	37	39
1d.	43	49	55	60	62	61	57	49	41 34	29	29	32	39	47	54	61	63	61	56	49	41	35	33 35	41
2d.	48	57	63	66	64	58	49	38	29	24	25	31 40	51	61	68	69	65	56	46	37	30	28	31	39
3d.	49 60	67	69	&c.																				
		*			*			*			*		*			*			*			*		
																					&c.	46	42	40
12d.	39	41	46	52	58	62	64	62	57 51	45	38	34	33	35	39	46	52	56	58	57	54	50	45 41	40
Sums	701	648	676	583	635	599	721	657	738	659	752	706	698	702	629	588	605	602	578	685	662	631	720	699
Divisors	14	14	14	13	14	14	15	14	15	13	14	14	14	14	14	13	14	14	14	15	14	13	15	14
Means	501	463	483	448	454	428	481	469	492	507	537	504	499	501	449	452	432	430	413	457	473	485	480	499

The harmonic analysis with columns I., II., III., IV., V., VI., VII., VIII. gives

$A_1 = -\cdot 0658$, $B_1 = +\cdot 1303$; ζ_0 lies in 2nd quadrant.

$$\log B_1 = 9\cdot 1149$$
$$\text{colog } A_1 = 1\cdot 1818$$
$$\log \tan \zeta_0 = \cdot 2967$$
$$\zeta_0 = 180^\circ - 63^\circ\ 12' = 116^\circ\cdot 8$$

$$\log \text{cosec } \zeta_0 = \cdot 0494$$
$$\log B_1 = 9\cdot 1149$$
$$\log 1\cdot 0029 = \cdot 0013$$
$$\log R_0 = 9\cdot 1656$$
$$R_0 = \cdot 146$$

PORT BLAIR, ANDAMAN ISLANDS; lat. 11° 41′ N., long. 92° 45′ E.

Observation commences at epoch, 0^h mean time, April 19, 1880. Long. 92° 45′ E. = $6^h\cdot183$ E.

N.A. p. 1 ☊ = 280° ; sin ☊ = − ·985 ; sin 2☊ = − ·34.
cos ☊ = + ·174 ; cos 2☊ = − ·94.

Angles.

$$\nu = 12^\circ\cdot9 \sin ☊ - 1^\circ\cdot3 \sin 2☊ = -12^\circ\cdot26\,;$$
$$\xi = 11^\circ\cdot8 \sin ☊ - 1^\circ\cdot3 \sin 2☊ = -11^\circ\cdot18.$$
$$\nu' = 8^\circ\cdot8 \sin ☊ - 0^\circ\cdot6 \sin 2☊ = -\ 8^\circ\cdot46\,;$$
$$2\nu'' = 17^\circ\cdot8 \sin ☊ - 0^\circ\cdot5 \sin 2☊ = -17^\circ\cdot36.$$

Factors.

$$f = 1\cdot000 - \cdot037 \cos ☊ = \cdot994\,;$$
$$f' = 1\cdot006 + \cdot116 \cos ☊ - \cdot009 \cos 2☊ = 1\cdot035.$$
$$f'' = 1\cdot024 + \cdot285 \cos ☊ + \cdot008 \cos 2☊ = 1\cdot066\,;$$
$$f_0 = 1\cdot009 + \cdot189 \cos ☊ - \cdot015 \cos 2☊ = 1\cdot056.$$

The mean value of ☉'s parx. for the fortnight commencing April 19 is ☉'s parx. on April 25 = 8″·89 (N.A. 1880); mean parx. from Preface to N.A. = 8″·95 ; difference = −0″·06 ; multiply by $19\frac{1}{3}$ = −1″·16 ; change ″ to ° = −1° 10′ ; sin (−1° 10′) = − ·020 ; $p_\prime = 1 - \cdot020 = \cdot980$.

Arguments at Epoch.

☽'s daily motion 13° 11′ ; hourly 0°·55 ; ☽'s motion in $6^h\cdot18$ = 3°·40
☉'s hourly motion 0°·041 ; ☉'s motion in $6^h\cdot18$ = 0°·25

N.A. (Moon's Libration)—

0^h G.M.T. Ap. 20 ☽ =	159° 27′
− one day's motion = −	13° 11′
0^h G.M.T. Ap. 19 ☽ =	146° 16′
=	146°·27
− $6^h\cdot18$ E. long. = −	3 ·40
☽ =	142 ·87
− ξ = +	11 ·18
☽ − ξ =	154°·05
2(☽ − ξ) =	308°·10
− 2(☽ − ξ) =	51°·90

Sid[l] time 0^h G.M.T. Ap. 19 $= 1^h\ 51^m\ 51^s$
$= 1^h\ 51^m{\cdot}85$
$= 1^h{\cdot}864$
$\frac{1}{2}$ sid[l] time $=$ 932

$\odot\ 0^h$ G.M.T. Ap. 19 $= 27^\circ{\cdot}96$
$-6^h{\cdot}18$ E. long. $= -{\cdot}25$

$\odot = 27^\circ{\cdot}71$
$-\nu = +12\ {\cdot}26$

$\odot - \nu = 39\ {\cdot}97$

$2(\odot - \nu) = 79\ {\cdot}94$
$-2(☽ - \xi) = 51\ {\cdot}90$

Sum $V = 131^\circ{\cdot}84$

$\odot = 27^\circ{\cdot}7$
$-\nu' = 8\ {\cdot}5$
$270^\circ = 270$

Sum $V' = 306^\circ{\cdot}2$

$\odot - \nu = 39^\circ{\cdot}97$
$-2(☽ - \xi) = 51\ {\cdot}90$
$+90^\circ = 90$

Sum $V_0 = 181^\circ{\cdot}87$

Compute $2\odot - \nu'$ and V'' with mean values of $\odot$. The reduction is to cover a fortnight, and therefore a week later than April 19 is the middle of the period, and $\odot$ has increased by seven days' motion or 7°.

April 19, $\odot = 28^\circ$
a week's increase $= 7^\circ$

mean $\odot = 35^\circ$

$2\odot = 70^\circ$
$-\nu' = +8^\circ$

$2\odot - \nu' = 78^\circ$

$2\odot = 70^\circ$
$-2\nu'' = 17^\circ$

Sum $V'' = 87^\circ$

Reductions.

M_2, *Principal Lunar Semi-diurnal.*

From harmon. anal. $\zeta_m = 147^\circ{\cdot}93$
$+ V = 131\ {\cdot}82$, $H_m = \frac{R_m}{f} = \frac{2{\cdot}178}{{\cdot}994} = 2^{ft}{\cdot}191$

Sum $\kappa_m = 280^\circ$

K_2, *Lunisolar Semi-diurnal, and* S_2, *Principal Solar Semi-diurnal.*

$f'' = 1{\cdot}066$; $p_{,} = {\cdot}980$; $R_s = {\cdot}731$; $\zeta_s = 297^\circ{\cdot}9$; $V'' = 87^\circ$;

$$H_s = \frac{3{\cdot}67 \cos\psi}{3{\cdot}67p_{,} + f'' \cos V''} R_s ;$$

Compute—

$\log f'' = {\cdot}0278$
$\log \cos V'' = 8{\cdot}7188$

$\log f'' \cos V'' = 8{\cdot}7466$

$f'' \cos V'' = +0{\cdot}056$
$3{\cdot}67p_{,} = +3{\cdot}597$

$3{\cdot}67p_{,} + f'' \cos V'' = 3{\cdot}653$
$\log 3{\cdot}653 = {\cdot}5626$

$\log f'' = \cdot 0278$
$\log \sin V'' = 9 \cdot 9994$
$\text{colog } 3 \cdot 653 = 9 \cdot 4374$

$\log \tan \psi = 9 \cdot 4646$

$\sin V''$ is +, therefore ψ is +, and
$\psi = +16° \; 15' = +16° \cdot 3$
$\zeta_s = 297 \cdot 9$

Sum $\kappa_s = 314° = \kappa''$

$\log \cos \psi = 9 \cdot 9823$
$\log 3 \cdot 67 = \cdot 5647$
$\log R_s = 9 \cdot 8639$
$\text{colog } 3 \cdot 653 = 9 \cdot 4374$

$\log H_s = 9 \cdot 8483$
$H_s = \cdot 705$

$$H'' = \frac{H_s}{3 \cdot 67} = \cdot 192$$

K₁, *Lunisolar Diurnal, and* P, *Solar Diurnal.*

$2\odot - \nu' = 78°$; $\cos (2\odot - \nu') = + \cdot 208$; $\sin (2\odot - \nu') = + \cdot 978$;
$f' = 1 \cdot 035$; $R' = \cdot 468$; $\zeta' = 2° \cdot 2$; $V' = 306° \cdot 2$;

$$H' = \frac{3 \cos \phi}{3f' - \cos(2\odot - \nu')} R'$$

Compute—

$3f' = 3 \cdot 105$
$-\cos (2\odot - \nu') = - \cdot 208$

$3f' - \cos (2\odot - \nu') = 2 \cdot 897$

$$\tan \phi = \frac{\sin (2\odot - \nu')}{3f' - \cos (2\odot - \nu')} = + \frac{\cdot 978}{2 \cdot 897} = + \cdot 338, \; \phi \text{ is } + ;$$

$\phi = +18° \; 40' = 18° \cdot 7$
$V' = 306 \cdot 2$
$\zeta' = 2 \cdot 2$

Sum $\kappa' = 327° = \kappa_p$

$\log \cos \phi = 9 \cdot 9765$
$\log 3 = \cdot 4771$
$\text{colog } 2 \cdot 897 = 9 \cdot 5381$
$\log R' = 9 \cdot 6702$

$\log H' = 9 \cdot 6619$
$H' = \cdot 459$; $H_p = \frac{1}{3} H' = \cdot 153$

O, *Lunar Diurnal.*

$V_o = 181° \cdot 9$; $f_o = 1 \cdot 056$; $R_o = \cdot 146$; $\zeta_o = 116° \cdot 8$

Compute—

$V_o = 181° \cdot 9$
$\zeta_o = 116 \cdot 8$

Sum $\kappa_o = 299°$

$$H_o = \frac{R_o}{f_o} = \frac{\cdot 146}{1 \cdot 056} = \cdot 138$$

RESULTS OF HARMONIC ANALYSIS of 15 days' hourly observations at Port Blair, commencing 0h, April 19, 1880.

				Mean of Three Years Hourly Observation.
	$A_0 = 4 \cdot 74$ ft.	-	-	$4 \cdot 740$ ft.
M_2	$H_m = 2 \cdot 19$ ft.	-	-	$2 \cdot 022$ ft.
	$\kappa_m = 280°$	-	-	$278°$
S_2	$H_s = 0 \cdot 71$ ft.	-	-	$0 \cdot 968$ ft.
	$\kappa_s = 314°$	-	-	$315°$
K_2	$H'' = 0 \cdot 19$ ft.	-	-	$0 \cdot 282$ ft.
	$\kappa'' = 314°$	-	-	$311°$
K_1	$H' = 0 \cdot 46$ ft.	-	-	$0 \cdot 397$ ft.
	$\kappa' = 327°$	-	-	$327°$
P	$H_p = 0 \cdot 15$ ft.	-	-	$0 \cdot 134$ ft.
	$\kappa_p = 327°$	-	-	$326°$
O	$H_o = 0 \cdot 14$ ft.	-	-	$0 \cdot 160$ ft.
	$\kappa_o = 299°$	-	-	$302°$

The second column is inserted for the sake of comparison, and gives the results of three years of continuous hourly observation by the tidal department of the survey of India. The concordance between the two affords evidence of the utility of even so short a series of observations as a fortnight.

IV.—THE CONSTANTS TO BE USED IN COMPUTING A TIDE TABLE.

The possibility of computing a tide table depends on the knowledge of certain tidal constants appropriate to the port. In the preceding example we have shown how these constants are derivable from a short series of observations. The constants are there presented in what is called the harmonic method, and an example is worked out below for Port Blair, with such constants as have been derived above from a fortnight of observation. The values used, however, are taken from the extended series of observations made by the Indian Survey.*

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* The incompleteness of the data, with which we are supposed to be working, necessitates the use of certain approximations which would not have been used if "the elliptic tides" had been evaluated.

The harmonic notation is, however, rather recent, and is not adopted in the tide tables of the Admiralty. We must, therefore, show how the principal constants of the harmonic method are derivable from the other notation, and thus the present method of computation will be made available, wherever anything is known of the tides.

In the Admiralty tide tables the tides are specified by giving the time of high water at full and change of moon, and the rise at spring and neap. The semidiurnal constants of the harmonic method are derivable from these very easily. Spring rise is the average height between low and high water marks at spring tide; neap rise the average height between high water-mark at neap tide and low water-mark at spring tide; neap range is the average height between high and low water marks at neap tide. The average should be taken from a great many springs and neaps.

Then—

$$\mathrm{H_m}+\mathrm{H_s}=\tfrac{1}{2} \text{ spring rise.}$$
$$\mathrm{H_m}-\mathrm{H_s}=\tfrac{1}{2} \text{ neap range.}$$
$$\mathrm{H_m} \quad =\tfrac{1}{2} \text{ neap rise.}$$

If the age of the tide be known, and a be the age expressed in hours, then a in degrees is an angle; and if D be the ratio of the neap rise to the excess of spring rise above neap rise, so that $D=\frac{\mathrm{H_m}}{\mathrm{H_s}}$. Then—

κ_m (in degrees) = time of H.W. at full and change in hours, multiplied by $29-\tan^{-1}\frac{\sin a}{D+\cos a}$, and $\kappa_s=\kappa_m+a$.

If the age be unknown, we may take a as 36°, and

$$\tan^{-1}\frac{\sin a}{D+\cos a}=\tan^{-1}\frac{3}{5D+4}.$$

For example, at Dungeness, Straits of Magellan (Adm. Tide Table) H.W. at full and change is 8h. 30m. $=8^h\cdot 5$.; spring rise is 36 ft. to 44 ft., or say, 40 ft., neap rise is 30 ft.

Hence $\mathrm{H_m}+\mathrm{H_s}=20$; $\mathrm{H_m}=15$; therefore $\mathrm{H_s}=5$, and $D=\frac{\mathrm{H_m}}{\mathrm{H_s}}=3$.

The age of the tide being unknown, we assume 36h. as a likely value, so that $a=36°$, and

$$\tan^{-1}\frac{3}{5D+4}=\tan^{-1}\frac{3}{19}=\tan^{-1}\frac{1}{6\cdot 33}=8°.$$

Again multiplying the time of H.W. at full and change by 29, we have $8\cdot 5\times 29=247°$, so that $\kappa_m=247°-8°=239°$, and $\kappa_s=239°+36°=275°$.

The diurnal inequality is complex, and it seems unnecessary to enter into details excepting in the harmonic notation.

Where it is stated that the tides are "affected by diurnal inequality," it is not possible to predict the tides from the information contained in the so-called tide table.

A tide table is first computed with reference to mean water-mark, but it is usual in navigational works to refer to "the mean level of low water of ordinary spring tides." The datum level may be taken as $H_m+H_s+H'+H_0$ below mean water-mark, and hence to refer to the datum level we must add $H_m+H_s+H'+H_0$ to both H.W. and L.W. heights.

This datum has been defined for the first time in the prefaces to the Indian Tide Tables for 1887, and is called "Indian spring low-water mark." It has been chosen so as to agree as a general rule with "Low water of ordinary spring tides." Accurate agreement was out of the question, since the Admiralty datum does not appear susceptible of an exact scientific definition.

In many estuaries and rivers the water rises much more rapidly than it falls, and we sometimes find a double H.W. To take account of these phenomena we should have to include, according to the schedule for Harmonic Analysis, the terms A_4, B_4, both from the M sheet and S sheet. It is not possible, without devoting too much space to the subject, to show how these "over-tides" are to be included in the computation of the table. It is proper to remark that in such an estuary either the H.W. or L.W., as computed by the method below, may be found considerably in error.

V.—The Computation of a Tide Table.

The method of computation will be explained most easily by an actual numerical example.* The computation is divided into a number of sections and schedules, each line of each schedule is independent of all the others, and thus a single tide may be computed as easily as a complete table. The numerical value of any quantity required in the computation of any column of a schedule is written at the top of the column, but outside of the boundary line of the schedule. In several cases explanatory headings are also put outside of the boundary line, but the process of derivation of each column from what goes before is accurately stated inside the boundary line. It will be stated below in § VI. how the computations may be abridged where accuracy is not desired.

Tide Table for Port Blair E. long. $6^{h}\cdot 183$, commencing Feb. 1, 1885.

Tidal constants serving as basis of table—

$$\left.\begin{matrix} H_m = 2\cdot 022 \\ \kappa_m = 278^\circ \end{matrix}\right\} \quad \left.\begin{matrix} H_s = 0\cdot 968 \\ \kappa_s = 315^\circ \end{matrix}\right\} \quad \left.\begin{matrix} H'' = 0\cdot 282 \\ \kappa'' = 310^\circ \end{matrix}\right\}$$

$$\left.\begin{matrix} H' = 0\cdot 397 \\ \kappa' = 327^\circ \end{matrix}\right\} \quad \left.\begin{matrix} H_p = 0\cdot 134 \\ \kappa_p = 326^\circ \end{matrix}\right\} \quad \left.\begin{matrix} H_o = 0\cdot 160 \\ \kappa_o = 302^\circ \end{matrix}\right\}$$

A.—*Computation of Constants for a Fortnight, commencing Feb.* 1, 1885.

$$\text{N.A. } \Omega = 187^\circ;\ \sin\Omega = -\cdot 122;\ \sin 2\Omega = +\cdot 24.$$
$$\cos\Omega = -\cdot 993;\ \cos 2\Omega = +\cdot 97.$$

Compute from the formula—

$$\Delta = 16^\circ\cdot 51 + 3^\circ\cdot 44 \cos\Omega - 0^\circ\cdot 19 \cos 2\Omega.$$

Therefore—

$\Delta = 16^\circ\cdot 51 - 3^\circ\cdot 416 - 0^\circ\cdot 184 = 12^\circ\cdot 91$; $2\Delta = 25^\circ\cdot 82 = 25^\circ\ 49'$; $\log\cos 2\Delta = 9\cdot 9543$.

By the formulæ in reduction § III. with above value of Ω, we find—

$$\nu = -1^\circ\cdot 89;\ \xi = -1^\circ\cdot 75;\ f = 1\cdot 037;\ f' = \cdot 882;\ f_o = \cdot 807.$$
$$\nu' = -1^\circ\cdot 22.$$

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* The reasoning on which the following processes are based is given in a report to the Brit. Assoc., 1886.

Find mean value of ☉'s parx. and decl. for a fortnight, beginning Feb. 1.

Parx. on Feb. 10 is (N.A.) $8''\cdot96$; mean parx. (Pref. N.A.) $8''\cdot85$; diff. $+0''\cdot11$; multiply by $19\frac{1}{3}$, and read as degrees $= +2^\circ\cdot13 = 2^\circ\ 8'$; $\sin 2^\circ\ 8' = \cdot037$; $p_{,} = 1\cdot037$.

Decl. on Feb. 8, $\delta_{,} = 14^\circ\ 50'$; $2\delta_{,} = 29^\circ\ 40'$; $\cos^2\delta_{,} = \frac{1}{2}(1+\cos 2\delta_{,}) = \frac{1}{2}\times 1\cdot8689 = \cdot935$; $1\cdot086\ p_{,} \cos^2\delta_{,} = \cdot970$; $H_s = 0^{\text{f}}\cdot968$;

$$1\cdot086\ p_{,} \cos^2\delta_{,} H_s = 1^{\text{ft}}\cdot020 = S.$$

Note that the 1·086 which occurs here is an absolute constant for all times and places.

Compute "age of declinational inequality" as below:—

$$\text{'Age'} = 52^{\text{h}}\cdot2 \tan(\kappa'' - \kappa_m), \text{ and } \kappa'' - \kappa_m = 310^\circ - 278^\circ = 32^\circ.$$

Therefore—

$$\text{'Age'} = 52^{\text{h}}\cdot2 \tan 32^\circ = 32^{\text{h}}\cdot6.$$

The $52^{\text{h}}\cdot2$ which occurs here is an absolute constant for all ports.

With constants, absolute for all ports, C_1, C_2 (whose logarithms are given below) compute $\alpha = C_1 H'' \cos(\kappa'' - \kappa_m)$; $A = \alpha \cos 2\Delta$; $\beta = C_2 \frac{H''}{H_m} \sin(\kappa'' - \kappa_m)$; $B = \beta \cos 2\Delta$, as follows:—

$\log C_1 = \cdot6344$	$\log C_2 = 2\cdot3925$
$\log \cos(\kappa'' - \kappa_m) = 9\cdot9284$	$\log \sin(\kappa'' - \kappa_m) = 9\cdot7242$
$\log H'' = 9\cdot4502$	$\log H'' = 9\cdot4502$
	$\text{colog } H_m = 9\cdot6942$
$\log \alpha = \cdot0130$	$\log \beta = 1\cdot2611$
$\log \cos 2\Delta = 9\cdot9543$	$\log \cos 2\Delta = 9\cdot9543$
$\log A = 9\cdot9673$	$\log B = 1\cdot2154$
$A = 0^{\text{ft}}\cdot927$	$B = 16^\circ\cdot42$

Computation of Angles determining the Position of ☉ and ☽ at 0h. *Feb.* 1, 1885, *Port Blair M.T.*

N.A. (Moon's Libration)—

☽ Jan. 31 = $138^\circ\cdot6$	E. long. $6^{\text{h}}\cdot18$
1 day's motion = $+13\cdot2$	Hourly increase of ☽ $0^\circ\cdot55$
☽ Feb. 1 = $151\cdot8$	
Corr^n for E. long. = $-3\cdot4$	Corr^n for E. long. $-3^\circ\cdot399$
☽ = $148\cdot4$	
$-\xi = +1\cdot8$	
☽ $-\xi = 150^\circ\cdot2$	
$2(☽ - \xi) = 300^\circ\cdot4$	
$-2(☽ - \xi) = 59^\circ\cdot6$	

N.A. Sid[1] time at 0^h G.M.T. Feb. 1 $\} = 20^h{\cdot}8$

$\frac{1}{2}$ sid[1] time $= 10{\cdot}4$

Sum, $\odot$ 0^h Feb. 1 $= 312°$

$-\nu = +2$

$\odot - \nu = 314$

$-2(☽ - \xi) = 60$

$+90° = 90$

$V_0 = 104°$

At epoch $\odot = 312°$

$-\nu' = +1$

$+270° = -90$

$V' = 223°$

$2\odot - \nu'$ is to be computed with the mean value of $\odot$ for a fortnight; add therefore 7° to $\odot$ at epoch :--

$\odot$ at epoch $= 312°$

motion for 1 week $= +7$

mean $\odot = 319°$

mean $2\odot = 278°$

$-\nu' = +1$

$2\odot - \nu' = 279°$

Compute as follows :—

$\cos(2\odot - \nu') = +{\cdot}156$; $3f' = 2{\cdot}646$; $3f' - \cos(2\odot - \nu') = 2{\cdot}490$.

$\sin(2\odot - \nu') = -{\cdot}988$.

$$\tan\phi = \frac{\sin(2\odot - \nu')}{3f' - \cos(2\odot - \nu')} = -\frac{{\cdot}988}{2{\cdot}490} = -{\cdot}397\ ;$$

ϕ is $-$, and $\phi = -21°40' = -21°{\cdot}7$.

$$R' = \frac{3f' - \cos(2\odot - \nu')}{3\cos\phi} H'\ ;\ H' = 0{\cdot}397.$$

Compute—

$\kappa' = 327°$

$-\phi = +22$

$\kappa' - \phi = 349$

$-V' = -223$

$\kappa' - \phi - V' = \zeta' = 126°$

$\log\sec\phi = {\cdot}0318$

colog $3 = 9{\cdot}5229$

$\log 2{\cdot}490 = {\cdot}3962$

$\log H' = 9{\cdot}5988$

$\log R' = 9{\cdot}5497$

$R' = 0{\cdot}355$

$$R = f_o H_o = \cdot 807 \times \cdot 160 = \cdot 129.$$

$\,_{o} = 302^\circ$	$\log f = \cdot 0158$
$-V_o = -104$	$\log H_m = \cdot 3058$
Sum $\zeta_o = 198^\circ$	$\log R_m = \log f\, H_m = \cdot 3216$
	$\log 3 = \cdot 4771$
	$\log 3\, R_m = \cdot 7987$
	$R_m = 2 \cdot 097$

Collecting constants.

$$R_m = 2^{ft} \cdot 097 \; ; \; S = 1^{ft} \cdot 020$$
$$\text{og } 3\, R_m = \cdot 7987 \; ; \; \text{`Age'} = 32^h \cdot 6$$

$$A = 0^{ft} \cdot 927 \; ; \; \log \alpha = \cdot 0130 \; ; \; R' = 0^{ft} \cdot 355 \; ; \; R_o = 0^{ft} \cdot 129$$
$$B = 16^\circ \cdot 42 \; ; \; \log \beta = 1 \cdot 2611 \; ; \; \zeta' = 126^\circ ; \; \zeta_o = 198^\circ$$

Compute also—

the mean interval $i = \frac{\kappa_m}{29} = 9^h \cdot 59$; and $\gamma = \kappa_s - \frac{30}{29}\kappa_m = 27^\circ \cdot 4$

S, R′, ζ' must be recomputed for each month, the remaining constants would serve for six months, or perhaps a year, of continuous tidal computation. The value of R_o would serve for six months, but care must be taken in computing each month that ζ_o be computed by reference to the first noon of the month as a new epoch.

B.—*Parallactic Correction of Lunar Semi-diurnal Tide.*

The semi-range of the lunar semi-diurnal tide is R_m ($=2^{ft} \cdot 097$) and it has to be corrected for the ☽'s parx. The parallactic correction is found by multiplying R_m by the factor p, where

$$p = (\text{☽'s parx.})^3 \div (\text{☽'s mean parx.})^3.$$

The ☽'s mean parx. is 57′ 2″, but the ☽'s parx. in question must be taken at a time anterior to H.W. by the "age" ($-32^h \cdot 6$).

To find p (approximately) subtract 57′ 2″ from the ☽'s parx., substitute ° ′ for ′ ″, look out the sine of the angle, multiply it by 3, and add 1 to the result; then p is less than 1 if the ☽'s parx. is below its mean value, because the sine of a − angle is −, and *vice versâ.*

We begin by making a table of $\delta_1 R_m$ (the parallactic corrections to R_m) for each 0′·5 of parx. above or below the mean, to be applied + when the parx. is greater than 57′, and − when it is below.

Tables B and C. serve for all time, so long as the same tidal constants are used.

B.—Auxiliary Table for Parallactic Corrections, denoted by $\delta_1 R_m$.

log 3 R_m = ·7987

I.	II.	III.	IV.
Minutes of Parx. in excess or defect above or below 57′ 2″.	Read Degrees for Minutes in I., and enter log sin (I).	II. + log 3 R_m.	Natural Number of III. $\pm \delta_1 R_m$.
′			
0·5	7·9408	8·7395	·05
1	8·2419	9·0406	·11
1·5	8·4179	9·2166	·16
2	8·5428	9·3415	·22
2·5	8·6397	9·4384	·27
3	8·7188	9·5175	·33
3·5	8·7857	9·5844	·38
4	8·8436	9·6423	·44
4·5	8·8946	9·6933	·49
5	8·9403	9·7390	·55

C.—*Declinational Correction to Lunar Semi-diurnal Tide.*

A declinational correction has also to be applied to R_m, say $\delta_2 R_m$; to κ_m, say $\delta_2 \kappa_m$; to i, say $\delta_2 i$; to γ, say $\delta_2 \gamma$.

If δ be the ☽'s decl. at a time anterior to H.W. by the 'age'; $\delta_2 R_m = \alpha \cos 2\delta - A$; $\delta_2 \kappa_m = \beta \cos 2\delta - B$; $\delta_2 i = i + \frac{1}{29} \delta_2 \kappa_m$; $\delta_2 \gamma = \gamma - \delta_2 \kappa_m$.

We begin by forming a table of declinational corrections for each degree of decl. either N. or S.

C.—Auxiliary Table for Declinational Corrections, viz., $\delta_2 R_m$, $\delta_2 \kappa_m$, and corrected i and γ.

log α = ·0130 A = ·93 log β = 1·2611 B = 16°·42 i = 9h·59 γ = 27°·4

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
Degrees of N. or S. decl. of ☽	log cos (2×I.).	log α+II.	Nat. No. of III.	Corrn to R_m IV.−A ($\delta_2 R_m$)	log β+II.	Nat. No. of VI.	Corrn to κ_m VII.−B ($\delta_2 \kappa_m$)	VIII.÷29 $=\frac{1}{30}$VIII.$+\frac{1}{30^2}$VIII.	Corrd i i+IX.	Corrd γ γ−VIII.
°						°	°		h.	°
0	0·0000	·0130	1·03	+·10	1·2611	18·24	+1·82	+·061+·002=+·06	9·65	25·6
1	9·9997	·0127	1·03	·10	1·2608	18·23	1·81	+·060+·002= ·06	9·65	25·6
2	9·9989	·0119	1·03	·10	1·2600	18·20	1·78	+·059+·002= ·06	9·65	25·6
3	9·9976	·0106	1·02	·09	1·2587	18·14	1·72	+·057+·002= ·06	9·65	25·7
4	9·9958	·0088	1·02	·09	1·2569	18·07	1·65	+·055+·002= ·06	9·65	25·7
5	9·9934	·0064	1·01	·08	1·2545	17·97	1·55	+·052+·002= ·05	9·64	25·8
6	9·9904	·0034	1·01	·08	1·2515	17·84	1·42	+·047+·002= ·05	9·64	26·0
7	9·9869	9·9999	1·00	·07	1·2480	17·70	1·28	+·043+·001= ·04	9·63	26·1
8	9·9828	9·9958	·99	·06	1·2439	17·54	1·12	+·037+·001= ·04	9·63	26·3
9	9·9782	9·9912	·98	·05	1·2393	17·35	0·93	+·031+·001= ·03	9·62	26·5
10	9·9730	9·9860	·97	·04	1·2341	17·14	0·72	+·024+·001= ·03	9·62	26·7
11	9·9672	9·9802	·96	·03	1·2283	16·92	0·50	+·017+·001= ·02	9·61	26·9
12	9·9607	9·9737	·94	+·01	1·2218	16·67	+0·25	+·008+·000=+·01	9·60	27·1
13	9·9537	9·9667	·93	·00	1·2148	16·40	−0·02	−·001−·000=−·00	9·59	27·4
14	9·9459	9·9589	·91	−·02	1·2070	16·11	0·31	−·010−·000= ·01	9·58	27·7
15	9·9375	9·9505	·89	·04	1·1986	15·80	0·62	−·021−·001= ·02	9·57	28·0
16	9·9284	9·9414	·87	·06	1·1895	15·47	0·95	−·032−·001= ·03	9·56	28·4
17	9·9186	9·9316	·85	·08	1·1797	15·13	1·29	−·043−·001= ·04	9·55	28·7
18	9·9080	9·9210	·83	·10	1·1691	14·76	1·66	−·055−·002= ·06	9·53	29·1
19	9·8965	9·9095	·81	−·12	1·1576	14·38	−2·04	−·068−·002=−·07	9·52	29·4

D.—*Parallactic and Declinational Corrections to Lunar Semi-diurnal Tide.*

Each H.W. follows a ☽'s transit at the port, approximately, by the interval i ($9^{h}\cdot 6$), and we require the ☽'s parx. and decl. at a moment anterior to H.W. by *age of tide.* Times are to be reduced to G.M.T. and round numbers used. To reduce to G.M.T. subtract E. long., $=6^{h}\cdot 2$ for Port Blair. (Add for W. long.) The local time of ☽'s transit is G.M.T. of transit less 2^{m} for each hour of E. long.; for Port Blair less $12^{m}=0^{h}\cdot 2$ (for W. long. add this corrn.)

G.M.T. at which we want ☽'s parx. and decl. $\left\{\begin{array}{l} = \text{G.M.T. of ☽'s transit} - \text{long. corrn. for transit } (0^{h}\cdot 2) - \text{E. long. in time } (6^{h}\cdot 2) + \text{mean interval } i\ (9^{h}\cdot 6) \\ \quad - \text{age of tide } (32^{h}\cdot 6). \end{array}\right.$

= G.M.T. of ☽'s transit $- 29^{h}\cdot 4$.

In the following table we determine roughly this moment of time, in correspondence with each transit of ☽, look out parx. and decl. and find corrected R_m from auxiliary tables B and C. These corrected values we shall call m_0, M_0; m_1, M_1, &c., large letters being associated with upper, and small with lower transits and the subscript numbers being the numbers of the days of the tide table, the first day being numbered zero.

The corrected intervals, also from tables B and C, we call i_0, I_0; i_1, I_1; &c., and the corrected values of $\kappa_s - \frac{30}{29}\kappa_m$ (or γ) we call γ_0, Γ_0; γ_1, Γ_1; &c.

D.

Determine the times at which to find ☽'s parx. and decl.			Find excess of parx. above mean.		Parx. corrⁿ to R_m. $R_m=2{\cdot}10$		Decl. corrⁿ to R_m.		Corr^d heights.	Corr^d intervals.	Corr^d γ's.
I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
Date of ☽'s upper or lower transit.	G.M.T. to nearest hour, from N.A.	Date of II − 29^h.	☽'s parx. at the Greenwich noon or midn. nearest to III. from N.A.	IV. − 57′.	$\delta_1 R_m$ interpolated from IV. of B.	R_m + VI.	☽'s decl. at III. from N.A.	$\delta_2 R_m$ interpolated from V of C.	VII. + IX.	Corr^d interval i interpolated from X. of C.	Corr^d γ interpolated from XI. of C.
	h.	h.	′	′	ft.	ft.	°	ft.	ft.	h.	°
Feb. 1 L	2	Jan. 30, 21	60·0	+3·0	+·33	2·43	N 11·0	+·03	$m_0=2{\cdot}46$	$i_0=9{\cdot}61$	$\gamma_0=26{\cdot}9$
U	14	31, 9	59·6	2·6	·28	2·38	9·1	·05	$M_0=2{\cdot}43$	$I_0=9{\cdot}62$	$\Gamma_0=26{\cdot}5$
2 L	3	22	59·2	2·2	·24	2·34	6·9	·07	$m_1=2{\cdot}41$	$i_1=9{\cdot}63$	$\gamma_1=26{\cdot}1$
U	15	Feb. 1, 10	58·8	1·8	·20	2·30	4·7	·08	$M_1=2{\cdot}38$	$I_1=9{\cdot}64$	$\Gamma_1=25{\cdot}8$
3 L	4	23	58·4	1·4	·15	2·25	2·4	·10	$m_2=2{\cdot}35$	$i_2=9{\cdot}65$	$\gamma_2=25{\cdot}6$
U	16	2, 11	57·9	0·9	·10	2·20	N 0·3	·10	$M_2=2{\cdot}30$	$I_2=9{\cdot}65$	$\Gamma_2=25{\cdot}6$
4 L	4	23	57·5	+0·5	+·05	2·15	S 1·9	·10	$m_3=2{\cdot}25$	$i_3=9{\cdot}65$	$\gamma_3=25{\cdot}6$
U	17	3, 12	57·0	0·0	·00	2·10	4·1	·09	$M_3=2{\cdot}19$	$I_3=9{\cdot}65$	$\Gamma_3=25{\cdot}7$
5 L	5	4, 0	56·6	−0·4	−·04	2·06	6·1	·08	$m_4=2{\cdot}14$	$i_4=9{\cdot}64$	$\gamma_4=26{\cdot}0$
U	17	12	56·2	0·8	·09	2·01	7·9	·06	$M_4=2{\cdot}07$	$I_4=9{\cdot}63$	$\Gamma_4=26{\cdot}3$
6 L	6	5, 1	55·8	1·2	·13	1·97	9·8	·04	$m_5=2{\cdot}01$	$i_5=9{\cdot}62$	$\gamma_5=26{\cdot}7$
U	18	13	55·4	1·6	·17	1·93	11·4	+·02	$M_5=1{\cdot}95$	$I_5=9{\cdot}61$	$\Gamma_5=27{\cdot}0$
7 L	7	6, 2	55·1	1·9	·21	1·89	13·0	·00	$m_6=1{\cdot}89$	$i_6=9{\cdot}59$	$\gamma_6=27{\cdot}4$
U	19	14	54·8	2·2	·24	1·86	14·3	−·03	$M_6=1{\cdot}83$	$I_6=9{\cdot}58$	$\Gamma_6=27{\cdot}8$
8 L	7	7, 2	54·6	2·4	·26	1·84	15·4	·05	$m_7=1{\cdot}79$	$i_7=9{\cdot}57$	$\gamma_7=28{\cdot}2$
U	20	15	54·4	−2·6	−·28	1·82	S 16·5	−·07	$M_7=1{\cdot}75$	$I_7=9{\cdot}55$	$\Gamma_7=28{\cdot}6$

E.—*Determination of Local Mean and apparent Times of Moon's Transit, and of Angles for Computing the Fortnightly Inequality.*

It is convenient to treat the upper and lower transits separately in schedules of similar forms. The angle x_0, X_0, x_1, X_1, &c., on which the fortnightly inequality of time and height depends, is twice the apparent time of transit converted to angle at 15° per hour, and with the corresponding angles γ_0, Γ_0, γ_1, Γ_1, &c. subtracted.

The corrections for long. of port are − for E., + for W. long.

E.—Lower Transits.

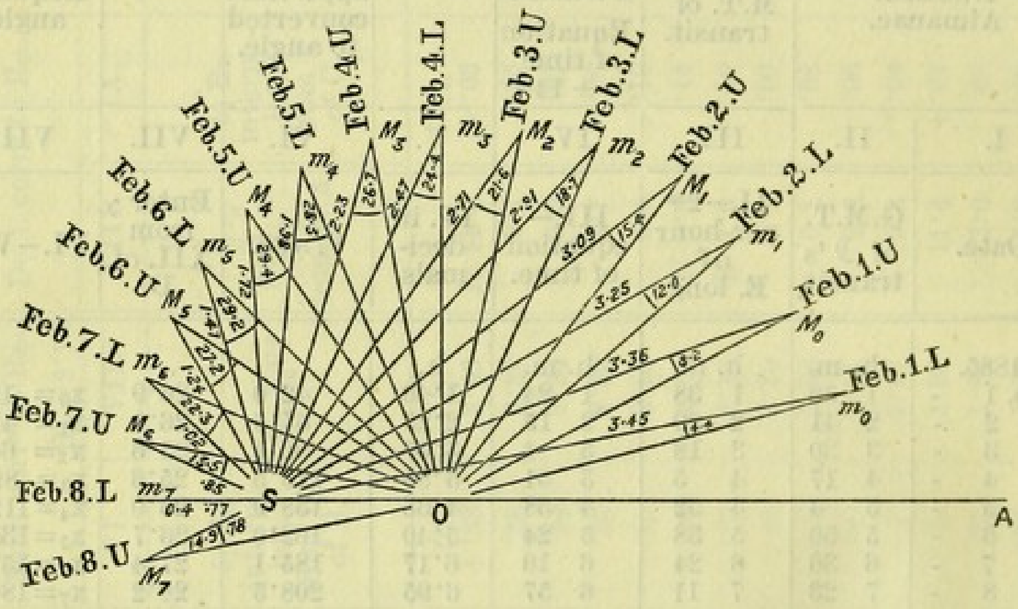
Nautical Almanac.		Port Blair M.T. of transit.	Port Blair appt. time of transit. Equation of time = + 14m.		Twice appt. time converted to angle.		Required angles.
I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Date.	G.M.T. of ☽'s transit.	II. − 2m per hour of E. long.	III. − equation of time.	IV. in decimals.	V. × 30.	Enter γ from XII. of D.	VI. − VII.
1885.	h. m.	h. m.	h. m.	h.	°	°	°
Feb. 1 -	1 50	1 38	1 24	1·40	42·0	26·9	x_0 = 15·1
" 2 -	2 41	2 29	2 15	2·25	67·5	26·1	x_1 = 41·4
" 3 -	3 30	3 18	3 4	3·07	92·1	25·6	x_2 = 66·5
" 4 -	4 17	4 5	3 51	3·85	115·5	25·6	x_3 = 89·9
" 5 -	5 4	4 52	4 38	4·63	138·9	26·0	x_4 = 112·9
" 6 -	5 50	5 38	5 24	5·40	162·0	26·7	x_5 = 135·3
" 7 -	6 36	6 24	6 10	6·17	185·1	27·4	x_6 = 157·7
" 8 -	7 23	7 11	6 57	6·95	208·5	28·2	x_7 = 180·3

E.—Upper Transits.

Nautical Almanac.		Port Blair M.T. of transit.	Port Blair appt. time of transit. Equation of time, = + 14m.		Twice appt. time converted to angle.		Required angles.
I.	II.	III.	IV.	V.	VI.	IV.	VIII.
Date.	G.M.T. of ☽'s transit.	II − 2m per hour of E. long.	III. − equation of time.	IV. in decimals.	V. × 30.	Enter Γ from XII. of D.	VI. − VII. − 360°.
1885.	h. m.	h. m.	h. m.	h.	°	°	°
Feb. 1 -	14 15	14 3	13 49	13·82	414·6	26·5	X_0 = 28·1
" 2 -	15 5	14 53	14 39	14·65	439·5	25·8	X_1 = 53·7
" 3 -	15 53	15 41	15 27	15·45	463·5	25·6	X_2 = 77·9
" 4 -	16 40	16 28	16 14	16·23	486·9	25·7	X_3 = 101·2
" 5 -	17 27	17 15	17 1	17·02	510·6	26·3	X_4 = 124·3
" 6 -	18 13	18 1	17 47	17·78	533·4	27·0	X_5 = 146·4
" 7 -	18 59	18 47	18 33	18·55	556·5	27·8	X_6 = 168·7
" 8 -	19 46	19 34	19 20	19·33	579·9	28·6	X_7 = 191·3

F.—*Figure for Times and Heights of Semi-diurnal Tide.*

The next step is to find the resultant of the lunar and solar tides. Draw the straight line OA. Produce AO to S, and take OS = S (for Port Blair S = $1^{\text{ft}}\cdot020$) on any convenient scale. With OA as initial line set off the angles x_0, X_0, x_1, X_1, found in VIII. of E, for a fortnight; a new figure is desirable for the next fortnight. On Om_0, OM_0, Om_1, OM_1, &c. set off to adopted scale the heights m_0, M_0, m_1, M_1, &c. found in X of D.



Join m_0S, M_0S, m_1S, M_1S, &c., and measure all the lengths m_0S, M_0S, m_1S, M_1S, &c. on adopted scale. These are the successive heights of H.W.

Measure all the angles Om_0S, OM_0S, &c. and count them as + in the upper half of the figure, and − in the lower half. Each height and each angle is associated with one upper or lower transit of ☽.

G.—*Formation of Tide Table for Semi-diurnal Tides.*

The successive heights Om_0, OM_0, Om_1, OM_1, &c., of H.W. have been found graphically in F. The angles Om_0S, OM_0S, Om_1S, OM_1S, &c. found in the figure F must be reduced to time at the rate of 29° per hour, and subtracted from the mean time of ☽'s transit found in III. of E, to these have to be added the corrected intervals i_0, I_0. i_1, I_1, &c. from XI. of D. Next a time half way between consecutive H.W.'s is taken as the time of L.W.; and the height of L.W. is taken as the mean of the H.W. before and after with a − prefixed.

These processes are carried out in the following schedule. If the time comes out greater than 24^h, the tide in question really belongs to the next day.

				G.		H.W. times.	L.W. times.	H.W. heights.	L.W. heights.
I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Day, and upper or lower transit.	Angles OMS. from figure.	II.÷29.	Mean time of transit from III. of E. in decimals.	IV.–III.	Corrected *i* from XI. of D.	V+VI.	Interpolate in VII.	Hts. from figure.	Interpolate in IX.
1885.		h.	h.	h.	h.	h.	h.	ft.	ft.
Feb. 1. L	+ 4·4	+0·15	1·63	1·48	9·61	11·09		3·45	
							17·24		−3·41
U	8·2	0·28	14·05	13·77	9·62	23·39		3·36	
							5·55		−3·31
„ 2. L	12·0	0·41	2·48	2·07	9·63	11·70		3·25	
							17·85		−3·17
U	15·4	0·53	14·88	14·35	9·64	24·00		3·09	
							6·15		−3·00
„ 3. L	18·7	0·64	3·30	2·66	9·65	12·31		2·91	
							18·46		−2·81
U	21·6	0·74	15·69	14·95	9·65	24·60		2·71	
							6·75		−2·59
„ 4. L	24·4	0·84	4·08	3·24	9·65	12·89		2·47	
							19·05		−2·35
U	26·7	0·92	16·47	15·55	9·65	25·20		2·23	
							7·36		−2·10
„ 5. L	28·3	0·98	4·86	3·88	9·64	13·52		1·98	
							19·70		−1·85
U	29·4	1·01	17·25	16·24	9·63	25·87		1·72	
							8·06		−1·59
„ 6. L	29·2	1·01	5·63	4·62	9·62	14·24		1·47	
							20·47		−1·35
U	27·2	0·94	18·02	17·08	9·61	26·69		1·24	
							8·96		−1·13
„ 7. L	22·3	0·77	6·40	5·63	9·59	15·22		1·02	
							21·56		− ·94
U	+13·5	+0·47	18·78	18·31	9·58	27·89		·85	
							10·33		− ·81
„ 8. L	− 0·4	−0·01	7·19	7·20	9·57	16·77		·77	
							23·20		− ·77
U	−14·9	−0·51	19·57	20·08	9·55	29·63		·78	

H.—*Correction for Diurnal Inequality.*

We first enter the tide table as found in the final columns of G, bringing, however, the times greater than 24^h into the succeeding day.

The successive processes are then adequately explained in the following schedule.

Columns VII., VIII., and XIII., XIV. are conveniently taken from a traverse table, for disregarding the decimal points, R' or R_0 may be considered as distances run, the angle in VI. or XII., as the "course," and R' cos VI. or R_0 cos XII. is the "Diff. lat.," whilst R' sin VI. or R_0 sin XII. is the "Dep."

Tide Table without Diurnal Corrections.				$\zeta' = 126°$.	Angles on which First Diurnal Tide depends.		First Correction to Heights. R′ = 0·36 ft.		
I.	II.	III.	IV.	V.	VI.		VII.	VIII.	IX.
No. of Day, Date, and H.W. or L.W.	Heights from IX. and X. of G.	Times from VII. and VIII. of G.	First entry of III. for each Day multiplied by 15.	IV. − ζ'.	1. V. + No. of Day.	2. Fill Blanks in 1. by adding once, twice, thrice 93°.	R′ cos VI.	R′ sin VI.	Subtract 1° from IV. for each Hour of III.
	ft.	h.					ft.		
Feb. 1. H.W.	+3·45	11·09	166°	40°	40°		+·27	+·23	155°
0 L.W.	−3·41	17·24				133°	−·25	+·27	
H.W.	+3·36	23·39				226°	−·25	−·26	
Feb. 2. L.W.	−3·31	5·55	83	317	318		+·27	−·24	77
1 H.W.	+3·25	11·70				51	+·23	+·28	
L.W.	−3·17	17·85				144	−·29	+·21	
Feb. 3. H.W.	+3·09	0·00	0	234	236		−·20	−·30	0
L.W.	−3·00	6·15				329	+·31	−·19	
2. H.W.	+2·91	12·31				62	+·17	+·32	
L.W.	−2·81	18·46				155	−·33	+·15	
Feb. 4. H.W.	+2·71	·60	9	243	246		−·15	−·33	8
L.W.	−2·59	6·75				339	+·34	−·12	
3. H.W.	+2·47	12·89				72	+·11	+·34	
L.W.	−2·35	19·05				165	−·35	+·09	
Feb. 5. H.W.	+2·23	1·20	18	252	256		−·09	−·35	17
L.W.	−2·10	7·36				349	+·35	−·07	
4. H.W.	+1·98	13·52				82	+·05	+·36	
L.W.	−1·85	19·70				175	−·36	+·03	
Feb. 6. H.W.	+1·72	1·87	20	262	267		−·02	−·36	26
L.W.	−1·59	8·06				0	+·36	+·00	
5. H.W.	+1·47	14·24				93	−·02	+·36	
L.W.	−1·35	20·47				186	−·30	−·04	
Feb. 7. H.W.	+1·24	2·69	40	274	280		+·06	−·35	37
L.W.	−1·13	8·96				13	+·35	+·08	
6. H.W.	+1·02	15·22				106	−·10	+·35	
L.W.	− ·94	21·56				199	−·34	−·12	
Feb. 8. H.W.	+ ·85	3·89	58	294	299		+·17	−·32	54
L.W.	− ·81	10·33				32	+·31	+·19	
7. H.W.	+ ·77	16·77				125	−·21	+·29	
L.W.	− ·77	23·20				218	−·28	−·22	
8. Feb. 9. H.W.	+ ·78	5·63	84	318	326		+·30	−·20	78

	Angles on which Second Diurnal Tide depends. ζ_o=198°.		Second Correction to Heights. R_o= 0·13 ft.			Total Correction to Heights.	Corrected Heights.	Reduction to "Indian Spring Low Water." $H_m+H_s+H'+H_o$ =3·55 ft.	Total Correction to Time.	Corrected Times.
X.	XI.		XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.
[illegible] multiplied by No. of Day.	1. $X.-\zeta_o.$	2. Fill Blanks in 1. by adding once, twice, thrice, 87°.	$R_o$cos XI.	R_o sin XI.	VIII.+XIII.	VII.+XII.	XV.+II.	XVI.+H_m+H_s+$H'+H_o$.	XIV.÷II.	III.−XVIII.
			ft.		h.	ft.	ft.	ft.	h.	h.
5°	317°		+·10	−·09	+·14	+·37	+3·82	7·37	+·04	11·05
		44°	+·09	+·09	+·36	−·16	−3·57	−·02	−·11	17·35
		131°	−·09	+·10	−·16	−·34	+3·02	6·57	−·05	23·44
2	214		−·11	−·07	−·31	+·16	−3·15	·40	+·09	5·46
		301	+·07	−·11	+·17	+·30	+3·55	7·10	+·05	11·65
		28	+·12	+·06	+·27	−·17	−3·34	·21	−·09	17·94
09	111		−·05	+·12	−·18	−·25	+2·84	6·39	−·06	·05
		198	−·12	−·04	−·23	+·19	−2·81	·74	+·08	6·07
		285	+·03	−·13	+·19	+·20	+3·11	6·66	+·07	12·24
		12	+·13	+·03	+·18	−·20	−3·01	·54	−·06	18·52
92	94		−·01	+·13	−·20	−·16	+2·55	6·10	−·07	·67
		181	−·13	−·00	−·12	+·21	−2·38	1·17	+·05	6·70
		268	−·00	−·13	+·21	+·11	+2·58	6·13	+·09	12·80
		355	+·13	−·01	+·08	−·22	−2·57	·98	−·03	19·08
76	78		+·03	+·13	−·22	−·06	+2·17	5·72	−·10	1·30
		165	−·13	+·03	−·04	+·22	−1·88	1·67	+·02	7·34
		252	−·04	−·12	+·24	+·01	+1·99	5·54	+·12	13·40
		339	+·12	−·02	+·01	−·24	−2·09	1·46	+·01	19·69
59	61		+·06	+·11	−·25	+·04	+1·76	5·31	−·14	2·01
		148	−·11	+·07	+·07	+·25	−1·34	2·21	−·04	8·10
		235	−·08	−·11	+·25	−·10	+1·37	4·92	+·17	14·07
		322	+·10	−·08	−·12	−·26	−1·61	1·94	+·08	20·39
45	47		+·09	+·10	−·25	+·15	+1·39	4·94	−·20	2·89
		134	−·09	+·09	+·17	+·26	−·87	2·68	−·15	9·11
		221	−·10	−·09	+·26	−·20	+·82	4·37	+·25	14·97
		308	+·10	−·09	−·21	−·24	−1·18	2·37	+·22	21·34
37	39		+·10	+·08	−·24	+·27	+1·12	4·67	−·28	4·17
		126	−·08	+·11	+·30	+·23	−·58	2·97	−·37	10·70
		213	−·11	−·07	+·22	−·32	+·45	4·00	+·29	16·48
		300	+·07	−·11	−·33	−·21	−·98	2·57	+·43	22·77
35	37		+·10	+·08	−·12	+·40	+1·18	4·73	−·15	5·78

K.—*Final Tide Table.*

It remains to reduce the decimals of an hour to minutes, and to change from the astronomical to the civil date at the port. It will be found more convenient to keep the heights in decimals of a foot, and not reduce to inches. The times and heights are given in XX. and XVIII. of table H.

K.—Tide Table for Port Blair, the Heights being referred to "Indian Spring Low Water Mark."

Civil Date.	Times of H.W. and L.W.	Heights of H.W. and L.W.	Civil Date.	Times of H.W. and L.W.	Heights of H.W. and L.W.
1885.	h. m.	ft.	1885.	h. m.	ft.
Feb. 1. p.m.	11 3	H.W. 7·4	Feb. 6. a.m.	1 24	H.W. 5·5
„ 2. a.m.	5 21	L.W. ·0	a.m.	7 41	L.W. 1·5
a.m.	11 26	H.W. 6·6	p.m.	2 1	H.W. 5·3
p.m.	5 28	L.W. ·4	p.m.	8 6	L.W. 2·2
p.m.	11 39	H.W. 7·1	„ 7. a.m.	2 4	H.W. 4·9
„ 3. a.m.	5 56	L.W. ·2	a.m.	8 23	L.W. 1·9
p.m.	0 3	H.W. 6·4	p.m.	2 53	H.W. 4·9
p.m.	6 4	L.W. ·7	p.m.	9 7	L.W. 2·7
„ 4. a.m.	0 14	H.W. 6·7	„ 8. a.m.	2 58	H.W. 4·4
a.m.	6 31	L.W. ·5	a.m.	9 20	L.W. 2·4
p.m.	0 40	H.W. 6·1	p.m.	4 10	H.W. 4·7
p.m.	6 42	L.W. 1·2	p.m.	10 42	L.W. 3·0
„ 5. a.m.	0 48	H.W. 6·1	„ 9. a.m.	4 29	H.W. 4·0
a.m.	7 5	L.W. 1·0	a.m.	10 46	L.W. 2·6
p.m.	1 18	H.W. 5·7	p.m.	5 47	H.W. 4·7
p.m.	7 20	L.W. 1·7			

In the official Indian Tide Tables the tides of Port Blair are referred to a datum 3·13 ft. below mean water, that is to say 0·42 ft. higher than the datum here used. To effect a comparison then subtract 0·42 ft. from all these heights, and the concordance will be found fairly satisfactory.

The Indian Tide Tables are formed by the tide predicting instrument, by which the approximations here used are avoided, and are based on much wider data than those supposed to be here available.

VI.—On Abridgements which may be adopted in Computing a Tide Table.

For navigational purposes a very rough tide table will often suffice. Such a table may be computed as follows :—

H_m, H_s, κ_m, κ_s, and mean establishment may be derived from spring and neap rise, age, and establishment as shown in § IV. If the "age" be unknown it may be assumed as 36h., and $\kappa_s - \kappa_m$ may be taken as 36°.

Then let A be the apparent time of any ☽'s transit reduced to angle at 30° per hour, and we have for the height of H.W. from spring L.W. mark—

$$2H_m + H_s\,[1 + \cos\,(A - \kappa_s + \kappa_m)],$$

and for the height of L.W. from same level—

$$H_s\,[1 - \cos\,(A - \kappa_s + \kappa_m)].$$

The time of H.W. is—

$$\text{M.T. of ☽'s tr.} + \text{mean estab.} - 2^h \frac{H_s}{H_m} \sin\,(A - \kappa_s + \kappa_m).$$

And the time of L.W. is 6h. 12m. later, or half way between two consecutive H.W.'s computed by above rule.

For example :—

At Port Blair $H_m = 2\cdot0$ ft., $H_s = 1\cdot0$ ft., $\kappa_s - \kappa_m = 37°$, mean establishment $= 9^h.6$m.; and we found M.T. of ☽'s lower transit on Feb. 5, 1885 = 4h. 52m. $= 4^h\cdot9$, and appt. time of transit reduced to angle at 30° per hour is 139°, so that A = 139°.

Then—

$$A - \kappa_s + \kappa_m = 102°\ ;\ \cos 102° = -0\cdot2\ ;\ \sin 102° = +1\cdot0.$$

$$H_s\,[1 + \cos 102°] = 0\cdot8\ ;\ 2H_m = 4\cdot0.$$

$$H_s\,[1 - \cos 102°] = 1\cdot2\ ;\ 2^h \frac{H_s}{H_m} \sin 102° = 2 \times \tfrac{1}{2} \times 1 = 1^h\cdot0.$$

$$\text{Time of H.W.} = 4^h\cdot9 + 9^h\cdot6 - 1^h\cdot0 = 13^h\cdot5.$$

$$\text{Time of L.W.} = 13^h\cdot5 + 6^h\cdot2 = 19^h\cdot7.$$

Hence—

H.W., Feb. 6, at 1h. 30m. a.m., height 4·8 ft.

L.W., Feb. 6, at 7h. 42m. a.m., height 1·2 ft.

It must be noticed that we are here supposed to know nothing of the diurnal tides, and the datum level being $H_m + H_s$ or 3·0 ft. below mean water is considerably higher than that used above.

The results are more nearly in accordance with the complete value as found in the preceding section than would usually be the case.

A graphical method of using the same data would be more accurate. The figure would be the same as that of the last section, but the m's and M's would be determined by sweeping a circle with radius H_m about O as centre, and OS would be taken as equal to H_s.

The further step in accuracy would be to proceed as in computation of § V., but to compute auxiliary tables B. and C. for each minute of parx. and each 2° of decl. only. Table D. may be abridged by computing corrections for parx. and decl. for upper transits only, and columns XI., XII. may be omitted entirely. Table E. for lower transit may be omitted. Figure F. may be drawn for upper transits only, and the entries in G. for lower transits may be filled in by interpolation. In Table H. for diurnal tides only the first entry for each day in VI. (2) and XI. (2) need be made, and only the first two entries for each day of VII., VIII., XII., XIII., XIV., XVIII. computed. The third and fourth entries for each day of XV. and XIX. may be taken as respectively numerically equal to the first and second ones, but with the opposite signs. These abridgements would reduce the computation by nearly a half. Other abridgements will doubtless occur to the computer, but they will all involve loss of accuracy.

VII.—Works of Reference.

A general account of the theory of tides will be found in most Popular Astronomies, but we are not aware of any book which gives a complete exposition of tidal theory and practice. Airy's well known article on "Tides and Waves" in the Encyclopœdia Metropolitana may be referred to, but as great advances have been made since the time of its publication, it would seem preferable to refer to the article by the present writer, which is about to be contributed to Encyclopædia Britannica.*

A complete list of all papers on the tides published since the time of Newton will be found in the Bibliographie Astronomique, Houzeau and Lancaster, Brussels, 1882. For an account of the harmonic method and its connexion with the method of hour angles, &c, *see* the Reports to the British Association for 1883 and 1885, and 1886, for an explanation of the methods here used.

Tables of the harmonic tidal constants at a considerable number of ports are given in a paper by A. W. Baird and G. H. Darwin in the Proceedings of the Royal Society, 1885.

Computation forms for the reduction of a long series of tidal observations, and copies of the British Association Report, 1883, may be purchased of the Cambridge Scientific Instrument Company.

A manual of practical tidal observation by Major A. W. Baird, R.E., will shortly be on sale by Messrs. Taylor and Francis, Red Lion Court, Fleet Street.

* A book founded on that article may probably be published separately in the course of a year or two from the date of this manual.

ARTICLE IV.

TERRESTRIAL MAGNETISM.

Originally written by the late Sir EDWARD SABINE. Revised for this edition by Professor G. F. FITZGERALD, F.R.S., with the assistance of Staff-Commander E. W. CREAK, R.N., F.R.S., and Mr. G. M. WHIPPLE, B.Sc.

1. The magnetic observations which have been made and are at present being made by naval officers have for their object the determination of the *amount* and *direction* of the *Earth's magnetic force* in different parts of the globe.

2. The amount of the magnetic force at any point of the Earth's surface may either be measured in *absolute* value, or its *ratio* may be ascertained to the value of the force at another station where its absolute measure is already known. No means have yet been devised for measuring *absolute* values at sea; consequently all determinations of the magnetic force on board ships are necessarily of the *relative* class; these give the ratio, or proportion, which the force at the geographical position in which the ship is at the time when an observation is made bears to its value at some land station which is included in the same series of relative observations, but where an absolute determination has also been made. Ships are therefore supplied with instruments for both absolute and relative determinations; the latter to be used chiefly at sea, but also on land at times when the ship is in harbour; the former to be used exclusively on land.

Absolute *Measurement of the Magnetic Force.*

3. No satisfactory method has yet been generally practised for the direct absolute measurement in one operation of the *whole* magnetic force of the Earth (called the "total

force") at any particular point of its surface. But that portion of the force which acts in a direction parallel to the surface of the Earth (called the "horizontal component") may be measured with considerable accuracy by a process of which the following brief description may suffice to give a general idea. If a magnet be suspended horizontally by a few fibres of silk, and made to vibrate in the horizontal plane on either side of its position of rest, the square of the number of vibrations in a given time is proportional to the horizontal component of the magnetic force of the Earth. But it also depends on the individual properties of the magnet employed; these properties influence the time of vibration, first, by the greater or less magnetic moment* which the magnet itself possesses, and, secondly, by the effects of the form and weight of the magnet. The latter effect, that of the form and weight of the magnet, may be eliminated when its moment of inertia† is learnt; and this may either be calculated by known rules, or may be ascertained experimentally by vibrating the magnet 1° in its usual state, and 2° with its moment of inertia increased by a known amount. The magnetic moment of the magnet is eliminated by determining its amount, and this is accomplished by using it to deflect a second magnet similarly suspended in another apparatus. The deflecting magnet is placed at one or more well-measured distances from the centre of the suspended magnet, and perpendicular to it. The deflections thus produced (*i.e.*, the angular differences in the positions of rest of the suspended magnet, 1° when influenced solely by the Earth's magnetism, and 2° when in equilibrium between the Earth's magnetism and that of the deflecting magnet at the distances employed) furnish the *ratio* of the force exerted by the Earth to the magnetic moment of the magnet; and as the *product* of the same two quantities is given by the vibrations of the deflecting magnet when suspended as in the experiments first described, the values of either force may be separately ascertained. The influence of the magnetism of the magnet

* The magnetic moment is measured by the product of the strength of either pole of a magnet multiplied by the distance between the poles.

† The moment of inertia of a body with respect to an axis is measured by the sum of the products of the mass of each part of the body multiplied by the square of its distance from the axis.

and of its form and weight being thus eliminated, a measure is finally obtained of the force of the Earth's magnetism, independent of the individual properties of the magnet employed in the determination.

4. The numerical expression by which the measure of the Earth's force thus obtained is denoted depends on the units of space, of mass, and of time employed in the measurements and calculation. The units employed in scientific work are the centimetre as the unit of length, the gramme as the unit of mass, and the second as the unit of time. The system of measures founded upon these units is known as the C. G. S. system (centimetre, gramme, second), and the International Polar Conference of Vienna in 1884 decided that all magnetic observations made in connexion with the International Commission should be reduced in accordance with the C. G. S. system. Formerly, in conformity with instructions published under the authority of the Royal Society, the foot, the grain, and the second were the units employed, but they have recently recommended that the C. G. S. system be employed in accordance with the recommendations of the International Polar Conference. The relation between the unit magnetic force and unit magnetic moment of the two systems is that the F. G. S. (foot, grain, second) unit magnetic force is ·04611 C. G. S. units, and the F. G. S. unit magnetic moment is 1305·6 C. G. S. units. The horizontal component of the Earth's magnetic force has been found by the observations hitherto made to vary at different points of the Earth's surface from 0 to about 0·4 C. G. S. units of magnetic force.

5. Wherever the horizontal component of the force has been ascertained in absolute measure, there also, if the magnetic direction be known, the "total force" in absolute measure is determined; since it consists of the horizontal component multiplied by the secant of the angle which the magnetic direction makes with the horizon. As ships are supplied with instruments by which this angle, called the *dip* or *inclination* of the needle, is measured, the observations on land, when the ship is in harbour, give determinations of the *total force*, which serve as *base determinations*, to which are referred the *relative* results obtained at sea in the passage from one station of well-assured *absolute* determination to another, a practice corresponding to that which prevails in determinations of longitude, where stations of well-assured longitude are taken as *base stations* to which

intermediate observations are referred. The total force of the Earth's magnetism has been found to vary at the different points of the Earth's surface where observations have been made from about 0·3 to 0·7 C. G. S. units. Before the practice of determining absolute values was adopted, various relative scales were employed, not always commensurable with each other. The one most generally used (and which still continues to be frequently referred to) was founded on the time of vibration of a magnet observed by M. de Humboldt about the commencement of the present century, at a station in South America where the direction of the inclination needle was horizontal, a condition which was for some time erroneously supposed to be an indication of the minimum of magnetic force at the Earth's surface. From a comparison of the times of vibration of M. de Humboldt's magnet in South America and in Paris, the ratio of the magnetic force at Paris to what was supposed to be its minimum was inferred; and from the result so obtained, combined with a similar comparison made by the late Gen. Sir E. Sabine between Paris and London in 1827 with several magnets, the ratio of the force in London to that of M. de Humboldt's original station in South America has been inferred to be 1·372 to 1·000. This is the origin of the number 1·372, which was formerly employed by British observers not furnished with the means of making absolute determinations, to express the value of the magnetic force at their base station, viz., London. The essential disadvantage, however, under which any relative scale of the nature referred to labours, is that the magnetic force of the Earth has been found to be subject to *secular variations*, so that at no one spot on the surface of the globe can the intensity be assumed to remain constant, and thus to afford a secure unvarying basis for such a scale; whereas by *absolute* measurements we are not only enabled to compare numerically with one another the results of experiments made in the most distant parts of the globe, with apparatus not previously compared, but we also furnish the means of comparing hereafter the intensity of the force which exists at the present epoch with that which may be found at future periods.

6. The instrument with which the absolute value of the horizontal component of the force is measured is called the Unifilar Magnetometer, invented by Gauss and Weber about 1836; its description, and that of the process by which

results are obtained with it, are given in Appendix No. 1. A tolerably practised observer will complete the process by which a measure of the absolute horizontal force is obtained in about two hours, including the time required for setting up and adjusting the instrument. It is desirable that there should be at least five or six repetitions at places which are to serve as base stations. There are certain constants (such as the moment of inertia of the magnet and stirrup in which it rests,—the change which the magnetic moment of the magnet undergoes from an alteration of one degree of temperature,—and the coefficient in the correction required for change of moment of the magnet in certain positions with regard to the magnetic meridian in which it may be used, produced by induction from the earth) which have to be determined for each magnet once for all, and require for their determination apparatus which is not afterwards needed. These constants have hitherto been usually determined at the Kew Observatory before the instrument is put into the hands of the officer who is to use it elsewhere.

Relative *Measurements of the Magnetic Force.*

7. These are the observations which are made *at sea*, to determine the ratio of the total force, in the geographical position of the ship at the time when the observation is made, to its value at some base station where the instrument has been landed and used in observations precisely similar to those made on board ship. The instrument is the well-known apparatus devised by Mr. Fox, which has contributed more to a knowledge of the geographical distribution of terrestrial magnetism than any other recent invention. The following description may serve to give a general idea of the apparatus and of the mode of obtaining results with it; more full directions for its use being given in Appendix No. 3. It consists of a dipping-needle and graduated circle, differing little from the accustomed form of an Inclinometer, except that the needle is supported by the ends of the axle, which terminate in cylinders of small diameter working in jewelled holes. A small grooved aluminium wheel is carried on the axle, and receives a thread of unspun silk, furnished at each extremity with hooks to which small weights may be attached, for the purpose of deflecting the needle from its position of rest in the magnetic direction, and causing it to take up a new position in which

it is in equilibrium between the opposing forces of the Earth's magnetism and of the deflecting weight. The weight being constant, and the magnetic moment of the needle assumed to be so, the intensity of the Earth's magnetic force in different localities is inversely as the sines of the angles of deflection. For greater accuracy, several constant weights are employed on each occasion; and each weight is successively attached to each of the two hooks, a mean being taken of the deflections on either side of the position of rest. The apparatus when used at sea is placed on a gimball table, by which the motion of the vessel is greatly counteracted; and when the weather does not permit the manipulation of the weights, deflecting magnets are substituted, the operation of which may be understood from the detailed instructions in Appendix No. 3. With the gimball table as now constructed, it is found that but very few days occur during a voyage in which the angles of deflection, either with weights or deflectors, cannot be satisfactorily ascertained by a careful observer. It is necessary that a spot should be selected for the observations to be made on board ship, and that the instrument should always be used in the spot so selected. Although many needles have proved most remarkable in preserving their magnetism unchanged for years and in all climates, it is desirable that reference to a base station should be made as often and with as short intervals as may be convenient; and evidence of this nature must always be furnished that the magnetism of the needle has not changed in a certain interval, before the relative determinations made during that interval can be relied on. The more frequently references are made to base stations at which the value of the magnetic force is known, the less danger exists that the labour bestowed on observations at sea will prove unproductive; and the more stations are multiplied which afford opportunities of such reference, the greater become the facilities for accurate determinations at sea.

Direction of the Earth's Magnetic Force.

8. The direction of the Earth's magnetic force undergoes every possible variation at different parts of the Earth's surface. For the purpose of determining and representing this direction, it has long been customary to refer it to two planes—the horizontal and the vertical—and to take the

geographical north as the zero of the horizontal plane, and the horizontal line as the zero of the vertical plane. The *declination* (or *variation*, as it is more usually called by naval men) is the angular difference, measured on the horizontal plane, between the direction of the north end of a magnet or needle and the geographical north point; and the *inclination* (or *dip*, as it is sometimes called) is the angular difference, measured on the vertical plane, between the direction of the same north end of a magnet or needle and the horizontal zero point. (The north end of a magnet here spoken of is that end which in Europe points towards the north, and dips below the horizon.) The declination is called East, if the direction of the north end of the magnet or needle is to the East of the geographical North, and is reckoned from 0° to 180°, passing from North through East to South. In like manner, the declination is called West, if the direction of the north end of the needle is to the West of the geographical North, and is reckoned from 0° to 180°, passing from North through West to South. The positive and negative signs are also sometimes applied instead of the terms East and West, in which case + signifies East, and — signifies West Declination.

The Inclination is counted positive, or has the sign *plus* prefixed, when the north end of the needle inclines below the horizon; and is counted negative, or has the *minus* sign prefixed, when the north end of the needle inclines above the horizon. Sometimes, instead of the signs + and —, the terms North and South are used, in which case North Inclination or Dip is when the north end of the needle dips below the horizon, and South Inclination or Dip is when the south end of the needle dips below the horizon. Thus an Inclination of — 30° is equivalent to 30° South Dip.

9. The Declination or Variation is measured by the standard azimuth compass, which should be fixed in the most advantageous position with regard to surrounding iron in the ship as well as for facility of observation.

Although the standard azimuth compass may be supplied free from error, it has been found that from the usage incidental to sea service the prism may become slightly disturbed and the cards distorted; it is necessary therefore that comparisons should occasionally be made with it on land, either where a fixed magnetic observatory is established, or with the Unifilar Magnetometer, and the index correction thus ascertained.

In vessels constructed chiefly of wood, a careful observer attentive to the practical rules published in the Admiralty Manual for deviations of the compass may, with the standard compass, obtain excellent results in harbour and at sea, and near land stations where local attraction exists, the ship—the effects of the iron in which may be eliminated by the process of swinging—will be found a valuable auxiliary for observing the normal declination, due to geographical position.

In iron and composite ships observations of the declination should be restricted to such times as it may be convenient to swing the ship slowly, and when upright on a number of equidistant directions of the ship's head, commencing with North. Observations should at least be made on the four cardinal points.

On land valuable results may be obtained with a good azimuth compass, provided that the index correction be observed as already mentioned.

The use of the dipping-needle (which measures the Inclination) not being so generally familiar to naval officers, full directions for its employment are given in Appendix No. 2.

Local Attraction.

10. It has been found that the results of magnetic observations, whether of the declination, inclination, or the intensity of the magnetic force, are liable to be influenced by local attraction proceeding from the rocks or soil in the vicinity of the instrument, and particularly so at stations where the rocks are of igneous character, such as traps, basalts, granites, &c. As a precautionary measure, therefore, magnetic instruments should always be used on stands which raise them 3 or 4 feet above the ground; and those stations are to be preferred of which the geological character is sedimentary or alluvial. Stations of igneous character, though less eligible for obtaining results which show the correct magnetic elements corresponding to the geographical position of the station, may nevertheless be serviceable as stations of comparison between the land and sea instruments; but for this purpose it is essential that the different instruments to be compared should be used precisely on one and the same spot at the station, in which case the local attraction may be supposed to be a constant quantity. And if the station be one frequently resorted

to by vessels from which magnetic observations are made, it is desirable that the spot should be carefully marked or be susceptible of a definite and well-recognisable description.

Summary of the Observations to be made.

11. An officer, therefore, who proposes to make observations of the three magnetic elements, the declination, inclination, and total magnetic force, or to cause them to be made on board his ship, has to attend to the following points :—

As soon as the ship is selected, he must see that suitable positions on board are determined for the standard compass, and Fox's Circle, and cause all iron capable of removal to be replaced by mixed metal.

At an early opportunity observations for the determination of the quantities λ, and μ, as detailed in the Admiralty Manual for deviations of the compass, should be made at both positions. λ is the mean value of the proportion of the force to north of earth and ship to the earth's horizontal force. μ is the mean value of the proportion of the vertical force of earth and ship to the earth's vertical force. The nearer both λ and μ approach to unity, the more valuable will be the observations of the three magnetic elements subsequently to be made at sea.

Satisfactory results having been obtained from these preliminary observations, the pillar for the standard compass, and the gimball stand for the Fox's Circle, may be fixed in their respective positions.

The officer will also ascertain that the number of the instruments is complete, and comprises at least the following, in addition to the usual standard azimuth compass.

For Observations on Land.

1. One Unifilar Magnetometer, with fittings, for observing the declination.
2. One Barrow's Dip Circle with two reversible needles.

For Observations at Sea and on Land.

1. One Fox's Apparatus or Circle with two non-reversible needles.
2. One compass similar to the standard in a bowl fitted to occupy the place of the Fox's Circle.

3. One flat lenticular needle, 7·0 ($2\frac{3}{4}$ inches) centimetres long, for observing horizontal vibrations.

The several instruments should be examined at Kew, or some other fixed magnetic observatory for the determination of the several constants and index errors, and if the intended observer be inexperienced in their use, he should engage in some preliminary practice with them.

When ready for sea, the ship should be swung for the deviations of the standard compass as directed in the Admiralty Instructions, and the compass specially provided should be temporarily placed on the Fox gimball table and compared with it, in order to obtain the ship's magnetic coefficients at the place of the Fox Circle as well as at the place of the standard. Before and after swinging observations for λ and μ should also be made at both places.

The ship will now require to be swung a second time, and the deviations of the observed dip and total force both with deflectors and weights ascertained on 16, or at least eight, principal points of the compass with the Fox Circle mounted on the gimball table.

The first base station since leaving the fixed observatory, or primary station, should now be formed by landing the whole of the magnetical instruments at some suitable place in the neighbourhood of the port, and making a complete set of observations of the absolute and relative values of the three magnetic elements.

The series of observations here described will serve as an example of what is desirable to carry out as far as possible at succeeding base stations, and it may be taken as a precaution that these base stations must be multiplied in proportion to the defect of λ and μ from unity at the first base station.

This completes the preparations to be made before the ship's departure. Whilst at sea, the observations of dip and intensity described in Appendix No. 3, as well as those of the declination or variation by the standard compass, should be made daily, whenever the weather and other circumstances permit. Whenever the ship is in harbour, and time and opportunities are suitable, it is important that the instrument should be taken on shore, and used at a spot selected as least likely to be influenced by any local attraction; and that the declination, inclination, and absolute horizontal force should there be determined, and the comparative observations made with Fox's apparatus. If the ship has materially changed her geographical position since the last occasion when the deviations were ascertained, or if changes have been made in her equipment by which the deviations may have been affected, it is necessary that the process for their examination by swinging should be repeated; and lastly, the *harbour observations here described should not fail to be repeated whenever the ship finally returns to England, and the constant and index errors determined at the same fixed observatory as before starting on the voyage.*

Record and Transmission of the Observations.

12. Blank forms are supplied for the entry of observations of all classes, and for the first or uncorrected calculation of those which require that process to be gone through at the time. It is desirable that the forms should be filled up in duplicate, and that one copy should be retained, and the other sent to England from time to time, as soon as circumstances make it convenient. On their arrival they should be immediately examined, and any suggestion to which they may give rise communicated at once to the observer.*

Application of the Results.

13. The observations when thus received require that the several corrections arising from the influence of the iron, the variations of temperature, the changes in the magnetic force of the magnets, and from various other sources, should be sought out, computed, and applied, and the true or corrected results finally derived. These form the materials from which it is intended to construct maps, showing the variations of the magnetic force, and of the magnetic direction in its two co-ordinates of inclination and declination, corresponding to the present epoch, over the whole surface of the globe. The distribution of the three elements are shown on these maps by lines connecting, for example, in the maps of the magnetic force, those points where the intensity is observed to be the same; in the maps of the inclination, those points where the inclination is observed to

* This has hitherto been done on all occasions when practicable, and it is very desirable that it should always continue to be done.

be the same; and, in the maps of the declination, those points where the declination is observed to be the same. These lines are known by the names of Isodynamic, Isoclinal, and Isogonic lines. The Isogonic lines, which form the maps of the declination (or variation) charts, have a direct practical importance and value in navigation, which in a notice addressed to naval officers needs not to be dwelt on. In theoretical respects, the Isodynamic and Isoclinal lines are not less essential; the three form the basis of a systematic view of terrestrial magnetism, as it manifests itself to us on the surface of the globe.

The mode in which the results are made to contribute to the formation of these maps is the following:—The results of the observations of the three elements when finally corrected are entered, each in its proper geographical position, on maps on a large scale, severally appropriated to the force, the inclination, and the declination. Each result has a small characteristic mark denoting the observer. When any portion of the globe is sufficiently covered by the results of observations in proper distribution, the isophenomenal lines are drawn for that portion of the globe in correspondence with the observations, with a free hand, but with a careful judgment, aided occasionally by a process of calculation which is not necessary here to describe. From these maps tables of double entry are formed, having the latitude at the side, and the longitude along the top of the page, and the values of the magnetic elements corresponding to the several latitudes and longitudes are placed at the points of intersection. By proper care in the process, the step of forming the tables from the maps need involve no additional uncertainty whatsoever. Maps and tables thus prepared when completed, form an experimental exposition of terrestrial magnetism, in which the facts of nature are shown with greater or less exactness, in proportion as the observations are numerous, correct and suitably distributed, and as they are more or less correctly represented in the maps. Mathematical formulæ, based on general mathematical views, having numerical coefficients of which the values are derived from these maps, may also serve for the computation of the magnetic elements at *any* geographical position on the surface of the globe; and, if the points taken from the maps to serve as the basis of the numerical values ot the coefficients are sufficiently numerous, and have a proper distribution over the surface of the globe, and, if the formulæ are carried to a sufficient number of terms, it may be expected that the elements computed from them will have the same degree of exactness as the maps from which their coefficients are taken.

In prosecuting a work of this general and purely experimental character, unconnected with hypothesis of any sort, the phenomena of all parts of the globe must be viewed in the abstract as possessing an equal importance ; and it does not appear desirable, therefore, to name any one of the lines, whether isogonic, isoclinal, or isodynamic, as deserving the special attention of observers in preference to others. There is one direction, however, which may be safely given, and which it may be well to remember at all times, viz., that "the value of each new station is directly proportional to " its distance from those where observations have already " been made."

APPENDIX No. 1.

Description and Use of the Unifilar Magnetometer.

The Unifilar Magnetometer consists of two parts ; an apparatus for observing deflection, and an apparatus for observing vibration. These correspond with the two parts of the process by which the absolute horizontal force is determined ; the experiments of deflection consist in observing the angular deflection of a suspended magnet produced by the influence of a second magnet, which is placed on a support at one or more known distances from the suspended magnet, and in a line drawn in a horizontal plane from its centre perpendicular to its direction ; the experiments of vibration consist in suspending the magnet which was used as the deflecting magnet in the experiments of deflection, and observing its time of vibration. By the first part of the process (or the experiments of deflection) we obtain the *ratio* of the magnetic moment of the deflecting magnet to the Earth's horizontal magnetic force at the place of observation ; the latter being to the former as 1 to the sine of the angle of deflection multiplied by half the cube of the distance employed ; or, if m denote the magnetic moment of the needle, X the Earth's horizontal force, r the distance apart of the centres of the magnets, and u the angle of deflection, the expression is—

$$\frac{m}{X}=\frac{1}{2}r^3 \sin u\left(1-\frac{P}{r^2}+ \&c.\right)$$

P being a constant depending upon the distribution of magnetism in the two magnets employed, and which may be determined by observations of the angles of deflection produced by placing the deflecting magnet at two or more distances.

By the second part of the process (or the experiments of vibration) the *product* of the same two quantities is obtained: being the quotient of a constant, which we may call π^2 K (see p. 2), divided by the square of the time of vibration. Or, if T be time of vibration,

$$m\,X = \frac{\pi^2 K}{T^2}.$$

The values of m X and $\frac{m}{X}$ being known, those of m and X may be obtained separately: for, if we call $m\,X = \alpha$ and $\frac{m}{X} = \beta$, m (the magnetic moment) $= \sqrt{\alpha\,\beta}$, and X (the horizontal component of the Earth's magnetic force) $= \sqrt{\frac{\alpha}{\beta}}$

A. *Observations of Deflection.*

1. Fit up the tripod stand, carefully screwing the leg screws to make it as rigid as possible, and place the circle upon it; attach the reading telescope and scale, the suspension tube and thread, and the deflection bar. Level the apparatus by means of the level attached to the circle. Suspend the brass plummet, and allow it to come to rest, turning the torsion circle at the top of the suspension tube, until the marked side of the lower suspension piece is towards the east. Remove the plummet and suspend the magnet, with the mirror facing the telescope, taking care not to twist the thread in the operation. Observe whether the magnet hangs horizontally, and, if not, move the sliding rings upon it until it does. Adjust the magnet to the same height as the deflecting magnet will be when placed upon its supports; this is done by viewing it through the sight tube placed upon the carriage intended to support the deflecting magnet upon the deflection bar. Close the sides of the box: if the divisions of the scale are seen too high or too low in the field of the telescope, the inclination of the magnet mirror may be corrected by means of the adjusting screws attached to the back of it for the purpose.

2. Place the deflecting magnet in its stirrup upon its carriage at the distance of 30 c.m.* to the East of the suspended magnet, and with its north end towards the East. Turn the circle in azimuth until the middle division of the scale is bisected by the wire of the telescope; it will be necessary in this operation to make use of a small magnet (such as the screwdriver or steel adjusting pin magnetized) for the purpose of bringing the magnet

* When the deflection bar is graduated to feet and inches, the deflecting magnet should be placed at a distance of one foot; and when time permits for bservations at a second distance, at 1·3 feet.

to rest. Clamp the circle, read the verniers, and record the temperature of the magnet, as shown by a thermometer laid on the circle.

3. Reverse the magnet with its carriage, and place it at the same distance, 30 c.m. East, north end to West. Turn the circle in azimuth as before, until the wire again bisects the middle division of the scale; read off the verniers and thermometer.

4. Remove the deflecting magnet with its carriage to the West side of the suspended magnet, and place it with its centre at the same distance as before, viz., 30 c.m. West, north end to West. Observe as before.

5. Reverse the magnet with its carriage, and place it at the same distance, 30 c.m. West, north end to East.

6. Take a mean of the circle-readings in the 1st and 4th positions of the deflecting magnet, and another mean of the readings in the 2nd and 3rd positions; half the difference of these means will be the angle of deflection required.

7. The operations above described should always be repeated *at least* twice, so as to obtain two separate values of the angle of deflection. If these values differ more than 30″ or 40″, a third set of observations should be taken. The value of the angle of deflection should be always deduced on the spot, so as to guard against accidental errors. As this can be done in two or three minutes, the precaution should never, if possible, be neglected.

8. When time permits, deflections should be observed alternately at the distances 30 and 40 c.m.; from a sufficient number of such pairs of deflections the quantity P may be calculated.

9. The arc-value of the scale-divisions is given in the table of constants supplied with the instrument, but may be readily obtained thus:—The magnet being brought to a state of rest, with the wire of the telescope cutting one of the divisions near one extremity of the scale, read the verniers. Move the circle until a division near the other extremity is bisected, and again read the verniers. The angle through which the circle has been turned, divided by the corresponding difference in the scale-readings, is the value of one division. This process applies also to the collimator magnet employed for observations of vibration and declination.

B. *Observations of Vibration.**

1. Dismount the suspended magnet from the Unifilar Magnetometer, remove the suspension-tube, the arm carrying the telescope and scale, and the deflection bar. Screw into the place previously occupied by the suspension-tube the vibration-box, with its sus-

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* A vibration is a movement of the magnet from a position of maximum displacement on one side of the meridian to a corresponding position on the other side.

pension-tube and thread for vibration; place the telescope in its V's and screw the thermometer in its place; suspend the plummet and remove the torsion approximately from the thread; attach the deflecting (collimator) magnet; level, by means of the telescope-level and the cross-level on the top of the box; turn the circle in azimuth until the middle division of the magnet-scale is cut by the wire of the telescope when the magnet is brought to rest. Cause the magnet to vibrate through an arc extending to about 60′ (30 scale divisions) on each side of the middle line of the scale, and observe the time of vibration in the following manner.

2. Determine roughly (to the nearest second) the time required by the magnet to make 10 oscillations. When observing with a pocket chronometer which beats 10 times in four seconds, watch the movement of the scale as the north end of the magnet moves towards the *East*. Count the first beat of the chronometer *after* the central division has passed the wire as 1, and continue the counting 2, 3, &c., to 10. At the 10th beat note the reading of the chronometer (which will thus be 4 seconds after the actual time) as the time * of the central division passing the wire at the 0th vibration. Add to the number now written down the approximate time for 10 oscillations, deduct 7 seconds from the sum, and, when the chronometer points to the resulting time, place the eye to the telescope and note the next passage of the central division across the wire in the same direction as before. This is the 10th vibration. Again, calculate the expected time of the 20th vibration, and observe as before, and so on till the 50th. From the 50th vibration calculate in like manner the expected time of the 60th; in this case, however, on placing the eye to the telescope, allow the passage of the central division to go unobserved, and take the next passage, which will be in the opposite direction, or north end of magnet moving West. This is the 61st vibration, from which calculate the time for the 71st, and so on till the 111th. There is now an interval of some minutes, during which the observer may, from the observed interval between the 0th vibration and the 50th, and between the 61st and 111th, calculate the approximate time for the 200th and 261st vibrations; the 200th, 210th, &c., and the 261st, 271st, &c., being observed in the same manner as the earlier vibrations. Subtract the time of the 0th vibration from that of the 200th, the 10th from the 210th, &c., and the 50th from the 250th. This will give six inde-

* The observations may be taken to one tenth of a second by estimating the relative distances of the central division of the scale from the wire at the chronometer beat *before* and the beat *after* the central line passing the wire; that is the 0th and 1st beat as counted. An expert observer may find it more convenient, instead of following the order of observation detailed above, to observe the 0th, 5th, 10th, 15th, &c., to the 55th vibration, and again the 200th, 205th, &c. In high magnetic latitudes, where the time of vibration becomes so great that 300 oscillations cannot be obtained at once, on account of the magnet coming to rest, it will be better to observe thus, and to take 100 instead of 200 oscillations.

pendent values of the time of 200 oscillations, the north end of the magnet moving East. Similarly subtracting the 61st from the 261st, the 71st from the 271st, &c., we have other six values for the time of 200 oscillations, the north end of the magnet moving West; the mean of the two series divided by 200 will give an exact value for the time of one oscillation.

3. Observe the reading of the thermometer at the commencement and termination of the series of observations. If the arc of vibration does not exceed the amount stated above, no correction on account of the size of the arc is required. The rate of the chronometer should be approximately stated.

4. The torsion force of the suspending thread is determined as follows. After having completed the observations of vibration, bring the magnet to rest and observe the scale-reading a. Turn the torsion circle through $+ 90°$, the numbers on the torsion circle increasing; observe the scale-reading b; turn back to the original position and read the scale a'; turn through $- 90°$ (the numbers diminishing), and read the scale c; finally turn to the original position and read the scale a''. Then $b - \frac{a + a'}{2} =$ effect of $+ 90°$, and $c - \frac{a' + a''}{2} =$ effect of $- 90°$; the arithmetical mean of these two quantities, multiplied by the arc-value of one scale division, is the effect of 90° of torsion in minutes.

5. The deflecting magnets usually employed are collimator magnets, having double scales, the one (a short scale) being at right angles to the principal scale. When the line of collimation of the reading telescope (which has a level attached) is horizontal, the horizontal wire ought to cut that point of the short vertical scale which has been found to correspond with the magnetic axis of the magnet. This point may be found at first by making the short scale horizontal, and determining the magnetic axis by reversal in the manner afterwards described for the declination magnet. This point having been once determined and noted, the magnet may be levelled at any time by sliding it in its stirrup until the wire cuts the required point of the verticle scale.

When properly adjusted, the magnet should be fixed firmly in its stirrup, and not removed again until a considerable change of geographical position necessitates a readjustment of the horizontality of the magnet.

C. *Calculation of the Value of the Horizontal Component of the Earth's Magnetic Force from Observations of Vibration and Deflection.*

T_0=Observed time of one vibration of the magnet.

$T_{,}$=Time of vibration, corrected for rate of chronometer and arc of vibration.

T = Time of vibration, corrected for rate of chronometer, arc of vibration, torsion force of the suspending thread, temperature, and induction.

s = Daily rate of chronometer, + when gaining, — when losing.

α, α' = Semiarc of vibration, at the beginning and end of the observation, expressed in parts of radius.

$\frac{H}{F}$ = Ratio of the force of torsion of the suspending thread to the magnetic directive force. [This is obtained from the formula $\frac{H}{F} = \frac{u}{90^\circ - u}$, where u = the angle through which the magnet is deflected by a twist of 90° in the thread.]

q = The correction for the decrease of the magnetic moment of the magnet produced by an increase of temperature of 1°. [This correction is not constant at all temperatures, and the correction is more exactly expressed by a formula of the form,—correction to $t_0 = q\,(t_0 - t) + q'\,(t_0 - t)^2$, t_0 being the observed temperature, and t an adopted standard temperature.]

K = Moment of inertia of the magnet, including its suspending stirrup and other appendages. [This is constant for the same magnet and suspension, but varies slightly with temperature, owing to the expansion of the materials.]

π = Ratio of the circumference to the diameter of a circle = 3·1415927.

μ = The increase in the magnetic moment of the magnet produced by the inducing action of a magnetic force equal to unity of the system of absolute measurement.

r_0 = Apparent distance between the centres of the deflecting and suspending magnets in the observation of deflection.

r = Distance corrected for error of graduation and temperature. [$r = r_0 \{1 + 0{\cdot}00002t\}$ + Correction for scale error.]

u_0 = Observed angle of deflection.

P = A constant depending upon the distribution of magnetism in the deflecting and suspended magnets. [This is to be determined from several series of observations of deflection at two or more distances. The most convenient distances to be employed for this purpose are 30 and 40 cms. The correction is small, and may remain unapplied until the conclusion of the series.]

m = Magnetic moment of the deflecting or vibrating magnet.

X = Horizontal component of the earth's magnetic force.

$\frac{m_0}{X_0}$ = Approximate value of $\frac{m}{X}$.

$\frac{m'}{X'}$ = Value of $\frac{m}{X}$ before the application of the correction $\left(1-\frac{P}{r_\circ^2}\right)$

$$T^1=T_\circ\left\{1-\frac{s}{86400}-\frac{\alpha\,\alpha'}{16}\right\};\ T^2=T_1^2\left\{1+\frac{H}{F}-q\,(t_\circ-t)+\mu\frac{X_\circ}{m_\circ}\right\}$$

$$mX=\frac{\pi^2 K}{T^2}$$

$$\frac{m_\circ}{X_\circ}=\tfrac{1}{2}\,r^3\sin.u_\circ;\ \frac{m'}{X'}=\frac{m_\circ}{X_\circ}\left\{1+\frac{2\mu}{r_\circ^3}+q\,(t_\circ-t)\right\};\ \frac{m}{X}=\frac{m'}{X'}\left(1-\frac{P}{r_\circ^2}\right)$$

Let A=value of $\frac{m'}{X'}$ from deflection at the distance r.

and A′= „ „ r';

then $P=\dfrac{A-A'}{\dfrac{A}{r^2}-\dfrac{A'}{r'^2}}$

The quantity K is obtained by observing the time of vibration of the magnet alternately with its usual mounting, and with its moment of inertia increased by the addition of a cylinder of known weight and dimensions.

The value of K is obtained from the formula $K=W\left(\frac{l^2}{12}+\frac{d^2}{16}\right)\frac{t^2}{t'^2-t^2}$ where W is the weight of the cylinder in grammes, l and d its length and diameter expressed in centimeters; t' and t being the times of vibration (corrected for torsion, temperature, &c.) of the magnet with and without the additional weight.

D. *Observations of Declination with the Unifilar Magnetometer.*

1. Suspend the collimator magnet, after having carefully removed the torsion from the suspension-thread. Carefully level the apparatus until the axis of the mirror is exactly horizontal, as shown by the riding-level (which ought to be reversed in the operation) in all azimuths, but especially when the telescope is directed towards the sun's position.

2. Raise the magnet by the rackwork motion until the line of vision of the telescope is clear through the magnet-box. Put a dark glass in front of the eye-piece of the telescope and move the circle in azimuth and the transit-mirror in altitude until the sun is visible in the telescope. Clamp the circle, and observe the time at which each limb of the sun passes the wire of the telescope; read the verniers; reverse the transit-mirror in its bearings, and repeat the observation of the sun's passage over the wires, and again read the verniers.

3. Lower the magnet and remove the dark glass; turn the circle in azimuth until the scale of the magnet is in the field of the telescope; steady the magnet, and by the tangent-screw bring the wire of the telescope as exactly as possible to the zero division of the scale (or the point of the scale corresponding to the magnetic axis of the needle); read the verniers, noting also the time approximately by a chronometer.

4. When time permits, repeat the operations (2 and 3) until a good mean result is obtained. The more frequently and at the longer intervals the operation (3) is repeated, the greater will be the probability that the diurnal variation is eliminated. The hours best adapted for observations of the declination are 7 to 10 A.M., and 4 to 6 P.M., as at these times the magnet is nearly in its mean position, and the sun is most advantageous for observation.

5. From the operation (2), knowing the true local time, the latitude of the place, and its approximate longitude, the sun's azimuth may be computed, and the circle-reading corresponding to the astronomical meridian determined. From the operation (3) the circle-reading corresponding to the magnetical meridian is directly given. The difference between the computed circle-reading for the astronomical meridian and that obtained for the magnetical meridian is the magnetic declination.

6. Before commencing a series of observations, and occasionally when opportunity offers in the course of the series, it is necessary to determine very exactly the zero point of the scale, or the reading of the scale corresponding to the magnetic axis of the magnet. This is done as follows: suspend the magnet with its stirrup, with the scale erect; move the circle until the divisions near the middle of the scale are in the middle of the field of the telescope. Clamp the circle firmly, and note the scale-reading. Invert the magnet (that is, turn the magnet on its horizontal axis through 180°), the circle remaining clamped; read the scale. Again invert, and repeat the operation several times, until a good mean is obtained. Having obtained, say, five observations, "scale erect," and four observations, "scale inverted," the zero point of the scale is—

$$\tfrac{1}{2}\left\{\begin{array}{l}\text{mean of readings, "scale erect" +}\\ \text{mean of readings, "scale inverted."}\end{array}\right\}$$

This quantity ought to be constant for the same magnet; but care should be taken that neither the scale nor lens of the magnet is unscrewed or otherwise altered. If time permits, in order to remove any doubt as to the constancy of the zero point, the magnet should be inverted at each observation.

7. The torsion of the thread should be removed at every possible opportunity. This is done by removing the magnet, and substituting a brass plummet and bar of *equal weight*, allowing the bar to hang until it has assumed a steady position, and turning the top of the suspension-tube until the bar hangs steadily

in the line of the telescope. The magnet may then be replaced and fixed in its stirrup for observation, the scale being always made horizontal and the divisions erect. In replacing the magnet, care should be taken that a turn or half turn of torsion is not introduced into the thread. In carriage, and when the magnet is not in use, the suspension pin is fixed in the tube by a cork in such a way that torsion cannot readily be introduced. Whenever time allows, the torsion should, however, be removed.

8. There are three adjustments required for the transit-mirror:—

1st. The axle to which the mirror is attached must be horizontal. This adjustment is performed by means of a riding-level.

2nd. The mirror must be parallel to the axis of the cylindrical axle to which it is attached.

3rd. The line of collimation of the telescope must be perpendicular to the axis.

Since the telescope is furnished with a collimating eye-piece, when the plane of the transit-mirror is vertical the image of the wire of the telescope will be seen by reflection from it. Then by means of the proper adjusting screws both the second and third adjustments may be effected by making the wire seen directly coincide with its image seen by reflexion before and after reversal of the transit axis. Both these adjustments can thus be readily verified before each observation.

APPENDIX No. 2.

Observations of the Inclination and Total Force with Barrow's Circle furnished with Microscopes and Verniers.

A.—*Inclination.*

1. Place the instrument on the tripod stand, and level it by means of the foot-screws; then bring the vertical circle into the magnetic meridian by the following process:—Place the needle designed for the observation of the dip on the agate supports, with the side of the needle on which the letters are inscribed facing the microscopes. Turn the vernier plate so that the microscopes may be nearly in a vertical line; clamp the plate, and set the lower vernier to 90° by the tangent screw. Turn the vertical circle in azimuth, so that its face may be towards the South, and until the North pole of the needle is bisected by the wire of the microscope; raise the Y's and lower gently; if the bisection of the needle has been altered, correct by turning the circle in azimuth. Clamp the horizontal circle, and read off

its vernier, calling the reading A. Now set the upper vernier to 90°, unclamp the horizontal circle, and move in azimuth (if required) until the South pole of the needle is bisected by the wire of the upper microscope. Raise the Y's and lower gently; correct the bisection (if necessary) by moving the circle in azimuth; clamp the horizontal circle and read its vernier, calling the reading B. Now unclamp the horizontal circle, and turn the vertical circle 180° in azimuth, so that its face (by which is meant the side on which the microscopes are), which was before to the South, may now be to the North. Repeat the process described above, which will give two other readings of the vernier of the horizontal circle, which call C and D. Then

$$\frac{A+B+C+D}{4}=E:$$

E being the division of the horizontal circle to which the vernier should be set, in order that the plane of the vertical circle may be at *right angles* to the magnetic meridian; therefore, when the vernier is set to 90+E, the plane of the vertical circle will coincide with the magnetic meridian.

The stops on the base plate are then to be screwed firmly in such positions that the circle will read 90+E after reversal, both with face East and face West.

2. The vertical circle being now placed in the magnetic meridian, with its face to the *east*, and the marked side of the needle towards the face of the instrument, the needle will direct itself approximately to the inclination; raise it by the Y's, and lower it gently on its supports; repeat this operation two or three times before commencing to record the readings; bring the lower microscope to bisect the north end of the needle, clamp and adjust exactly by the tangent-screw, and read off the vernier. By means of the tangent-screw of the vernier-plate bring the upper microscope to bisect the south end of the needle, and read its vernier; raise the Y's, and lower gently; repeat the readings, commencing now with the south end. The mean of the four readings for the inclination (*with poles direct; face of needle to face of instrument; face of instrument east*) $= a$ (suppose).

3. Turn the vertical circle 180° in azimuth, and repeat the process of No. 2, taking again the mean of the four readings, which will be the inclination (*with poles direct; face of needle to face of instrument; face of instrument west*) $= a'$.

4. Reverse the needle on its bearings, and observe as before: *poles direct; face of needle reversed; face of instrument west*, inclination $= a''$.

5. Turn the vertical circle 180° in azimuth, and observe: *poles direct; face of needle reversed; face of instrument east*, inclination $= a'''$. The concluded inclination, *poles direct*, will then be

$$\alpha = \frac{a+a'+a''+a'''}{4}.$$

6. The poles of the needle must now be reversed by means of the bar magnets, by the following process :—Take the needle off the agates, holding it by the end which in the preceding observations was a South pole, and which is now to be converted into a North pole; place it with the flat side (which is lettered) uppermost in the wooden frame designed to prevent any injury occurring to the axle, being careful that the end to be made a North pole is placed towards that part of the wooden frame which is marked accordingly; secure the needle by the brass centre-piece, and place the frame with one end towards the right hand and the other towards the left. Now take the bar-magnets, one in each hand, and let the *North* pole of the bar-magnet be lowermost in the hand which is towards the end of the frame in which that end of the needle is placed which is to be made a *South* pole; and let the *South* pole of the bar-magnet in the other hand be lowermost. Draw the magnet about 10 times along the flat side of the needle, the North pole of one bar-magnet being drawn along the end of the needle which is to be made a South pole, and the South pole of the other bar-magnet being drawn along the end of the needle which is to be made a North pole. The needle must then be turned over in the wooden frame, so that its other flat side may become uppermost, which must also be rubbed by the magnets 10 times in the manner already described.

The bar-magnets should be held one in each hand, nearly in a vertical position, the lower ends resting on the needle, and must be drawn along in the wooden frame from near the centre to beyond the ends of the needle, their edges being kept in contact with one raised edge of the frame. When the process thus described has been gone through, it will be found on replacing the needle on the agates that the end which previously dipped below the horizontal line is now inclined above it.

7. The observations described in Nos. 2, 3, 4, and 5 must now be repeated, which will give four other mean readings, b, b', b'', b'''. The inclination with the *poles reversed* will then be

$$\beta = \frac{b+b'+b''+b'''}{4};$$

and the *true* Magnetic Inclination of the place of observation will be

$$\theta = \frac{\alpha+\beta}{2}.$$

8. Two such determinations will generally be found sufficient; but if the results differ from each other more than $3'$ or $4'$ it is desirable to repeat the observations.

9. On arriving at a new station it is always desirable to magnetise the needle afresh before the observations are commenced. It is indifferent whether an observation is commenced with the end marked A as a North or as a South pole; but it is convenient to call that state of the needle in which the end A is a South pole,

and the end B a North pole, "poles direct," and the other state "poles reversed."

B.—*Total Force.*

1. Dr. Lloyd, of Dublin, suggested a mode of employing the dip-circle for measuring the variations of the total force independent of changes in the magnetic moments of the needle or needles employed. For this purpose the instrument is furnished with two additional needles, which may be called for distinction Nos. 3 and 4, *the poles of which are at no time to be reversed or disturbed;* Nos. 1 and 2 being the needles used for observing the inclination in the usual way. No. 3 is an ordinary dipping-needle; No. 4 is a similar needle loaded with a small fixed and constant weight, acting in opposition to magnetism. The frame carrying the microscopes of the circle is also fitted to receive and to retain No. 4 securely in a constant position, when it is used as a deflector of No. 3.

2. The observations consist of two processes; by the one process the position of equilibrium is observed of No. 3 between the action of the earth's magnetism, and that of No. 4 used as a deflector, having its North pole directed alternately towards the magnetic North and South; and by the other process the position of equilibrium of No. 4 is observed between the action of the earth's magnetism and that of the small constant weight with which it is loaded.

3. The observations for the inclination and total force may be conveniently taken in the following order:—

1°. Needle No. 1 is to be placed on the agate planes, and a complete observation of the inclination taken with it in the manner already described.

2°. Needle No. 3 is now to be substituted for No. 1, and No. 4 firmly attached to its supports between the microscopes, protected from the breath by the brass cover, and always in the same position. The inclination of No. 3 to the horizon is then to be observed in one position of the needle and circle. The observation is to be repeated with the north end of No. 4 turned in the opposite direction by the revolution of the movable arms which carry the microscopes; half the difference of the readings in the two positions is the angle of the deflection u'.*

3°. Needle No. 3 is now to be removed, and the loaded needle, No. 4, substituted; and its inclination to the horizon, η, is to be observed in the four positions of the needle and circle. The

* The circle being divided in quadrants, care must be taken in observations of deflection that when the needle is deflected beyond the *vertical* the difference of the observed reading from 180° must be taken as the true reading. When it is deflected beyond the *horizontal*, the observed circle reading is to be entered with the *negative* sign prefixed, in which latter case the mean deflection will be half the arithmetical *sum* of the observed readings.

deviation of this needle from the position due to the earth's magnetic force alone is $u = \theta - \eta$, the angle η being *positive* (+) when measured at the same side of the horizontal line with θ, and *negative* (−) in the contrary case.

4°. Repeat the observations (2°).

5°. Make a complete observation of the inclination with needle No. 2.

4. The value of the force is given by the formula—

$$R = A\sqrt{\cos \eta}, \text{ where } A = \frac{X}{\cos \theta}\sqrt{\frac{\sin u \sin u'}{\cos \eta}}$$ as observed at a base station, where X (the horizontal component) has been determined with the unifilar magnetometer, and the inclination θ has been also observed.

5. The method now described is, however, only applicable to a limited portion of the globe, being especially useful in the higher magnetic latitudes, and cannot be applied (without a readjustment of the loaded needle at a fresh base station) to the opposite hemisphere. If, however, the instrument is furnished with a needle, such as those employed in Mr. Fox's apparatus (described in Appendix No. 3), in which the weight is attached to a fine thread passing round a light pulley, whose centre is on the axis of the cylindrical axle of the needle, the method becomes universally applicable. The above formulæ then become

$$R = A\sqrt{\frac{1}{\sin u \sin u'}}, \text{ and } A = \frac{X}{\cos \theta}\sqrt{\sin u \sin u'}.$$

6. By this means the absolute inclination and the total force relatively to its value at the base station where the constant A was determined may both be ascertained by the dip-circle alone, without displacement or alteration of its adjustment.

APPENDIX No. 3.

Directions for using Mr. Fox's Apparatus for observing the Magnetic Inclination and Force.

I.—General Remarks.

In fixing the gimball table it is convenient that it should be so arranged that, when the apparatus is placed on it, the zero divisions of the horizontal circle should coincide with the fore and aft midship-line of the ship.

In preparing for an observation at sea, the circle should be turned in azimuth until the vernier of the horizontal circle shows an angle with its zero corresponding with the difference between the magnetic meridian and the course which the ship is steering. The plane of the circle will then coincide with the magnetic meridian, when the ship is steadily steered. When from circumstances of weather, &c., the steerage is difficult, an assistant is required to indicate to the observer the times when the ship is steady on her course.

The apparatus is usually furnished with three or four needles, one of which is intended to be used on shore for the determination of the true inclination (when no special instrument is provided for the purpose), by the process previously described, Appendix 2, in which the poles are reversed. The other needles, which are intended for the intensity, are never to have their poles reversed, and care is to be taken not to place them inadvertently near other magnets or iron. Besides the needles two other magnets are supplied to be used as deflectors. In replacing the needles and deflectors in the travelling box, care should always be taken that the poles of each occupy the places marked for them in the box.

It is desirable to use always the same needle at sea, and to keep it always mounted, clamping it before it is put away for the day; but in case of its undergoing any considerable deterioration from use or accident, one of the other intensity needles may be substituted for it.

When changing the needles at a land station, be very careful not to injure the jewels, or the terminations of the axles of the needles; when a needle is changed it is desirable to hold it chiefly by the grooved wheel; the pivot should first be put into the outer jewelled hole, and the opposite pivot should be carefully guided into the hole at the back whilst the bracket is screwed up.

With respect to the constant weights, it is desirable that the smallest angle of deflection produced by any of the weights employed should not be less than 30°. On account of possible instrumental irregularities it is usual to employ more constant weights than one, with differences between each of ·05 grm. (as for example, ·2 grm., ·25 grm., ·3 grm., &c.). If the English system of measures be used, their weight may be 2 grains, 2½ grains, 3 grains, &c. Great care is taken that all the weights which have the same nominal value should be equiponderant, but it is desirable, if possible, to preserve the same identical weights throughout the whole observations of the same relative series.

II.—Observations at Sea.

A.—*Inclination.*

1. *Direct Observation.*—The instrument having been placed on the gimball stand and levelled, and the plane of the circle made parallel to the magnetic meridian, with the face of the circle towards the East, release the needle, which will immediately take

approximately the direction of the inclination: rub gently the centre pin at the back with the ivory disk, and read off successively the divisions of the limb indicated by the two ends of the needle; note the readings, which will be +, or positive, when the North pole of the needle dips, and —, or negative, when the South pole of the needle dips: repeat the observation four times, turning the bracket which supports the needle a small quantity before each observation, and being careful to rub the centre pin at the back with the ivory disk whilst reading off. The bracket is turned by means of the screw-heads at the back of the circle, and the object of turning it is to cause the ends of the axle of the needle to have different points of bearing on the jewels in each observation. It is desirable, when four observations are taken, to turn the bracket (say) to the right before each of the first and third observations, and in the opposite direction before each of the second and fourth.

In reading the divisions on the limb, be careful always to bring the division nearest to the needle to coincide with the corresponding division of the second graduated circle immediately behind it, by which means parallax is avoided.

The mean of the four observations or eight readings above described is the apparent inclination by direct observation with the face East.

2. *Observation with Deflectors.*—Having made the preceding observation, screw in the deflector N (or the north pole of a second needle used as a deflector), and adjust the circle at the back by means of its verniers, so that the deflector may be 40° on one side of the division which in the preceding process (1) was read off as the direct observation with the face East. The needle will then be repelled, and will settle on the opposite side of the dip. Read off (always whilst rubbing with the ivory disk) the divisions indicated by the two ends of the needle. Repeat the observation four times, altering the bearings of the ends of the axle before each observation as above directed. Turn the back circle through 80°, so that the deflector may be 40° on the other side of the apparent dip. Move the needle by the bracket, so that it may be deflected on the opposite side of the apparent dip to what it was before, and make four observations. The mean of the eight observations or 16 readings is the apparent inclination with a deflector, face East.

Instead of placing the deflector at 40°, another angle, as 45° or 50°, may be taken; or a second angle may be used for the purpose of varying the observations when it may be desired to repeat them; the only essential point being, that the angle at which the deflector is placed should be the same on each side the apparent dip.

Instead of deflector N (or the North pole of a second needle used as a deflector), deflector S (or the South pole of the second needle) may be screwed into the opposite point of the back circle, and eight observations taken with it will give as before the apparent inclination with a deflector, face East.

When time permits, and the circumstances are favourable, the observations prescribed in (1) and (2) may be repeated with the face of the circle to the West.

In writing down the observations the following directions must be attended to; if the needle be deflected past the *vertical*, the division of the limb should be read off according to the graduation and noted accordingly, but the mean of the readings must be taken from 180°, in order to give the true arc corresponding to the position of the needle: if it be deflected past the *horizontal*, the readings must be entered as marked on the limb, but with the negative sign prefixed, in which case the mean result will be half the *difference* of the means of the negative and positive readings.

The apparent inclination obtained as above directed, whether by the direct method, or with deflectors, requires three corrections to give the true inclination, viz.—1st, the index-correction of the particular needle employed; 2nd, a correction for the influence of the ship's iron dependent on the direction of her head at the time of observation; and 3rd, a correction for the vertical force of the ship independent of the ship's head. The mode of obtaining the index correction will be subsequently explained.

B.—*Total Force.*

3. *With Weights.*—The instrument being on the gimball table and levelled, the plane of the circle parallel to the magnetic meridian, with its face to the East, and the needle showing the magnetic dip, place the silk carrying the hooks on the grooved wheel; attach one of the constant weights to one of the hooks, and take four readings of the division of the limb at which the needle is in equilibrium, using the precautions already directed of altering the points of support of the axle before each observation, and rubbing with the ivory disk whilst reading off.

If the needle is deflected past the vertical or horizontal, read and enter the angles as already directed under the head of Inclination.

Change the weight to the other hook, when the needle will be deflected to the opposite side of the apparent dip to what it was before, and take four more observations. Half the difference of the mean of the arcs with the weight on either hook is the angle of deflection due to the constant weight employed; or half their *sum*, if one of the arcs was past the horizontal, and has therefore the negative sign prefixed.

4. *With Deflectors.*—The instrument being adjusted as already described (and without using the hooks, which are only designed for the observations in which the weights are used), adjust the circle at the back by means of its verniers to the apparent dip, so

that the deflectors, when screwed in, may coincide with the line of the dip; the needle will then be repelled to one side; make four observations of the division to which the needle is thus deflected, observing the usual precautions of moving the bracket at the back, reading both ends of the needle, and rubbing with the ivory disk.

Move the needle past the deflector to the other side of the dip by means of the bracket, and take four more observations; if the needle is deflected past the vertical or horizontal, read and enter the angles in the manner already described; half the difference of the arcs on either side of the apparent dip, or half their sum if one be past the horizontal and have the negative sign, will be the angle of deflection produced by the deflector. Instead of the deflectors, a second needle may be used as a deflector, either with the end of the needle-case marked N (containing the north pole of the needle) screwed into the arm marked N, or the end marked S screwed into the arm marked S.

The thermometer attached to the circle must be observed at the commencement and close of the observations of intensity, whether with deflectors or weights.

5. A convenient routine of the observations at sea may be stated as follows:—

1. Take four observations of the apparent dip by the direct observation.

2. Screw in the deflectors N and S, and adjust the back circle to the dip. Make four observations of the angle of deflection produced on either side of the apparent dip; this furnishes one result for the intensity of the magnetic force.*

3. Repeat No. 2 with a second needle used as deflector N, which will give a second result for the intensity of the force.

4. Repeat No. 2 with the second needle used as deflector S, which will give a third result for the intensity of the force.

5. Remove the deflector and repeat No. 1, which will give a second result for the apparent inclination.

On days when the weather permits, observe the intensity also by the constant weights.

6. *Calculation of the Observations; 1st, with Weights.*—Let R be the intensity, expressed either in absolute or relative measure, and u the angle of deflection produced by a constant weight at the base station; R_0 and u_0 being the intensity and deflection at any other station; then

$$R_0 = \frac{C}{\sin u_0} \left\{1 + q\,(t_0 - t)\right\}$$

where $C = R \sin u$, a constant; t_0 the temperature of the needle at the second station; t that at the base station; and q the correction for the decrease of the magnetic moment of the needle

* In places where the terrestrial magnetic intensity is low it is more convenient to use the deflectors N or S separately.

produced by an increase of temperature of 1°, a quantity which must be experimentally determined at a fixed observatory for each needle.

2ndly. *With Deflectors.*—Where deflectors are used in the manner hitherto adopted, that is, with the deflector placed at right angles to the plane of the instrument, the intensity is obtained by the formula

$$R_0 = \frac{R\, w_0 \sin v}{w \sin v_0}\Big(1 - q\ (t_0 - t)\Big)$$

where R, v, and w are the intensity, angle of deflection, and equivalent weight at the base station; and R_0, v_0 and w_0 those at any other station.

A table of "equivalent weights" may be formed in the following manner:—The plane of the instrument being placed perpendicular to the magnetic meridian, and the needle in its natural position of rest (which in such case is a vertical position), the deflector is placed successively at angles from the vertical, each differing one degree from the preceding: the needle is thereby deflected to an angle on the side of the vertical opposite to the deflector, and is brought back to its natural position of rest by weights applied to the grooved wheel on the axle. These weights are called the equivalent weights, corresponding to the angles from the vertical at which the deflector was successively placed, and which ought to include all the angles likely to occur in the course of the observations. As the permanency of the magnetism of the deflectors cannot be assured, the observations for the values of the equivalent weights should be repeated occasionally. If a graphic representation of the results be made it is sufficient to observe with the deflector at every 5° from the vertical.

III.—Observations on Shore.

1. The instrument being adjusted with the plane of the circle coinciding with the magnetic meridian, and the face East, make a complete series of observations of the Inclination with and without deflectors, and of the Intensity with the deflectors and weights, similar in all respects to the observations which have been or which are intended to be made at sea; the needle, deflectors, and weights to be those employed, or to be employed, in the sea observations.

2. Repeat the same with the face West.

3. If unfurnished with a separate apparatus for determining the true inclination, substitute in Mr. Fox's apparatus the needle which admits of its poles being reversed (viz., that needle which is not intended to be used in observations of intensity), and obtain the true inclination from the mean of the angles read in eight different positions of the instrument, following the order of observations described in Appendix No. 2. The differences

between the true inclination thus obtained, and the apparent inclinations with the face East and West observed with the needle used at sea, ascertained at the several shore stations, furnish one of the data from which the index correction to be applied to the observations made at sea is to be computed.

4. When Mr. Fox's apparatus is furnished with more than one needle for the observations of intensity, each needle must be successively substituted in the shore observations for the needle used at sea, and the inclination as well as the angles of deflection with constant weights observed with it.

Calculation of the corrections to be applied to the Observations of Declination or Variation, Inclination or Dip, and Total force made at sea for effects of the iron in the ship. Modified by Staff-Commander CREAK from Mr. ARCHIBALD SMITH'S equations.

1°. *Declination or Variation.*

In order to correct the observations of the variation made with the standard compass, we require to know the coefficients A, B, C, D, E, at that position, and they may be calculated by an easy process, fully described in the Admiralty Manual for Deviations of the Compass, from the deviations observed at each position of swinging.

Of these coefficients A, D, E, if of real value, remain constant in all magnetic latitudes. C changes inversely as the horizontal force when the iron is symmetrically distributed on either side of the compass as it generally is. B generally consists of two parts, P, due to hard iron; c to vertical induction in vertical soft iron. When values of B have been obtained in two widely different magnetic latitudes, P and c may be calculated by the formula—

$$\frac{P}{\lambda} + \frac{c}{\lambda} H \tan\theta = \mathfrak{B}H$$

$$\frac{P}{\lambda} + \frac{c}{\lambda} H' \tan\theta' = \mathfrak{B}'H'$$

in which H and H′ represent the horizontal force expressed in terms of the horizontal force at Greenwich = 1·0; θ and θ' the inclination, $\mathfrak{B}$ and $\mathfrak{B}'$ the exact coefficients of deviation at the two positions.

The coefficients being known the deviation δ on any point of the compass may be computed by the following equation—

$$\delta = A + B\sin\zeta' + C\cos\zeta' + D\sin 2\zeta' + E\cos 2\zeta'$$

ζ' denoting the azimuth of the ship's head as shown by the standard compass.

(See Ad. Man. dev. compass, p. 45.)

2°. *Inclination or Dip.*

In order to correct the observed inclination, we require to know the coefficients c, d, A′, N, and R in addition to the B, C, D, already obtained for the Fox circle position from the deviations observed when swinging.

The variable coefficients c and N may be computed from the observations of the dip with Fox's circle whenever the ship is swung by the formula—

$$c \cos \zeta + \mathrm{N} = (1 - 2 \sin \mathrm{D} \sin \zeta + \sin \mathrm{C}) \operatorname{cosec} \zeta' \tan \theta'$$

for all other points than north and south, and with the ship's head north and south by—

$$c \cos \zeta + \mathrm{N} = (\cos \zeta + \sin \mathrm{B}) \sec \zeta' \tan \theta'.$$

In these formulæ ζ is the magnetic azimuth of the ship's head, θ' the observed dip corrected for index error and ζ' the direction of the ship's head by the compass at the Fox circle position.

N may also be computed by taking the mean of the observations of dip whenever the ship is swung.

The coefficients d and R can be calculated from the results of swinging near the base stations by the formula—

$$\frac{\mathrm{R}}{\mathrm{A}'\,\mathrm{H}} + d \tan \theta = \Delta = \tan \theta - \mathrm{N}$$

$$\frac{\mathrm{R}}{\mathrm{A}'\,\mathrm{H}'} + d \tan \theta' = \Delta' = \tan \theta' - \mathrm{N}'.$$

In this formula H is the horizontal force at two base stations differing widely in magnetic latitude, and expressed in terms of the horizontal force at Greenwich=1·0, θ the inclination at the same stations, N being taken from the results of swinging.

The coefficient A′ may most conveniently be calculated from the formula—

$$\mathrm{A}' = \lambda\,(1 + \mathfrak{D})$$

λ and $\mathfrak{D}$ are constant in all latitudes, but they should occasionally be re-determined.

$\mathfrak{D} = \sin \mathrm{D}$ being taken from the coefficients of declination.

Corrections for the deviations of the inclination needle due to the direction of the ship's head may be computed by the formula—

$$\tan \theta' = \frac{c \cos \zeta + \mathrm{N}}{\sin \zeta\,(1 - 2 \sin \mathrm{D}) + \sin \mathrm{C}} \sin \zeta'$$

for all courses between N.E. and S.E., N.W. and S.W., and by the formula—

$$\tan \theta' = \frac{c \cos \zeta + \mathrm{N}}{\cos \zeta + \sin \mathrm{B}} \cos \zeta'$$

when the ship's head is nearer the north and south points.

The several coefficients having been obtained the observed inclinations on board the ship require three corrections.

1. For index error.
2. For the direction of the ship's head.
3. Finally for the vertical force of the ship $= \Delta$.

3°. *Total Force.*

Tables of corrections for deviations in the total force due to the direction of the ship's head can be formed by means of the formula—

$$\phi' = A' \, H \, (c \cos \zeta + N) \operatorname{cosec} \theta'$$

ϕ' being the total force and θ' the observed inclination for any given azimuth of the ship's head. The difference between the several computed values of ϕ' and the mean of the whole $= \phi^\circ$ will be the correction.

When the ship is swung the mean of the observed values of ϕ' may be taken as the best value of ϕ°, or the total force before the final correction for the vertical force of the ship has been applied.

With the values of Δ taken from the corrections for the inclination, and the values of θ already obtained from the corrected values of θ', the total force can be calculated by the formula—

$$\phi = (\phi^\circ \sin \theta^\circ + \Delta \, H) \operatorname{cosec} \theta$$

The values of θ° can be taken from those of $N = \tan \theta^\circ$.

4°. *Graphic method of forming deviation tables for the three magnetic elements.*

In connexion with a series of magnetic observations on board ship, the use of graphic methods of forming deviation tables is recommended with the twofold object of eliminating doubtful observations and saving labour in calculation.

Thus, when the ship is swung on eight or sixteen azimuths of the ship's head, with the aid of a simple graphic representation of the results, the deviation on any intermediate azimuth may be measured from the curve.

A useful graphic method in connexion with the declination is described in the "Course of Instruction in Compasses" for acting sub-lieutenants, published by the Admiralty, only in the case of the inclination the vertical line there mentioned must be taken to represent the value of θ°, and in that of the total force the value of ϕ°.

ARTICLE V.

METEOROLOGY.

By ROBERT H. SCOTT, M.A., F.R.S.

(Replacing the article by Sir J. Herschel in previous editions.)

There is no branch of physical science which can be advanced more materially by observations taken at sea than meteorology, and for two principal reasons. Firstly, the area of the sea far exceeds that of the land, and it is so infinitely more accessible in every part that a much wider field of observation is laid open, and a far more extensive basis is afforded, for the deduction of general conclusions. Secondly, the number and varieties of disturbing influences at sea are much less than on land, by reason of the uniform level, and the homogeneous nature of its surface.

Moreover, when we take into consideration the circumstance that, of all physical sciences, meteorology is that on which the success of voyages and the safety of voyagers most immediately depends, we see that a personal interest of the most direct kind is infused into its pursuit at sea, greatly tending to relieve the irksomeness of continued observations, and to insure precision in their registry.

The subject will be divided into two sections :—

A. The ordinary meteorological observations taken at sea, and deductions from them.

B. Weather and the Law of Storms.

A.—The Ordinary Observations.

The requisite instruments for the ordinary observations, as well as Instructions in their use, with meteorological logs for the entry of observations, can be obtained from the storekeepers at any of the royal dockyards. These instruments may almost be called standards, at least, they have all been compared with the standard instruments at the Kew Observatory. This establishment issues with each instrument a certificate of this comparison, with a note of the errors, if any, which have been detected. An instrument exhibiting more than a very slight amount of error is never allowed to pass into service.

The necessary meteorological outfit of a ship consists of a barometer, a set of six thermometers, of which a pair are fitted for use as a hygrometer, and a third is reserved for taking the temperature of the sea water; a set of four hydrometers and a thermometer screen.

In addition, a few ships are provided with aneroids, rain-gauges, maximum and minimum thermometers, and occasionally with anemometers, but these instruments, as will be explained hereafter, are for special purposes and not for the regular observations at sea. If this article were only to be read by those who are about to keep a meteorological log it would suffice to refer to the "Instructions" above-mentioned for particulars respecting the instruments and their use, but as it may come into the hands of other persons, it seems advisable to repeat here a portion of what is contained in those Instructions.

The Barometer.—In handling barometers it should be remembered that they are delicate and expensive instruments. The result of rough treatment is breakage; and for scientific purposes, observations with an instrument repaired and not verified by comparison with an instrument whose error is known are almost useless.

When in use at sea barometers are slung in gimbals, and suspended from arms at least a foot long, so as to be perfectly free to assume the vertical position under every movement of the ship, and at the same time to keep clear of the bulkhead against which the arm is fastened. It is desirable to place them in such a position as not to be in danger of a side blow from persons passing near, and also sufficiently far from the deck above to allow for the spring of the metal arm in cases of sudden movements of the ship. If there be risk of the instrument striking anywhere when the vessel is pitching or rolling heavily, it will be well to put some soft padding on that place. It is essentially necessary that the instrument should have free swing, and no steadying springs or stays should be used, for by their weight they at all times keep the barometer slightly out of the vertical, and when they come under stress the instrument is in an abnormal position. *Care should be taken that no readings from a barometer which is not hanging truly vertically should ever be recorded.* Such readings will always be too high in proportion to the degree of obliquity.

The instrument should be fixed in a convenient place for observing, if possible, with the light coming from behind the observer, and where it is not liable to considerable changes of temperature, and therefore out of sunshine or the direct heat of fires or lamps.

The height of the cistern of the barometer above the level of the sea should be ascertained and noted in the log at the beginning of each passage, and if any change of position is made during the passage it should be noted.

The following hints for suspending and packing up barometers may be found useful :—

The bracket having been screwed up the instrument should be carefully lifted out of its box, the hinged part of the suspension arm bent back, and the barometer slipped into the bracket. The holding screws should not be driven quite home until the instrument is in position. The mercury will then fall gradually, and the instrument will usually be ready for use in about an hour; but as local temperature affects the instrument slowly, it may be well not to record observations from it for some hours after fixing. In a new tube sometimes the mercury does not readily quit the top of the tube. If, after an hour or so, the mercury has not descended, tap the cistern end rather sharply, or make the instrument swing a little in its gimbals, which should cause the mercury to rise and fall in the tube. If this method does not succeed, the force of the tap may be slightly increased, but violence should never be used. The box should be safely stowed away, for use when the instrument has to be removed.

Whenever it may be necessary to take down a barometer and place it in its box, the vernier should be brought down to the bottom of the scale. Then, having lifted the instrument out of the bracket, bring it gradually into an inclined position, and so hold it for a few minutes, to allow the mercury to flow very gently to the top of the glass tube, avoiding any sudden movement which would cause the mercury to strike the top of the tube with violence and might break it, the absence of air from the tube making the force of the blow little different from that given by a solid rod of metal. The barometer should then be taken lengthwise and laid in its box. To be carried with safety it should be held with the cistern end upwards or lying flat, and it must not, on any account, be subjected to jars or concussions.

Reading the Barometer.—The principle of the barometer vernier and the actual mode of reading off the height of the mercury are fully explained in the "Instructions for keeping "the Meteorological Log," and to these matters no further reference need here be made.

Corrections of Readings of the Barometer.

As the column of mercury in the tube lengthens when heated and shortens when cooled, it is necessary to apply a correction for this, called the correction for temperature, to show what the reading would have been at the temperature of 32° F., which has been adopted by common consent as the standard temperature to which all barometric readings are reduced. It is therefore essential to make and register a careful reading of the thermometer fixed to the instrument, usually called "the attached thermometer," whenever an observation of the barometer is made. When the thermometer attached to the barometer is above 28°, the correction, for which a table will be found at p. 189, must be subtracted, and when at or below 28°, must be added. A similar correction is also required for the brass scale, to compensate for the changes of length caused by variations of temperature.

The readings taken on board ship, where the temperature is usually above the freezing point, will therefore commonly be higher than the values given on charts which show the mean height of the barometer, corrected for temperature, the difference depending on the temperature at which the barometer on board happens to be at the time the reading is taken. For a temperature of 80° and a barometrical reading of 30 inches, the correction, to be subtracted from the observed height, is 0·138 inches.

As a general rule this is the only correction required to be applied to barometrical readings taken *at sea,* for the barometers supplied to Her Majesty's ships are so constructed as to obviate the necessity for applying corrections, either for capillarity, which tends to depress the mercury in the tube, or for capacity, *i.e.*, for the varying quantity of mercury in the cistern, which are required for some old-fashioned barometers. The certificate, which is always to be found in the box belonging to the barometer, indicates the instrumental error, which has been determined at Kew Observatory. This is always very slight.

There is, however, another correction which requires notice. The pressure of the air is reduced as we rise above the sea level, and a correction is necessary to obtain the pressure at sea level. It amounts to about ·001 inch for each foot above the sea, and is always to be added. On board ship the height of barometers above the sea level being usually small, and not being liable to vary, this correction will commonly be unimportant, but the case is very different if observations are made on shore. It is not considered necessary to give tables for this correction in this manual.

A simple and approximately accurate rule for ascertaining the relative elevation of two stations is to multiply the difference in barometrical readings between the stations taken in hundredths of an inch by nine ; the result will give the difference of elevation in feet between the stations. This rule is sufficient for the ordinary problems as to elevation which occur, *e.g.*, during a walking tour, when the height is roughly measured by means of aneroid readings. It depends on the fact that the difference of height corresponding to a difference in barometrical readings of ·1 inch is approximately 90 feet. For instance, for the change of level from 200 to 290 feet the difference in barometrical readings (the sea level reading being 30 inches) is ·101 inch at 40° and ·098 at 50°.

The problem of reduction to sea level is, however, not quite so simple as might be imagined. What is required is to find the weight of the vertical column of air which would extend from the level of the upper station to that of the sea. This weight must depend on the temperature of the air, for when that temperature is high a longer column is required to make the same weight than when it is low, and this temperature is different at the levels intermediate between the two stations, and may be affected by other conditions. However, for moderate heights, not exceeding about 1,000 feet, the temperature is assumed to be that of the external air at the station where the upper barometer is placed.

It is scarcely necessary to say that the same principles as enable us to ascertain the barometrical reading at one level from that at another, when the relative heights of the two stations are known, will enable us conversely, to determine the difference of height between two stations, if we know the barometrical readings and the temperature taken at each. *In other words, we can determine the height of a mountain by barometrical readings* taken on the summit and at the sea level.

These readings ought to be taken at the same time, because it is not likely that the pressure and temperature of the air will remain unaltered while the ascent is being carried out.

The following is a specimen of the complete correction of a barometer reading. The instrument is supposed to possess a Kew correction, including the corrections for index, error, capacity, and capillarity.

Suppose that—

Barometer reading - -	= 29·946 ins.
Attached thermometer (affected by the heat of the room in which it is placed) -	= 68°
Kew correction for instrument -	= + ·014 in.
Temperature of air by dry bulb thermometer (in the open air) -	= 50°
Altitude of cistern above the mean sea level -	= 105 ft.

Then we have—

Uncorrected reading -	=	29·946 ins.
Add for Kew correction -	+	·014
Reading - -		29·960
Deduct temp. correction for 68° and 30 ins. -	−	·106
Reading at 32° F.	=	29·854
Add for altitude of 105 ft. at temp. of air 50° and *approximate* pressure at sea level 30 ins. -	+	·116
Reading corrected and reduced to 32° F. at mean sea level -	=	29·970 ins.

Aneroids.—The use of these instruments, as ***substitutes*** for mercurial barometers, is never to be recommended, though for convenience of easy consultation they are useful, and they show very well the changes of atmospheric pressure which are in progress, though they seldom indicate its absolute amount correctly. Here it may be well to remark that by setting the index of an aneroid just before giving it a slight tap, the change which takes place in the reading, after the tap, indicates whether the barometer is rising or falling *at the time.* The aneroid is not an independent instrument, but is graduated by comparison with the mercurial barometer, and must be compared therewith from time to time in order to ascertain if its indications have varied owing to any change in its mechanism. An aneroid can of itself give no sign of being out of order. A fall off a table is often sufficient to alter the readings by two or three tenths of an inch, and the error cannot be detected until the instrument is compared with a mercurial barometer. If these comparisons are frequently carried out the instrument is serviceable, and the small automatic aneroids which have recently come into general use can be employed on board ship with considerable advantage, showing as they do, by tracing on paper, the changes of pressure which have taken place, or are in progress, at the time the instrument is consulted.

Thermometers.—These instruments are exposed in the louvred screen, of which an engraving will be found in the "Instructions." This screen should be placed in such a position that it shall be freely exposed to the air, and also, as much as possible, sheltered from the sun. This latter condition cannot be completely fulfilled, and, unfortunately, the pattern of screen in use does not afford sufficient protection against the effects of solar radiation.

However, even if this protection were afforded, as the thermometer screen is generally placed in the after part of the ship, the instruments in it will indicate too high a temperature, when there is a head wind, owing to their being under the influence of heated air drifting aft from the ship.

Suggestions have been made to have larger screens made and to sling them in some part of the rigging, say under the forestay, but such a plan presents manifest inconveniences.

There is, however, a comparatively simple mode of detecting approximately the amount of error which would be incurred if the sun were shining on the screen at the moment of reading. It is found that if a thermometer attached to a string be swung round the head for a minute or so it will give a reading which differs very slightly from that which would be obtained from a thermometer placed in a screen which is in the shade, but freely exposed to the air. It is a remarkable fact that it makes very little difference whether such a thermometer is swung in full sunshine or in the shade; accordingly a comparison between the observations made with a thermometer so swung and those made with the thermometer in the screen will give approximately the error of the latter due to imperfect exposure.

Accordingly the employment of the sling thermometer (*thermomètre fronde* of the French) is strongly to be recommended when it is desirable to ascertain speedily the temperature of the air. It is mainly by the use of such thermometers that the influence of sunshine or of heated air from engine-rooms, &c., on thermometers placed in a fixed screen has been ascertained and determined.

It need scarcely be said that a pair of these sling thermometers may very well be mounted for use as a dry and wet bulb hygrometer.

Though sling thermometers are not yet supplied to the Navy, they would be found a useful addition to the ordinary instrumental outfit of a ship. Simultaneous records of wet and dry sling thermometers, and of the ordinary hygrometer on board, would be very valuable observations.

The Hygrometer.— The mode of mounting the thermometer, to be used as a wet bulb, is explained in the "Instructions," but it is desirable to repeat more fully what is there said about its management.

In the first place, the muslin covering of the wet bulb must be very thin, else there is danger that true thermic equilibrium will not be established between the outside of the coating, where the evaporation is going on, and the actual bulb. In, the second place, the supply of water must be carefully regulated, so that the bulb shall be constantly moist, and yet not too wet. Accordingly we ought to have a more ample supply in dry weather than in damp, or we shall find that on a hot summer's day the cotton wick becomes perfectly dry, and no longer acts as a siphon, the bulb itself becoming dry; while if a sufficiency of water be provided to meet such an emergency there will be a brisk drip going on from the damp bulb in damp weather, which is not right.

The cup, glass, or other small holder of water ought not to be under, or too near, the dry thermometer, but should be placed at some distance on the off side of the wet thermometer, that is, as far as possible from the dry, which should not receive moisture either from rain, spray, or otherwise. Of course if moisture be found on the dry bulb, this should be wiped and left for a while, to assume the true temperature of the air. The water for the wet bulb should be either distilled or rain water, or, if this be not procurable the softest pure water which can be had, to avoid the inconvenience of the deposit of lime, &c. on the bulb. The water vessel should be replenished *after*, or some *considerable time before*, observing; because observations are incorrect if made while the water is warmer or colder than the air.

The muslin and cotton should be well washed before being applied, and occasionally while in use. They should be changed once or twice a month, or even oftener, according to the quality of the muslin, &c., and the exposure to *dust* or *blacks*. Accuracy depends much on the care taken for cleanliness, and for a proper supply of fresh water.

The great difficulty with the instrument is found at a time of frost. The water on the cotton freezes, and the capillary action is at an end, so that the bulb soon becomes as dry as in hot weather. If, then, the temperature be below the freezing point it is obvious that water cannot be placed on the coating of the wet bulb without raising the temperature of the instrument. The thermometer will not be fit for an observation until the freshly-added water has become frozen and the temperature of the thermometer has ceased sinking.

When the damp bulb is frozen it should be wetted, by means of a camel-hair brush or a feather, with some cold water taken from under ice, care being taken to raise its temperature as little as possible. After waiting a few minutes the moisture will first freeze, then cool down to the temperature of the air, and finally the thermometer will fall a trifle lower than the dry one, and then the reading may be noted.

In time of hard and continued frost, if a coating of ice be allowed to form on the coating of the damp bulb this will remain for several days before the bulb will become dry again. When the bulb has such a coating the evaporation will be going on from the surface of the ice, and the thermometer will act in the same way as if its bulb were damp.

In some rare cases, *e.g.*, during thick fog or in very cold calm weather, it may sometimes happen that the wet bulb reads *above* the dry bulb. This arises from the fact that when there is no loss of heat by evaporation the muslin coating prevents its indicating the temperature of the air as correctly as the unprotected bulb. In such cases the readings are to be considered as identical with each other, the air being perfectly saturated.

Maximum and minimum Thermometers.—These are, as a rule, not supplied to ships, as the constant motion would have a tendency to disturb their indices, thus rendering the readings useless. Inasmuch, however, as they may be used at shore stations or in port, it is desirable to allude to the most common defect of minimum thermometers, the separation of a portion of the spirit from the main column; this defect is owing to the fact that a portion of the spirit becomes volatilized and is then condensed in the upper end of the tube, so that the continuous column is curtailed by a length, of perhaps, several degrees. It is to this liability to error of spirit minimum thermometers that some of the extraordinary discrepancies in reports of severe cold are probably to be attributed.

If a spirit thermometer reads lower than a correct mercurial thermometer close beside it, there is reason to suspect the existence of the defect above mentioned. The spirit is also liable to become broken into several detached portions, especially if the instrument is being transmitted from place to place; or the index may be shaken entirely out of the spirit into the upper part of the tube. In all these cases the thermometer should be swung briskly to and fro several times, holding it bulb downwards, until all the liquid which may have been visible at the upper end of the tube shall have been dislodged. The instrument should then be placed in an upright position, bulb downwards, and left there for half an hour or so. This treatment will usually have the effect of setting the instrument right.

Sea-surface Temperature.—The observation of the surface temperature of the sea is a very simple one, there are only a few points about it which call for remark.

The water must not be pumped, but drawn by a bucket direct from the sea, and in steamers drawn forward of the ejection pipe. A canvas bucket should be used, and the thermometer should remain in the water for a couple of minutes. It should then be read while *its bulb is still immersed in water.* This is ensured if the thermometer is provided with a metal case. If the thermometer is not so provided the bulb must on no account be raised out of the water till the reading has been taken. The reason is that if the thermometer be exposed to the air, when its bulb is wet, evaporation will at once set in and the indications of the instrument will consequently be too low.

When water can be brought direct from the sea beneath the surface, either by letting a sea tap run for some time or by working a pump so long that it brings water direct from the sea, it is interesting to know the temperature of such water, stating the depth at which it was obtained. This observation is especially valuable in parts of the sea where rapid changes in the surface temperature are observed. If any great difference between the temperature of the water on the surface and beneath it is noticed the fact should be confirmed by a second observation.

The entire subject of deep sea temperatures and their determination falls within the department of deep sea sounding, which is more or less distinct from meteorology.

The Hydrometer.—The Specific Gravity is determined by means of the hydrometer. The observation is rather a difficult one when the ship has much motion, or the surface of the water in the bucket is exposed to much wind. In cases of extreme motion it is better to omit the observation than to give a doubtful result.

A large, well-filled bucket appears to answer the purpose well, and the hydrometer should be slightly spun in the centre; it soon loses all up and down motion, and the scale can be read before the turning motion has entirely ceased.

In every case when the specific gravity is determined the temperature of the water which is tested should be recorded. It is also particularly important to determine the specific gravity of any water taken from beneath the surface.

Rain Gauges.—These instruments are sometimes supplied to ships. They are of special construction and fitted with gimbals or some other contrivance to retain the receiver in a horizontal position. The great difficulty is in finding a position for the instrument on board ship, as the sails produce serious eddies which affect the fall of rain. It is found that two gauges placed one on the weather, the other on the lee side, will never register the same amount of rain. It has been suggested to place the gauge on the poop, as far aft as possible; but even that is not thoroughly satisfactory.

Anemometers.—The use of these instruments is nearly as disappointing as that of rain gauges. The indications are affected not only by the wind to which the instrument is exposed, but also by the direction and velocity of motion of translation of the ship, and the reading must therefore be corrected, a process which involves a mathematical calculation in each instance. Moreover, there is as much difficulty in selecting a place for the anemometer as in erecting a rain gauge. If it is set up in any spot where it is convenient to be read it is nearly sure to be exposed to eddies from the hull, bulwarks, &c., which will render its indications deceptive.

Clouds.

The careful record of cloud forms, their changes and their motions, is most important, and the opportunities for observing and watching these at sea are much greater than they can possibly be on land. The classification of clouds which is still generally adopted is that of Luke Howard, first proposed in 1803, no attempt to remodel this having hitherto met with much favour.

Howard recognised three principal types: (1) *cirrus*, (2) *stratus*, and (3) *cumulus*, and four secondary types, being combinations of the foregoing, (4) *cirro-stratus*, (5) *cirro-cumulus*, (6) *cumulo-stratus*, and (7) *cumulo-cirro-stratus* or *nimbus*.

These types group themselves in two categories according to the level at which they float. Nos. 1, 4, and 5 are called upper clouds, the others lower clouds. In the following brief account Howard's definitions are given in inverted commas at the beginning of each description. A plate illustrating the different forms will be found in the "Instructions for keeping the Meteorological Log."

Upper Clouds.

The clouds belonging to this class are considered, on good grounds, to be frequently composed of particles of ice, inasmuch as the phenomena of halos, &c. are produced by them, and these can only be explained by the refraction of the rays of light through ice crystals.

Cirrus (cir.). "Parallel, flexuous, or diverging fibres, "extensible by increase in any or in all directions."

This is the very lofty cloud which looks like hair, thread, or feathers, and when curved in form, is often called "mares' tails." It frequently moves in a direction differing from that of the wind at the earth's surface, but the motion often appears to be so slow that it is very difficult to ascertain it correctly without watching for a very considerable time so as to mark the motion over some *fixed* object, but the importance of the observation makes it very desirable that special attention should be devoted to it.

Anything peculiar in the shape of *cirrus* clouds should be noted, as well as the point from whence they radiate, and the relation between their longitudinal extension and the direction in which they are moving. It should also be noted if they are more developed in one part of the sky than in another.

Cirro-cumulus (cir.-c.). "Small, well-defined, roundish "masses in close horizontal arrangement or contact."

This is also a high cloud, though usually at a lower level than the *cirrus*. It differs from the *cirrus* in being more globular in form, as it consists generally of small detached rounded masses, like a flock of sheep lying down, or like the markings on a mackerel, whence the name "mackerel sky." When seen at lower levels it may be difficult to distinguish these clouds from small *cumuli*. In such cases the fact should be noticed in the "Remarks" column.

Cirro-stratus (Cir.-s.) "Horizontal or slightly inclined "masses, attenuated towards a part or the whole of their "circumference, bent downward or undulated; separate "or in groups consisting of small clouds having these "characters."

This cloud is usually generated by increased condensation on the *cirrus* already formed, which consequently sinks to a lower level.

When bad weather is approaching the cloud increases in compactness and density and sinks to a lower level, at times entirely intercepting the direct rays of the sun or moon and presenting the appearance of a uniform sheet overspreading the sky.

Such uniform sheets have generally been classed as *cirro-stratus*, but the observer should enter a special note of their occurrence in the "Remark" column, so that there shall be no risk of confusion between this appearance and that of the true *cirro-stratus*. This is the more necessary inasmuch as when the cloud sinks to a yet lower and lower level, it assumes more and more the character of the lower stratum, becoming a vapour cloud instead of an ice cloud.

Anything peculiar in the appearance of the cloud should be noted especially, as "cir.-s. high and hard," or "cir.-s. low and soft." Clouds are seen at all levels between the highest *cirrus* and the lowest *stratus*, so that it is often difficult to determine whether a particular sheet or layer of cloud belongs to the upper or the lower system. In such cases the observer will be greatly assisted by remembering how the clouds have become formed, whether by the gradual subsidence of the highest forms, or by the ascent of the lower clouds.

It is in *cirro-stratus* that the optical phenomena of halos, mock suns, and mock moons are manifested, and these prove that *cirro-stratus* is an ice cloud. The more common appearances of *coronæ*, rings or burrs, round the moon are produced by minute drops of water and appear when any thin cloud crosses the moon.

Lower Clouds.

The clouds belonging to this class are usually composed of particles of condensed vapour, *i.e.*, of droplets of water, not of ice crystals.

Stratus (Str.). "A widely extended continuous horizontal "sheet, increasing from below upward."

This is a sheet or layer of cloud, of uniform thickness generally. It has but little variety of light and shade, and belongs essentially to the lower regions of the atmosphere, so much so that Howard speaks of it as "ground fog," the cloudy formation which spreads over low grounds in the evening, and disappears as soon as the temperature rises in the morning.

The *stratus* is generally a fine weather cloud, appearing during the nights and mornings of the brightest days. At times it overspreads the whole sky in the form of a low, gloomy, foggy canopy, the atmosphere at the same time being more or less foggy under it. All low detached clouds, which look like a piece of lifted fog, and are not in any way consolidated into a definite form, are *strati*, and may be called "detached" *stratus*.

Cumulus (Cum.). "Convex or conical heaps increasing "upward from a horizontal base."

This class of clouds comprises all those of the lower stratum which have a globular or rounded form. The *cumulus* sometimes takes a cylindrical shape, forming itself into long horizontal rolls, between which gleams of light are seen, but which are often so closely packed as to hide the blue sky.

Cumulo-stratus (Cum.-s.). "The 'cirro-stratus' blended "with the 'cumulus,' and either appearing intermixed with "the heaps of the latter, *or superadding a wide-spread* "*structure to its base.*"

This is the *cumulus* as it were changing into a *nimbus*. It is dark and flat at its base, and is traversed by horizontal lines of dark cloud.

Nimbus (Nim.). "The rain cloud. A cloud or system "of clouds from which rain is falling. It is a horizontal "sheet above which the 'cirrus' spreads while the 'cumulus' "enters it laterally and from beneath."

Whilst on the horizon, or as it advances towards the observer, the front of this cloud frequently presents a marked outline like that of a very heavy *cumulo-stratus* with rain falling from it, and with some *cirrus* above, so that Howard has called it the *cumulo-cirro-stratus.* When it has overspread the whole sky, it is usually so mixed up with, or concealed by, the falling rain that it generally assumes a uniform dark appearance.

Inasmuch, however, as rain, &c. may fall from clouds of various shapes, anything peculiar in the form, height, &c. of the *nimbus* should be mentioned in the "Remarks."

Scud is a term used to indicate loosely formed, detached clouds drifting rapidly before the wind. These may be either at a high or low level; in the former case they probably belong to the *cirro-stratus* or *cirro-cumulus*, in the latter to *stratus*, but the word "scud" simply implies that they are fragments of cloud in rapid motion.

It is believed that the foregoing description is sufficient to explain the ordinary forms of clouds, but the appearances are much intermixed. Thus, before rain we often see a dirty background of *cirro-stratus*, over which black patches of *cirro-cumulus* are travelling. Such combinations, when seen, should be carefully noted.

The direction *from* which all clouds, especially upper clouds, come is very important, and should be recorded, whether they are moving with the wind or not. The relative motion of some clouds past others, or past any movable object, is so deceptive that it should never be recorded. If the upper clouds move quickly, a remark should be made to that effect.

It is particularly desirable that the contractions *Cir.*, *Cir.-c.*, *Cir.-s.*, *Str.*, *Cum.*, *Cum.-s.*, *Nim.*, should always be used in describing clouds, as any other contractions are likely to mislead.

Amount of Cloud.—The scale for the amount of cloud is that of 0 "Blue sky," 10 "Entirely overcast."

Observations on Waves.

"It is well known that the behaviour of a ship in a seaway is in a high degree dependent on the relation which the *period* of the waves bears to the *period* in which the ship naturally continues to oscillate, when she has been artificially set in motion in still water.* Without tracing the consequences of this relation in full detail, it may be stated generally that the deepest rolling which a given ship can exhibit occurs when she is exposed broadside on to a series of waves, the period of which is the same, or nearly the same, as her own; and that under these circumstances her rolling may be, and generally will be, very deep indeed, even though when broadside on to waves of a different period she has seemed almost insensible to their effect.

"Another condition materially influential on the behaviour of a ship is the rate at which such an artificial oscillation as has been described becomes extinguished by resistance, swing by swing, after the original impulsive force has ceased. There is good reason to assert that, *cæteris paribus*, the more rapid the extinction the smaller will be the maximum angle of rolling reached by the ship in a given seaway.

"The height, also, of the wave (measured vertically from the bottom of the hollow to the top of the ridge) and its length from crest to crest are also materially influential on the ship's behaviour; for on these depends (1) the angle or steepness of the wave slope, which condition, *cæteris paribus*, governs the disturbing influence of the wave on the ship, and (2) the relative magnitude of the wave and the ship, for it is easily seen that however steep the slope may be its effect on the ship may be small if the dimensions of the wave are small in comparison with those of the ship.

"Exact information, derived from experiment and observation, is almost wholly wanting in relation to these funda-

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* By the *period* of a wave is meant the interval of time which elapses between the transits of two successive *wave crests* past a stationary floating body, the wave crest being the highest line along the ridge.

By the *period* of a ship is meant the time which elapses while, when artificially set in motion in still water, she completes a double swing, that is (say), from starboard to port *and* back again, or *vice versâ*.

mental conditions of a ship's behaviour, and it is of great importance that the want should be supplied. So far, indeed, as it depends on the ship herself, it may perhaps be more easily and more correctly obtained before she proceeds to sea. But it is only by frequent and careful observations while at sea that a full knowledge of the periods and dimensions of waves can be obtained."

The foregoing remarks are reprinted from a memorandum on wave observations at sea, drawn up by the late William Froude, Esq., F.R.S., for the use of the officers of H.M.S. "Challenger."

Subsequently, Professor G. G. Stokes, F.R.S., drew up the following detailed instructions for the observations:—

"The observation requires no more apparatus than a common watch with a second hand. A single person can observe very well, but it is more satisfactory when two work in concert, as one can then keep his eye on the rock (or ship) while the other keeps his eye on the watch, when the time draws near for the crest of the wave to reach the rock (or ship). In that case the second person notes and writes down the time when the first calls out 'Now.'

"Waves usually come in sets, followed by a comparative lull, during which observations might be uncertain, and great care should be taken not to observe any of the uncertain waves. The periodic times of several sets should be taken when possible, though three or even two sets would give a good result; being very careful to note the direction towards which the wave is moving, and the course and speed of the ship when the observation is taken at sea. With these data the observed periodic time can be corrected for the ship's motion, when the observations are received in England.

"A word or two may be useful as to the mode of observation. I found it better to observe when the waves reached a particular rock than when their ridges, seen edgeways as they entered a small bay, were in a line with an object on shore. A rock should be selected if possible in sufficiently deep water for the waves not to break before they reach it. If the form of the coast permit of the observer stationing himself so as to get a side view of the waves as they approach the rock, so much the better, as the observer can then see their ridges as they approach the rock, and is better prepared to note the exact moment when they reach it. If the watch used has a gaining or losing rate of sufficient magnitude to be sensible in the observation, its gain or loss in a certain time should also be recorded. The time (second or half second alone) of transit of each wave of such sets as seem worth keeping should be recorded, and the time of day when the observations were made. In the case of remarkable swells the observation should be repeated at intervals of a few hours, as the gradual alteration of periodic time is a matter of interest.

"It is desirable to observe the *height* of the waves as well, and *in case of shoal water the depth of the sea should be recorded.* I do not know any very satisfactory way of determining the height of waves at sea, especially of long swells; the best seems to be that adopted by the late Captain Owen Stanley, R.N., as shown in the following paragraph quoted from a letter of his in the Report of the British Association for 1848, Part ii., page 38.

"'For measuring the height of waves I adopted a plan recommended to me by Mrs. Somerville, which I have tried for 10 years with success. When the ship is in the trough of the sea, the person observing ascends the rigging until he can just see the crest of the coming wave on with the horizon, and the height of his eye above the ship's water line will give a very fair measure of the difference of level between the crest and hollow of a sea. Of course in all these observations the means of a great many have been taken, for even when the sea is most regular apparently there is a change in the height of individual waves.

"'I regret that we have had so few opportunities of making these observations, but it is only under very favourable circumstances, when the ship is going directly before both wind and sea, that they can be made with any chance of success.'"

This is followed by a table showing that the distance between the crests of various waves; the *wave length* varied between 32 and 57 fathoms.

Professor Stokes remarks, with reference to the above quotation from Capt. Stanley's letter:—

"It seems to me that the height would be very sensibly under estimated (if the ship was before the wind). The waves observed were from 33 to 57 fathoms in length, so that a ship would be riding on two waves, at stem and stern, when her middle was in the trough. Hence at the trough the water would be considerably below the water line, which

I understand to mean the line in which the water would cut the ship, if all were perfectly still.

"To carry out this method for long low swells the observer would have to climb down outside the ship, unless one of the cabin windows happened to be just of the right height. As to pitching, the observer can choose his station where there is no sensible motion up or down, except (in the case of long waves) of the ship as a whole.

"Rolling, if there be much, is more difficult to manage, for he cannot see from the middle line of the ship (except when the crests are above, not below, the deck) when the ship is in the trough, unless he be at the bow or stern, and then the least pitching would vitiate his height.

"I hardly expect to get more than a fair estimate of the height; but, on the other hand, it is not of much interest to know the height more than approximately.

"For observing the height from shore much must depend upon circumstances. Supposing rollers break on a shelving beach, I should say, ascend till the crests of the waves, just as they begin to break, are in a line with the horizon, and take the height of the eye above the average height of the water at the water's edge."

"In observing the period (apparent period generally) from ship, or the actual period from shore, it is well to wait till there is a prospect of a fairly regular series of half a dozen waves or so, noting the time of transit of each across a given part of the ship or a detached rock, as the case may be, and stopping when the waves begin to get irregular, then when you can get fair regularity to take another series. If there be anything like regularity three, or even two, series would give a very good result.

"It would be desirable to direct special attention to very long swells, even though they should not be conspicuous as to height. I have myself observed in a heavy surf on the north coast of Ireland a period of 17s., the calculated wave length of which in deep water is 1,481 feet, or 247 fathoms. Low swells of such great length would hardly, perhaps, attract attention unless the observer were specially on the look out for them. But it is just these very long swells that I take to be the origin of the Rollers (*e.g.*, at Ascension and St. Helena).

"The following is the rule for combining the observations of a series to get the best result :—

"Suppose $n + 1$ waves of a series (comprising, therefore,

n intervals) have been observed. Reducing the times, starting from any convenient minute, to seconds, write the first under the last, the second under the last but one, and so on until the middle is reached, subtract, multiply by 1, 3, 5, &c., or by 2, 4, 6, &c., according as n is odd or even, add the results and divide by $\frac{1}{6} n (n + 1) (n + 2)$.

" Of course if n be even, it will be shorter to multiply by 1, 2, 3, &c., and divide by $\frac{1}{12} n (n + 1) (n + 2)$.

" The observer may perhaps want to have an idea how deep water must be, in order that it may be regarded as " deep " in relation to waves.

Calling l the wave length corresponding *in deep water* to the period of the waves and 1,000 the velocity of propagation, I find on the same scale the following velocities of propagation corresponding to the respective depths :—

$$\text{Depth} \quad \infty \quad l \quad \frac{l}{2} \quad \frac{l}{4} \quad \frac{l}{8}.$$

Velocity 1,000, 1,000, 996, 933, 429.

" If the depth, therefore, be as much as half the wave length corresponding in deep water to the observed period, the velocity of propagation, and consequently the wave length which changes in the same proportion, the period being given, is reduced by less than 0·5 per cent., which we may neglect. A depth, therefore, as great as $\frac{l}{2}$ or $\frac{g\tau^2}{4\pi}$, where τ is the period, may practically be regarded as infinite. I do not know what the period of the Rollers at Ascension and St. Helena may amount to at the greatest. I think it was 24s. Mr. Froude told me he had once got at Plymouth. For 24s., the length in deep water is 2,952 feet, and $\frac{l}{2} = 246$ fathoms. For such *very* long waves the bottom begins to tell even at depths much beyond ordinary soundings. In many such cases the depths would probably be known approximately from published charts.

" It would be difficult to recognise at all low swells of 500 fathoms length out at sea, especially as there would be generally shorter waves as well, which, from a ship, would appear much more conspicuous ; but in crossing a bank the long waves would mount up, while the shorter waves would be unaffected, the depth for them being still practically infinite.

"There would therefore be a special interest in the observation of the periodic time of heavy swells over the Agulhas Bank and in similar localities."

Though long low swells in deep water are of very little consequence to the navigator, their observation may be useful even in relation to the shipping interest; for the rollers which they produce on shore are very trying to harbour works, and the observations may be useful to the marine engineer, as warning him what it is necessary to provide against in the construction of piers and breakwaters.

Professor Stokes summarises the observations required as follows:—

"*For a Ship at Sea.*

"(1.) The apparent periodic time, observed as if the ship were at rest.

"(2.) the *true* direction from which the waves come; also the ship's *true* course and speed per hour.

"(3.) A measure or estimate of the height of the waves.

"(4.) The depth of the sea if it is known, but at any rate the position of the ship as near as possible, either by cross-bearings of land or any other method, so that the depth may be got from charts or other sources.

"*For a Ship at Anchor.*

"(1.) The periodic time.

"(2.) The true direction from which the waves come.

"(3.) A measure or estimate of the height of the waves.

"(4.) The depth of water where she is anchored.

"*For an Observer on Shore.*

"The same as for the ship at anchor, with the depth near the rock over which the swell passes, instead of near the ship."

For further remarks on waves, *see* W. H. White, a Manual of Naval Architecture. 2nd edition. London. John Murray, 1882. In Chapter V. "Deep Sea Waves," the author deals with the subject at some length, and gives an account of the results obtained by French naval officers, as well as by our own.

Deductions from the Observations.

There are two distinct directions in which meteorology may be advanced by observations taken at sea. Firstly, by the ordinary observations made at regular intervals of ship's time, usually at least four-hourly, and which are employed mainly to elucidate the climate of such parts of the ocean as may be visited. Secondly, by what are called synchronous or simultaneous observations, which are taken daily at the same hour of Greenwich time and which are intended, when combined with similar observations taken at the same hour on board other ships, to give a representation of the weather experienced at that hour all over the district where those ships are situated.

We shall here treat of the climatological observations only, the synchronous observations can only be dealt with, in connexion with Weather and the Law of Storms, when the records have been collected from a large number of ships.

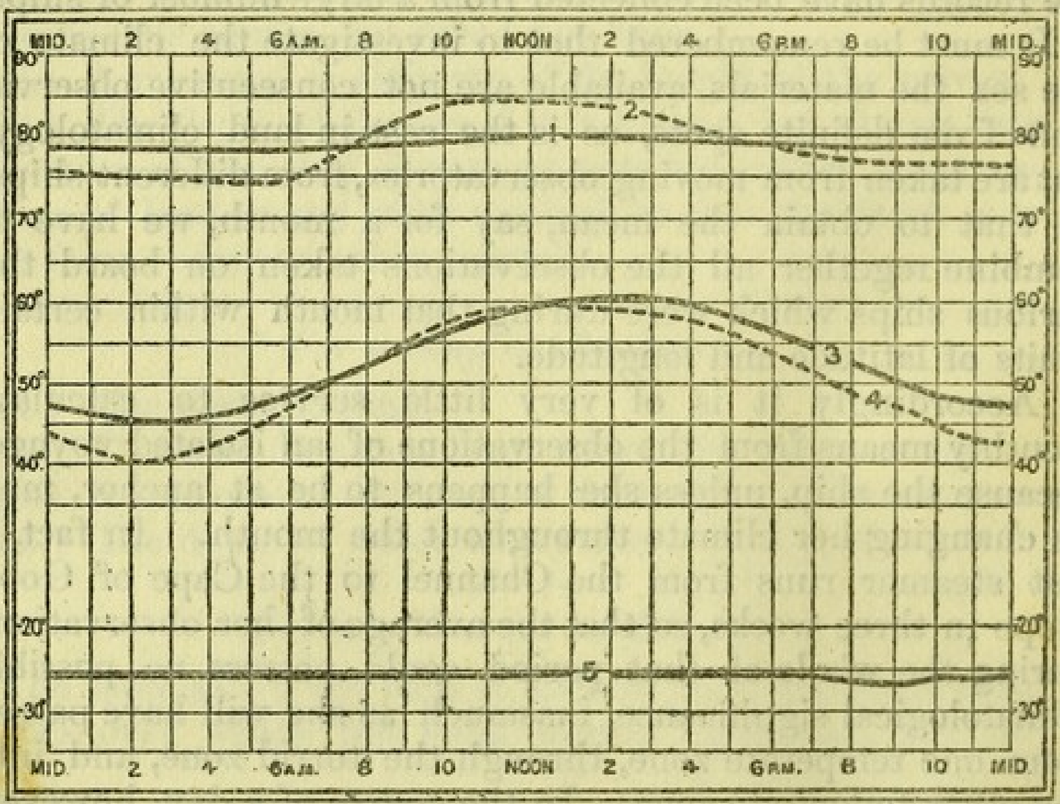
It must be remembered that to investigate the climate of the sea the materials available are not consecutive observations from definite spots, as is the case in land climatology, but are taken from moving observatories, from different ships, so that to obtain the mean, say for a month, we have to combine together all the observations taken on board the various ships which were during that month within certain limits of latitude and longitude.

Accordingly it is of very little service to calculate monthly means from the observations of an isolated voyage, because the ship, unless she happens to be at anchor, may be changing her climate throughout the month. In fact, a fast steamer runs from the Channel to the Cape of Good Hope in three weeks, so that the average of her observations during the whole of that period could possess no possible climatological significance, inasmuch as she will have passed from one temperate zone, through the torrid zone, and into the other temperate zone. In the course of a day, however, the change of position is not great, and, accordingly, daily means have some real value.

Air Temperature.—Dealing first with *temperature*, we do not at sea find a difficulty in selecting special hours of observation in order to obtain a trustworthy daily mean value at all to the same extent as is the case on land. This difficulty on land arises from the existence of a strongly marked diurnal range of temperature; this diurnal range is directly connected with solar radiation, for it is scarcely perceptible in observations from the polar regions while the sun is beneath the horizon, and is almost obliterated, even in the British Isles, by cloudy weather or fog. Moreover, in order to produce a marked diurnal range the sun's rays must strike on land, for while there is a decided range curve even for the small island of Ascension, the curve for the adjacent region of the Atlantic Ocean is almost a straight line.

The following diagram, Fig. 1, illustrates the above remarks, for it shows the range curves for the month of May, for two pairs of stations—firstly, for Ascension and a neighbouring ten degree square of sea surface; secondly, for Greenwich and Barnaoul in Central Siberia, showing what a close resemblance these two curves bear to each other, and lastly, for Boothia Felix in the month of January.

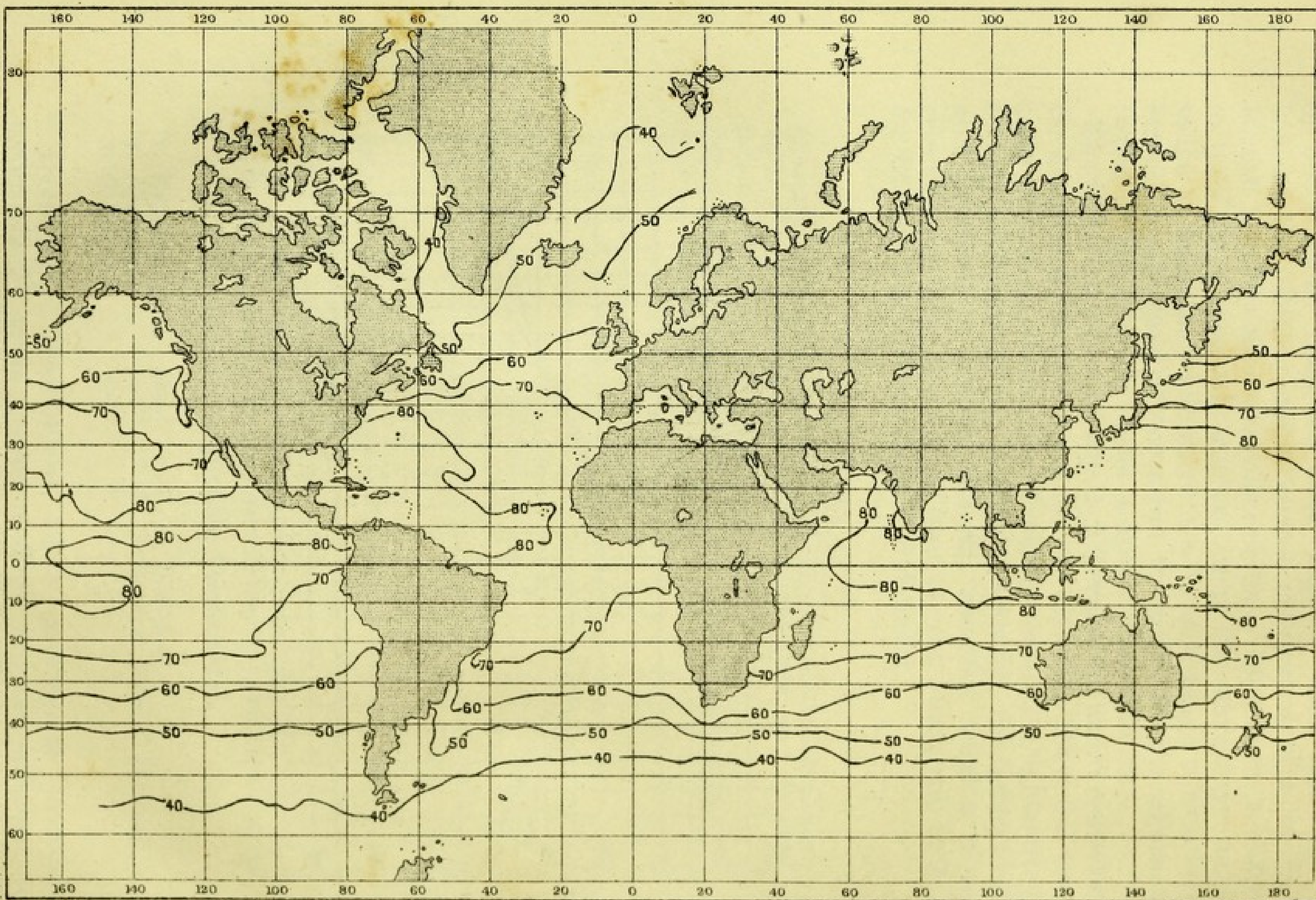
Fig. 1.



Diurnal Range of the Thermometer.

1. Equator at sea. May.
2. Ascension. —
3. Greenwich. —
4. Barnaoul. —
5. Boothia Felix. January.

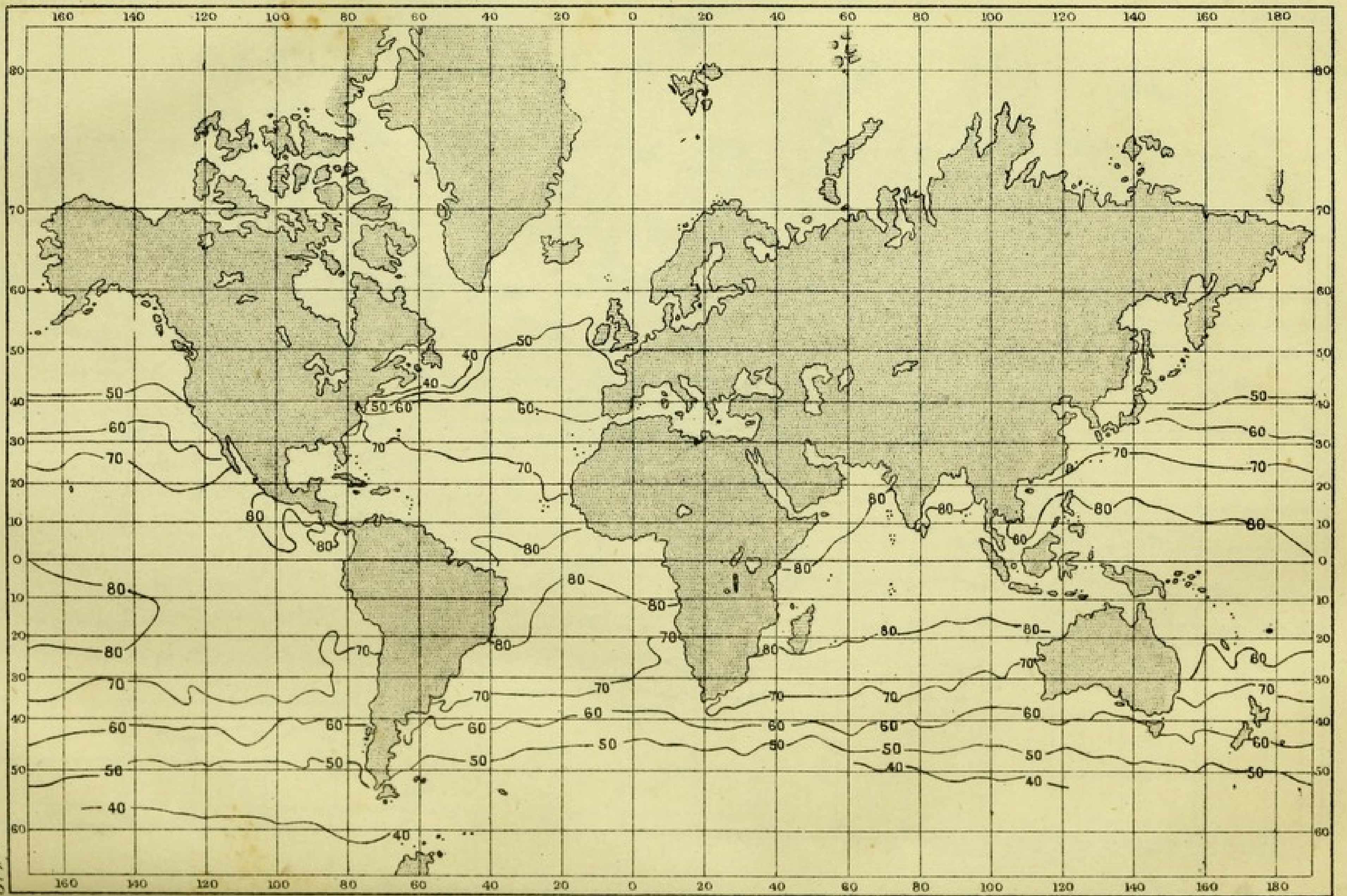
Accordingly, observations taken at regular intervals during the 24 hours of even a single day are sufficient to give a reasonably fair representation of the mean daily



Frederick Dangerfield, lith. London 3.86 11567

AUGUST – SEA SURFACE ISOTHERMS.

p. 149.



p.149

Frederick Dangerfield, lith, London. 3.86.11567.

march of temperature during the month at the position where the ship may be.

The distribution of temperature over the surface of the globe is mainly regulated by the distribution of land and water, and it has not been considered necessary to reproduce maps of air temperature in this Article. There is, however, a point of view from which air temperature observations, are of great practical utility to the seaman. The changes of temperature which are observed over and above those due to changes of season, that is, to annual range, or to changes of the ship's position, are those connected with changes of weather, the temperature rising with Southerly and South-westerly winds, and falling with Northerly and Easterly winds, speaking of the northern hemisphere. To this subject we shall return when speaking of weather and the storms of the temperate zone, p. 176.

Sea Surface Temperature.—The observations on the temperature of the surface water have led to results which are very interesting to the seaman, and also most important in their bearing upon climate. Plates I. and II. represent the conditions for the months of February and August respectively, which are taken as typical of the extreme positions of the isotherms for the year.

The highest surface temperatures which have been met with range about 90°, and it is probable that the strata exhibiting such an abnormal degree of temperature are very thin, and that at a moderate depth much cooler water would be found. The coldest temperature found is about 32°. The freezing point of pure sea water is 27°·7, but when salt water freezes the water has a tendency to crystallise away from the salt that it contains, so that the ice of floes, when melted, yields water much fresher than the sea in which the ice was floating. The fresher the water is the nearer will its freezing point be to 32°, so that when the sea surface actually freezes its temperature cannot be much below that point.

In both charts it will be seen that in low latitudes in all oceans the mean temperature ranges about 80°, not reaching 90°, and only falling to 70° in August, the southern winter, on the west coasts of Africa and South America. In the Atlantic, however, the warm water shifts its position very materially between February and August.

In the same ocean the lower isotherms have very irregular courses. In August those of 50° and 40° run almost N.

and S. In February, that of 50° exhibits a sharp bend just outside the Irish coast.

This extension of comparatively cold water into high latitudes in the North Atlantic is caused by the Gulf Stream pouring its volume of heated water along the channel which separates Europe from America, and bringing to the western shores of the former continent the mild and damp climate which characterises them.

The striking depression of the isotherms, which in both charts are packed close together, along the coast of Nova Scotia and the New England States, is probably owing to the action of the Arctic Current which forms the "cold wall" of the Gulf Stream.

Both the charts show unmistakeably the fact that in the southern hemisphere the general north-easterly set of the cold water brings the isotherms on the western coasts of the continents into lower latitudes, the action being most perceptible in the case of the isotherm for 70° on the coast of Peru. On the eastern coasts of Africa and South America the warm waters of the equatorial currents exert an opposite action.

The form of the basin containing the Atlantic Ocean facilitates the warming action of the Gulf Stream, for it affords an easy passage into the Arctic Ocean for the water of that current, whereas in the Pacific the way for the Kuro Siwo is effectually barred by the narrowness and deficiency of depth of Behring's Strait. The water of this latter warm stream is therefore forced to return on itself at about the fiftieth parallel of latitude, and the Arctic Ocean north of Behring's Strait is left undisturbed by its heating influence.

Atmospheric Pressure.—We now come to deal with atmospheric pressure, and the registration of this is about the most important instrumental observation in the domain of meteorology which the seaman can make.

If the readings of the barometer be taken carefully and regularly at equal intervals of time, it will be found that consecutive readings will rarely coincide exactly with one another. By such observations the changes which take place from hour to hour, and from day to day, in the pressure of the atmosphere may be observed and recorded, and useful indications obtained of the approach of disturbances likely to be accompanied by strong winds and storms.

The changes of pressure shown by the barometer may conveniently be classed as those which are regular or irregular in their occurrence, or, in other words, those that are periodical or non-periodical. The periodical changes of pressure, which depend on the time of the day or year, are hardly connected with changes of weather, it being the non-periodical which specially call for attention, as being indicative of probable strong winds or dangerous storms.

All the changes in the pressure of air, whether periodical or non-periodical, depend mainly on the changes of temperature, which take place at different hours of the day, or at the various seasons of the year, or arise at different places on the earth from various causes, among which may be mentioned, position with respect to latitude, distribution of land and sea, greater or less abundance of cloud or rain, or quantity of vapour in the air. Speaking generally, since air expands with heat and contracts with cold, the result of any place being more heated than its neighbourhood is that the air over it expands, and the higher strata flow away from it over the surrounding less heated area. Conversely, over a relatively cold area the air will contract, and the upper strata will flow in towards it from the neighbouring areas. Over those tracts *from* which the air thus flows the pressure will be reduced, while over those *to* which it flows the pressure will be increased.

In text-books on meteorology and in the wind and current charts for the Atlantic, Pacific, and Indian Oceans, published by the Hydrographic Office in 1872, charts will be found showing the mean barometrical pressure over the globe for the months of January and July. On these charts lines are drawn, at intervals of each tenth of an inch, showing where certain barometric pressures, indicated by the figures upon them, are observed. These lines are termed isobaric lines, or isobars, because they pass over places having equal barometrical pressure.

From these charts it will be seen that, speaking generally, in both hemispheres, in the winter the barometer is highest over the land, which is then colder than the sea; and lowest over the sea, which is then warmer than the land. In the summer the barometer is lowest over the land, which is then relatively hot, and highest over the sea, which is then relatively cool. The summer and winter occurring at opposite times of the year in the north and south hemispheres, the greatest development of high barometer readings in the northern hemisphere is seen in the January chart, and in the southern hemisphere in the July chart, and *vice versâ* for low readings.

Over the equator, and between the tropics, where the temperature is always comparatively high, the barometer is low, relatively to the neighbouring zones just beyond the tropics, where the temperature is relatively low, and the barometer is high.

The variations of pressure which thus arise over certain tracts of sea and land are closely related to the *permanent* winds, such as the Trades, and the *periodical* winds, such as the Monsoons, those last named following a corresponding periodical change of pressure over the tracts where they are established.

Before proceeding to consider more at length the relations which exist between winds and barometric pressure, it is desirable to convey to the seaman a general conception of the usual distribution of pressure over the globe, and of the readings he may expect to obtain, as well as of the inferences which he may deduce from his own observations.

Plates III. and IV. show, *for the oceans exclusively*, the mean barometrical pressure (reduced to sea level and to the temperature of 32° F.*) from the months of February and August respectively. These two months have been selected

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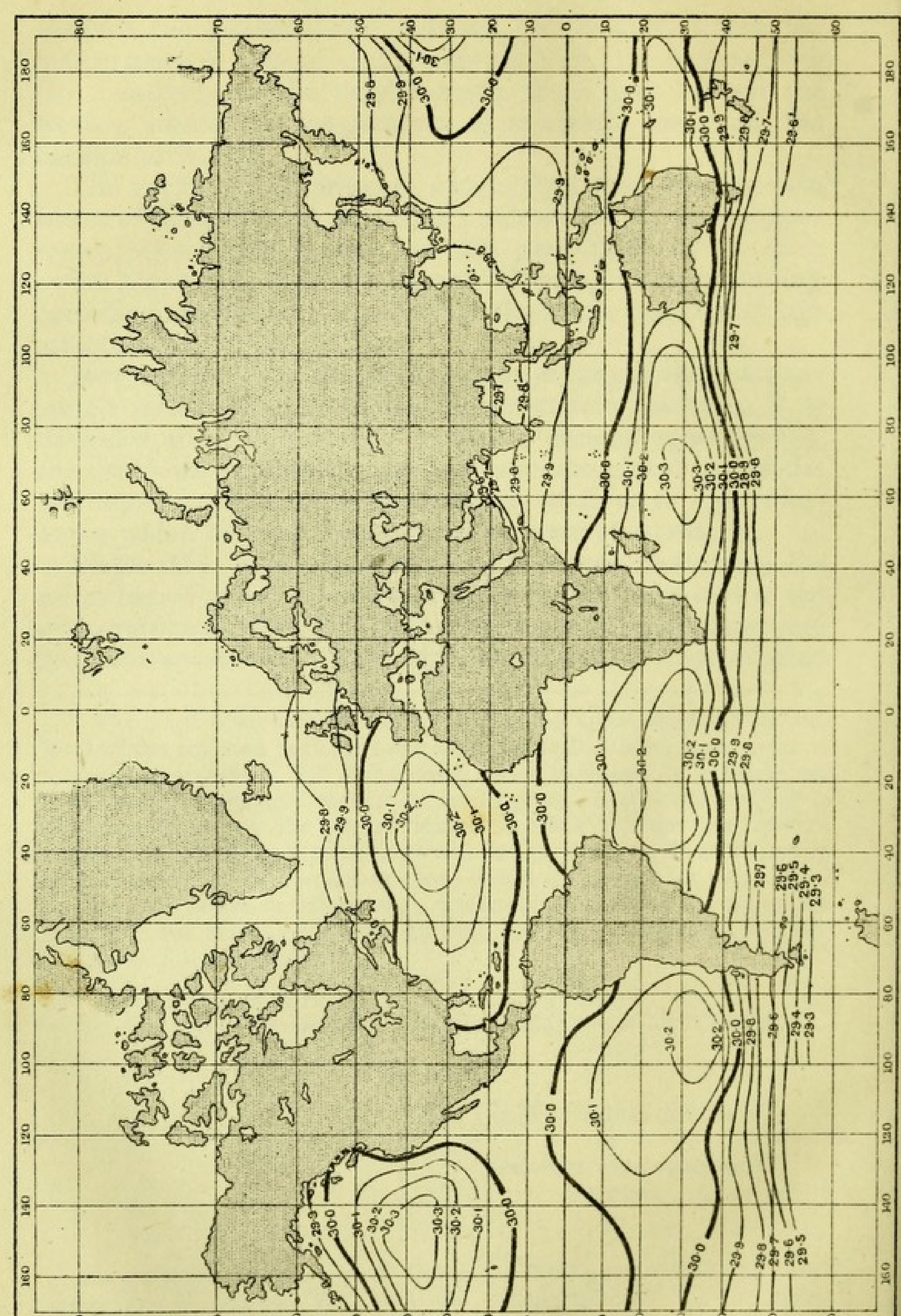
* The coast observations have, in all cases, been corrected to the level of the sea, and both land and sea observations have been reduced to the temperature of 32° Fahrenheit. For purposes of comparison between the charts and barometer readings as actually observed, it is therefore necessary for the navigator to allow for the temperature correction, which, as the readings will not vary greatly from 30 inches at the sea-level, will amount to about 0·014 of an inch for every 5° of temperature above or below 28½°, and should be added to the values shown on the charts, or subtracted from his own observations, according to the following table :—

Temp. of Air or Attached Thermometer.	Correction. Height of Barometer 30·0 inches.	
35°	0·018	*Add* to values on charts, or *Subtract* from observed values.
40	0·031	
50	0·058	
60	0·085	
70	0·111	
80	0·138	
90	0·164	

For example, in the Atlantic Ocean on the Equator, with the barometric line of chart 29·900, and the temperature 80° F., the navigator's barometer would be 30·038.

When the air temperature is *below* 28½° F. the corrections must be *subtracted* from the values on the charts, or *added* to the observed values, to admit of proper comparison.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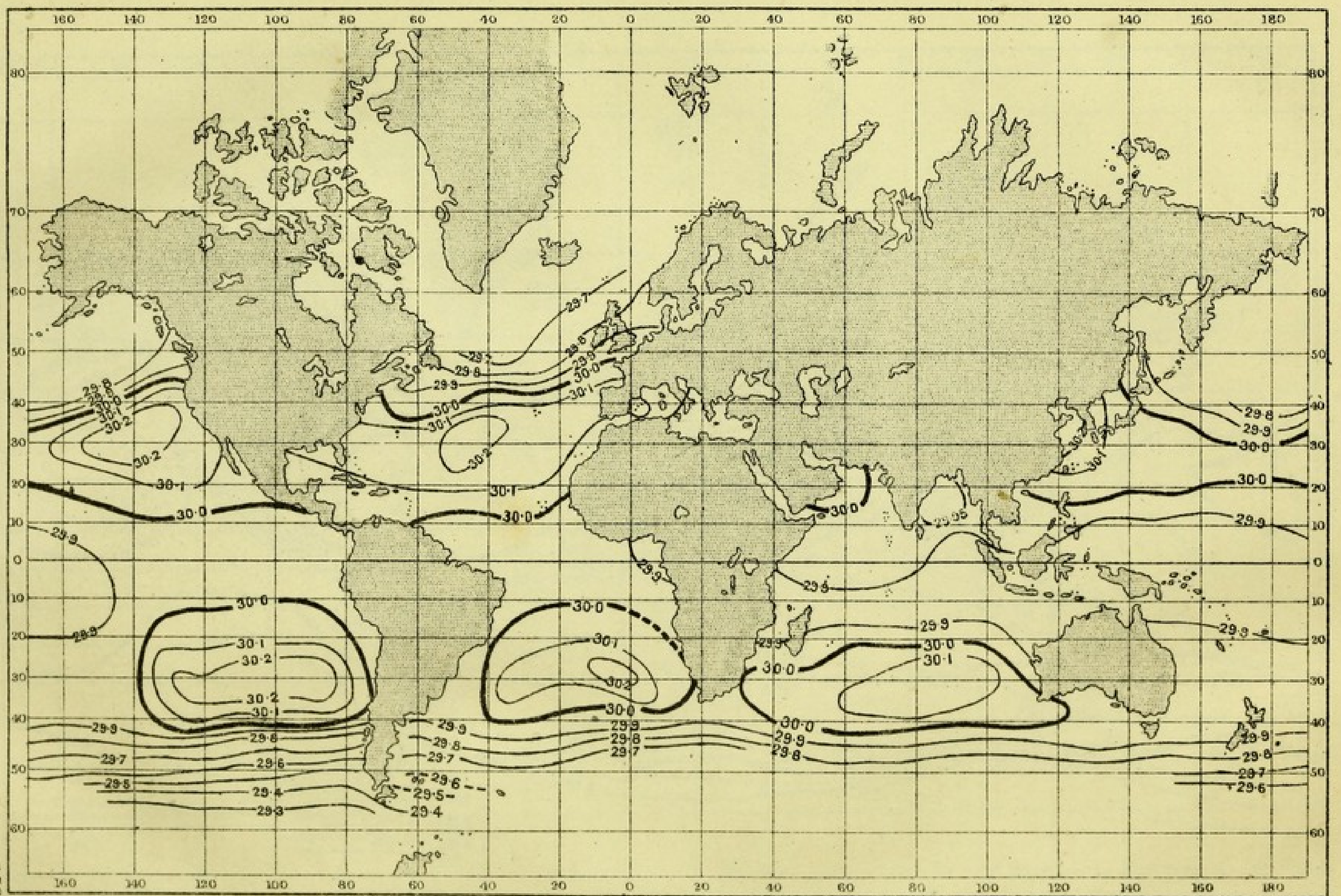

FEBRUARY – ISOBARS.

p. 153

because they represent the winter and summer at sea, where the seasons culminate about a month later than on land.

The main features brought out by an examination of these charts are that in all the oceans, without exception, there is a region where the pressure is high (generally above 30·2 inches). This region does not extend to the coasts in any case, and is situated about the 30th parallel of latitude North and South. In the Pacific Ocean it lies on the American side, near the coast.

Along the Equator the readings are relatively low, about 30 inches or a little below it.

On the polar sides of the areas of high pressure above mentioned the figures show a marked decrease, although from the paucity of observations in high latitudes the isobars are hardly drawn in either hemisphere in higher latitudes than 50°, except in the vicinity of Cape Horn and of the British Isles. In the northern hemisphere the lowest isobars shown are those for 29·7 inches in the Atlantic and 29·8 inches in the Pacific Ocean. It is, however, in the southern hemisphere that the most marked deficiency of pressure is shown, for in the neighbourhood of Cape Horn the value is about 29·4 inches in both charts, and further south the readings show a still greater decrease.

From the results of the Antarctic Expedition under Captain Sir J. C. Ross it appears that the actual lowest readings were found between 70° and 75° South and that nearer the pole the barometer began to read higher.

In the British Islands and adjacent waters, proceeding from south to north, the mean barometrical pressure in both charts ranges during ordinary weather from 30 inches to 29·75 inches.

From these charts it will also be seen, that during a voyage, made at any period of the year, from England to the Australian colonies by way of the Cape of Good Hope and thence back to England by way of Cape Horn, the readings of the barometer will, in the average conditions of weather, and in the absence of any disturbing atmospheric causes, have varied as much as seven tenths of an inch, that is between 30·2 inches, found in the high pressure areas of the North and South Atlantic Oceans, and 29·5 inches, found in the low pressure zone on the parallel of Cape Horn.

On the other hand, in a voyage from London, by way of the Suez Canal, to Bombay or Calcutta, or to ports in China, the barometer, under similar average conditions of weather, will not in February stand below 29·9 inches, whereas in August the readings will range from 30·1 inches in the Atlantic Ocean to 29·75 at the Indian and Chinese ports; the low pressures last named mainly depending on the high summer temperature of the adjoining great continental masses of land, due to the influence of a sun nearly vertical in June.

Having thus briefly described the main features of the distribution of mean barometrical readings over the globe, we now come to the subject of the degree of accordance with these mean values which the individual barometrical readings may be expected to exhibit.

In all climates and at all parts of the earth the pressure of the air and the height of the mercury in the barometric column are constantly varying. In the higher latitudes these variations have a range of two inches and more, and the familiar terms "high" and "low" barometer are applied when there is some marked difference in the readings above or below the average value at any place. Moreover, as wind is a more or less direct consequence of alterations in the pressure of the atmosphere, it becomes desirable to discriminate carefully between the varying degrees of importance to be attached, in different seasons of the year and in different latitudes, to any observed high or low barometer, in relation to the winds which accompany, or result from, the alterations of pressure so indicated.

We have now to consider the subject of the changes of pressure, which, as already explained, may be classed under two heads, Periodical and Non-periodical.

Periodical Variations of Pressure.

Of the periodical changes the *diurnal variation,* though small in its amount, chiefly demands the consideration of seamen when navigating in the tropical and adjacent seas, where it is one of the most regular of recurring phenomena.

In fact, if the observations recorded in a log do not exhibit the normal diurnal range in ordinary weather, while the ship is near the Equator, grave doubt is thrown on the trustworthiness of the observations throughout the rest of the voyage.

This diurnal variation of pressure consists of a double oscillation, there being two periods of increase and two of decrease; the barometer rising from about 4 a.m. to about 10 a.m., then falling to about 4 p.m., and again rising till about 10 p.m., when it once more falls to 4 a.m. The morning maximum is commonly, but not invariably, higher than the night maximum; and the former usually occurs rather before than after 10 a.m., while the latter tends rather to be later than earlier than 10 p.m. The afternoon minimum is, with rare exceptions, lower than the morning minimum, and occurs rather after than before 4 p.m.

At sea the diurnal variation attains its greatest magnitude within the tropics, and gradually diminishes in higher latitudes, being hardly perceptible within the arctic and antarctic circles. The extent of the oscillation of the mercury due to this cause, at any place at different times of the year, depends much on the range of daily temperature, and the times of maxima and minima are influenced by the times of sunrise and sunset. At sea within the tropics, therefore, the range of temperature and the length of the day not being subject to any considerable change in the course of the year, the diurnal variation does not change in any important feature from one month to another. On land beyond the tropics it is otherwise, and the daily range of pressure fluctuates both in amount and period accordingly.

In tropical seas the daily range of the barometer between the highest and lowest may be taken at about 0·07 of an inch or 0·08 of an inch, the greatest rise above the mean of the 24 hours being somewhat less than the greatest fall below it. The mean pressure in these seas will be found to occur between noon and 1 p.m. and between 6 a.m. and 7 a.m.

At Calcutta the daily range varies from about 0·14 inch in April and May, when the range of temperature is greatest, to about 0·09 inch in July, when it is least.*

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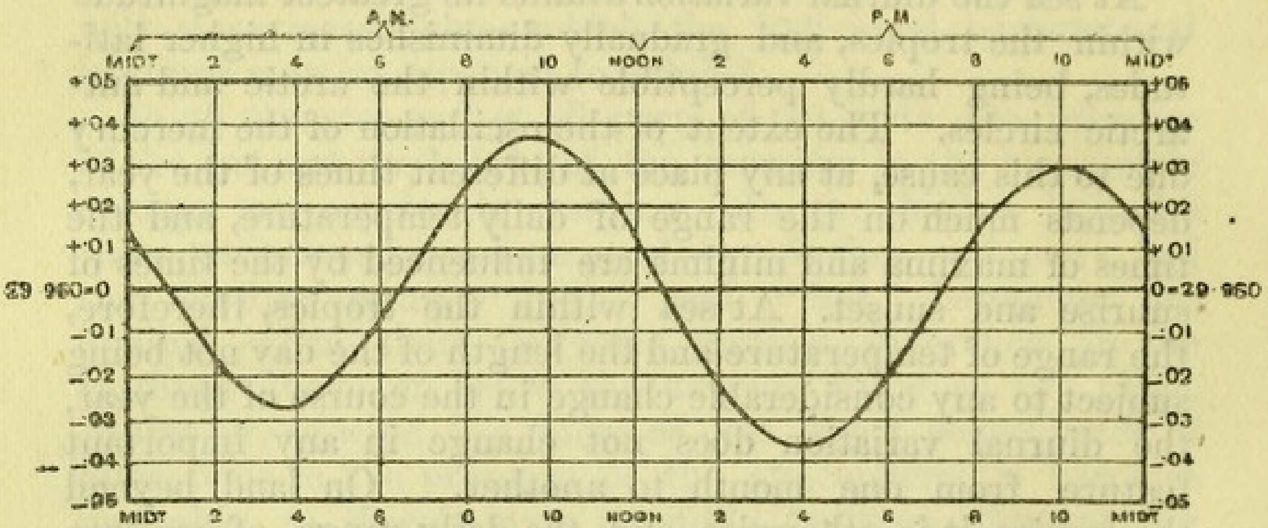
* The following examples are instructive; the values (in decimals of an inch) indicated by + and − signs, show approximately the mean rise or fall above and below the average reading of the barometer:—

Calcutta [22½° N. lat.].		Ascension [8° S. lat.].	Mauritius [20° S. lat.].
Jan.	July.	Mean of the Year.	Mean of the Year.
3½ a.m. − ·019	− ·017	3 a.m. − ·020	3½ a.m. − ·018
9½ a.m. + ·076	+ ·039	9 a.m. + ·035	9½ a.m. + ·030
4½ p.m. − ·051	− ·054	3½ p.m. − ·040	3½ p.m. − ·040
10½ p.m. + ·008	+ ·026	10 p.m. + ·027	9½ p.m. + ·029

In the British Isles the changes of pressure due to this cause are hardly more than one fourth of those observed in the tropics, amounting on the average to about 0·02 inch, so that unless in very calm settled weather the daily oscillations can seldom be recognised in the hourly readings of the barometer during a single day, though they become quite apparent in the means of such a period as a month.

Fig. 2.



Diurnal range of the barometer near the Equator (Atlantic).

The diagram (Fig. 2) represents the mean curve of daily range of the barometer for the central portion of the Atlantic between lat. 5° N. and the Equator, which may be taken as typical of the daily variation in tropical seas. If, then, in the tropics the seaman observes in the reading of his barometer any marked deviation from such a curve, he may anticipate that some considerable atmospheric disturbance has arisen, and that a change of weather, possibly a hurricane, is impending.

The *annual variation* of pressure is also a well-marked phenomenon within the tropics both on land and sea, following the apparent motion of the sun north and south of the Equator, and giving rise to modifications of the Trade Winds, and producing periodical winds such as the Monsoons of the Indian Seas. The extent of the variation thus caused amounts to about 0·10 inch between the highest and lowest monthly mean, on approaching the land it becomes much greater, being about 0·30 inch at Bombay, while at Calcutta it reaches 0·45 inch, and in the interior of Asia the yearly variation is as much as 0·80 inch.

As, however, the annual variation takes place very gradually, it has no characteristics which make it of special importance to seamen in relation to possible sudden changes of weather, and it therefore calls for no further comment here.

Non-Periodical Variations of Pressure.

The non-periodical changes of pressure, which, as before said, are those immediately associated with changes of weather, next demand notice. The extent of these changes, under ordinary conditions, and taking the average of the various seasons of the year, varies with the latitude, being smallest near the Equator and increasing as we recede from it.

Within the tropics, the ordinary fluctuations of the barometer, including the diurnal variation, seldom exceed three or four tenths of an inch, except in the event of one of those furious and dreaded revolving storms commonly known as hurricanes, cyclones, or typhoons (according to the part of the globe in which they occur), when the barometer may fall much more, as will be explained hereafter, and in the dangerous part of the storm field may fall to the extent of two inches or more.

At Ascension in lat. 8° S., the greatest range observed in two years scarcely reached four tenths of an inch. The highest reading, 30·178, was recorded in June, the lowest, 29·800, in April. Similarly, in the tropical zone of the Atlantic Ocean, between the Equator and 10° N. lat. and between 20° and 30° W. long. (as extracted from a large mass of observations extending over many years), the highest reading, 30·138, was observed in July, the lowest, 29·725, in December, a range of only 0·413.

The range of the barometer gradually increases with the latitude, and appears to reach its maximum—at least in the northern hemisphere—between the 60th and 65th parallels; thence towards the pole decreasing. The magnitude of the range in the higher latitudes, as compared to the tropics, is exemplified in the British Islands, where the average range in the course of a month is about 1·7 inch for January, and 0·9 inch for July.

Between the years 1841–58, the highest barometer reading at Greenwich was 30·695 inches; the lowest 28·460; the range being 2·235 inches. Older records give a range of

3 inches, 30·9 to 27·9, but these excessive ranges must be considered exceptional, and refer to a long series of years.*

The following tabulated values, arranged according to latitude, have been compiled from all available authorities, and may, under ordinary conditions, and excluding exceptional storms of great severity, such as tropical cyclones, be accepted as the approximate range of the barometer, in the months of January and July respectively, over the several oceans:—

	January.	July.
	Inches.	Inches.
Between 65° and 60° N.	1·70 to 1·80	1·0.
60° „ 50° „	1·80 „ 1·50	1·00 to 0·80.
50° „ 40° „	1·50 „ 1·25	0·80 „ 0·60.
40° „ 30° „	1·25 „ 0·65	0·60 „ 0·40.
30° „ Tropic	0·65 „ 0·40	0·40 „ 0·30.
Tropic „ Equator	0·40 „ 0·20	0·30 „ 0·20.
Equator „ Tropic	0·20 „ 0·35	0·20 „ 0·35.
Tropic „ 30° S.	0·35 „ 0·55	0·35 „ 0·60.
30° „ 40° „	0·55 „ 0·80	0·60 „ 1·00.
40° „ 50° „	0·80 „ 1·20	1·00 „ 1·60.
50° „ 55° „	1·20 „ 1·30	1·75.

For the smaller ranges the assumption that the variations of the height of the barometer are of nearly equal amount on each side of the mean reading is sufficiently exact for practical purposes; in the greater ranges it requires modification. An examination of the behaviour of the barometer at Greenwich, between 1841 and 1858 (excluding extraordinary disturbances), goes to show, that in January—as typical of the winter months when the fluctuations are greatest—the mercury falls below the mean reading in the proportion of about five parts of the whole range to a rise above the mean reading of three parts of the whole range; while in July—as typical of the summer months when the fluctuations are least—the rise and the fall in the range appear nearly equally divided.

Thus with an average barometer reading in the English Channel of 29·95 inches, we should have in the winter, with a range of 1·5 inch, a fall of 0·95 and a rise of 0·55 as representing the lowest and highest barometer (29·00 and 30·50) that might be expected. Under similar condi-

* In the storm of Jan. 26, 1884, a reading of 27·32 ins. was recorded, at Kilcreggan, near Greenock.

tions, in the southern hemisphere, when off Cape Horn, with an average barometer of 29·50 inches and a winter range of 1·75 inch, assuming the same proportion between the extent of rise and fall, 28·40 and 30·15 would represent the probable lowest and highest readings.

By the aid of these considerations, an estimate can be formed with a fair approach to precision from the figures in the above table, and those entered on the isobaric charts, of the probable ordinary range of a high or a low barometer at any place where a vessel may be, from which, when compared with the barometrical readings taken in the vessel, a judgment may be formed as to whether there is any serious departure in these readings from the mean value of the pressure either in the way of excess or deficiency, and this knowledge, combined with observations of the actual direction and force of the wind, and of the changes that take place in them, will furnish the seaman with the means of guiding his action, as will be further explained hereafter.

Pressure and Wind.

Having thus briefly described the broad features of the distribution of pressure over the globe, we must now show how this affects the winds which are felt in various parts of the world.

Wind is air in motion, and air is set in motion, in the first instance, by differences of temperature, while that motion is subsequently modified by the movement of rotation of the earth on its axis. The general principles of this motion are explained in modern text books of meteorology, and the following brief summary will therefore suffice for these pages.

The atmosphere may be supposed to be arranged in concentric layers around the globe, and the pressure of the successive layers decreases with the elevation, when the air is at rest. If now any portion of the earth's surface be heated the air over it will be expanded, the lowest layers will be most affected, and will rise so that the pressure at the upper levels will be mechanically increased. That this really takes place is shown by the fact that, *e.g.*, in the Alps, the stations at high levels show higher barometrical readings in summer when the air in the lowlands is heated, than in winter when it is chilled, while at the lower levels, as at Geneva, the readings in January and in July are alike.

Now the portion of the earth's surface where this surface heating is most active is the Torrid Zone, and there then the expansion of the atmosphere is greatest, and its upper layers are raised to such a height that they, so to speak, slide off and tend to flow away. As a proof that this represents the actual facts of nature, it may be stated that whereas, at the Equator, the sea level pressure is less than it is in lat. 39° N.; at the level of 13,000 feet (in the Andes and Rocky Mountains respectively) the greater pressure is at the Equator, the lesser in the Temperate Zone.

This distribution of pressure shows that there is a tendency near the Equator for an under current of air towards the Equator and an upper current of air away from the Equator.

A similar action causes a local circulation of the atmosphere over locally heated areas, the air tending to flow in towards heated regions and to flow out from regions which are abnormally cold. The great Monsoon system of Asia is thus explained.

The surface heating of the atmosphere is, however, a phenomenon not confined to land areas, for the action is really more regular in the case of the oceans than in the case of the continents. The sea surface is not so much heated by day as the land, but it is scarcely cooled at all by night, so that it preserves a comparatively equable temperature throughout the twenty-four hours, the water making up by constancy of action what it wants in intensity.

The great under currents of air in the vicinity of the Equator are known to all sailors as the Trade Winds, and the return upper currents were called by Sir John Herschel the Anti-trades.

When we reach the edge of the Trade Wind zone we find the upper currents gradually descending to the sea level. On the Peak of Teneriffe (lat. 28° N.), for instance, there are constant South-west winds at the summit. As the autumn comes on the sun moves southwards, the Trade Winds follow him, and the South-west wind creeps slowly down the mountain side until in winter the whole of the island, from summit to base, is enveloped in this return current, which in summer touches only the highest peak.

It is not possible to ascertain the precise motions of the upper strata of the atmosphere by direct observation, and the only mode of gaining an insight into them is by observations of cloud motions, especially of the upper clouds, Observers at sea are in a position to render most efficient aid to meteorology by carefully conducted observations of this nature.

The return currents from the Equator partly descend to the surface of the earth outside the tropics, and are drawn back into the Trade Wind circulation, and partly flow on towards the poles. In latitudes higher than the 40th parallel the lower air currents are no longer simply Trades or Return Trades, but are regulated chiefly by the contrasts in temperature between the continents and oceans, and by the differences in pressure induced thereby.

The question now arises, Why are these lower currents near the Equator not true North and South winds, on the opposite sides of the Equator, and the return currents South and North winds respectively?

The answer to this is that by certain experiments with a pendulum made by M. Foucault in Paris it has been shown that the deflection of a body moving on the earth, which itself is rotating on its axis, is uniform in all directions and depends entirely on the latitude and the velocity of the moving body.

The deflection per second is $\nu\ \omega\ \sin\ \lambda$, where ω is the angular velocity of the earth's rotation, ν the velocity of the moving body (in this case the wind), and λ the latitude.

This principle shows that all winds have a tendency to be deflected to the right.

Accordingly the Trade Winds blow from N.E. and S.E. instead of from N. and S. respectively, and the Anti-trades from S.W. and N.W. instead of from S. and N.

The Trade Wind system changes its position as the sun changes his declination, and we have accordingly in each hemisphere four regions or belts of winds—

I. The equatorial calm belt, with variable winds, close to the Equator.

II. The belt which is constantly in the Trade Wind throughout the year.

III. The belt which is in the Trade Wind in summer, and outside it in winter.

IV. The belt of variable winds, principally Westerly, which lies on the polar side of the Trade Wind region.

All these winds are mainly regulated by the varying distribution of pressure, and before we proceed to describe more minutely the distribution of the winds it is necessary to explain in general terms the mode in which the phenomena of atmospherical pressure are related to those of atmospherical temperature, and also the precise relations which exist between wind and pressure.

The barometer falls—

I. When the lower strata of the atmosphere are heated, causing the surfaces of equal pressure to rise, and the upper layers to slide off, as already explained, for by this means the weight of air pressing on the unit of area below is reduced.

II. When the air is damp, for as the density of aqueous vapour at the temperature of 60° and pressure of 30 inches is $= 0 \cdot 622$, air being $= 1$, damp air does not press so heavily as dry air.

III. When vapour is condensed into the form of clouds, or into rain or snow. This action heats the air (by means of the latent heat set free) and thus increases the force of the ascending column. It is not, however, till the rain or snow has actually fallen that the entire action on the barometer of vapour, as a constituent of the air, is removed.

IV. When the air is in motion, for fluids and gases in motion exert much less pressure on the walls of their containing channels than when they are at rest.

Conversely: The barometer rises—

I. When the air is very cold, for then the lower strata are denser and more contracted than when it is warm, and air flows in above to fill up the deficiency.

II. When the air is dry, for then it is denser than when it is moist.

III. When the air flows in towards any region and a corresponding outflow does not exist.

These general principles show us how regions which are extremely cold are always those where the barometer is relatively high, and, conversely, regions which are extremely hot are always those where the barometer is relatively low.

We have now to see how the foregoing principles affect the motion of the air and determine the course of the wind.

As the air is an elastic gas it tends to flow into regions where the pressure is less, and out of regions where the pressure is greater than its average amount in order to restore atmospheric equilibrium.

If now we suppose an ascending motion to be imparted in any way to a mass of air, for instance by local heating of its lowest stratum, currents of air will set in from all sides towards that one spot, and as these will all be caused to deviate in one way, the result must be that a gyratory movement will be generated round that spot. The wind thus set in motion must, in the northern hemisphere, leave the point of lowest barometrical readings on its left-hand side, and must move round that point *against* watch hands; in the southern hemisphere it must leave the corresponding point on its right-hand side, and must move round it *with* watch hands.

The wind in each hemisphere respectively must move round a spot of high barometer readings in the opposite direction to the above.

This principle is expressed in the following law, known as Buys Ballot's, from the name of the Dutch professor who first stated it in these concise words:—

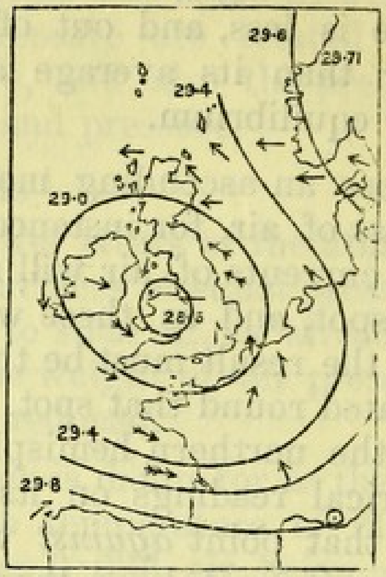
"Stand with your back to the wind and the barometer will be lower on your left-hand side than on your right."

This law is exactly reversed in the southern hemisphere.

The force of a wind accompanying a difference of pressure over two areas is found to be greater as that difference is greater, and it therefore depends not on the mere height of the barometer at any particular place, but on the difference between that height and that which subsists over the neighbouring places. These differences of pressure are spoken of as barometric gradients; and the standard for their comparison that has been adopted by international agreement is the difference of pressure, expressed in hundredths of an inch, in 15 miles of distance. The greater the difference, the steeper will be the gradient, the closer will be the isobaric lines on a chart representing the pressure, and the stronger will be the winds.

Fig. 3 illustrates the application of the foregoing observations to the northern hemisphere. It shows the conditions

Fig. 3.



Circulation of wind round an area of low pressure, November 29, 1874.

of barometrical pressure, and the direction and force of the wind consequent on the formation of an area of low pressure over the British Isles.

The lines drawn on the map are isobars, which, as before stated, are lines indicating equal barometrical readings. The arrows indicate the direction and force of the wind; arrows with one barb signifying light winds, with two barbs stronger winds, those representing gales being feathered according to their intensity.

It will be seen that, in accordance with Buys Bailot's Law, the wind blows so that at each point the observer with his back to the wind would have a lower barometer on his left hand than on his right. Further, though circulating generally round the isobaric lines, the arrows cut these lines at an acute angle, and generally so as to show an indraft towards the area of least pressure.

No general law has yet been established determining *the angle of indraft* of the wind, that is to say, the angle which the wind makes with the direction of the isobar at the place, but it is generally agreed by meteorologists that 20° may be taken as a fair average value of this angle, though it is not certain that it is the same in all azimuths.

Inasmuch as the distribution of barometric pressure is subject to almost infinite variety and change, the occurrence of regularly formed areas of high or low pressure over any place is comparatively rare, but the more violent the wind the more regular does the distribution of the isobars round the centre of a cyclone tend to become, and whatever be the arrangement of the isobars, the winds will be found to blow along or round them in accordance with the general principles that have been explained, as is shown in Figs. 4 and 5.

Fig. 4.

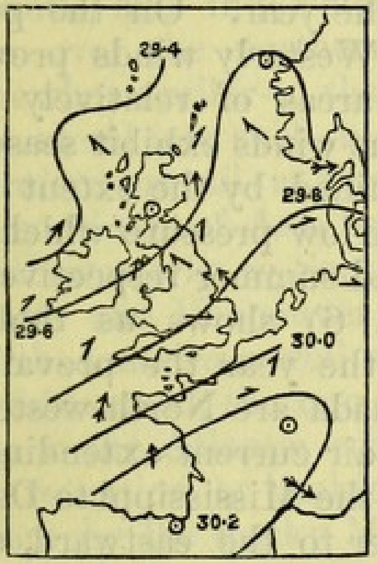
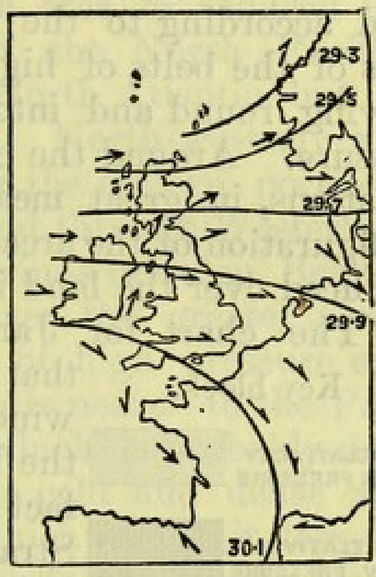


Fig. 5.



Relations of wind to Isobars.

Prevailing Winds at various Seasons over different Parts of the Globe.

From these considerations it will be seen how a knowledge of the relative distribution of mean atmospheric pressure on the earth's surface at different times of the year will enable us to indicate the prevailing winds, and, conversely, how a knowledge of the prevailing direction and force of the winds will enable us to indicate the relative distribution of mean atmospheric pressure.

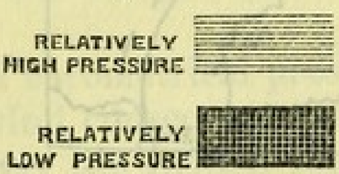
The main features of the relation between the mean barometic pressure and the prevailing winds over the globe are well described in the following extract from a work published in 1880 under the authority of the Meteorological Council, entitled "Aids to the Study and Forecast of Weather," by the Rev. W. Clement Ley, and will usefully supplement what has been previously said on these subjects :—*

"The prevailing winds, shown by the arrows in Figs. 6 and 7 (pp. 166 and 169), are determined by the interaction of these two general laws (*i.e.*, the greater heat of the continents

* The charts which accompanied Mr. Ley's memoir have been modified and reduced in scale, as shown in Figs. 6 and 7.

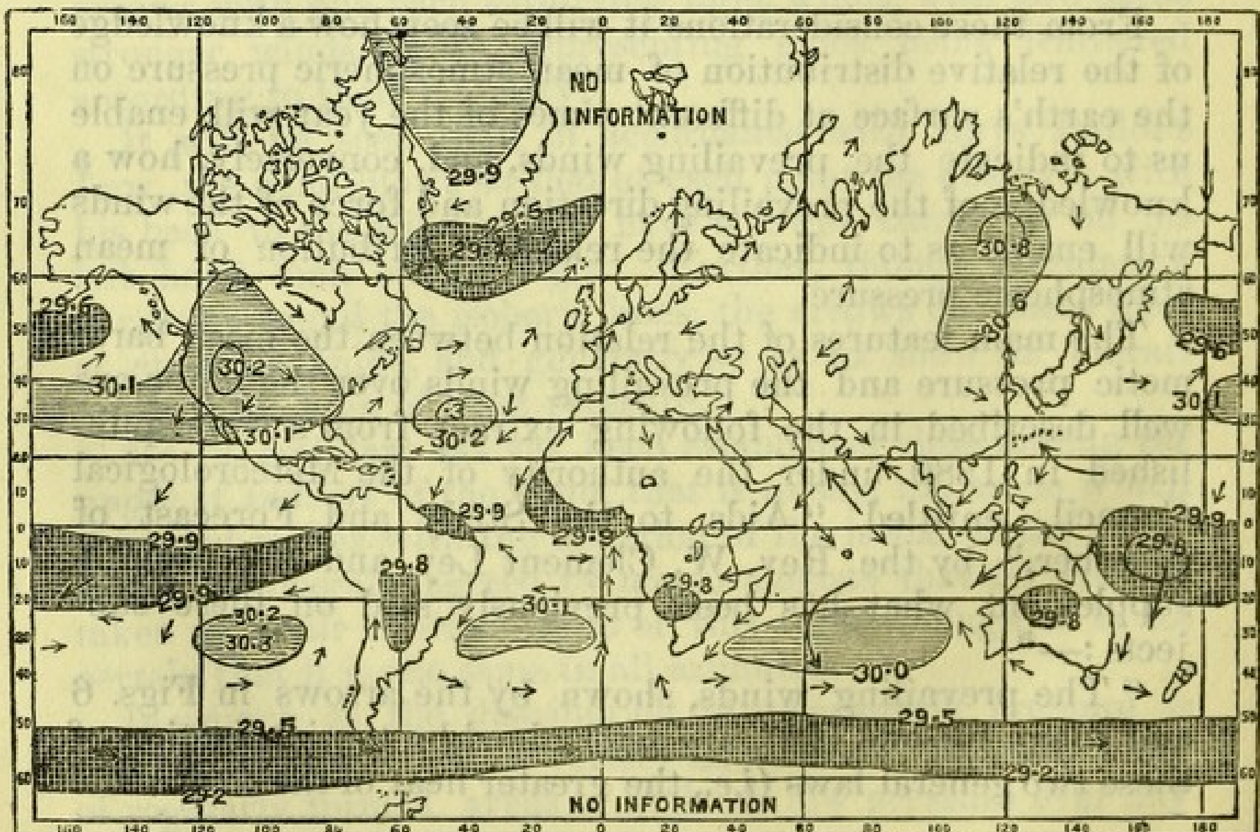
in relation to the sea, during the summer, and their greater relative cold in the winter), and it will be seen that these winds, as regards the relation between their direction, and the distribution of pressures, follow the law above explained (*i.e.*, Buys Ballot's law). Thus over the Atlantic and Pacific Oceans the air currents pour out of the northern and southern belts of high pressure into the equatorial belt of low pressure, the latter shifting its position northward or southward according to the season of the year. On the polar sides of the belts of high pressure Westerly winds prevail, blowing round and into the polar areas of relatively low pressure. Around the continents the winds exhibit seasonal variations, in great measure determined by the extent and configuration of the areas of high and low pressure which are produced over the land in winter and summer respectively.

Key block.



"The chart for January (Fig. 6) shows us that at that period of the year the prevailing winds over Canada are North-westerly, the belt of this air current extending in fact nearly from the Mississippi to Davis' Straits. Further to the eastward, over the western portion of the North Atlantic, the prevailing air current is from the West, while from

Fig. 6.—January



the Azores up to the extreme northern point of Siberia an extensive South-westerly wind prevails. Two prolongations or arms are observed to extend from the area of low pressure whose centre lies to the south of Iceland, one of these stretching north-westward to Baffin's Bay, the other north-eastward over the Arctic Sea. An area of relatively high pressure existing over Greenland, Northerly and North-easterly winds are experienced in the high latitudes of the Atlantic and the Polar Seas. The area of reduced pressure over the northern portion of the North Pacific is somewhat similar to that over the North Atlantic, but does not extend into such high latitudes. North-westerly winds therefore prevail at this season over the eastern portion of the continent of Asia, sweeping round through Westerly and South-westerly to South-easterly winds between Behring's Straits and Vancouver Island. Over the greater part of North America a well-marked area of high pressure exists at this season, the nucleus of which is nearer to the Pacific than to the Atlantic coasts, a fact which is probably due to the retention or banking up of the cold and dense atmosphere by the Rocky Mountains, which render it less easy for the air to escape westward towards the Pacific than in an eastward direction, where the earth's surface presents fewer obstacles to its movements. A corresponding, but very much greater and more remarkable, area of high pressure covers nearly the whole of Asia. This area has a somewhat similarly shaped nucleus which, probably, for a corresponding reason, lies near the eastern shores of the continent.

"South of latitude 30° N. we find predominant North-easterly winds round the greater portion of the globe, extending in most regions to the Equator. In the Indian Ocean these air currents cross the Line, and, changing in their direction in obedience to the law of relation between wind and pressure for the southern hemisphere, there blow from North-west and constitute a North-west "Monsoon," or periodical wind.

"January being a summer month in the southern hemisphere, areas of low pressure are exhibited over the interiors of the southern continents, South America, the southern part of Africa, and Australia, around which the winds necessarily tend to circulate in a direction from the front towards the right hand. These last-mentioned continental districts form at this season interruptions in the southern hemisphere high-pressure belt.

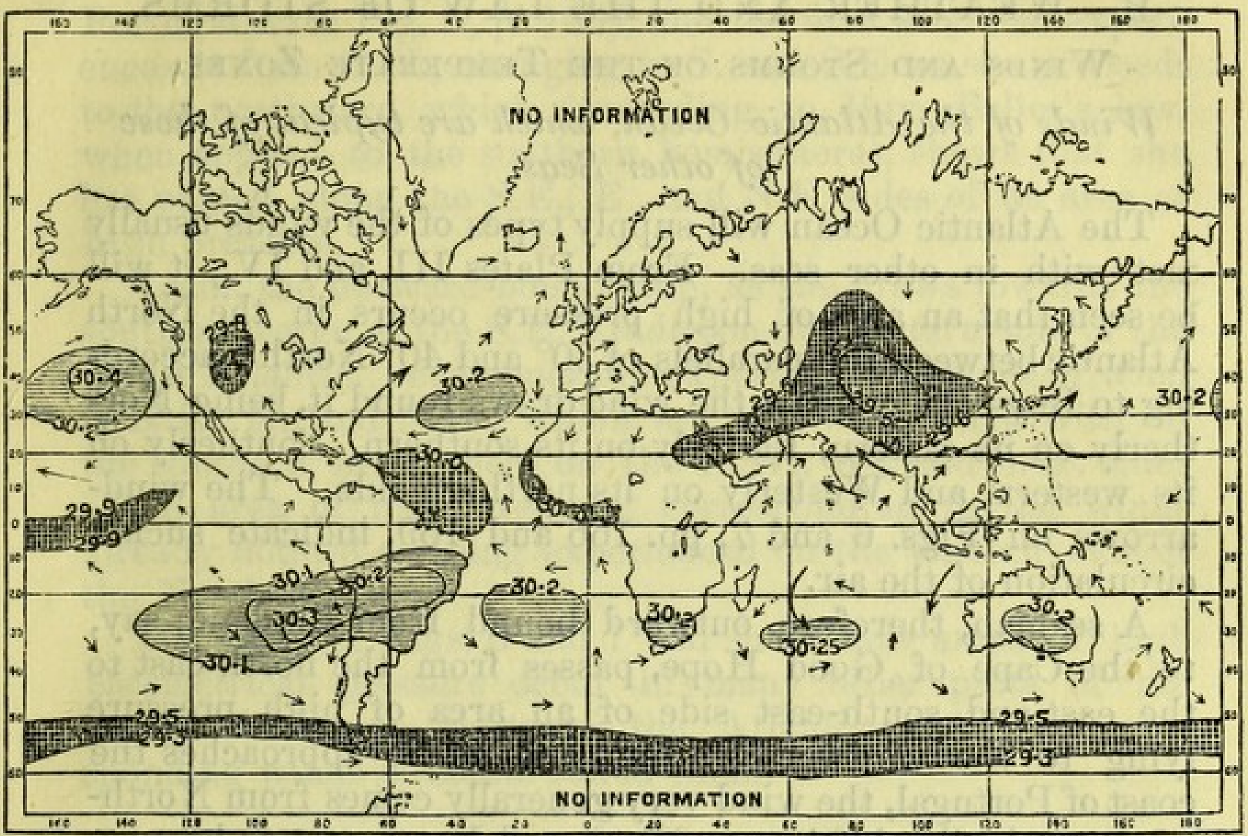
"To the south, again, of this belt the mean pressure rapidly decreases, and, as far as ships go, south of latitude 40° S., Westerly and North-westerly wind appear to be predominant round the globe, blowing with a force and persistency which has given to this region, in the language of the sailors, the title of the 'Roaring Forties.'

"In the spring of the northern hemisphere a great and rapid change takes place in the distribution of mean pressures over that half of the globe. This change is least marked in the oceanic districts of the high-pressure belt. Over the interior of the continents the barometers fall briskly, this change being much the most serious over the southern part of Asia. At the same time, and owing probably to this dislodgement of a portion of the atmosphere from the continental districts, a marked though temporary increase of pressure occurs in high latitudes, a fact to which the North-easterly surface winds, so frequently experienced in the British Isles at this season, seem to be due. The equatorial zone of low pressure is now travelling northwards, and over a portion of the North Indian Ocean, where this zone coalesces with the continental area of low pressure, the winds which are felt as the South-east Trade on the south of the Line, are felt on the north of it as an incipient South-west Monsoon.

"This being the autumn of the southern hemisphere, pressure is increasing over the southern portion of South America, South Africa, and Australia.

"Most of these changes have reached their consummation in July (see Fig. 7, p. 169). Mean pressure is now low over the interior of North America, the major axis of this depression nearly coinciding with that of the figure of the continent. A similarly shaped, but far vaster, depression lies over Central Asia, causing the winds in the extreme east of Europe to become North-westerly. The area of very low pressure noticed over the North Atlantic in our winter has now almost ceased to be traceable. The equatorial zone of low pressure has crossed the Line on the Atlantic side and apparently on a portion of the Pacific side also; and the South-east Trades, where they penetrate into the northern hemisphere, are felt as South-westerly winds in lower northern latitudes. The conditions already described as showing themselves over the North Indian Ocean in spring are now greatly intensified. Meanwhile the depression noticed in winter in South Africa has crossed to the northern portion of that continent, causing predominant Northerly winds over

Fig. 7.—July.



the Mediterranean. In the southern hemisphere the high-pressure belt is now very wide and well marked, and appears to extend round the globe.

"In our autumn the general changes are the reverse of those noticed during the spring, and their character may therefore be easily inferred. It will be sufficient here to call attention to the rapid development of the area of low mean pressure in the neighbourhood of Iceland, about the time of our usual autumnal storms, as contrasted with the increase of the northern pressures in spring.

"One inference deserves mention here. Since the winds, in respect of one component of their motion, flow across, and not directly along, the lines of equal pressure, it is obvious that in order that the pressure areas should be maintained the circulation of the atmosphere must be vertical as well as horizontal ; that is to say, whatever air passes over the earth's surface from the areas of high pressure to those of low must be restored in upper currents from the latter to the former. Observations on the movements of the higher clouds bear out the truth of this statement. The return currents over the Trade Winds are frequently noticed ; and in our own latitudes it is observed that when you stand with your back to the wind the movement of the higher clouds is most commonly a little from your left hand to your right."

B.—WEATHER AND THE LAW OF STORMS.

WINDS AND STORMS OF THE TEMPERATE ZONES.

Winds of the Atlantic Ocean, which are typical of those of other Seas.

The Atlantic Ocean will supply types of the winds usually met with in other seas. From Plates III. and IV., it will be seen that an area of high pressure occurs in the North Atlantic between the parallels of 30° and 40° North; according to Buys Ballot's law the wind draws round it, being Northerly on its eastern, Easterly on its southern, Southerly on its western, and Westerly on its northern side. The wind-arrows on Figs. 6 and 7, pp. 166 and 169, indicate such a circulation of the air.

A seaman, therefore, outward bound from England, say, to the Cape of Good Hope, passes from the north-east to the east and south-east side of an area of high pressure lying to the westward of him, and as he approaches the coast of Portugal, the wind very generally comes from North-west, gradually shifting to North and North-east as he proceeds to the southward.

On the other hand, when a homeward-bound ship approaches the northern verge of the N.E. Trades, she finds that the wind draws to the eastward, with a rising barometer. As the area of highest pressure is reached the barometer ceases to rise, and the wind dies away. These are the dreaded "calms," or, as Maury calls them, "Doldrums of Cancer." There being no difference of pressure there is no wind, and these calms coincide with a large area of high and even pressure, where a ship will experience little or no wind until she has crept to a part of the sea where the pressure commences to decrease.

If, as occasionally happens, it is found that the N.E. Trade gradually turns into a S.E., S., and S.W. wind, it will be understood from what has already been said, that a vessel experiencing these changes has passed round the S.W., W., and N.W. sides of this area of high pressure, thereby avoiding the region of calms altogether.

There is a similar area of high pressure in the South Atlantic, with a corresponding circulation of the wind round it.

The homeward-bound ship, after rounding the Cape of Good Hope, is at the polar edge of the S.E. Trade on the eastern side of the South Atlantic, just as the outward-bound ship is at the polar edge of the N.E. Trade when off the coast of Portugal (*see* Fig. 6, p. 166), and the first wind she experiences is from S.W., changing to S. and S.E. as she proceeds to the northward, which (according to Buys Ballot's law, when applied to the southern hemisphere), shows that she has passed along the S.E., E., and N.E. sides of an area of high pressure.

Again, the outward-bound ship, as she draws towards the southern verge of the S.E. Trades on the western side of the South Atlantic, very generally experiences changes of wind to N.E., N., and N.W., which are the winds met with in the southern hemisphere on the N.W., W., and S.W. sides of an area of high pressure, corresponding to the winds already noticed as being experienced on the western side of the North Atlantic.

The study of Figs. 6 and 7 will show how areas of high barometrical pressure occur in many other parts of the ocean, similar to those of the Atlantic, and how corresponding winds circulate round them.

Cyclonic Gales of the Temperate Zones.

The great currents of the atmosphere, which give rise to the prevailing winds, are thus seen to be regulated by the positions of the permanent areas of high and low pressure, and in these currents, subsidiary areas of low pressure make their appearance, and are carried along with them. These travelling areas frequently give rise to gales, to the characteristics of which attention will be next given.

In the Temperate Zone of the North Atlantic these gales, which almost invariably travel to the eastward with the prevailing atmospheric current from the west, generally commence at S. and end at W. or N.W., with little or no East wind. The probable reason of this is that the areas of low pressure to which they are related have steep gradients only on their E., S.E., S., and S.W. sides, there being little or no difference of pressure between their centre and the more permanent depression which lies to the north of them.

The ordinary gales of high southern latitudes are similar in character to those of the northern hemisphere. They also accompany areas of low pressure travelling to the eastward, and considering that the wind blowing from the equatorial regions here is North instead of South, the winds are similar, for they commence at N., and end at W. or S.W., with little or no Easterly wind, probably because the pressure to the southward is much lower than that to the northward of the district in which they occur.

Whenever areas of both high and low pressure are liable to pass over any region it is obvious that the direction of the wind, taken alone, will not be a sufficient guide as to what weather is to be expected. If, for instance, in the northern hemisphere an area of *high* pressure be passing off to the eastward, the wind in the rear of it will veer through S.E. to S. Although this direction of the wind shows that the barometrical readings are lower to the westward than to the eastward, it is not by any means an indication that a serious diminution of pressure, which may possibly bring a storm with it, is approaching, although the wind in front of such a depression would be Southerly also. It is therefore necessary in such circumstances to look for other signs, besides the mere direction of the wind, when striving to foresee what is coming.

If we could tell the shape of an area of low pressure, its gradients, or the difference of pressure in a given distance on all sides, the rate at which it is increasing or decreasing in intensity, the direction in which it is moving, and its speed, we could calculate very correctly what sort of weather would be experienced during its passage at a land station or on board a ship at sea. It is upon observations of this description, made simultaneously at many places, that forecasts of weather are based; but the seaman can have no certain knowledge of these data, and has to make the best estimate he can, from the indications afforded by the wind and the barometer, as observed on board his own vessel alone.

Moreover, it must always be remembered that, although it is most commonly in connexion with considerable falls of the barometer that severe storms are experienced, yet the sudden large increase of pressure which not infrequently follows such depressions, or takes place in their proximity, is often accompanied by very violent winds. Caution, therefore, will always be requisite on the occasion of any sudden change of pressure, whether it be in the direction of increase or decrease.

The cyclonic storms of the Temperate Zones do not often present the phenomena of a central calm, with the winds blowing from nearly opposite directions on each side of it. There is, therefore, not so much risk of being taken aback as in tropical cyclones; but it is advisable for a captain to know on which tack it will be safest to lie-to if obliged to do so, and this will be the same as that for the cyclones of the respective hemispheres.

The most serious sudden shift of wind which is to be expected in these storms is that from South-west to North-west in the northern hemisphere, or from North-west to South-west in the southern. This is generally accompanied by heavy rain or hail, with thunder and lightning, while the temperature falls several degrees with the first blast of North-west or South-west wind, as the case may be, according to the hemisphere.

In considering how to act in such circumstances, there are two matters to which the seaman's attention should be directed, as they seriously affect the conclusions he should draw from his barometer readings.

The first is that on the one tack his barometer has a tendency to rise, on the other it has a tendency to fall. *The tack of rising barometer is the starboard in the northern, the port in the southern hemisphere.* This may be explained as follows:—

According to Buys Ballot's law, in the northern hemisphere (see Fig. 8), the lower barometer is on your left when

Fig. 8.

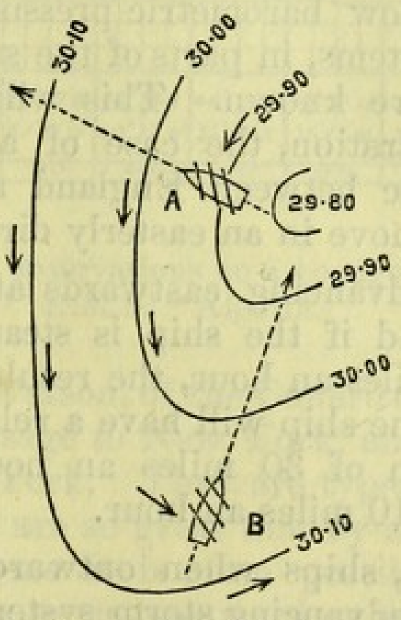


Diagram showing how the tack a ship is on affects the barometer readings taken on board.

A. Vessel on starboard tack.
B. Vessel on port tack.

your back is turned to the wind, and as when you are thus placed a ship on the starboard tack is advancing towards your right, she goes towards the higher barometer and recedes from the lower. In the southern hemisphere this is reversed, and the ship on the port tack advances towards the higher and leaves the lower barometer.

But this rule will only be strictly applicable so long as no change takes place in the barometric pressure, and it may so happen that an area of high pressure towards which the ship is going may be receding from her faster than she sails, and an area of lower pressure may be coming up astern and overtaking her ; or it may be that a lower pressure towards which the ship is sailing may be moving away faster than she sails. Still the influence of the tack must always be felt, and on the whole it may be said that in the northern hemisphere, a rising barometer on the starboard tack is not a sufficient indication of improving weather, and other signs should be looked for before trusting it. In all cases for the northern hemisphere a rising barometer on the port tack is a valuable indication of improving weather, while a falling barometer on the starboard tack is an important warning that the weather will probably be worse. This order is reversed in the southern hemisphere.

The second point to consider is the relation which the course and speed of the ship bear to the tracks and progress of the areas of low barometric pressure and their corresponding wind-systems, in parts of the sea where the general tracks of storms are known. This will be easily done by taking, as an illustration, the case of a steamer traversing the North Atlantic between England and America, where storms generally move in an easterly direction.

If a storm is advancing eastwards at the rate of, say, 20 miles an hour, and if the ship is steaming at the average rate of, say, 10 miles an hour, the result will be that, when going westward, the ship will have a relative rate of motion towards the storm of 30 miles an hour, but when going eastward, of only 10 miles an hour.

In other words, ships when outward bound across the Atlantic meet the advancing storm systems, which commonly travel from west to east, and when homeward bound run with them, consequently the rapidity with which the barometer falls or rises and the wind shifts is proportionately greater in the former case than in the latter.

Figs. 9 and 10 illustrate these cases. The arrows fly with the wind, and the curves give the height of the barometer at every sixth hour. They represent observations

Fig. 9.

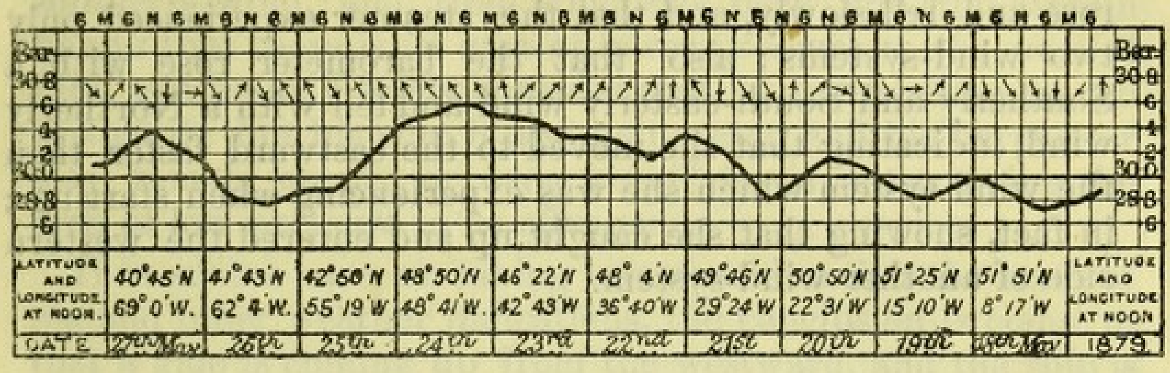


Diagram showing observations on a voyage to New York, R.M.S. "Algeria."

Fig. 10.

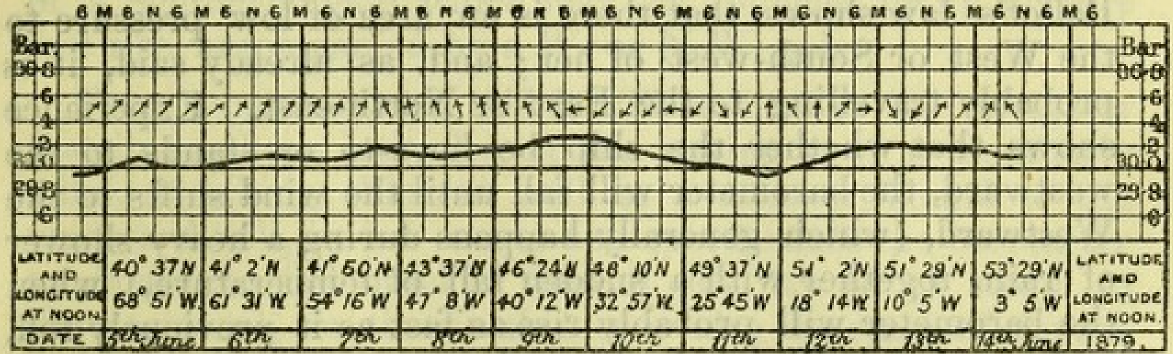


Diagram showing observations on a voyage from New York, R.M.S. "Algeria."

taken by Capt. W. Watson, of the Cunard steamer "Algeria," Fig. 9 during a passage *to* New York, and Fig. 10 during a passage *from* New York. They are types of the differences experienced, which are so great that by a comparison of her barometer curves alone it is often possible to tell whether a vessel was steering to the eastward or westward.

In Fig. 9, where the passage was to the westward, the dates run from right to left. It shows that the barometer fell and rose quickly, and that the steamer met with six alternations of high and low pressure, with their accompanying wind-systems. Also, that the fall of the barometer was generally accompanied by a South-easterly or Southerly wind, and that with a rise the wind drew more Westerly and Northerly.

In Fig. 10, p. 175, where the passage was to the eastward, the dates run from left to right. It shows that the barometer rose and fell slowly, and that the steamer experienced only two wind-systems; also that the barometer rose with a Southerly and South-easterly wind and fell with a Northerly wind, indicating that she moved to the eastward faster than the wind-system which she was experiencing when starting; in fact, showing that she caught up and entered the western side of another wind-system.

Gales of the North Temperate Zone.

The ordinary gales of the North Temperate Zone commence at S.E. or S. and end at W. or N.W. If a ship in these latitudes experiences a fresh S. or S.E. wind, with a relatively high temperature and falling barometer, Buys Ballot's law shows that there is an area of low pressure to the West or South-west of her; and, as already said, it is probably travelling to the East or North-east. Experience shows that whether the ship be hove-to or stands to the westward, the barometer will fall until the wind shifts to the Westward, (which generally happens during a heavy shower of rain, together with a sudden fall of temperature,) when the barometer will probably rise as fast as it previously fell, and a strong N.W. wind will set in.

The general belief that the speed at which the barometer falls is an indication of the strength of a Southerly gale in these latitudes requires some qualification. The fact that the force of wind depends on the amount of the barometrical gradient supports this idea; but we must also take into consideration the speed at which the area of low pressure is travelling. Suppose, for instance, that having a very steep gradient it stood still, as sometimes happens, the wind would blow furiously, although the barometer would cease falling unless the depression were becoming deeper. Then, again, suppose that a depression with a slight gradient were passing very quickly, the barometer would fall quickly, though the wind would not be strong.

It is also important to consider the ship's course and speed in connexion with the course and speed of the area of low pressure as illustrated by Figs. 9 and 10 (p. 175).

The following instance may be cited as an illustration of what frequently occurs to a sailing ship. A homeward-bound ship in about 45° N. and 30° W., falls in with a fresh southerly wind, and from what has been said, the captain knows that there is an area of lower pressure to the west of him, and he may safely consider that it is travelling to the eastward; but his ship is also going east, and his barometer may remain steady, or even rise if he is outstripping the area of low pressure in its advance.

If in such a case, on taking into consideration the state of sea and other weather indications, the conclusion is come to that a gale is coming up from the westward, and the ship is likely to have to reduce her speed, on closing with the land, or otherwise, it may be well to prepare for worse weather. In the event of heaving-to, the amount of fall in the barometer per hour is a good though not certain guide, as before said; a fall of ·04 to ·10 of an inch per hour is usually considered to be a serious indication of the approach of a Southerly gale, which may be followed by an equally fast rise, accompanied by a W. or N.W. gale.

From what has been said it will be clear to the navigator that in northern latitudes, at the setting in of a Southerly wind, a sailing ship, as well as a steamer, bound to the westward will, by her course and speed, cause the barometer on board to fall quicker than if she lay to or stood to the eastward, so that in this case also the state of the sea and other appearances ought to be considered, or her captain may be lead to anticipate worse weather than is really coming.

With a Southerly wind and falling barometer a ship bound to the westward might gain by running to the northward, with the object of causing the wind to back to the Eastward, but the type of gale in which this is possible resembles a cyclone, and does not represent the ordinary gales of these latitudes, which begin at S. and end at W. or N.W. Again, it might be possible for a ship, with the first of the Southerly wind which exists on the east side of the area of low pressure, to find less wind by running to the north, but as the extent in latitude of the cyclone area is not known, and as there is no certainty that she would get into more moderate weather by doing so, she might do herself more harm than good.

It seems, then, probable that a ship bound to the southward or westward must face one of these gales if she meets it. A weak ship, whose object is to stem the sea and get safely through, without considering progress, should lie-to on the starboard tack, as the wind generally shifts from S. to S.W., W., and N.W. This would of course be the best plan for any ship which found the gale too heavy for her. But a well-conditioned ship, bound to the westward, may keep on the port tack until the wind shifts to West with a rising barometer, and then tack to the south-westward. This plan would, of course, tend to bring her into the trough of the sea, and she would be more likely to be caught aback as the wind changed, but we are assuming that her captain will be prepared to meet these risks.

When the wind has shifted to N.W. the starboard tack takes her away from the centre of such a disturbance, though she may soon sail into the Southerly wind of the eastern side of another low-pressure area coming towards her. This would be a very common occurrence in winter.

Gales of the South Temperate Zone.

The prevailing gales of high southern latitudes resemble those of northern, and in describing them it is only requisite to remember that *there* north and south changes places. For instance, as a ship bound to Australia gets into 40° S., "The Roaring Forties," she experiences a series of gales which, commencing at N. or N.E., end at W. or S.W. Now with a Northerly wind in the southern hemisphere there is a lower pressure to the westward, and the way in which the wind usually changes proves that those areas of low pressure are also travelling to the eastward. Ships which keep a steady Westerly wind for days as they run to the eastward in high southern latitudes, are probably keeping company with one of these areas of low pressure, and if they had lain-to or commenced beating to the westward they also would have experienced many changes, just in the same manner as our steamers bound *to* America do, whilst those *from* America frequently keep a steady barometer and Westerly wind for days. This receives abundant confirmation from the frequency of the barometrical oscillations, and of changes of wind, experienced by ships bound to the westward, in rounding either the Cape of Good Hope or Cape Horn.

The best method for dealing with a heavy gale, or with a weak ship in an ordinary gale, is reversed for high southern latitudes: there the port is the "coming up" tack, which enables her to stem the sea, as the wind usually shifts from N. by N.W. to S.W., and the port tack with a S.W. wind takes her away from the region of low pressure to which the wind is related, though of course it may, and in the winter months most probably will, soon take her into the Northerly wind of the eastern side of another system of low pressure coming towards her.

For a ship beating to the westward, of course the best progress is made by keeping on the starboard tack with the wind N. and N.W. until it shifts to W. and S.W., when she ought to tack to the north-westward; but it will be seen that, as in the best method for making progress to the westward in high northern latitudes, the ship will be headed off, and get into the trough of the sea; she will also be more liable to be taken aback, as the wind changes, than if she were on the port tack.

From what has been said respecting the ordinary gales of high latitudes which have usually little or no Easterly wind, it must not be supposed that there are not some which have steep gradients on *all* sides, and consequently strong Easterly as well as Westerly winds. These are not nearly so common as the others, and must be treated like cyclones.

Tropical Storms.

Hurricanes, Typhoons, or Cyclones of Tropical Seas.

Of all atmospheric disturbances, of the approach of which the barometer can supply indications, and the dangers of which it may enable the seaman to avoid, by giving him warning of their proximity and position, the most serious are the revolving storms of the tropics.

These storms, which may all properly be termed cyclones, occur in the Atlantic, Pacific, and Indian Oceans; but are seldom experienced within 5° or 6° of the Equator, and have not been traced into very high latitudes. They appear to be most frequent and most severe in the West Indies, in the vicinity of Mauritius, in the Bay of Bengal, and in the China Seas; and in these seas they are most prevalent during the months following the summer solstice, from July to October in the northern hemisphere, and from December to April in the southern. In the Arabian Sea and in the Bay of Bengal cyclones occur most frequently from April to June, and in October, November, and the beginning of December.* Such storms are commonly known as hurricanes in the West Indies, cyclones in the Indian Ocean, and typhoons in the China Seas.

Cyclones have, in addition to a motion round a centre, an onward movement. The wind blows in a more or less circular course round the centre, and at the same time the storm field advances on a straight or curved track, sometimes with great velocity, and at times appearing to pause or scarcely to advance more than a few miles in an hour.

The space over which these storms have been known to extend varies from 20 or 30 miles to some hundreds of miles in diameter ; the wind blowing with an ever varying force, now lulling into little more than a strong breeze, and as the centre is approached often rising into a blast of irresistible fury.

It is an invariable characteristic of their revolution, that the gyration of the storm field takes place in one direction in each hemisphere ; in the northern in the opposite direction to the hands of a watch, and in the southern with the hands of a watch. The knowledge of this law is most important, as it not only supplies the seaman with direct means

* TABLE of recorded HURRICANES, CYCLONES, and TYPHOONS, in various parts of the World.

—	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
West Indies, 300 years - -	5	7	11	6	5	10	42	96	80	69	17	7	355
South Indian Ocean (39 years, 1809 to 1848) - -	9	13	10	8	4	—	—	—	1	1	4	3	53
Bombay. 25 years -	1	1	1	5	9	2	4	5	8	12	9	5	26
Bay of Bengal, 139 years - -	2	—	2	9	21	10	3	4	6	31	18	9	115
China Sea, 85 years -	5	1	5	5	11	10	22	40	58	35	16	6	214

of distinguishing these storms from gales in which the direction of the wind varies little if at all, but also reveals to him the approximate position of the centre or vortex, the region of greatest danger, where the fury of the wind is most extreme, the changes of its direction most sudden, and the sea most to be dreaded.

These features of cyclones will be understood to be in great measure due to the causes already explained, which lead to the formation of a system of winds revolving round a central area of low pressure produced by some local atmospheric disturbance, towards which the surrounding air is drawn in from all sides.

In the Atlantic and South Indian Ocean these storms commence to the eastward; for some days they travel along a path not exactly west, but inclining a point or two towards the pole of that hemisphere which they are crossing; and as they advance they seem more inclined to curve away from the equator. When they reach the 25th degree of latitude they generally curve still more, until they move to the N.E. in the northern hemisphere, and to the S.E. in the southern hemisphere. The Atlantic storms almost always wheel round to the northward in the Mexican Gulf, or in its vicinity, and follow the sea-board of North America.

Tracks of some of the most remarkable hurricanes, or cyclones, are shown by thick arrows in Figs. 6 and 7 (pages 166 and 169). For a more complete list of their seasons, *see* the foot-note to p. 180. The tracks are copied from the "Wind and Current Charts of the Pacific, Atlantic and Indian Oceans," published by the Admiralty.

The cyclones of the Bay of Bengal appear to originate near the Andaman Islands, those of the Arabian Sea near the Laccadives. These generally travel to the westward and north-westward, the former sometimes crossing the Indian peninsula, sometimes passing off over Bengal and curving back to the eastward. The typhoons of the China Seas commonly take a westerly or north-westerly course.

The rate of movement of these storms, though variable, may be averaged at 300 miles a day in the West Indies, in the Arabian Sea, in the Bay of Bengal, and in the China Sea, 200 miles a day; whilst in the southern Indian Ocean their rate vary from 50 to 200 miles a day.

The indications of the approach of a revolving storm are the usual ugly and threatening appearance of the weather which forebodes most storms, and the increasing number and severity of the gusts with the rising of the wind.

These signs are in some cases preceded by a long heavy swell and confused sea, which comes from the direction in which the storm is approaching, and travels more rapidly than the storm centre.

The best and surest of all warnings, however, will be found in the barometer. In every case there is great barometric disturbance, the barometer at the centres of some of the storms standing fully two inches lower than outside the storm field. Accordingly if the barometer falls rapidly; or even if the regularity of its diurnal variation (*see* page 156) be interrupted, danger may be apprehended.

No positive rule can be given as to the amount of depression to be expected. There are numerous records of the barometer falling below 28 inches in the West Indies, and the suddenness of the fall may be realised by an authenticated record of a fall of 1·7 inches in one hour and ten minutes. Meldrum says that in the severest cyclones of the southern Indian Ocean the barometer falls below 28 inches, and in the Bay of Bengal a pressure of 27·58 inches is said to have been observed. The average barometric gradient near the vortex of the most violent of these storms is said to be rather more than 1 inch in 50 nautical miles.

As the centre or vortex of the storm is approached, unless the vessel be on the line of its advance, the more rapid become the changes of wind, till at length, instead of veering gradually, as is the case on first entering the storm field, the wind flies round at once to the opposite point, the sea meanwhile breaking in mountainous and confused heaps. There are many instances on record of the wind suddenly falling in the vortex, and the clouds dispersing for a short interval, though soon the wind blows again with renewed fury. Few vessels have ever passed through the vortex without losing either masts or rudder, or meeting with some worse disaster, and therefore, at whatever cost, the central part of the storm-field should be avoided.

The first care of the commander of a vessel caught in a cyclone will be to find how the centre bears from him. In the northern hemisphere let him, facing the wind, take eight points to the right of the direction of the wind, and that will be the *approximate* bearing of the centre; in the southern hemisphere take eight points to the left. Thus in the northern hemisphere with the wind from N.E., the centre will bear S.E., and in the southern hemisphere with the wind from N.W., the centre will bear S.W.

For the sake of simplicity, the motion of the wind in a cyclone, will be treated as approximately circular. But this is not strictly the case, for there is evidence to show that frequently in some parts of the storm-field there is more or less indraft. At a considerable distance from the centre, and before the barometer shall have fallen much below its normal value, the centre may bear 10 or 12 points from the direction of the wind (reckoned to the right or left according to the hemisphere) ; but after *the barometer has fallen five or six tenths of an inch* it is probable that the wind then blowing forms part of the central storm-circle and the bearing of the centre may be taken as eight points from the direction of the wind.

It was said that the commander's first care will be to know how the centre bears. His next care will be to know on which side of the storm's path his vessel is situated, and the direction in which the storm is moving. In the northern hemisphere if she be situated on the right-hand side or semicircle of a storm travelling to the westward—looking in the direction to which the storm is travelling—the wind will shift from N.E. to E., S.E., S., &c., or with the hands of a watch; on the left-hand side the wind will shift from N. to N.W., W., &c., or against the hands of a watch.

Similarly, in the southern hemisphere, if the vessel be in the right-hand semicircle of a storm travelling to the westward—looking in the direction to which the storm is moving—the wind will shift from S. to S.W., W., &c., or with the hands of a watch ; in the left-hand semicircle it will shift from S.E. to E., N.E., N., &c., or against the hands of a watch.

In speaking of the shift of wind such a shift is meant as would be observed on a vessel hove-to ; for if the vessel be moving faster than the storm, and in the same direction, the shift may be in the opposite direction to what has been stated.

If while the vessel is hove-to the wind be found to remain in the same direction, increase in violence, and be accompanied by a falling barometer, it is probable she lies in the path of the advancing storm.

The wind in front of the storm-field is, from the nature of the case, directed across the path of the centre; blowing towards the path on one side, and away from it on the other. Consequently, if we suppose the cyclone to be bisected by a line representing its path, a little consideration will show that in the semicircle on one side of the path, a ship running before the wind may probably be brought to cross the path of the storm in front of its centre, and therefore under circumstances of great danger; in the semicircle on the other side of the path a ship running before the wind will probably cross the path in rear of the centre. The former of these semicircles is called the "dangerous" semicircle.

An inspection of the diagram (Fig 11) will best explain these and other important particulars. The circles

Fig. 11.

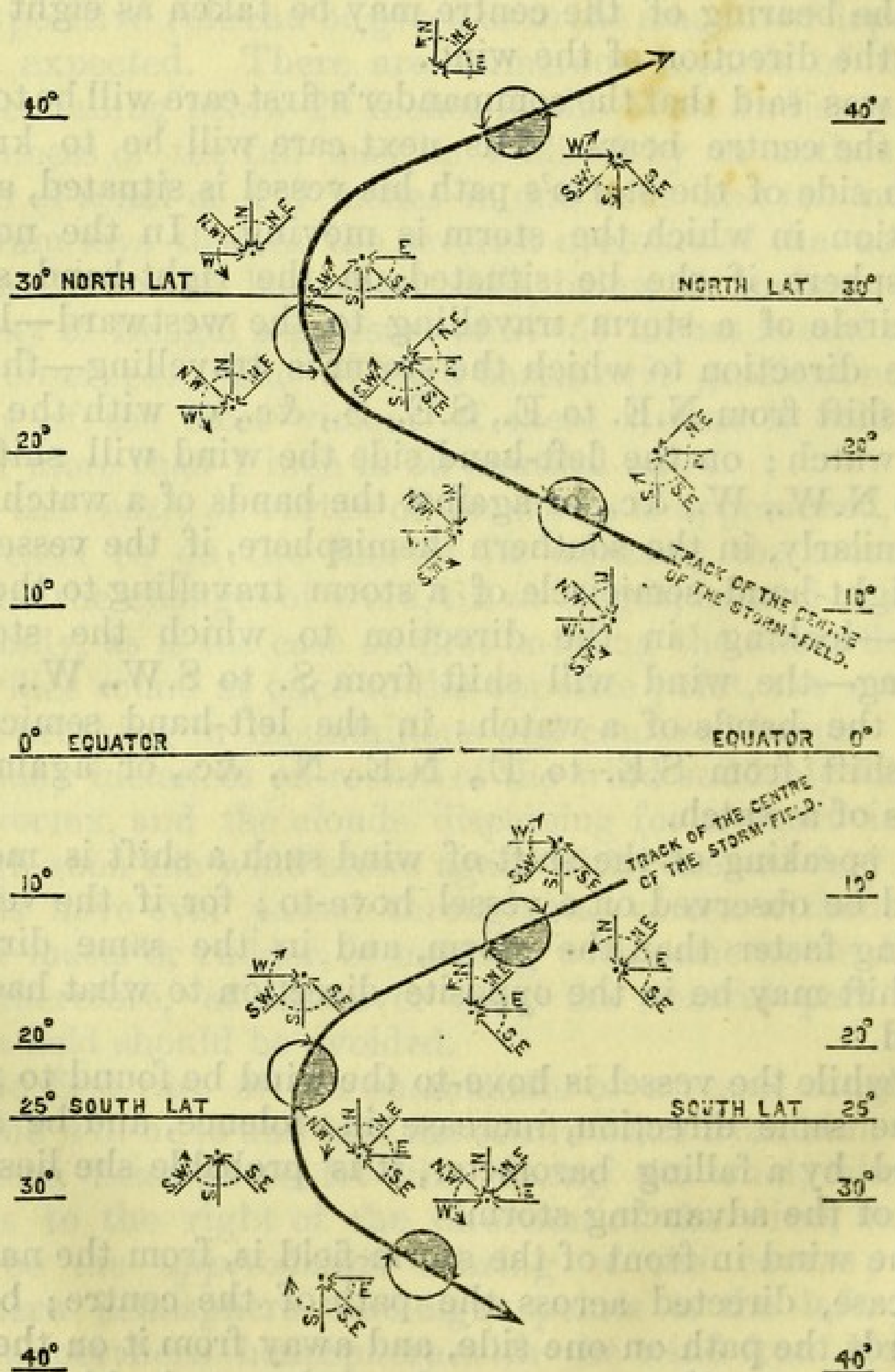


Diagram showing average cyclone tracks in both hemispheres.

represent the storm field; the arrow heads show the direction of its revolution in the northern hemisphere against the hands of a watch, in the southern hemisphere with the hands of a watch.

The shaded portions of the circles are the dangerous semicircles. The groups of arrows with the embracing dotted arrows, on either side of the track of the storm, indicate the directions in which the winds would be observed there to blow and shift by a vessel hove-to.

When looking in the direction in which the storm is travelling the dangerous semicircle is always on your right hand in the northern hemisphere, on your left hand in the southern hemisphere; also, in both hemispheres, to a ship lying-to. The semicircle with winds shifting with watch hands is the dangerous semicircle in the northern hemisphere; the semicircle with winds shifting against watch hands is the dangerous semicircle in the southern hemisphere.

The recurvature of the path always takes place towards the side on which the dangerous semicircle is situated, *i.e.*, to the right in the northern, to the left in the southern hemisphere. Hence in the northern hemisphere, so long as the vortex is travelling to the west, the winds in front of the advancing centre are North-easterly; as the vortex turns to the north the winds in front are Easterly; and after it has turned to the eastward the winds in front are South-easterly. A similar sequence will arise in the southern hemisphere, but in the opposite order, the winds in front of the vortex beginning with South-east and ending with North-east when the vortex has turned to the eastward.

We derive, then, the following rules to find *the most dangerous wind*, supposing always that the track of the storm is such as is shown in Fig. 11 (p. 182), recurving in about lat 30° N. or lat. 26° S.:—

Northern Hemisphere.		Southern Hemisphere.	
Between the Equator and 30° N. lat. - -	N.E.	Between the Equator and 26° S. lat. - -	S.E.
About 30° N. lat. - -	E.	About 26° S. lat. - -	E.
Northward of 30° N. lat.	S.E.	Southward of 26° S. lat.	N.E.

These winds are most dangerous, because in each case if the wind continues steady from that point and the barometer continues to fall rapidly the ship must be on the path of the storm and directly in front of it, so that she is in a position of great peril.

It is difficult to estimate the distance of the centre of the vortex from a vessel. This arises partly from uncertainty as to the relation between the bearing of the centre and the direction of the wind (p. 183), but mainly from there being no means of knowing whether the storm be of large or small dimensions. If the barometer falls slowly, and the weather only gradually gets worse, it is reasonable to suppose that the centre is distant ; and conversely with a rapidly falling barometer and increasing bad weather the centre may be supposed to be approaching dangerously near.

Practical Rules for Seamen in Tropical Cyclones.

When in the region, and at the season of revolving storms, be on the watch for the premonitory signs. *Constantly and carefully observe and record the barometer.*

When there are indications of a cyclone being near, lie-to, and carefully observe and record the changes of the barometer and wind, so as to find the bearing of the centre, and ascertain by the shifting of the wind in which semicircle the vessel is situated.

The simplest mode of ascertaining whether the ship is on the correct tack or not is to see whether she is coming up to the wind or falling off from it. If the wind is heading her and she is falling off she is on the wrong tack. Much will depend upon lying-to in time.

When, after careful observation, there is reason to believe that the centre of a cyclone is approaching, the following rules should be followed in determining whether to remain lying-to or not, and the tack on which to remain lying-to :—

Northern hemisphere.—If in the right-hand semicircle, lie-to on the starboard tack. If in the left-hand semicircle, run, keeping the wind, if possible, on the starboard quarter ; and when the barometer rises, if necessary to keep the ship from going too far from her proper course, lie-to on the port tack.

Southern hemisphere.—If in the right-hand semicircle, run, keeping the wind, if possible, on the port quarter ; and when the barometer rises, if necessary to keep the ship from going too far from her proper course, lie-to on the starboard tack. If in the left-hand semicircle, lie-to on the port tack.

Both hemispheres.—When the ship lies in the direct line of advance of the storm—which position is, as previously observed, most dangerous — run. And in all cases act so as to increase as soon as possible the distance from the centre; bearing in mind that the whole storm field is advancing.

Lying-to in both hemispheres.—If the ship be in the right-hand semicircle, lie-to on the starboard tack. If in the left-hand semicircle, lie-to on the port tack; these being the tacks on which the ship will "come up" as the wind shifts.

In receding from the centre of a cyclone, the barometer will rise, and the wind and sea subside.

It should be remarked that in some cases vessels may, if the storm be travelling slowly, sail from the dangerous semicircle across the front of the storm, and thus out of its influence. But as the rate at which the storm is travelling is quite uncertain, this is a hazardous proceeding, and the seaman should hesitate and carefully consider all the circumstances of the case, particularly observing the rate at which the barometer is falling, before he attempts to cross.

Cyclones of the South Indian Ocean.—The researches of Dr. Meldrum, Director of the Government Observatory at Mauritius have shown that, in the South Indian Ocean, a vessel approaching a cyclone on its southern side almost always encounters a strong Trade wind, which freshens to a gale. It is difficult to tell when the Trade forms part of the storm *circle*; consequently the bearing of the centre can seldom, in this position, be inferred from the direction of the wind.

It is therefore recommended under such circumstances to lie-to and watch the wind and barometer; when the wind has shifted decidedly to the East or South the passage of the centre with respect to the vessel's position may be approximately inferred: and when the barometer *has fallen six tenths of an inch* from its height at the commencement of the storm, the bearing of the centre may be taken as nearly at right-angles to the direction of the wind.

If the wind shift from S.E. decidedly towards the South, run to the north-west. Or, if the wind remain steady at S.E., increase in force, the barometer still falling, it is probable the storm is advancing directly towards the vessel; in such case, the most dangerous of all, run to the north-west.

It is also stated that in the cyclones of the South Indian Ocean, North-easterly and Easterly winds often, if not always, blow towards the centre. Such being the case, it is better to make as much easting as possible.

It might easily be shown, the same writer remarks, that all the homeward-bound vessels that put into Mauritius for repairs do so in consequence of damage sustained in a cyclone which they entered on its northern side. There is a strong temptation to such vessels to run on with a favourable breeze; but a freshening Northerly or North-easterly wind, with a falling barometer and threatening appearance of the weather, should warn them to lie-to in time.

APPENDIX.

TABLE of CORRECTION to be applied to BAROMETERS with *Brass Scales*, extending from the CISTERN to the top of the MERCURIAL COLUMN, to reduce the Observation to 32° Fahrenheit.

Temp.	INCHES.															Temp.
	24·0	24·5	25·0	25·5	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	
	CORRECTION TO BE ADDED.															
°	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	°
0	·061	·063	·064	·065	·067	·068	·069	·071	·072	·073	·074	·076	·077	·078	·080	0
1	·059	·061	·062	·063	·064	·065	·067	·068	·069	·071	·072	·073	·074	·076	·077	1
2	·057	·058	·060	·061	·062	·063	·064	·066	·067	·068	·069	·070	·072	·073	·074	2
3	·055	·056	·057	·059	·060	·061	·062	·063	·064	·065	·067	·068	·069	·070	·071	3
4	·053	·054	·055	·056	·057	·058	·059	·061	·062	·063	·064	·065	·066	·067	·068	4
5	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062	·063	·065	·066	5
6	·049	·050	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062	·063	6
7	·046	·047	·048	·049	·050	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	7
8	·044	·045	·046	·046	·048	·049	·050	·051	·052	·053	·054	·054	·055	·056	·057	8
9	·042	·043	·044	045	·046	·046	·047	·048	·049	·050	·051	·052	·053	·054	·054	9
10	·040	·041	·042	·042	·043	·044	·045	·046	·047	·047	·048	·049	·050	·051	·052	10

Table of Correction, &c.—*continued.*

Temp.	INCHES.															Temp.
	24·0	24·5	25·0	25·5	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	
	CORRECTION TO BE ADDED.															
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
11	·038	·039	·039	·040	·041	·042	·042	·043	·044	·045	·046	·046	·047	·048	·049	11°
12	·036	·036	·037	·038	·039	·039	·040	·041	·042	·042	·043	·044	·045	·045	·046	12
13	·033	·034	·035	·036	·036	·037	·038	·038	·039	·040	·040	·041	·042	·043	·043	13
14	·031	·032	·033	·033	·034	·035	·035	·036	·037	·037	·038	·038	·039	·040	·040	14
15	·029	·030	·030	·031	·032	·032	·033	·033	·034	·035	·035	·036	·036	·037	·038	15
16	·027	·028	·028	·029	·029	·030	·030	·031	·032	·032	·033	·033	·034	·034	·035	16
17	·025	·025	·026	·026	·027	·027	·028	·028	·029	·030	·030	·031	·031	·032	·032	17
18	·023	·023	·024	·024	·025	·025	·025	·026	·026	·027	·027	·028	·028	·029	·029	18
19	·021	·021	·021	·022	·022	·023	·023	·024	·024	·024	·025	·025	·026	·026	·027	19
20	·018	·019	·019	·020	·020	·020	·021	·021	·021	·022	·022	·023	·023	·023	·024	20
21	·016	·017	·017	·017	·018	·018	·018	·019	·019	·019	·020	·020	·020	·021	·021	21
22	·014	·014	·015	·015	·015	·016	·016	·016	·016	·017	·017	·017	·018	·018	·018	22

Table of Correction, &c.—*continued*.

Temp.	INCHES.															Temp.
	24·0	24·5	25·0	25·5	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	
	CORRECTION TO BE ADDED.															
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
23°	·012	·012	·012	·013	·013	·013	·013	·014	·014	·014	·014	·015	·015	·015	·015	23°
24	·010	·010	·010	·010	·011	·011	·011	·011	·011	·012	·012	·012	·312	·012	·013	24
25	·008	·008	·008	·008	·008	·008	·009	·009	·009	·009	·009	·009	·009	·010	·010	25
26	·005	·006	·006	·006	·006	·006	·006	·006	·006	·006	·007	·007	·007	·007	·007	26
27	·003	·003	·003	·003	·004	·004	·004	·004	·004	·004	·004	·004	·004	·004	·004	27
28	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	28
	CORRECTION TO BE SUBTRACTED.															
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
29	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	29
30	·003	·003	·003	·004	·004	·004	·004	·004	·004	·004	·004	·004	·004	·004	·004	30
31	·005	·006	·006	·006	·006	·006	·006	·006	·006	·006	·007	·007	·007	·007	·007	31
32	·008	·008	·008	·008	·008	·008	·008	·009	·009	·009	·009	·009	·009	·010	·010	32

Table of Correction, &c.—*continued.*

Temp.	24·0	24·5	25·0	25·5	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	Temp.
	INCHES.															
	CORRECTION TO BE SUBTRACTED.															
33°	— ·010	— ·010	— ·010	— ·010	— ·011	— ·011	— ·011	— ·011	— ·011	— ·012	— ·012	— ·012	— ·012	— ·012	— ·012	33°
34	·012	·012	·012	·013	·013	·013	·013	·014	·014	·014	·014	·015	·015	·015	·015	34
35	·014	·014	·015	·015	·015	·015	·016	·016	·016	·017	·017	·017	·018	·018	·018	35
36	·016	·017	·017	·017	·017	·018	·018	·019	·019	·019	·020	·020	·020	·021	·021	36
37	·018	·019	·019	·019	·020	·020	·021	·021	·021	·022	·022	·022	·023	·023	·024	37
38	·020	·021	·021	·022	·022	·023	·023	·023	·024	·024	·025	·025	·026	·026	·026	38
39	·023	·023	·024	·024	·024	·025	·025	·026	·026	·027	·027	·028	·028	·029	·029	39
40	·025	·025	·026	·026	·027	·027	·028	·028	·029	·029	·030	·030	·031	·031	·032	40
41	·027	·027	·028	·029	·029	·030	·030	·031	·031	·032	·033	·033	·034	·034	·035	41
42	·029	·030	·030	·031	·031	·032	·033	·033	·034	·034	·035	·036	·036	·037	·037	42
43	·031	·032	·032	·033	·034	·034	·035	·036	·036	·037	·038	·038	·039	·040	·040	43
44	·033	·034	·035	·035	·036	·037	·037	·038	·039	·040	·040	·041	·042	·042	·043	44

Table of Correction, &c.—*continued.*

Temp.	INCHES.															Temp.
	24·0	24·5	25·0	26·5	26·0	25·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	
	CORRECTION TO BE SUBTRACTED.															
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
45°	·035	·036	·037	·038	·038	·039	·040	·041	·041	·042	·043	·044	·044	·045	·046	45°
46	·038	·038	·039	·040	·041	·042	·042	·043	·044	·045	·045	·046	·047	·048	·049	46
47	·040	·041	·041	·042	·043	·044	·045	·046	·046	·047	·048	·049	·050	·051	·051	47
48	·042	·043	·044	·045	·045	·046	·047	·048	·049	·050	·051	·052	·052	·053	·054	48
49	·044	·045	·046	·047	·048	·049	·050	·050	·051	·052	·053	·054	·055	·056	·057	49
50	·046	·047	·048	·049	·050	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	50
51	·048	·049	·050	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062	51
52	·050	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062	·063	·064	·065	52
53	·053	·054	·055	·056	·057	·058	·059	·060	·061	·063	·064	·065	·066	·067	·068	53
54	·055	·056	·057	·058	·059	·060	·062	·063	·064	·065	·066	·067	·068	·070	·071	54
55	·057	·058	·059	·060	·062	·063	·064	·065	·066	·068	·069	·070	·071	·072	·073	55
56	·059	·060	·061	·063	·064	·065	·066	·068	·069	·070	·071	·073	·074	·075	·076	56

Table of Correction, &c.—*continued.*

Temp.	INCHES.															Temp.
	24·0	24·5	25·0	25·5	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	
	CORRECTION TO BE SUBTRACTED.															
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
57°	·061	·062	·064	·065	·066	·068	·069	·070	·071	·073	·074	·075	·076	·078	·079	57°
58	·063	·065	·066	·067	·069	·070	·071	·073	·074	·075	·077	·078	·079	·081	·082	58
59	·065	·067	·068	·070	·071	·072	·074	·075	·076	·078	·079	·080	·082	·083	·085	59
60	·068	·069	·070	·072	·073	·075	·076	·077	·079	·080	·082	·083	·085	·086	·087	60
61	·070	·071	·073	·074	·075	·077	·078	·080	·081	·083	·084	·086	·087	·089	·090	61
62	·072	·073	·075	·076	·078	·079	·081	·082	·084	·085	·087	·088	·090	·091	·093	62
63	·074	·076	·077	·079	·080	·082	·083	·085	·086	·088	·089	·091	·093	·094	·096	63
64	·076	·078	·079	·081	·082	·084	·086	·087	·089	·090	·092	·094	·095	·097	·098	64
65	·078	·080	·082	·083	·085	·086	·088	·090	·091	·093	·095	·096	·098	·100	·101	65
66	·080	·082	·084	·085	·087	·089	·090	·092	·094	·096	·097	·099	·101	·102	·104	66
67	·083	·084	·086	·088	·089	·091	·093	·095	·096	·098	·100	·102	·103	·105	·107	67
68	·085	·086	·088	·090	·092	·094	·095	·097	·099	·101	·102	·104	·106	·108	·109	68

Table of Correction, &c.—*continued.*

Temp.	24·0	24·5	25·0	25·5	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	Temp.
	INCHES.															
	Correction to be Subtracted.															
69°	—·087	—·089	—·090	—·092	—·094	—·096	—·098	—·100	—·101	—·103	—·105	—·107	—·109	—·110	—·112	69°
70	·089	·091	·093	·095	·096	·098	·100	·102	·104	·106	·108	·109	·111	·113	·115	70
71	·091	·093	·095	·097	·099	·101	·102	·104	·106	·108	·110	·112	·114	·116	·118	71
72	·093	·095	·097	·099	·101	·103	·105	·107	·109	·111	·113	·115	·117	·119	·120	72
73	·095	·097	·099	·101	·103	·105	·107	·109	·111	·113	·115	·117	·119	·121	·123	73
74	·097	·099	·102	·104	·106	·108	·110	·112	·114	·116	·118	·120	·122	·124	·126	74
75	·100	·102	·104	·106	·108	·110	·112	·114	·116	·118	·120	·122	·125	·127	·129	75
76	·102	·104	·106	·108	·110	·112	·114	·117	·119	·121	·123	·125	·127	·129	·131	76
77	·104	·106	·108	·110	·112	·115	·117	·119	·121	·123	·126	·128	·130	·132	·134	77
78	·106	·108	·110	·113	·115	·117	·119	·122	·124	·126	·128	·130	·133	·135	·137	78
79	·108	·110	·113	·115	·117	·119	·122	·124	·126	·128	·131	·133	·135	·137	·140	79
80	·110	·113	·115	·117	·119	·122	·124	·126	·129	·131	·133	·136	·138	·140	·143	80

Table of Correction, &c.—*continued.*

Temp.	INCHES. 24·0	24·5	25·0	25·5	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	Temp.
	CORRECTION TO BE SUBTRACTED.															
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
81°	·112	·115	·117	·119	·122	·124	·126	·129	·131	·134	·136	·138	·141	·143	·145	81°
82	·114	·117	·119	·122	·124	·126	·129	·131	·134	·136	·138	·141	·143	·146	·148	82
83	·117	·119	·121	·124	·126	·129	·131	·134	·136	·139	·141	·143	·146	·148	·151	83
84	·119	·121	·124	·126	·129	·131	·134	·136	·139	·141	·144	·146	·149	·151	·154	84
85	·121	·123	·126	·128	·131	·133	·136	·139	·141	·144	·146	·149	·151	·154	·156	85
86	·123	·126	·128	·131	·133	·136	·138	·141	·144	·146	·149	·151	·154	·156	·159	86
87	·125	·128	·130	·133	·136	·138	·141	·143	·146	·149	·151	·154	·157	·159	·162	87
88	·127	·130	·133	·135	·138	·141	·143	·146	·149	·151	·154	·157	·159	·162	·165	88
89	·129	·132	·135	·137	·140	·143	·146	·148	·151	·154	·156	·159	·162	·165	·167	89
90	·131	·134	·137	·140	·142	·145	·148	·151	·153	·156	·159	·162	·164	·167	·170	90
91	·134	·136	·139	·142	·145	·148	·150	·153	·156	·159	·162	·165	·167	·170	·173	91
92	·136	·139	·141	·144	·147	·150	·153	·156	·158	·161	·164	·167	·170	·172	·175	92

Table of Correction, &c.—*continued*.

Temp.	INCHES. 24·0	24·5	25·0	25·5	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	Temp.
	CORRECTION TO BE SUBTRACTED.															
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
93	·138	·141	·144	·147	·149	·152	·155	·158	·161	·164	·167	·170	·172	·175	·178	93
94	·140	·143	·146	·149	·152	·155	·157	·161	·163	·166	·169	·172	·175	·177	·180	94
95	·142	·145	·148	·151	·154	·157	·160	·163	·166	·169	·172	·175	·178	·180	·183	95
96	·144	·147	·150	·153	·156	·159	·162	·165	·168	·171	·174	·178	·181	·183	·186	96
97	·146	·149	·152	·156	·159	·162	·165	·168	·171	·174	·177	·180	·183	·186	·189	97
98	·148	·152	·155	·158	·161	·164	·167	·170	·173	·176	·179	·183	·186	·188	·191	98
99	·151	·154	·157	·160	·163	·166	·169	·173	·176	·179	·182	·185	·188	·191	·194	99
100	·153	·156	·159	·162	·165	·169	·172	·175	·178	·181	·184	·188	·191	·194	·197	100

ARTICLE VI.

GEOGRAPHY.

BY THE LATE W. J. HAMILTON, ESQ., F.R.G.S.

Revised and extended by General Sir Henry Lefroy, R.A., F.R.S., F.R.G.S.

No intending traveller can at the present day hope to render services of any great value to geographical science unless he has acquired, or is determined to acquire, a competent knowledge of the use of some at least of the various instruments employed by the scientific traveller for the determination of latitude and longitude, the height of mountains, the distances travelled, and the like. He should make himself acquainted with the use of the Nautical Almanac and of the tables contained in books of navigation; with the stars; with the most concise forms for calculation, and with the instructions commonly given to observers and collectors in any department of natural history or science to which his inclinations or opportunities point. The Royal Geographical Society of London has expressly organised a course of instruction in all these subjects, and a traveller starting from any other point than London, especially if he proceeds by sea, can almost always find some one to teach him, and obtain opportunities of practice on the way.

The prismatic compass is not an instrument of precision, but it is indispensable, its great portability making up for many defects. But the traveller must remember that it is very much affected by the geological character of the country, as in volcanic or basaltic regions or in the neighbourhood of intrusive dykes. Every compass should be tested for the accuracy of the north point, and great attention must be paid to the *declination* or variation, which in some regions, and going in some directions, may change in amount sufficiently to throw out distant bearings perceptibly between two stations. In making observations to determine the declination, the best hours to chose are between 9 and

10 a.m. and 5 to 7 p.m., when it does not differ much from its mean value. Avoid the early morning, the deviations (eastward of the mean value) being greatest from 6 to 8 a.m.

The equipment of the traveller will necessarily vary with his resources and his means of conveyance. The following, from the invaluable "Hints to Travellers," edited for the Council of the Royal Geographical Society, by a committee of its members,* constitutes a sufficient outfit for almost any purpose:—

6-inch sextant, with a stand for lunars.
Portable 3-inch or box sextant.
Artificial horizon, with spare mercury.
Small binocular.
A keyless silver half-chronometer watch, if possible a second and a third.
Prismatic compass, the circle graduated from 0° to 360° on silver or aluminium.
Lanthorn.
Thermometers.
Aneroid or mercurial barometer.
Note-books, and plenty of them.
Stationery, drawing materials, drawing instruments, the best maps or charts of the region; maps in blank on a conical projection, with parallels of latitude and meridians ruled at 1° apart, and subdivided if the scale is large enough.† It will be convenient to have

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† Fifth edition, 1883, Stanford, London.

* To lay down the meridians and parallels for a map of any given region on a conical projection. Draw a straight line upon a long table. Place the paper so that a straight line drawn across it centrally shall coincide with this line, and pin it down. From the central point on the paper A, set off a distance AC, which is to be thus found: Add together log cot lat. of A (the middle latitude of the intended map), log length of 1° in inches on the scale intended, and log of 57·29587. Add them together and take out the natural number corresponding to their sum. This will be the length of the required radius AC for the central parallel of latitude. From A set off on the vertical line distances equal to 1° on the intended scale, and from the same centre sweep arcs through them also; lastly, set off distances on either side of A along the parallel, representing 1° of longitude, each being equal to 1° of latitude × cos lat. of A, and from C draw straight lines through these points. The skeleton map is now ready for the insertion of the figures, which will complete it. Any places falling within it whose latitude and longitude is accurately known should be inserted.

these blank sheets on several scales, viz., 2, 4, and 8 geographical miles to the inch, and the traveller must establish the geographical mile (2027·51 yards) in his mind as the unit of distance instead of the statute mile. Sheets for daily use should be mounted on cloth.

A few simple medicines must not be forgotten.

A more extended schedule will be found in "Hints to Travellers," without which work no one should deliberately set forth. No costliness or perfection of equipment, however, will compensate for want of knowledge, the absence of observant habits, an active mind, cheerfulness and self-control, energy to contend against fatigue, want of sleep, bad food, and the like; nor can it be superfluous to point out that if the head of an expedition is to retain a moral influence over his subordinates he must set an example in his own person of the moral conduct he desires them to imitate.

Among the most important of minor suggestions is the necessity of acquiring a habit of writing down in a note-book, either immediately or at the earliest opportunity, the observations made and the information obtained. Where numerical data are concerned, the whole value of the information is lost, unless the greatest accuracy is observed; and amidst the hurry of business or professional duties the memory is not always to be trusted. This habit cannot be carried too far. A thousand circumstances occur daily to a traveller in distant regions, which from repeated observation may appear insignificant to himself, but which, when brought home in the pages of his note-book, may be of the greatest importance to others, either as affording new information to the scientific inquirer, or as corroborating the observations of others, or as affording the means of judging between the conflicting testimonies of former travellers.

It is also important, in order to secure accuracy, that the observations should be noted down on the spot. It is dangerous to trust much to the memory on such subjects; and if the observation be worth making, it is essential that it be correct. And here it may not be inappropriate to hold out a caution against too hasty generalisation. A traveller is not justified in concluding that, because the portion of a district, or continent, or island which he has visited is wooded or rocky, or otherwise remarkable, the whole district may be set down as similarly formed. He must carefully confine himself to the description of what he has himself seen, or what he has learned on undoubted authority.

The constant use of the compass is of the greatest consequence. No one attempting to give geographical information should ever be without this instrument. The bearings of distant points, the direction of the course of a river, however they may be guessed at by the eye, can never be accurately laid down without the compass; and these observations should be immediately transferred to the note-book. This and his compass should on all occasions be the traveller's constant and inseparable companions. In using the former he should not forget that slight sketches of the country, and of the peculiar forms of hills, however hastily and roughly made, will often be of more assistance in recalling to his own mind, or in making intelligible to others, the features of the district he has visited, than long and elaborate descriptions. Let him then acquire the habit of never being without his note-book and pencil, and his pocket-compass, and the traveller who acquires the habit of using them with readiness will never have reason to regret the delay, or the slight inconvenience of such equipment.

Having made these few introductory remarks, equally applicable to most other branches of science, let us proceed to describe as briefly and succinctly as possible some of the principal features to which the attention and the inquiries of the young geographer should be chiefly directed. For this purpose the subject of the present memoir is divided into two heads, Physical and Political Geography. By physical geography we understand the external features of the globe, its continents and islands, with their mountains, lakes, and rivers; their deserts and forests, and fruitful places; their atmospheric circulation, and varied climates and productions. The ocean with its tides and currents, and its vast influence on the intercourse of nations. The zones and circles, meridians and parallels, partly natural, partly conventional, by which the surface is divided. The distribution of animal and vegetable life. The broad features of its mineral constitution, and in some degree of their development in past ages by the agency of geological changes. Whatever time and nature have done to make it a fit habitation for man. By political geography we understand those conditions dependent upon the human race. Man's appropriation of its surface, with all the demarcations and boundaries of races or nations. The course of trade;

the influence of different social customs, religions, and forms of government; the distribution of races and tribal distinctions; and their attributes; their industries, their cities, and monuments.

Such being the objects of the geographer, we will now proceed to consider the subject at somewhat greater length under the above-mentioned general headings.

1. *Physical Geography.*

The physical outlines and features of a country exercise a great influence on the character of its inhabitants as well as on their social, political, and commercial circumstances; the monotonous level of the great western plains of North America would, there can be little doubt, with a stationary population, produce in a few generations characteristics in it differing widely from those of the parent stock; and the same people transported to a mountainous region would again, in a few generations, develop qualities wanting before. Nor are these physical features always of a permanent character, they vary from age to age, by natural causes, such as the elevation or depression of lands, or by artificial causes, such as the clearing of forests or drainage of marshes, and other applications of industry. The observant traveller has, therefore, to weigh the physical surroundings of a people as tending to make them what they are, as well as to furnish a clue to what, under favourable influences, they may become. He should also seek for traces of physical changes as often helping to account for the decadence of races. Thus, in the Northern Sahara of Africa, in Turkistan, in Chinese Tartary, in the Polar basin, in the islands of the Pacific, and elsewhere, are to be found many evidences of social or political changes attending and in great measure due to the slow operation of physical changes, often by the intervention of changes of climate. To assign consequences to their true causes usually requires more close investigation than the passing traveller has time for; confident statements resting on slender foundations of observation are misleading, but all information gained and all accurate observation made, however imperfect, especially in an early stage of our knowledge of a country, may contain truth which time and subsequent research will find of value. The traveller, therefore, must not be deterred from doing his best, but only from stating in positive terms what he cannot be sure of. The aspect of a country depends very much upon the season of the year in which we see it, as the rainy season, the dry season, and the like, conclusions as to water-supply, fertility, pastoral value, navigation of rivers, are often drawn too hastily, forgetting this circumstance; and dates are omitted, where much depends upon them.

However distinct may be the special provinces of geography and geology it is, nevertheless, important for the traveller to have some passing acquaintance at least with the latter science, and to be able to distinguish the formations he may meet with. The external features of a country are very much influenced by the prevailing rock, as well as its fertility, native vegetation, dryness or wetness, and sanitary conditions generally; such acquaintance is the more necessary because it is often impossible for him to encumber himself with many rock specimens. Fossils, however, should be carefully looked for and brought away, a single shell may speak a volume to the expert. Remember that the weathering of some rocks bears so close a resemblance to the action of the sea that very erroneous inferences have been drawn. On the other hand, unmistakable evidence of the recent presence of the sea has been found inland in situations where tradition had preserved no memory of the fact.

We may now proceed to consider in greater detail the various external features which our field of travel may present.

1. *Form of country; how far composed of hills, valleys, or plains.*—The physical configuration of a country is the first object which engages the attention of a traveller on entering a new locality, and this may be described in general terms as flat, undulating, hilly, or mountainous; or the country may be divided into districts, to each of which one of the above terms of configuration may be applied. Each of these, however, is susceptible of great modification. A *flat* country may be a sandy desert, an alluvial plain, or a marshy, boggy tract; it may be well watered by rivers and streams, or arid and parched up; it may contain numerous lakes; it may be rocky, or barren, or wooded, or cultivated as arable or grass land; nor must the nature of its soil be omitted, whether sand, or marl, or clay, as the appearance of the country will often depend greatly on this circumstance. In some cases the plain may stand at a higher level than the surrounding country. Such elevated

plains are usually called uplands, or plateau. Other important characteristics of a plain are its form and extent, and the natural features by which it is bounded, whether by mountains, rivers, or seas; how many miles wide, and how many long; whether extending parallel with the coast, or running up between hills into the interior.

Many of these characteristics, it will be observed, belong equally to the other forms which constitute the character of the district. An *undulating* country may be barren, wooded, or cultivated; it may be arid, or watered by, streams, &c. The undulations may be abrupt, or only gently swelling, and this may be in a great measure owing to the nature of the subsoil, whether it consists of gravel, or sand, or rock. A country of this description is easily described, but a *hilly* country, on the other hand, is more complicated. Not only is the term vague and uncertain, but other features have to be considered in reference to it. Neither hills nor mountains can exist without valleys, respecting which also there are many points of interest deserving notice, which will be farther alluded to hereafter. Then, again, the hills themselves may be of various forms and characters: Do they extend in long parallel chains or ranges, or are they detached and isolated? Do these ranges of hills radiate or converge? Do they rise abruply or gradually from the low country? and how are they wooded? What do the rocks which constitute their nucleus and their flanks consist of? If possible, it is desirable to ascertain their height, which, in the absence of complicated instruments and barometers, may be obtained approximately by marking the exact point at which pure fresh water boils. It is a well-known fact that water, when heated in an open vessel, boils at a *lower* temperature in proportion as we ascend to a *higher* elevation above the level of the sea. It is hardly necessary to observe that the same accuracy cannot be obtained as with the barometer, but much may be done, especially in the tropics, by repeated observation with well-graduated thermometers. The apparatus for this purpose is very simple, and not liable to the same derangements as the barometer. On a limited scale, and where the means of comparison are at hand, the aneroid barometer may be used for this purpose with great advantage. Another simple method of measuring the height of mountains within sight of the sea is by taking the angle of depression of the sea-horizon, from which the height of the station may be calculated by a very simple formula.

2. *Mountain ranges.*—The most important features in the configuration of a country are the mountain ranges by which it is traversed. The exact point of distinction between a hill and a mountain is difficult to describe; in some cases it will be purely comparative, in others it will depend on the general character of the country, and in some it will be arbitrary. But in all cases it will be desirable to endeavour to ascertain the height of the principal points, the direction of the main ranges or chains, and whether they are parallel or not. The ridges may be *serrated* (jagged like a saw), or smooth and even, and the summits themselves will be either pointed, or dome-shaped, or flat. Is the mountain insulated or not? and if so, is it conical and sloping on all sides to the surrounding plains, or does it consist of a detached ridge? Many of these points will be found to depend on the geological formation of the country, and, as we have already observed, this branch of our subject is very closely connected with geological science. Ascertain also how far the mountain tops are covered with perpetual snow, how far down their sides snow lies during the whole or any considerable portion of the year, noting the exposure; and how far glaciers, if they exist, can be traced down the valleys, as well as the extent of lateral or terminal *moraines.* Is there any marked difference in the slope on the one side or on the other? Does vegetation abound more on one side than on the other? *e.g.*, in Asia Minor it has been observed that the mountain ranges which extend from east to west (and this is their principal direction) are covered on their northern flanks with luxuriant vegetation and magnificent forests; while the southern flanks, exposed to the rays of an almost tropical sun, are void of vegetation, barren, and generally rocky. This superior vegetation on the northern flanks is probably owing to the less rapid melting of the snows or drying up of rain there than on the southern flanks; consequently, south of the equator, the phenomena would be reversed. It may also sometimes be owing to the fogs and vapours driven up by the sea breezes, condensed on coming in contact with a colder body, or attracted and retained by the hills themselves. But here, again, we enter on the province of the botanist; and yet the geographer should inquire how far vegetation extends up the mountain side, and what are the changes which it undergoes. How far is it influenced by the change of soil, or the abundance or absence of springs? Nor is our information respecting a mountain chain com-

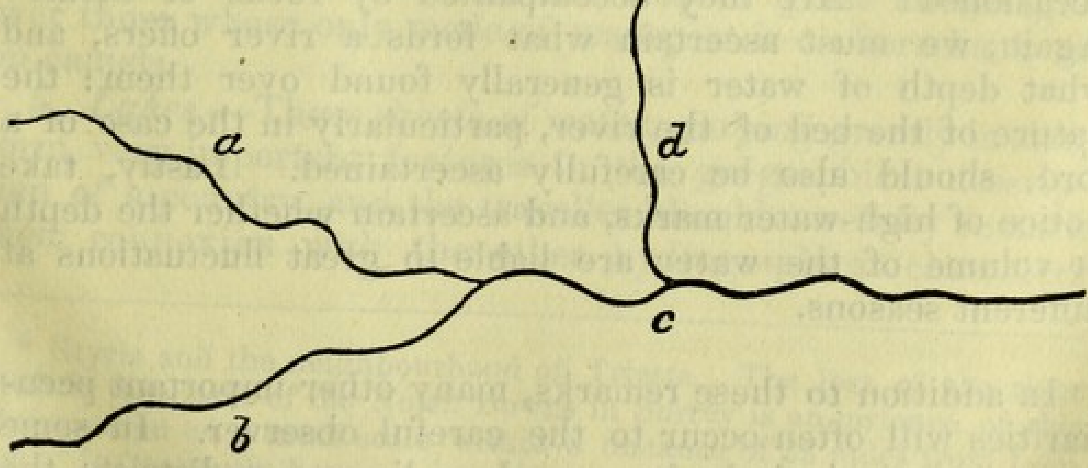
plete, unless we know the length to which it extends, and the breadth of country which it covers.

Valleys are a necessary complement to mountain masses, and there are many peculiarities connected with them well deserving observation. Are the sides precipitous or sloping? are they wide or narrow? well watered or arid? wooded or barren? Do the rocky sides correspond with each other in their salient and re-entering angles? How far do they extend into the bosom of the mountains? and how are the subordinate valleys connected with the principal one? There is also another peculiarity of valleys not to be lost sight of. There are some which convey to the traveller the impression that he is passing through a mountainous or hilly country, so steep, rugged, and lofty are the hills by which he is surrounded. It is only on reaching their summit that he becomes aware that the country through which he has been passing is an extensive plain, or table land, intersected by deep chasms and valleys, opened out by volcanic action, or cut through the soft soil by the constant efforts of the streams by which it is traversed; such valleys of excavation as these have been sometimes not unaptly called negative valleys.

3. *Rivers.*—Scarcely less important than the study of mountains is that of the effect of rivers in modifying the geographical configuration of a country. From their sources in the mountain recesses to their final disemboguing in the ocean, their course, their currents, and their shores afford an endless variety of remarks and observations. The depth and colour of the water, the rate at which it flows, the cataracts it forms with the rocks over which its waters are precipitated, the eddies and currents by which its course is marked, are all deserving of notice, as are also the rocks and shoals which obstruct its uniform progress, either interfering with its navigation, or, by projecting beyond its ordinary banks, throwing back the rushing torrent on the opposite shores, thus causing the gradual fall of the cliffs by undermining their precarious foundations. Nor in noting the size or extent of rivers should we neglect to state how far they are navigated or navigable, for what vessels, and by what means; whether the mouth is constantly free, or whether closed by a bar, and how much water there generally is over it, and how far up the tides usually extend. Some rivers, however, are not only closed by a bar, but, as in the case of Western Australia, are, during the periods

when the water is low, completely masked by the sand-hills or dunes which are blown up, forming a continuous bank with the hills which skirt the shores, and only when freshets of more than ordinary force come down are these sandy barriers overthrown and the rivers enabled to find an uninterrupted outlet. In other cases the effect of beaches thrown up by the constant set of currents in one direction is not so absolutely insurmountable, the streams are only partially deflected from their proper course, and, instead of flowing into the sea in a continued line, are compelled to run for some distance parallel to the coast, until the accumulated backwater has acquired sufficient power to overcome the diminished resistance of the sea-beach; this, however, more properly belongs to the consideration of the coast line.

But the description of a river will be imperfect unless we also state the number and character of the streams which fall into it. And here we have to consider the angle at which the rivers join each other, whether the direction of the main stream is altered or not by the junction, the relative size of two confluent streams, and which of them may be said to preserve its former course with the smallest deviation. On the true description of these details must depend the question as to which of two confluent rivers should be considered as the main or parent stream. Rivers are said to be confluent when both branches are nearly equally deflected from their former direction, and the united streams may be said to be the resultant of two contrary forces. An affluent is a stream which falls into another, called the recipient, without changing the direction of the latter, and entirely losing its own, as the Saguenay, where it joins the St. Lawrence.



a and *b* are confluent streams, *d* is an affluent falling into *c*, the recipient.

Here it may be remarked that there is great advantage in attending to the true and proper use of relative terms, rivers, streams, branches, torrents, rivulets, or brooks, the two latter being more or less synonymous, and a torrent being generally applied to a rapid mountain stream ; all these, more or less, bring down from the hills detritus, which is deposited at the mouths of the streams, or wherever other natural causes retard the rapid flow of water. In these cases deltas are formed which deserve examination, and are either fluviatile, lacustrine, or marine, according as the river empties itself into another river, a lake, or the sea. Thus the Saskatchewan forms a well-pronounced delta before it falls into Lake Winnipeg, and the Athabasca before falling into the lake of that name, each of these physical features being of considerable magnitude.

But there are other important characters which deserve attention in the description of a river; and chiefly the *name* is to be considered. Does it change during its course, and where and when? How far up from the mouth is the same name preserved? and is it the same on both banks? What is its origin, and by whom was it first given? Then we must inquire what islands are met with in its course? Where are they situated? Are they low? subject to inundation? marshy or rocky? or do they stand high above the level of the stream? Are they cultivated or not? What are their natural productions? By what animals are they inhabited? Again, is the river at all affected by rapids, or shoals, or cataracts, or beds of weeds? and what are the peculiar characteristics of these impediments to navigation? Does the tide flow in them, and how far up is it felt? Does the river present eddies or whirlpools, and how are they occasioned? Are they accompanied by rocks or shoals? Again, we must ascertain what fords a river offers, and what depth of water is generally found over them: the nature of the bed of the river, particularly in the case of a ford, should also be carefully ascertained. Lastly, take notice of high-water marks, and ascertain whether the depth or volume of the water are liable to great fluctuations at different seasons.

In addition to these remarks, many other important peculiarities will often occur to the careful observer. In some countries, particularly in secondary limestone districts, the rivers are remarkable for their subterranean courses.* Suddenly emerging in large volumes from the bases of lofty mountains, they flow across rich alluvial plains, and are then as suddenly lost in the cavities of another mountain, again to issue forth to the light of day in a distant region, after their subterranean courses. Nor should the traveller omit to notice, when crossing a river, the direction in which it flows as regards his own route, whether to the right or to the left. Instances are not wanting of distinguished travellers having been unable to connect their observations from not having sufficiently attended to this point.

4. *Springs.*—The phenomena connected with the outbursts of water from the surface of the earth are not only of the greatest interest, but a correct observation of them will be attended with much practical advantage. The traveller should state, approximately at least, their size or volume, the nature of the rock or soil out of which they rise, and whether the outflow is determined by the stratification; also whether they are pure or mineral, and what deposits are formed about the orifices through which they issue; how they are affected by different seasons; whether their flow of water is constant or intermittent, like the famous spring described by Pliny on the shores of the Lake of Como; whether they are of ordinary temperature or thermal; and, if the latter, it is necessary to ascertain the degree of heat by means of a thermometer: the touch alone is a very vague and uncertain test. Let him endeavour, also, when it can be done conveniently, to procure specimens, in closely sealed bottles, of the water of such springs as appear to possess mineral properties, or to contain salts in solution, for the purpose of analysis at home. Naval officers whose ships are at hand have in this respect great advantages over those whose only mode of transport is on horseback or on camels.

5. *Lakes.*—These sheets of water, varying greatly in size, form very important features in the geographical description of a country, and the traveller should carefully remark their connexion with the other hydrographical characters

* Styria and the neighbourhood of Trieste. The loss of the river Mole in the chalk of the North Downs in Surrey is an instance of this phenomenon on a small scale within a distance of 25 miles from London. It frequently happens in arid countries that water may still be found in the dry bed of rivers by sinking a few feet.

of the district. Whether they constitute the sources of rivers, or are their ultimate recipients; whether they are or are not connected with the ocean or other great seas; their levels with regard to the ocean, particularly when at a lower level, and their fluctuations of level; what rivers, if any, flow into or out of them, and whether they contain fresh water or salt.

The following remarks from a work by the late Col. J. J. Jackson, entitled "What to observe," are very appropriate:—

"With regard to lakes in general, the observations to be "made upon them may be comprehended under the following "heads:—Name; geographical and topographical situation; "height above the level of the sea, and as compared to other "neighbouring lakes; subterranean communication? form, "length, breadth, circumference, surface, and depth; the "nature of the bed and of the borders; the transparency, "colour, temperature, and quality of the water; the affluent "streams and springs? the outlets, the currents; the climate, "soil, and vegetation of the basins; the height and nature "of the surrounding hills when there are any; the pre- "vailing winds; the mean ratio of evaporation compared "with the quantity of water supplied, and any particular "phenomena; the navigation and fisheries of the lake; "its probable origin and its condition of permanence or "change by gradual increase of area or the reverse." This latter point, depending as it often does on the relative elevation or subsidence of the country, belongs also to the kindred science of geology.

Connected with the question of lakes are the scarcely less important features of lagoons and marshes, and smaller hollows or ponds; the extent of these should be ascertained, as well as whether they are connected with the sea or not, and what portions of them become dry and passable during the summer or at other periods of the year. Peat bogs, in many cases the remains of former lakes, may also be classed among these features, and their extent and depth and qualities should be ascertained, also whether animal or other remains are found in them.

6. *Line of coast, &c.*—This may be indeed said to be the peculiar province of the naval officer, and has been more fully treated of under the head of Hydrography; but as it forms one of the chief boundaries of those great geographical subdivisions, the details of which we have been here

alluding to, we must not omit a brief allusion to some of its most important features. And particularly, with regard to the actual line of coast itself, the traveller should remark the various headlands jutting out into the sea, as well as the deep bays and recesses running up into the land, and affording refuge from the dangers occasioned by the neighbouring headlands; and he should also notice all gaps and breaks in the continuity of hills or cliffs or mountain ranges, the oocurrence and nature of rivers and streams emptying themselves into the sea, the character and extent of their mouths, the nature of the detritus and alluvial matter brought down by them, and whether or not deltas are formed near their mouths. In another aspect he should inform us whether the coast is bold or flat, whether formed by cliffs or by sloping plains, and whether the rivers enter the sea by one or by numerous channels; and, if circumstances should enable him to do so, whether the coast is clear from danger, or whether sunken rocks and reefs render more than usual precaution necessary in approaching it; whether the sea deepens gradually or suddenly, and whether there are any extensive shoals or sand banks near the shore; and whether these appear to belong to the same formation as the adjacent mountains, or to have been carried thither by tides or currents, &c.

It is also desirable to obtain the fullest information respecting the changes which take place from time to time either in the line of coast or in shoals and sand-banks. The latter particulary when occurring near the mouths of large rivers, or of such as bring down much detritus from the interior, like the Mississippi or the Ganges, or even the Hermus in the Gulf of Smyrna, are very liable to shift, according to the prevailing winds and currents at different periods. The line of coast is also often subject to considerable changes in itself, in some places gradually extending out to sea, in others eating its way as gradually back inland, and it is remarkable that it is precisely the bold and lofty cliff which appears to offer such an insuperable barrier to the ocean waves, that crumbles away under their never-ceasing attacks, particularly when unprotected by a sloping talus of shingle; while the low, flat, marshy coast, offering no visible resistance to the advancing waves, and constantly covered by the muddy waters, is that which, owing to the deposits of mud and silt left by each succeeding tide, is gradually raised above its former level until it forms a real barrier to the waves, while it is slowly extended by the same process far beyond the spot which the sea formerly reached.

The nature of the shore also should be carefully ascertained, whether it consists generally of sand or mud, or rocks, either in the shape of reefs, or occurring as detached blocks; also whether the landing is easy or not on the beach, and whether this consists of sand or shingle. What bays or coves occur along the line of coast to serve as harbours of refuge? What is the nature of the anchorage? Are there any harbours along the coast? and how far have natural harbours been rendered more available and safe by the erection of breakwaters or piers?

7. *Oceans, their depths and currents; Islands, Rocks, Shoals, &c.*—With regard to the ocean itself, many of the objects of inquiry are the same as those which have been already mentioned with respect to lakes. Its depth and its colour, as well as other peculiarities, must be noted. The nature of the bottom should more especially be ascertained by soundings, whether consisting of mud or sand, or rock, or whatever other substances may be brought up from the bottom; when varied, the extent of each should be noticed. Not only is the important question of a good holding ground or anchorage connected with these facts, but the natural productions to be found in different seas depend chiefly on the character of the bottoms, and the algæ and other marine plants which grow on them. The direction and strength of currents must also be observed, as well as their prevalence or usual duration, where liable to change. Prevailing winds should also be noticed. The great improvements introduced into Atlantic navigation, dating from the publication of Lieutenant Maury's charts of the winds and currents of the North Atlantic, afford the best proof of the value of these observations. Tides also must not be forgotten; their amounts as well as their periods and duration are important. In some inland seas they appear to be rather influenced by meteorological than astronomical causes—to be dependent on the force of regular winds rather than on the attraction of the sun and moon. But other incidental peculiarities also require notice, such as storms and tempests, hurricanes and tornadoes, particularly when of frequent occurrence, or when recurring at regular intervals or at certain periods of the year. The permanent effects pro-

duced by them (if any) should also be registered, such as surfs, breakers, rollers, &c.

In the next place the maritime geographer should direct his attention to the islands, rocks, or shoals which occur in different seas; their extent and position should be carefully noted, as well as the depth of water round them; their harbours and facilities for landing; what supply of fresh water can be obtained; whether near the shore or not, or whether convenient for watering ships, &c.; what rivers or streams are met with, as well as their natural productions. Reefs and rocks, whether visible or sunken and constantly below the surface of the water, as well as shoals, should be examined and described, and the depth of water over them carefully ascertained.

In concluding this first division of the subject, we must also mention a few points connected with the physical features of the country, which, being of an accidental rather than of a normal character, did not easily find a place in the more obvious subdivisions of the subject. The traveller should pay particular attention to those phenomena in the physical structure of the country, which are sometimes called natural curiosities. Among the principal of these are grottoes, caves, and caverns; some of them are not only strikingly beautiful, but of great scientific interest. They are more usually met with in limestone districts than in any other; it is interesting to ascertain their size and extent, and the distance to which they have been traced. Are they traversed by subterranean streams; and if so, do these streams enter or escape by known channels or mouths, as is frequently the case in Istria and Carniola, and in the west of Ireland? Natural bridges present another instance of this kind of phenomena. How have they been formed, and what is the nature of the rock of which they consist? Are they stalactitic, or of a more compact nature? Mines are also to be noticed, although they come more directly under the head of geological observation. Volcanic phenomena and earthquakes are also deserving of notice. Springs of fresh water rising up in the sea are not of unusual occurrence, and any information respecting them is always desirable, such as the depth of water, and the effect of the fresh water on the surrounding ocean. Within the last few years several ancient sites on the coast of Greece have been satisfactorily identified by the discovery of these interesting springs. Any instances of that remarkable phenomenon observed near Argostoli in Cephalonia, where the sea water constantly flows inland, turning powerful mills, should also be carefully described. In short, it may be safely asserted that there is no single fact connected with the physical structure of the earth, falling under the notice of an intelligent and reflective observer, which may not be of value or importance either to himself or others, if he will only give himself the trouble of carefully noting it down on the spot, with as much accuracy and detail as circumstances will permit. With this view we must again urge what was stated at the beginning, and would add, in the words of Mr. Darwin, "Trust nothing to "the memory; for the memory becomes a fickle guardian "when one interesting object is succeeded by another still "more interesting."

II.—*Political Geography.*

We now proceed to notice some of the principal features to which attention should be directed on the subject of political or statistical geography. In many respects this branch of our subject approaches very closely to that either of statistics or of ethnology, to the consideration of which distinct and separate articles will be devoted. We will here, however, endeavour to confine ourselves to the definition already given, and to avoid those questions of detail which are more peculiarly the province of the statist or of the ethnologist. Nor can it be expected that the casual visitor should devote to the examination of documents and books the time that is necessary to arrive at any important results in reference to these questions, or to make much progress in the investigation of a subject, however important, when the whole value of the information depends on the extent and minute accuracy of its details; but yet there are many matters connected with man's social state which the traveller may easily elucidate by availing himself of the opportunities thrown in his way, and carefully preserving the information he obtains.

This branch of our subject may properly be divided into the following heads:—

1. Population; different races of inhabitants.
2. Language; words and vocabularies.
3. Government; ceremonies and forms.
4. Buildings; towns, villages, houses.

5. Agriculture ; implements of labour and peculiarities of soil.
6. Trade and commerce ; roads and other means of communication.

1. *Population.*—One of the most interesting inquiries on visiting new countries relates to the habits and customs of the people by whom they are inhabited. But the oral information first obtained by a stranger is almost invariably incorrect, and particularly so in barbarous countries and amongst an ignorant population, where truth and accuracy are equally disregarded. Various sources must be referred to before we can venture in such cases to place confidence in our information. Another and more interesting question, as regards the population of a country, is the nature and character of the races by which it is inhabited. We wish to know whether they all belong to one of the great races of the human family, or to a mixture of several; how far the national character has been affected or modified by such mixture; whether such changes took place long ago, or are of recent occurrence. In many instances casual intercourse with the natives will lead to information on this subject; local traditions will be found to have been preserved, which, after making due allowance for exaggeration and prejudice, will often give a clue to the details required. It is also worth noticing, when the population consists of various races, whether one race or nation is more confined to a rural or a town life than the other; whether there exists any feeling of hostility or jealousy between them; whether any particular trades or occupations are more exclusively practised or followed by one race than the other; whether one race is kept down or oppressed by the other, or whether they enjoy a state of comparative equality. In countries originally colonised by Europeans much light will be thrown on their present social state by reference to the original circumstances of such colonisation. Thus the enduring antagonism of Chili and Peru is greatly explained by the fact of the former having been chiefly peopled from the north, the latter from the south of Spain.

When the population of a country has up to a certain period consisted of one race, and a mixture has subsequently taken place, this change may have been occasioned in three different ways. The new race may have come down with force and violence on the original inhabitants, and having gained possession by right of conquest, may have constituted themselves the masters of the country; or, secondly, they may have been introduced as slaves in the first instance, captured in war or taken by stratagem by their more successful neighbours; or, thirdly, they may have come gradually, few at a time, with the free consent of the inhabitants, seeking to make their fortunes in a new country as settlers or as colonists. Any information on these points, where a mixture of races exists, will be interesting. Not only will the moral character of the united people be differently influenced, but even their political rights, their institutions, and form of government will have been greatly modified according to the different modes by which the union of the two people was effected.

In many cases, too, the traveller may have opportunities of making useful observations respecting the general character and disposition of a people. Are they of a warlike or a peaceful disposition? Have they made any progress in the arts of civilisation or of commerce? Do they evince taste or invention in native pottery, jewellery, carving, colouring, or ornamentation of any kind? Do they possess any and what extent of literature? Are they remarkable for their honesty or for contrary propensities? Are they open and frank towards strangers or the reverse? Do they make any distinction in their dealings between natives and foreigners? How do they dress and live? What are their domestic habits and relations? Do they encourage or prohibit polygamy; is female chastity highly esteemed; and are women treated with respect and consideration? Without going profoundly into the study of these questions, the attentive observer cannot fail to pick up many interesting details and facts on these subjects, all of which may hereafter be of use to himself or to others.

2. *Language.*—The traveller will have many opportunities of collecting much interesting information respecting the languages of those countries which he visits by taking notes of all the peculiarities he may observe respecting them, when he feels confidence in the accuracy of his information. These observations do not, of course, apply to the languages of Europe, and to those of the more civilised nations of the East, viz., the Arabic, the Persian, or Mahratta, &c., but are rather intended for the guidance of those who visit the islands of the Pacific, or the Indian Archipelago, Australia, Africa, and other lands, of which the languages are still imperfectly known.

In this respect there will in all probability be great analogy with the previous subject. Where a nation has sprung up from the fusion of two races, it will generally, if not universally, be found that the language bears traces of the same admixture, frequently in the employment of a different vocabulary by women and men. The various elements of combination will have produced an analogous result in a language partaking of the essential characters of those of which it was composed. Any information, therefore, showing how far the grammatical construction of the resulting language or particular words are derived from one or the other of the parent tongues will be important. Nor should these observations be confined to mere words and their affinities in different languages. It is equally desirable to obtain information respecting the genius and character of languages; to remark how far the idioms of one correspond with those of another; and whether the resemblances observed between the languages of various nations can in any way be traced to any original connexion between the nations themselves, or to political or commercial relations existing between them at a former period.

But it is not alone with reference to the comparisons to be made between different languages that it is desirable to obtain correct information. Even when the traveller has no opportunity of comparing several languages or dialects, he may collect much valuable matter by attention to anyone in particular. Above all things let him endeavour to make as complete a vocabulary as possible of all those words of which he can depend on obtaining the true and precise meaning. We could recommend for imitation the example of Lieut. F. E. Forbes, R.N., to whose exertions we are indebted for the discovery of traces of a *written* language amongst the negroes on the west coast of Africa.* Nor are words alone to be attended to; all peculiarities of diction, all idiomatical expressions and phrases ought to be remarked and carefully written down. With respect to the languages of many barbarous yet interesting tribes, it is only by the repeated observations of successive travellers, and by the comparison of such observations with those of others in different regions, that we can at least obtain any idea of their nature, their genius, and their origin. It is far from easy to persons not possessed of a very good ear to catch

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* *See* Journal of the Royal Geographical Society, vol. xx., p. 89.

native sounds, such as personal names, names of places, and like, every endeavour should be made to do so, and to ascertain their meaning and etymology. It may also be useful to ascertain how far foreign words have been introduced into the language, and to what extent they are used—whether confined to one or more classes of the population—whether they are more particularly used by the military, the commercial, or the manufacturing classes.

3. *Government.*—It is hardly to be expected that those for whom these remarks are principally intended will have the time or opportunity to make many inquiries, or to collect much correct information, on the details of government in its various branches, in the countries they may visit. Many of these details, even if they could be obtained, would be more appropriately noticed under the head of Statistics. There are, however, several points connected with this subject on which an intelligent traveller can hardly fail to make useful and interesting observations. Amongst these we may mention all kinds of forms, ceremonies, and processions, whether of a religious or civil nature; the observance of religious rites, where strangers are not superstitiously excluded; the ceremonies and processions which are generally a part of such rites, and which for the most part take place in the open air, afford many opportunities for remarks. It would be desirable to know how far the mass of the people participate or are interested in these proceedings, also what effect is produced by them on the morals and habits of the people. Royal pageants and processions, military manœuvres and encampments, the dress and bearing of the troops, are all worthy of notice. Many municipal institutions necessarily come under the observation of travellers, as matters of police and surveillance, passports and other documents required by the authorities, as well as any other regulations necessary, or supposed to be so, for the maintenance of peace and order. What are the principal taxes, how are they levied, and on what articles are they imposed? What is the principle of taxation—direct or indirect? Public institutions, also, in those countries where the state of society warrants their existence, and can secure their continuance, whether maintained by the liberality of the State, or supported by the zeal and resources of individuals, may well deserve a passing notice, even if more detailed information is not accessible. These, too, may be of very different characters, and may have various objects in view; they may

be intended for the promotion of literature amongst the old, or of education amongst the young; they may tend to the furtherance of trade and commerce, or they may look only to affording amusement and relaxation. Something at least on all these subjects will not escape the eye or ear of the most casual observer.

4. *Buildings.*—In considering the buildings of a people, they present themselves to our notice under several points of view. We may, in the first place, consider them as public or private. Amongst the former we shall find such as belong to the nation generally, either as the residence of the sovereign, or as belonging to the different departments of the executive government, or to the legislature, or as devoted to the alleviation of suffering or to the maintenance of health, as poorhouses, hospitals, and infirmaries of various kinds. They may be devoted to the service of God, or to the deities worshipped by uncivilised nations, as churches, temples, mosques, and other similar edifices; or they may be intended for the advancement of literature and science, such as colleges and university buildings, museums, picture galleries, &c.; or erected for the amusement and recreation of the people, or for the furtherance of public business, as market-places, town-halls, theatres, &c. With regard to private residences, the different purposes are not so numerous; but even here we may distinguish the habitations of the rich and of the poor, and those intended for town or country residences; the different styles of villages in the country, and the character of streets and houses in the town; villas, farm-houses, &c.; and, in some cases, the different dwelling of different tribes. This, in the case of those nomadic people who still dwell in tents, or of savages who live in huts, is not only very varied, but will afford much interesting information respecting their social habits and mode of life.

Again, we may consider the buildings of a people either with regard to the degree of civilization of which they may be considered as the evidence, or in reference to the progress in art and architecture which they may be held to indicate. For this purpose, not only is it desirable to point out the style in which they are erected, but also the materials which have been used, and the mechanical contrivances by which they have been assisted. In this case slight sketches will often convey a clearer idea of the object than long and minute description. Nor should we neglect altogether another class of buildings, partly private and partly public in their nature, which often convey much information with respect to the character and progress of a people: I mean their tombs and other sepulchral monuments erected to the memory of the dead, or for the purpose of preserving their bodies. It may be observed that few things indicate more directly the progress of a people through different stages and degrees of civilisation than the successive changes which have taken place in the style and character of their buildings, and of the arts by which these have been embellished, from the first rude attempts of Druidical and Cyclopean structure to the more elaborate and symmetrical proportions of what may be called the Palladian style.

5. *Agriculture.*—The geographer will have numerous opportunities, in his examination of a new country, of obtaining much valuable information on this subject and its collateral branches, by a little attentive observation and a few concise inquiries. Amongst the chief points to which his attention should be directed, we may mention the use of tools and agricultural implements, for the purpose either of cultivating the soil or of transporting its produce from one locality to another, the mode of ploughing or preparing the land for different crops, the manner of raising the crops themselves, of sowing, planting, and transplanting, of reaping and gathering in, of threshing, and other similar occupations, the rotation of crops, and whether, and under what circumstances, more than one crop is raised in the year.

Other inquiries may be usefully directed towards the animals used for agricultural purposes or domestic economy, in the field or in the farmyard; whether they are indigenous, or brought from distant or neighbouring countries; to what uses they are applied, whether for draught, for food, or for clothing. How are they fed? Are they of a hardy or delicate constitution? Have any changes taken place of late years in the state of agriculture and tillage? Is it in a state of progress or decay? What is the feeling of the inhabitants towards it? Is it practised by the majority or only by a small portion of the population? What buildings form a part of agricultural capital? All these depend on the social state of the inhabitants. Is the pursuit of agriculture esteemed or despised? What are the usual prices of provisions—animal and vegetable? To which do the inhabitants give a preference? What is the principal produce of the country—vegetables, fruits, *cerealia*, butcher's meat, or poultry? What is the tenure of land? Does it belong to the State or to individuals? Is it the common property of a tribe, or does each inhabitant claim a portion of it as his own? Is it distributed in large estates, or subdivided into small properties? Is it chiefly in fee, or held on long or short leases from year to year? Are rents paid in kind or in money or other substitutes, as the representative of given values? What is its chief feature—arable, meadow, grass, or woodland? What are the respective quantities of each? What is the nature of the soil, and what distinctions are there in it? Is one kind more adapted for one species of cultivation than another, and whence is this difference derived, and by what natural or artificial causes has it been occasioned or modified?

6. *Trade and Commerce.*—Our information respecting a country cannot be complete without some knowledge of its trade and commerce, and the manner and the means by which they are carried on. In this respect, also, without stopping to inquire very minutely into the statistical details of the resources and means of a country, the traveller can add much to our information by the mere record of the facts which come under his own observation. The following are some of the principal points to which his attention may be directed: What is the nature of the trades chiefly exercised by the different classes of the population, and by different tribes, where such exist? Are they principally employed in working up the raw materials produced in their own country, or those imported from other quarters? Are they workers in metal, and whence are the metals obtained? Are they workers in leather and similar materials? Or do they spin and weave, and what are the materials worked up in their looms—whether wool, cotton, flax, or silk—and which of them, if any, are raised in their own country, and from what other districts do they draw their supplies when requisite? Is their commerce chiefly domestic, foreign, or transit, and by whom is it carried on? What are the principal articles of import and export? Where do they come from, and whither are they sent? What is the medium of exchange? What progress have they made beyond the mere principle of barter? Is money used as a medium of exchange, or are other substitutes

employed, as cowries, salt, beads, cloth, or metals? What coins are known? Of what materials do they consist? Have the inhabitants any knowledge of bullion, paper, or bills of exchange? Have they any system of credit or bill-discounting? How is commerce conducted? What are the means of communication—water or land? If the former, what is the nature of their ships and vessels? Are they employed at sea, or on rivers or canals? What is the character of their sailors? If land communication is chiefly used, what is the nature of the roads and other tracts? Are they available for carts and waggons, or only for beasts of burden? What beasts are used—horses, mules, asses, bullocks, or camels? Which are most useful? How are the roads kept up? Are they in good or bad condition? Are the bridges well built and kept in repair? What is the ordinary rate of travelling, and the expense of carrying goods? What are the weights and measures used in the country? Are they the same in trade or commerce as in private life? Many of these questions are easily answered, and all will be found useful for one purpose or another.

Having thus gone through the different heads above alluded to, there still remains a subject which calls for a few remarks. Our information respecting distant lands and their inhabitants cannot be said to be complete without some knowledge of their past history and of the remains of antiquities still left to attest their former condition; and we therefore propose briefly to point out to the traveller a few of the objects to which his attention may be advantageously directed on this question of comparative geography. Let him carefully examine the sites and remains of ancient buildings. Where the remains appear to indicate the site of a ruined city, let him careful trace the line of the ancient walls, ascertain the position of the gates, describe or sketch their style of architecture, and state the materials of which they have been built. If the fallen fragments indicate the site of a temple or any analogous building, let the traveller endeavour to obtain precise measurements of its different component parts, the length and diameter of the columns, the details of architraves, capitals, and cornices, and of whatever other features may attract his attention. Above all things, let him diligently search for inscriptions, and then carefully copy *all* that he may find, endeavouring as much as possible to preserve the arrangement of lines, the precise form of the characters in which they are written, and the proportionate space of all illegible or broken spaces. This is best done upon cross ruled paper.

But other evidences of ancient art or history remain to be noticed—coins, and manuscripts, and works of art. With respect to the former, the traveller cannot be too industrious in collecting all that his means allow him to procure of those which come in his way—taking care, of course, in those counties where such practices obtain, that he is not imposed upon by forgeries. Manuscripts are of more rare occurrence, but even these may safely be collected when possible, and there is here less danger of deception than in the case of coins. With regard to works of art it is more difficult to lay down any precise rule, on account of their greater variety, as well as a certain degree of vagueness attaching to the term, and also on account of their bulk and cost. Two classes, however, may be mentioned which particularly deserve attention—statues and gems. Of the former of these the ordinary traveller will generally be enabled to make drawings, their size in most cases preventing their removal. Gems, on the other hand, whether cameos or intaglios, are amongst the most valuable and portable works of art which a traveller can collect. But here also let him beware of imposition; it is frequently and notoriously practised.

In concluding these observations, we must remark that they can only be looked upon as hints or suggestions of the sort of objects to which the geographer's attention should be directed. We are aware that many other features on the earth's surface might have been specially alluded to; but we trust that what has been here mentioned will suffice to point out the nature and multiplicity of the facts which it is important to notice. Geography, in the most extended sense of the word, embraces a multitude of subjects, and comes in contact with almost all the other branches of science which are noticed in this Manual. Hence the task of the scientific geographer becomes one of great responsibility. Astronomy, geology, botany, mineralogy, hydrography, ethnology, and statistics, besides other sciences, are all subservient to his duties. Whilst, on the other hand, without accurate geography, the sisterhood of science is incomplete. But we must not pursue this subject any further. Suffice it to repeat, and to assure the young geographer, that whoever brings back from distant lands accurate and well-digested facts on those and similar points to which we have directed his attention, will thereby be enabled to contribute his quota to the progress of universal science.

[For the most recent Geographical researches and discoveries, perhaps the most valuable of existing works is Petermann's "*Mittheilungen aus Justus Perthes' Geographischer Anstalt,*" *Gotha.*

ARTICLE VII.

ANTHROPOLOGY

[replacing the chapter *Ethnology* by Dr. Prichard in former editions.]

BY EDWARD B. TYLOR, D.C.L., F.R.S.

THE study of man and civilization has been much furthered by the observations of naval men in little visited parts of the world, and their opportunities are still so important as to make it well worth while to call their attention to points needing examination. One line of anthropological research, however, that concerning the bodily characters of the races of mankind, cannot well be taken up without a special anatomical training almost confined to medical men and professional naturalists. Naval surgeons and others thus qualified may be referred to the *Notes and Queries on Anthropology* (London : Stanford) drawn up by a committee appointed by the British Association, and containing directions for anthropological measurement of stature, proportions of head, trunk, and limbs, dimensions of skull, characteristic features, colour of skin, hair, and eyes, bodily strength, acuteness of sight and hearing, &c. Tables of such characteristics are valuable as anthropological material when made on a number of individuals as nearly as may be of the average male and female type, thus representing the general character of the population, exceptional cases such as those of giants and dwarfs being noted specially as extremes. Medical attention should be given to the constitutional differences between natives and Europeans, as shown in the immunity of Negros from yellow fever and the deadliness of measles among South Sea Islanders ; observation of such peculiarities, together with information as to length of life and rate of births, are important contributions to the life-history of a race. Opportunities occur from time to time of procuring skulls, or preferably, complete skeletons, as well as anatomical preparations of soft parts. Care is of course needed in such cases where tribes object to relics of the dead being disturbed; this objection is in some measure one of affection, but much more of fear lest the ghost, enraged at the remains of its body being meddled with, should wreak vengeance on the survivors. A somewhat different difficulty is met with in obtaining specimens of hair, which by its conformation and colour affords one of the most useful race-marks, but which it often taxes the collector's ingenuity to get a lock of. The reason of this lies in one of the most widespread ideas in the lower civilization, that magic influence can be brought to bear on anyone through any portion of his body, even after it is detached, such as clippings of hair or nails, wherefore these are carefully buried or destroyed. The kind of childish logic in this witchcraft notion is very instructive, and it holds its place even in the peasant life of Italy or Ireland, where girls scruple to give locks of hair lest love spells should be worked on them, and men lest their enemies should do them mischief.

For representing the features and expression of tribes, their attitudes and costume, the general appearance of their occupations and homes, nothing gives so lively an impression as good sketches, especially in colours. This is well known to the publishers of books of travel, who will insert illustrations even of poor quality rather than none. Photography, however, is now generally available, and of course gives better detail, especially in race-portraits; but the ordinary carte de visite size is too small to show features, the full cabinet size being desirable. In photographs taken for physical characters it is desirable that the body should be as little as possible concealed by clothing, and three portraits should be taken of each individual, front, profile, and back. On the other hand, when the object is to display life and habit, groups of natives in war-array or dancing or ceremonial costume may be taken in the appropriate and spirited attitudes which the savage knows as well as the civilized man how to assume, when he shows how a mat or skin-cloak is to be draped or a spear brandished.

The remark made as to the necessity of anatomical training for valid observation of race-types must by no means be taken as discouraging to non-medical observers in other departments of anthropology. Indeed naval officers, from their professional acquaintance with the arts of navigation and war, as well as with the multifarious crafts and pro cesses practised on board ship, are among the best judges possible of the civilization of a foreign tribe, as shown in their arts of construction, subsistence, and warfare. Also in collecting the specimens and models which illustrate civilization, the sailor's technical knowledge enables him better than the ordinary traveller to distinguish really genuine and instructive objects from the crooked spears, the soft wood clubs, and the rest of the worthless trade curios which even savages have now learnt to pass off on the white men. What anthropologists at home want is neither rubbish nor unpractical rarities, but rather weapons, implements, &c. of good quality, such as are or were in actual use in native life.

This raises a question which the explorer of remote regions has continually to deal with. Year by year the influence of traders and missionaries is breaking down the old native life and substituting European ways. This change is inevitable, indeed it exemplifies in an extreme form those movements in civilization which in every tribe have gone on from remote antiquity, by neighbouring tribes bringing in new arts, and improvements at home taking place by slow degrees. Thus where men have long lived, the ground becomes a depository of relics of successive stages of civilization, so that the anthropologist has to avail himself of the researches of the archæologist, and often finds it necessary to undertake them himself. The situations where the explorer in remote regions may expect to find traces of more ancient life are to a great extent similar to those he examines at home. He may not expect to find indeed in America or Africa anything approaching the record of the ground of London, where the excavator descends through deposits marked by fragments of modern earthenware and the like down through the remains of the middle ages to the Anglo-Saxon and Roman periods, and lower still to the yet earlier flakes and arrow heads of the stone age, even sometimes reaching in the underlying gravels the rude stone picks used by tribes contemporary with the mammoths whose teeth and bones lie buried hard by. But anywhere, on sites for ages occupied by man, it is worth while to dig for traces of earlier inhabitants. The rudely chipped stone picks just mentioned, belonging to the "palæolithic" period of the extinct elephant and rhinoceros, are found in the drift-gravels on the valley slopes of England and France, and as far east as the foot hills of Madras; they are known in North Africa, and are claimed to be found in America on the Delaware, in Mexico, &c. One district not very inaccessible and well deserving further examination is the Pampas inland from Buenos Ayres, where the clays and gravels exposed by the streams abound in remains of extinct animals, and of stone-age men, possibly in some cases contemporary with them. Caverns, especially the stalactitic caves of the limestone, are rich in relics of ancient man. In Perigord and elsewhere these have yielded not only the bones of extinct mammalia mixed with rudely flaked stone implements, but also the famous carvings representing mammoths, reindeer, &c. on pieces of bone or horn of the animals themselves. Thus the attention of exploring parties should be especially drawn to caverns as places where search under the layers of stalagmite may lead to interesting discoveries; their complete examination indeed requires weeks or months of excavation under careful supervision, for mere labourers rummaging in such places not only overlook and break interesting objects, but mix the contents and so confuse the order of superposition on which their scientific value depends.

Far easier to deal with are those enormous artificial deposits which fringe the coast line of the globe for many thousand miles, the shell-heaps or kitchen-middens formed of shells, fish-bones, and other refuse left by rude fisher-folk such as still build their huts on the shore, as their predecessors have done for untold ages. In Europe, especially on the shores of the Baltic, these shell heaps go back far into the stone-age, and have afforded valuable evidence as to the animals of that period. Alaska is a region where in the shell-heaps, under masses of broken sea-urchins and other leavings of natives leading the present Esquimaux life, are found the remains of still rougher people, who seem not even to have possessed the blubber-lamps now used at once for lighting, warming, and cooking. When it is considered that in South America such accumulations of shells are often 50 feet thick, and supply the limekilns for the neighbouring towns, it is evident that they will repay examination for relics of past time. Generally speaking, specimens of stone implements are to be found everywhere in the world at or near the surface of the ground. There are still a few out-of-the-way tribes, as in the Rocky Mountains and the forests of Brazil, who have not quite given up the stone arrow-heads and skin-dressers of their ancestors, but their practical use is almost past, and the best that is likely to be done is to get the old men to show how such things were formerly made and used. In this way the late Admiral Belcher learnt from the Esquimaux the art of shaping flint implements by chipping with the horn point, and such people as the Australians, Fuegians, or New Guinea tribes can still teach the old-world craft. But the memories of barbarians are short, and before they have had iron many generations they forget that the stone hatchets and spears they pick up were what their own forefathers used, and begin to fancy them of supernatural origin, as when the Pueblo Indians hunt among the ruins of their own old villages for magical stone arrows. Thus it is not surprising that in India the traveller sees ancient stone hatchets venerated under sacred trees, and that our own peasants treat them as wonder-working thunderbolts. However, where such hard stone axes are no longer shaped and ground, the polishing process and the boring by a stick or reed with sharp sand are still to be seen applied to stone beads and other ornaments, while even the African iron-worker does his forging with smooth stones for hammer and anvil. Bone instruments, such as awls, arrow-points, fish-hooks, &c., are worthy of careful looking at, and it is instructive to see how old implements in stone and bone are afterwards imitated in metal. Even the white man has been known to imitate the cleverly devised weapon of a lower race; thus the whaling harpoon with the loose point which comes off when struck, remaining attached by a cord to the floating shaft, is a civilized adaptation of an Esquimaux stone-headed instrument. The arts of metal-working, where found, have often points worth examination. The making of native steel in India is a curious process, as is the patching of a cast-iron vessel by the Chinese tinker, an art unknown to the tinmen of our country. Often the methods used throw light on the history of metallurgy; for instance, the skin-bellows with which the African reduces his iron ore may be compared with the bamboo air-pumps with their feather-pistons which answer the same purpose in the Far East.

Turning now to the arts of food-supply, the visitor will notice how every district has its own wild food. Berries, grass-seed, &c. are not neglected, and roots are so important to some low tribes like the Digger Indians, that a stick pointed in the fire is carried by the women to grub them up; this rude stick is worth bringing home, for it represents the germ whence have been developed the agricultural implements which made civilization. As to animal food, some small animals, grubs, lizards, shell-fish, &c., are caught or gathered by hand, but the crafts of the fisher and hunter lead everywhere to clever devices and instruments. Savages, seeing how fish are left behind in shallow pools by the retreating tide, imitate and improve on nature by fish-dams of stakes and wattles. Taught, perhaps, by the accident of poisonous plants falling into pools, they habitually take fish thus, using a variety of plants whose properties are interesting to the medical botanist. In spearing fish and shooting them with the arrow, savages often display extraordinary skill, and their barbed spears and arrows may be traced passing through interesting series of types. The fishhook, also remarkable from its varied forms, which possibly indicate derivation from the barbed spear, is native to most tribes of man, while artificial baits, such as those of gleaming mother-of-pearl among the South Sea Islanders, are used with effect. The art of netting, and the fishing-net, are found everywhere. Indeed the foregoing list is an example how, in an important art of support, civilized men may keep wonderfully close to the very patterns used by their savage predecessors. Now and then, in the midst of comparative uniformity, there appears some ingenious shift which shows invention at work among rude surroundings; for example, none but Melanesian Islanders know how to fly a palm-leaf kite dragging by a cord over the surface of the sea a tangle of spider's web so stout that the fish dashing at it are caught and held.

In hunting and trapping, various appliances are used which will repay study. Converging fences for driving game bear a certain resemblance in plan to those for fish. Various forms of cudgel (the English term for it is "squoyle") are thrown at birds and small ground game; these in India and other countries are flat and curved, and pass by a series of forms into the Australian boomerang. Darts are thrown by hand, or by a sling or throwing-stick which increases the length of the arm, a device frequent among the lower races, but hardly represented in Europe except by the amentum or thong of the Greek or Roman soldier's javelin. In many rude districts may be seen the loose-headed spear from which the shaft drops, but trails with the long cord which attaches it to the point, and the same principle is applied to arrows. There are savages, such as the Australians, who do not know the bow, but it is almost universal, and interest attaches to any evidence that may throw light on its origin and distribution. It has been suggested that the simple trap often set in tropical forests by fastening back a bent sapling or bough, so as to discharge a dart at the animal which by tread or touch releases it, may have given rise to the invention of the bow and arrow. At any rate such spring-traps pass into those actually armed with a bow and arrow; the whole series of forms, and indeed traps in general, are worth collecting specimens or models of. Not less interesting is the distribution of the two kinds of bow among mankind, the ordinary long-bow, and the Tatar or Scythian spliced bow which is strung by bending inside out; the latter kind extends through Asia into North America. Remarkable also is the appearance in the Indian Archipelago of the sumpitan or blow-tube, with an almost corresponding instrument in South America, both used with poisoned darts. Arrow-poison, discarded by the more powerful races, has still a large range among tribes whose weakness induces them to use it. Much mystery is made of it, and much bad information has been put on record by travellers, which wants correcting. On the whole it may be said that though sportsmen and travellers have done much in describing the weapons of the wild hunter, the subject will not be nearly exhausted before European guns have superseded them.

War, which after all is a kind of hunting, is carried on with weapons of similar type, though of special varieties, only such spears and bows as are useful against the fiercest wild beasts being adapted for battle among men. To a great extent clubs are now superseded in the warfare even of savages, so that their various forms and modes of use have to be studied from specimens and memories of old natives; this is the case with many curious weapons, such as the sharp-bladed patu-patu of the Maoris, or the Kingsmill Islanders' wooden instruments armed with shark's teeth. But among nations skilled in metal-work, types of sword or dagger are in use which the warriors would by no means change for the products of Sheffield or Liège; such is the tulwar of India, and the remarkable parang of the Malays with its blade made concave to coincide not with a straight cut but with a circular sweep.

A visit to the Pitt-Rivers Collection now established in the University Museum, Oxford, will not only show the above-mentioned stages in the history of weapons, but will afford the best introduction to the study of other implements and the arts they serve for, by the examination of their courses of development. Here, for instance, may be seen the differentiation of the early hatchet, serviceable both in peace and war, into later forms adapted to special ends, as the woodman's axe and the battle-axe. Or here may be seen the remarkable series of transformations through which the parrying-stick, used to ward off javelins in their flight, passed into the narrow slope-sided parrying-shield which is almost alike in Africa and Australia, and again this and the small circular target used for the same kind of defence against missiles passed into the large shields behind which the warrior ensconces himself. In barbaric armour, one point to be looked to is the use of hide, horn, or scales, showing how the natural defence of the animal served as material or model for the human warrior. Of disciplined warfare the explorer will find among barbaric races little more than the beginnings, but their war-parties and ambuscades are conducted by rule and with skill. The sight of such devices as pointed splints of bamboo, common in the Far East, carries our minds on to the mediæval times when the caltrop (as at Bannockburn) still had its part in battle. Early forms of fortification by earthworks and stockades, as seen among the hill-tribes of India or the South Sea Islanders, form instructive illustrations of what must have been the military history of Britain, at the time of the earthworks which still crown so many of our hills. One interesting point is to notice how by dams or cisterns a supply of water is retained to make such strongholds tenable even for weeks.

In the rude agriculture of barbarous tribes it is a good starting point to notice how the pointed rooting-stick already mentioned passes into the simplest agricultural implement, serving to break up the ground, and even when superseded for this by the hoe or the plough, continuing in use as the dibble for planting or sowing. Next comes the hoe, also an ancient implement; the stone blades once used, as in North America, are to be found in the ground, and those of bone and tortoiseshell are (though rarely) to be met with, the iron hoe, home made or imported, having everywhere prevailed. Where rude ploughs are in use they may either represent early types of the implement or they may be, as among the Indians of Chili, simply degraded forms of the European plough. It often happens that old forms of implements linger on in colonies for instance, to get an idea of the ancient Roman plaustrum, or bullock cart, with its solid wheels cut out of a tree-trunk, we need only look at that in use in the Azores, introduced by the mediæval Spaniards, who inherited it from Rome. Models of such implements thus have an interest. In Malay districts, or among the hill tribes of India, may still be seen one of the earliest kinds of tillage, faintly remembered in tradition as practised in Northern Europe; the trees are cut down on a plot of land, the wood and brush set fire to, and the land thus manured with wood ashes slightly broken up and sown, forming a field which lasts a few years, and which when exhausted is abandoned for a new patch. There are other special barbaric methods of cultivation sometimes to be seen which have a historical and, perhaps, even a practical value; such are the original planting of maize in little mounds by the North Americans, and the taro (yam) culture in Polynesia.

The pastoral life is sometimes met with of ancient institution, as among African tribes, while in America its introduction from the Old World has transformed the foot Indians of the pampas or prairies into horse Indians, such as the Patagonians or Navajos. The whole subject of domesticated animals and their relation to wild species is most important to anthropology, but it is best left for discussion by zoologists.

From the procuring of food we pass to its preparation, and to the preliminary fire-making. The traveller now seldom finds any fire apparatus in practical use more primitive than the flint and steel, or even the imported lucifer box, but there are many tribes who can still teach the European how to drill or rub two pieces of wood together, although on his return he usually fails to repeat the process, unless with the aid of some mechanical contrivance, such as a bow or archimedean drill. People trained to work the fire-drill do so with their unassisted hands; thus the Zulus lately in London produced fire in a few minutes from any bits of broken spear shaft, and, indeed, the art is traditional in Europe. Among simple modes of cooking, the process of smoking meat on a wooden grating or barbacoa in South America, and the baking in pits heated by hot stones in Polynesia, are still to be found, while on the west coast of North America may possibly be seen that primitive method of boiling food which consists of putting it with water into a wooden trough or basket, and dropping in red-hot stones. Among such people these rude vessels are being superseded at once by the iron kettles of the trader, without the intermediate stage of pottery. There are, however, many interesting forms of the early potter's art to be found in the world, which is not surprising when we consider that to this day in the Hebrides the old-fashioned earthen craggans or milk pots may be seen made without the potter's wheel; it is true that this manufacture is now only a curiosity, but it was a practical trade within a century. In more distant regions the rude varnished pottery of Fiji or Brazil is especially curious when of the genuine old-fashioned kind. In China and Japan the people are themselves collectors of their beautiful old ware, and prefer letting the foreigner have bastard articles, made by the gross to suit his taste. When it is remembered how modern a luxury is tobacco in the Old World, it is remarkable that there is already so much speciality in the pipes of different nations. The inhaling of the smoke of hemp and other drugs, however, goes back to an earlier time in Asia and Africa.

The art of navigation, making river and sea no longer an obstacle but a facility in the intercourse and migration of man, is still met with in forms so simple as probably to have been original. The log of light wood, with a peg to hold on by, which forms the "wooden horse" of South Africa, or the bundle of reeds of the Nile fisherman, are rather buoys than rafts or boats, but they lead naturally on to the catamaran or "tied trees" of the bay of Bengal or the balsa of Chili, and to the "dug-out" canoes which appear in the four quarters of the globe. With rude implements of stone the hollowing out of a tree trunk into a canoe used to be aided by fire; this is hardly to be seen now that the iron adze is used, but several Old World arts of boat-building may perhaps still be met with, such as softening the sides of the dug-out by water boiled by red-hot stones, so as to bend them to the desired shape. Gunwales are sometimes stitched on to the dug-out, and this leads on to the sewn Malay praus and the bark canoes which, both in framework and covering, are often most skilfully contrived. The seaworthiness of the Esquimaux kayak, in which skin replaces birch bark, is familiar to us from the wooden imitation canoes on our rivers, propelled by the Esquimaux double-bladed paddle, while ruder hide-covered coracles, to be seen in several parts of the world, have had their covering replaced by tarpaulin. In the Indian Ocean may be observed the curious series of forms in which the sailing catamaran passes into the double canoe and the out-rigger canoe, extending across from the Andamans to Easter Island. The whole course of invention of oars, sails, rigging, and rudder is illustrated by craft still to be seen afloat. Thus, although the successors of the Roman galleys have in this century disappeared from the Mediterranean, those of Birma and Siam show, even in details of prow and stern, curious reminiscences of them.

Primitive clothing and ornament, as seen among the lower races, comes best into view on days of festival or religious ceremony, when tribes of South India return to their ancient girdles of leaves, and the Malay in mourning casts aside his cloth and returns to the garment of bark. The ornamental patterns of matting distinguish one island from another. Our museums are full of South Sea Island tapa, but travellers have neglected to bring over the less showy bark garments of Eastern ascetics, or the South American bark shirts, taken off whole from the "shirt tree." The twisting of thread on the thigh, spinning by hand on the spindle, weaving by the rudest loom where the woof is threaded through the warp, and other stages of textile art may be met with, while the dyes and mordants used are worth examining, even for hints of practical value. Native painting and tattooing ranges from daubs of pipeclay and ochre, or the weals raised on negro's skins, to the artistic Japanese tattooing in colours, and the women's painting their lips with imported aniline dye. Both as to this decoration and the enormous variety of ear-rings, nose-rings, lip ornaments, &c., it is well to find out what ornaments or tattoo marks characterise particular tribes. Before the practice of artificially shaping children's heads has died out in the world, it may sometimes be possible to find out whether the natural heads of some admired tribe furnished the model, and it is worth while to collect the bandages and frames, or doll copies of them, where still to be had.

Passing from these material arts to the intellectual and social condition of a people, the difficulties of a short stay increase, and it is possible for even a careful observer to go away with very wrong impressions. Thus explorers have looked at seaport Indians in North-West America, and declared that they have no definite law of marriage, the fact being that they have strict rules, and, for instance, would consider the marriage of cousins, according to our law, as shamefully immoral. The law of savages and barbarians goes into ideas of relationship little noticed by the English-man, who, when inquiring into such matters, ought to find whether descent is reckoned on the mother's or father's side, and to distinguish between maternal and paternal uncles, relatives whom he is accustomed to treat as alike in kinship, but who to the savage or barbaric mind have not at all the same nature or rights. Such questions as whether "totem" clans exist, marked by the adoption of some animal or plant as a tribal badge, whether intermarriage is forbidden within these or other clans, whether the husband goes to live with the wife's family, or the wife with the husband's, whether the brother takes his deceased brother's widow, how inheritance of property and succession are arranged, will lead to answers showing the existence in every outlying country of a family system distinct from ours. In the politics of even rude tribes, hereditary and elective chiefship in peace and war may be observed in course of development, with distinctions of rank down to war-slavery and debt-slavery at the bottom of the scale. Primitive criminal justice, which is blood-vengeance and the *lex talionis*, is seen passing gradually into a judicial system, where, however, as yet the chief himself is usually the judge. The law of property among the lower races, and especially the tenure of land, is most instructive to the European mind, showing as it does the original communistic ownership of land, hunting and pasture being free to all, and the home and field of each family being only theirs so long as inhabited and cultivated, returning otherwise to the community. From this state of landholding to that of a king becoming by conquest lord of all the land, and distributing it on feudal tenure among his warriors, and from this again to something like individual freehold, every stage may be seen somewhere in the world. Judicial oaths and ordeals may be found occupying in barbaric law the place from which they have fallen among ourselves. In Africa or Asia one may still witness the ordeal by red hot iron or boiling water, or the mouthful of food which sticks in the throat of the false witness, almost exactly as in mediæval England, while the oath, often taken symbolically by such acts as touching a tiger's head or handling a spear, is a direct imprecation expected to be fulfilled, that death in such wise may fall on the perjurer. In the religious life of nations it is comparatively easy to get sight of the outward observances, the prostrations and sacrifices and ceremonial dances, but difficult to penetrate to their inner meaning. And yet, if he will take the necessary pains, the explorer of barbaric life has invaluable opportunities of seeing the early stages of religious thought through which the whole world passes. Among such tribes as Caribs or Fijians he may find dreams still convincing the dreamer that the personal phantoms or souls belonging to other men, alive or dead, came and walked and talked with him last night, or that his own phantom soul left his body and went elsewhere. Closely connected with this idea of souls going in and out of bodies are the early ideas of disease as caused by such phantom spirits, whether ghosts or demons, entering into the bodies of men to plague them with what we call diseases, such as fever, epilepsy, or madness, but which nations like the Birmese regard (as our own ancestors did) as demoniacal possession to be cured by the ancient rite of casting out devils. When looked into in this way, such rites as sacrifices to the dead or to demons and deities prove not to be meaningless superstitions, but practical acts done for definite purposes, from the point of view of a state of knowledge which the civilised world is leaving behind. Thus, also, the carved figures set up in savage huts or carried round their necks are not to be sent home indiscriminately labelled "idols" or "fetishes," but require their exact meaning to be ascertained, inasmuch as some are mere ornaments or representations of ancestors or mythical beings, others being real idols in which a spirit or deity takes up its abode as in a body, or real fetishes through which supernatural power is exerted. Magic is rife throughout the lower civilization, where burning hair tc hurt its owner, or pricking images to wound the enemy which they represent, represent the childish symbolical witchcraft just dying out in our own country; while the intermediate stages of culture, as in India and China, suffer under the grievous plague of diviners and astrologers. Few things surprise the Oriental in England more than to be shown one of our astrological almanacks, and to be told how the very methods of his native magicians linger in our rural hamlets.

It remains to mention in few words what the explorer can do in forwarding that great branch of intellectual life which turns on language. Landing often among people of whose language he is absolutely ignorant, he is led to notice closely the expressions of countenance by which he may judge of their feelings, and thence he may pass on to becoming a proficient in their pantomime or gesture language. This is really a fortunate opportunity, for nothing opens to the mind so clearly the inmost principles of thought and language as to have to express oneself and understand others through dumb show, where every sign does its work by actual likeness to the action or object it stands for. Lists of signs commonly used, and the order in which sentences (so to speak) are worked out, have been drawn up with great care among the North American Indians, and the same ought to be done for all other tribes who habitually use gesture language. As to spoken language, it has been customary in works on ethnology to lay down rules by which the traveller who meets with an outlandish tribe shall draw up a vocabulary of a few familiar nouns, verbs, &c. If nothing better has been or can be done, this may be worth doing, but, generally speaking, philology has outgrown such meagre materials. What is wanted is to master a language grammatically, and make a grammar and dictionary of it, or at least to get written down the knowledge possessed by native interpreters or Europeans, who by long and intimate intercourse have become familiar with the language, and can take the opinion of natives on the many doubtful points which arise. This linguistic knowledge, seldom valued at all by those who have it, will mostly die out unrecorded unless it can be saved by the visitor. A useful plan is to have native stories, traditions, or songs committed to writing with accurate translations; they thus become documents at once in philology and in the history, mythology, and social state of those who repeat them. Philological materials of this kind, where new, are gladly published by learned societies.

On the whole, the most useful counsel which can be given to navigators coming into contact with races whose native culture is changing or perishing is to combine the collection of illustrative specimens with thorough detailed examination of their purpose and meaning. Neither collections of unexplained curiosities nor note-book descriptions without specimens or sketches have half their proper value, but he who brings home objects of industry or war, social custom or religion, with thorough knowledge of what they are, has it in his power to make important contributions to the science of man.

ARTICLE VIII.

STATISTICS.

BY PROFESSOR C. F. BASTABLE, M.A.

STATISTICAL inquiries differ from most of the other investigations carried on by travellers, in that they are generally based on documentary materials, their subject being so widely extended in space and time as to be incapable of collection by a single inquirer. In some cases, however, these materials are wanting, and their place has then to be supplied by personal examination and by inferences from various kinds of indirect evidence, when great caution must be used, both with regard to the statements accepted, and more especially their exhibition in a statistical form.

The mode of expression taken by statistical returns is generally numerical, and the collected facts are arranged in the shape of tables: but this is not always requisite, and may even sometimes be misleading, as giving a semblance of accuracy which does not in reality exist; where possible, however, the tabular form should be adopted, and should be so arranged as to bring out the important points in the statement. No figures ought to be admitted except those that are strictly relevant; if any material be found which does not answer this test, but which it may not be thought right to exclude, it should be given in a separate table or in a less definite shape. Explanatory notes should be added where necessary, and in some cases a report, illustrated by tables, will be found the preferable form. A good deal of space may be saved by wise compression of figures, thus a whole column in which "millions" occur may be written as "thousands," "000 omitted" being placed at its head.

The general field of statistical investigation, which at first sight seems to include all matter capable of definite statement, has to be limited by remembering that, in the main, statistics are ancillary to economic and social science, and that though some other sciences receive materials from this source, it is only in a secondary way; even where facts relating to various branches of physical science are comprised in statistical returns, it is with special reference to their social and economic effects. Bearing the foregoing distinction in mind, the various topics on which information has to be sought may be stated in order as follows.

Territory and physical features.—The territory of a country is the first element affecting it which has to be considered: its area and distribution should be stated with the utmost attainable accuracy: the details under this head are, in reality, geographical, and will have been collected under that branch of inquiry, but the arrangement suitable for statistical purposes will in nearly all cases be different. A series of tables, giving the number of square miles situated at different elevations, together with the many facts relating to the climate and position of a country, regarded in their effects on its economy and social life generally, will be found useful additions to knowledge.

POPULATION.—The next subject for examination is the number and character of the population, which is sometimes regarded as the primary element in such inquiries. It is plain that little can be known of the real state of a country till the number and condition of its inhabitants has been ascertained. At present in every nation which claims to be civilised a census is taken at definite intervals, when the number of the population (with various other facts) is obtained by inquiry on a given day. In addition, estimates are usually made every year by the proper department as to the changes in population which have taken place during the preceding year. The principal details which have to be taken into account in thus estimating the total population are the returns of births and deaths. The return of marriages is also a guide in estimating the future increase of population.—These can in most cases be obtained by means of official documents, but it is often well to test such evidence by questions addressed to competent persons who are acquainted with the country, since in many instances the need of accuracy is not understood by the untrained officials, to whom the task of recording the results is entrusted. The returns of births and deaths in some districts of British India are said to show the need of this caution. If the returns of emigration and immigration have been collected they should also be examined, as affording evidence of changes in the number of the population, but in general they are of less relative importance than the main factors of births and deaths.

In countries where a census has not been taken, any statements as to the number of the people will naturally be received with hesitation, though various methods have been employed in order to form an approximate idea. Most of these are based on partial returns, such as local registers of births, marriages, and deaths (or in some cases of baptisms and burials), returns for revenue purposes, as the hearth-money returns for England, or those made for a poll-tax, estimates of the number of inhabited houses (which, in the rare case of the average number of inhabitants per house being known, afford a very sound datum for calculation), or of the number of men available for military service, or, finally, lists of voters. The numbers of the members of the various religious sects, if they can be ascertained, are also a valuable means of forming an estimate. The hearth returns were actually used by Gregory King as a guide to determining the number of the English people in 1690; and, at a later period, the registers of baptisms, marriages, and burials were utilised by Mr. Finlayson for a like purpose.

For uncivilised countries, a mode of estimating the population which, though necessarily imperfect, is, perhaps, the best that can be adopted, may be based on the capabilities of the territory for producing food, taken in connexion with the average standard of living which prevails in the country. Thorough exploration of a territory is a great aid towards forming a good conjectural estimate of its population, arrived at by computing the apparent proportion of inhabited houses per square mile, and the probable number of persons per house. All such statements must from the nature of the *data* be uncertain, and in these cases it is advisable to state the answer as one lying within limits, of which only the maximum and minimum possibilities are determined.

After the *number* of the population has been arrived at, as closely as possible, other details require to be investigated; such as the ages of the inhabitants, on which subject important inferences can be drawn with the aid of the returns of births and deaths, differences of longevity among different classes should, too, be carefully noted; the proportion of the sexes is also a matter of importance, as illustrating the social condition of the people in question, and information respecting it should be collected. The returns of births, deaths, and marriages have previously been referred to as assisting the investigator in ascertaining the number of the population; they are also needful for estimating the details known as *vital* statistics, or the rates of births, deaths, and marriages, which are usually expressed by the number per annum per 1,000. The facts bearing on this subject can in some countries be obtained from registers, but in others are only matters of conjecture. Separate tables for different classes, sexes, and districts should, where possible, be constructed, as throwing light on the conditions under which life is carried on in the country. The average age at which marriage takes place is also an interesting fact; moreover evidence, where available, should be collected on the causes of deaths, which ought, as far as possible, to be classified.

The *distribution* of the population ought to be made the subject of a special inquiry, and should be connected with the physical conditions noticed under the head of territory, as it is important to know the causes which determine the density of population in each district. Evidence as to changes in distribution is useful, as indicating relative progress or decline in the districts where such changes have taken place, and as affording evidence of the effect of various other elements of national life on the state of the people.

Sanitary Condition.—As supplementing the returns already mentioned, details relative to the health of a country should, if available, be collected; in most cases, however, it will be impossible to get anything more than general impressions on this subject, which should also include notices of the physical condition of the people, such as their stature, strength, and power of endurance.

Education.—The inquirer will next seek for information on the subject of education. In order to judge of the position held by the people in that respect, inquiry should be made as to the number of educational establishments, and the number of pupils attending each; those devoted to giving primary education being distinguished from those in which more advanced instruction is afforded. The general character of the training given and the mode in which the expenses incurred are provided for, whether by pupils' fees, private endowments, or direct aid from the State, or, if all three are combined, the proportion in which each source contributes to the total cost, ought to be ascertained. It would also be desirable to learn whether education is compulsory or optional, and if the former, how far it has been successful in promoting the diffusion of knowledge. The per-centage of persons able to read and write can be obtained from the census returns, if such exist. The condition of literature and the extent to which it is diffused will be some guide towards estimating the general standard of culture; thus the number of newspapers and periodicals will be obtained without difficulty.

The provision made for technical teaching is also a matter for investigation; and here the questions given above, as applicable to general education, will require to be repeated. Any evidence obtainable as to the effect of technical training in furthering the development of industry should also be noticed.

Religion.—The religious sects which exist in a country, and the number of members which each possesses, should be a subject of inquiry, as should also the amount of revenue received by each religious body. It is here necessary to distinguish between the funds, if any, supplied by the State and those obtained by gifts and contributions; the mode of paying the ministers of religion should be particularly attended to, as well as the general position which they hold in the community. It will further be advisable to learn whether special privileges are conferred on one or more sects, and how far religious freedom *in fact* exists. In many cases the educational and religious inquiries will have several points of contact, many teaching institutions being under the management or control of the clergy.

Criminality.—The inquirer having obtained information as to the agencies in operation for the promotion of intellectual and religious teaching will next seek for facts indicating the evils which that teaching aims at removing. Of these, the most important is the state of crime, which will need close investigation. Official returns will in general give the number of offences committed within a recent definite period, with figures showing the increase or decline, as the case may be, of criminality, by comparison with earlier returns. In the same manner a classification of the various kinds of offences can be obtained, with the proportion each bears to the total amount of crime by which the general character and disposition of the inhabitants will be instructively exhibited. Thus, in a comparatively rude community it is probable that crimes of violence, especially those arising from feelings of revenge, will bear a higher proportion to the sum of crime than among a more advanced society; but that, on the other hand, cases of criminal frauds, and in particular those needing foresight and ingenuity, will be more numerous among the latter. It will be necessary to seek for information as to the effect of sex, age, social condition and education, on the commission of crime, and all details on these subjects should be collected. Particular inquiry should be made as to the existence of a special criminal class and the conditions which have brought it into being. The number of offences for which no one has been made amenable to justice should also be ascertained, as well as the general sentiment of the people on the subject of crime; in this connexion the existence of special classes of crime, due to the law being unsuited to the habits of the people, may probably be brought to light. The effect of distress in producing crime can be shown by a comparison of the number of crimes in years of scarcity with that in years of average or more than average supplies of food. The means employed for the repression of crime should also be made a subject of investigation, such as the modes of punishment adopted, and the general treatment of prisoners, the number of capital sentences executed, and the efforts, if any, to make prisons partially self-supporting, as also the attempts to reclaim criminals, the reformatory system in particular being a subject of much interest. All such agencies for the prevention of crime, as industrial schools and training ships, will be suitably noticed under this head.

Illegitimacy.—The proportion of illegitimate births has sometimes been regarded as an important indication of the domestic morality of a country, and it is undoubtedly desirable to collect evidence on this head in order to ascertain the effect of physical, social, and legal conditions on the amount of illegitimacy; thus it is to be expected that where law or custom opposes obstacles to legitimate unions a larger number of illegitimate persons will be found than where no such obstacles are in force, a statement, the truth of which is abundantly exemplified by the statistics of Bavaria, where a law restraining marriages, unless the parties could prove that they possessed sufficient means, was in force up to 1868.

Immorality.—It may also be advisable to collect evidence as to the extent of other social evils, as drunkenness and prostitution, but in these cases the greatest care is needed to avoid the acceptance of exaggerated statements, since official returns will be only to a slight extent available.

Suicides.—The proportion of suicides to the total number of deaths is also a matter which should be ascertained as completing the circle of inquiries which have been included under the head of moral statistics. Evidence as to the effect of sex, age, education, and social condition on the commission of that act will be valuable, as will also details as to the relative number of suicides in each month of the year.

Economic Statistics.—The most extensive and fruitful field for the intelligent inquirer is, however, the economic condition of the people and the various forms of its industrial activities. His first inquiry will naturally be for reports, official or other, on the production of wealth, which again will be divided into those relating to agriculture and those dealing with manufactures.

Agricultural Production.—Under the former head it is necessary to seek for information on the amount of cultivated land as compared with that which is barren or uncultivated, also on the amount devoted to each particular crop, and the changes in cultivation in comparison with former years. The next fact to be ascertained is the amount of produce of each kind with its estimated value. It is desirable also to learn the average produce per unit of area and the average price per unit of quantity. In addition to these elementary agricultural statistics it is important to ascertain the numbers of livestock of various kinds which are maintained, distinguishing, as far as possible, between those that constitute part of the farmers' working capital and those that are intended for sale or consumption. The general modes in which agriculture is carried on, the amount of buildings, machinery, and labour employed in production are also matters which the investigator should carefully examine. The relation of agriculture to other forms of industry should also be specially noticed; thus it is well to know how far native agriculture furnishes the raw material worked up by manufactures, what is the proportion of agricultural labourers to the number of those that are otherwise employed, and whether any manufactures are carried on by agricultural workers in their spare hours. The comparative productiveness of large and small farms should be investigated under this head, and all details on so important a point should be duly collected.

Forestry and Fishing.—The principal facts regarding the minor but still considerable industries which deal with forests and fisheries should also be sought for; the amount of land under the former, the number of persons engaged in it, and the value of the produce thence derived, the number of boats with their average size, the total of men and boys engaged in the latter, and also the annual value of the produce of both sea and river fisheries are important items in productional statistics.

Mineral Produce.—The annual mineral production, the number of mines, both of coal and metals, in actual working, the number of persons employed in them, and the amount produced per head, should all be ascertained; the facts relating to the production of coal and iron are in particular worthy of being carefully collected, since their peculiar positions, the former as the principal motive power of machinery, the latter as the main substance from which its material is obtained, render the facts as to their production the most trustworthy indications of the state of industry in general.

Production of Manufactures. — The next subject on which information should he collected is the production of manufactured articles. Inquiry should be made as to the amount of raw material worked up in the case of each article, the number of persons employed in the various branches, and the extent to which hand labour is assisted by machinery. It will also be well to ascertain how far improved processes and more efficient machinery have been adopted in recent years, and the consequent changes in the cost of production of all articles thus affected. The manufacture of textile fabrics (woollen, linen, cotton, and silk), as also the great hardware industry, will, perhaps, need separate notice, and many apparently less important branches of production, such as the manufacture of machinery, chemicals, glass, paper, and pottery, should be closely examined; the value of the finished products of all those industries should be ascertained as well as the principle on which that value is estimated; the difference between the value of the raw material and that of the finished article is in many cases very striking. It will rarely be possible to obtain full official statistics on the production of manufactures, but in some countries reports on the condition of separate industries will be available; the returns of imports and exports will give the quantity and value of the raw materials imported, as also that of the finished products exported: moreover, trade circulars and the researches of native statisticians will in some countries supply a good deal of the further information needed.

Circulation of Wealth.—When all the knowledge obtainable as to the production of wealth has been collected, the modes by which it is circulated should be ascertained. Inquiry should be made respecting the roads in existence, their quality, and the manner in which the expense of their maintenance is defrayed, whether by tolls or taxation, either local or general; in many instances it will be possible to get fairly accurate estimates of the quantity of traffic carried on. The railway system furnishes a further subject for investigation. In almost every case it will be easy to arrive at the mileage, the quantity of rolling stock employed, the number of passengers and amount of goods carried within a recent defined period; it will also be advisable to ascertain the original cost of construction, the working expenses of the various lines, and the extent to which they have proved commercially successful. The inland navigation system, whether composed of rivers or canals, the way in which it is maintained, and the extent to which it is used as a means of transport, should form a supplementary head of inquiry. The amount of control exercised by the State over railways and canals should also be ascertained. Similar inquiries should be made regarding the postal and telegraphic arrangements, which are in general fully described in official documents. As it is evident that all wealth, except that consumed at the very spot where it is produced, must be transported to the place of consumption, the statistics obtained under the head of circulation will supplement and probably, also, in some degree correct those relating to production.

Foreign Trade.—The very important body of facts which is usually treated of under the title "foreign trade" may be best regarded as a branch of the circulation of wealth. The inquirer can ascertain the amounts and values of imports and exports from the Custom House returns, together with many other details of interest, such as the proportion which the imports intended for re-exportation bear to the total amount, the various countries from which imports are received, with the nature and value of those received from each, and in particular how far they are composed of raw materials as compared with partially or wholly manufactured articles; the extent to which the country habitually imports its food supplies being specially noticed. The same information will be needed with regard to the exports, and the method adopted in valuing both imports and exports should be stated to avoid misappre-sions. The changes in the course of foreign trade during recent periods should be investigated, but it must be remembered that mere vague statements, unsupported by well verified facts, deserve little attention. The principal facts relating to the shipping engaged, both in home and foreign trade, should also be ascertained, such as the number of native vessels employed, their tonnage, and the numbers of their crews, distinction being made between steamers and sailing ships. The same details are requisite with regard to foreign vessels trading to a country, and in addition it will be well to discover whether there is any change in the proportion between foreign and native vessels as compared with former years. All impediments to the free course of exchange are important enough to need special notice; the inquirer should, therefore, ascertain whether any restrictions are imposed on foreign vessels or any privileges given to native ones: the duties imposed both on imports and exports can be obtained from the tariff list, cases where countervailing duties are levied on home products being duly noted. It will be advisable to learn whether the duties are specific or *ad valorem*, and in the latter case the method of valuation which is used. Moreover, all trustworthy evidence should be collected as to the effect produced by such obstacles on foreign trade, and on the general condition of the country where they are imposed.

Money and the Machinery of Exchange.—As an essential part of the investigations comprised under the head of circulation, it will be necessary to procure information on the monetary system. The principal metal or metals of which the coinage is composed, and, if there is more than one, the manner in which their relative value is determined, the denominations, weights, and values of the various coins, both principal and subsidiary, the amount of the charge, if any, levied by way of seigniorage, as well as any restrictions imposed on free coinage, should all be ascertained. The extent to which paper money is used and the mode of issue, whether by the State, by a privileged company, or by companies and private persons with or without guarantees for the security of the public, will also furnish a topic for inquiry. Should an inconvertible paper currency constitute the principal medium of circulation it will be well to ascertain the amount of issues and the extent of depreciation, if any, together with the amount of the premium on the standard metal as compared with the paper issues, also whether any restrictions on the exportation of bullion are in force. The probable future course of these inconvertible issues should also be investigated, whether it be towards resumption of specie payments or towards further depreciation.

Credit.—The facts relating to credit, properly so-called, should also be duly collected. The amount of goods exchanged by the agency of credit in its various forms—book credit, bills of exchange, and cheques—compared with that exchanged by the actual intervention of money, as well as the proportion which these several forms of credit bear to each other, ought all to be ascertained. These details should be supplemented by information as to the changes in the amount of credit and the circulation of money at different seasons and from year to year. The organisation of banking as the centre of the credit system, the extent to which the method of clearances is carried, and the resulting economy in the use of coin, should be noticed; as should also the extension of the system to international trade and the movements of bullion in liquidating balances of debts.

Wholesale and Retail Trade. — Information as to the organisation of the distributing and commercial body in general ought also to be procured; it will be well to know the character both of wholesale and retail trade, the number of persons thus engaged, and the amount of capital employed therein, with the profits realised.

Weights and Measures.—An account of the system of weights and measures in use will form a suitable appendix to the information collected on the general topic of circulation; here it will be interesting to learn the methods of weighing and measuring adopted, the names of the various weights and measures, and the relations which exist between them and those in the metric system, or at all events those at present used in England. Cases in which the same name is applied to different weights or measures should be carefully noted. The existence of peculiar standards or curious modes of estimating amounts in some districts is worthy of observation, both for the practical effect produced in impeding trade, as well as for the historical interest of all such survivals of an older order of things.

Prices.—In connexion with researches into money weights and measures, it will be well not to neglect opportunities for procuring tables of prices, which may in some cases be of importance as illustrating the economic condition of the people during previous periods.

Distribution of Wealth.—The most complicated problem which the statistician has to handle is that of the distribution of wealth; the principal difficuty is to obtain the needful information. No State has up to the present thought proper to procure suitable distributional statistics, while the means which are used for arriving at the facts in the cases of production and circulation are not here available. The main sources of information will be found in official returns of the incomes of special classes, or in assessments for revenue purposes. The labour statistics of the State of Massachusetts afford an instance of the former, the English income tax returns of the latter kind. The amount of the total rent of land, the interest derived from the use of capital, the gains obtained by those actively engaged in business, and finally, the salaries and wages of the professional and labouring classes, are the parts into which the total amount of wealth has to be divided. In all these cases, by the aid of previously collected statistics, it will be possible in some degree to test the results arrived at by independent calculation; thus inquiries should be made as to the rate of interest which, combined with the amount of capital, will give the sum of interest: for computing the rent of land the average rent per unit of area would afford an index which might in some cases be checked by official estimates of the revenue of owners of land; and similar methods may be used in the other instances, though it must be added that wages, salaries, and employers' gains are even less susceptible of exact treatment than interest or rent.

Consumption and Accumulation of Wealth.—In addition to the preceding subjects of inquiry it is very desirable to ascertain the amount of the annual consumption; in this case also, nothing more than approximations can be looked for, but the average consumption of such important commodities as wheat and animal food, may and ought to be arrived at, while the consumption of various articles of luxury, especially when imported, may be computed with a close approach to accuracy. All wealth remaining over after the annual consumption constitutes the savings of the community, and will either take the form of capital or of unproductive hoards. It will, therefore, be well to procure information as to the various forms of investment with the amount devoted to each, distinguishing between those that are situated in the country, and those that are placed abroad.

Social Statistics.—In addition to the strictly economic inquiries which have just been indicated, it is advisable to procure information on several matters which, though partly economic, may more fitly be described as social; thus a leading subject for the investigator will be the actual division of wealth, and especially its comparative concentration or diffusion. Diligent inquiry will enable a tolerably correct estimate to be formed of the situation of a country in this respect. The existence of a class of very rich persons will speedily exhibit itself, and the proportion of the middle class, in its various gradations, will also be soon discovered. It is, however, on the condition of the great body of the people that most attention ought to be fixed; the money wages received by the average workman, the number of days in the year on which he is able to procure employment, the price of the articles of his necessary consumption, and the proportion which he receives of the total produce of his work, ought all to be made objects of investigation, as should also the variations of wages in different places and employments. In this connexion the industrial position of women will form a highly important branch of inquiry; the extent to which they take part in agricultural or manufacturing labour, the wages they receive and the limitations, whether legal or social, imposed on their industry, will all need investigation. Where married women take part in field or factory work it will be advisable to consider the physical and social effects produced both on them and their children. In those cases where all or most of the members of a family are in receipt of wages it is, of course, the earnings of the family that have to be taken into account, not those of the head only. Any reliable details respecting the employment of children will be worthy of attention. Information should also be collected respecting the effects produced by such agencies as trade unions, co-operation, and profit-sharing, the average number of working hours in the day in various employments, and the extent to which the factory system has supplanted domestic manufactures.

The land system of the country, and its effect on social and industrial development, ought to be examined. The number of proprietors of land, the conditions of tenancies, with such further details as the peculiar condition of the country may render desirable, specially those which might throw light on the comparative merits of industrial operations on a small and on a large scale should be ascertained. An admirable mode of exhibiting the condition of the various classes is the formation of *budgets* of income and expenditure for an average member of each class. In this attempt it will be necessary to take as many actual cases as possible into consideration, but great care must be used in order to eliminate all abnormal items, both of receipt and expense, while preserving those that are typical of the mode of living in the class. It will further be advisable to seek for evidence on the changes in class conditions which have been or are in progress.

Provisions for Relief of the Distressed.—The modes in which provision is made for those who are unable, to work, and who possess no other means of subsistence should also be investigated. It is desirable to make inquiries as to the regulations under which assistance is afforded by the State, and the number of persons who avail themselves of it, with the cost of their maintenance; where there is no State system of relief the ways in which private charity aids the distressed ought to be ascertained, as well as, in all cases, the extent to which it supplements the legal provision. It will also be well to obtain as much evidence as possible regarding the higher forms of charity, such as orphanages, almshouses, hospitals, asylums, and grants to persons of limited means. Moreover, all statistics on medical relief and the number of persons hindered from work by bodily or mental incapacity should be noticed.

POLITICAL STATISTICS.—Under this head are included several subjects which should by no means be neglected. Thus, the constitution of the country, with details as to the method of its working, should be ascertained; in particular, the number of voters and their qualifications can be easily discovered. The arrangements for local government ought also to be made a subject of inquiry, which will be in general assisted by official reports.

Finance constitutes a very prominent branch of political statistics, and here the inquirer will find it advisable to collect the principal details. He ought to ask for information as to the revenue of the State, whether general or local, distinguishing between that derived from the private domain and that obtained by taxation; the latter source, again, will have to be divided into direct and indirect, Customs and Excise, &c. State expenditure has to be considered, as well as revenue, therefore the several heads of outlay, with the amount incurred on each, should be ascertained, as should also the total of the national debt, together with the facts concerning its growth (or diminution) during recent years. The facts relating to the general structure of the administration should be collected, as well as the main outlines of *economic legislation;* these, in addition to the many mentioned under the head of *economic statistics*, would comprise the laws of inheritance, contract (especially that of partnership, including the law relating to commercial companies, which occupy so important a place in the modern industrial system), and bankruptcy. It will finally be advisable to procure information respecting the military and naval forces. Such matters as the strength of the standing army, the mode of recruiting, the length of service, the organisation of the reserve forces, the number and power of the ships in commission, and the state of the fortifications ought not to be omitted.

It cannot be expected that all the subjects outlined in the preceding suggestions will be investigated by any one inquirer or group of inquirers, but a single branch can be made the principal topic, while the others receive a subordinate place. Where such a course is adopted the inquirer will do well to remember that the narrow limits of the present article prevent the mention of some points of interest under each head which must be supplied by the care and intelligence of those who use it as a guide. With regard to less advanced nations, the absence of the phenomena constituting some of the subjects above specified will relieve the attention of the inquirer, so far as they are concerned, and where the area is limited it will be possible to bring together information on most of those we have mentioned. It may, moreover, be added that thorough investigation in a small district is likely to prove more fruitful than larger, but therefore necessarily more imperfect, researches carried on over a wider field.

For discussions on the theory of statistics and other matters too extensive for notice here, the *Traité theorique et pratique de statistique*, by M. Block, Paris, 2nd ed., 1886, may be recommended.

ARTICLE IX.

MEDICINE AND MEDICAL STATISTICS.

BY THE LATE ALEXANDER BRYSON, Esq., M.D., F.R.S.

(*Revised for this Edition by William Aitken, Esq., M.D., F.R.S.*)

As a large proportion of the naval force of this country is generally employed on foreign stations, it will necessarily happen that amongst the first things which will engage the attention of a medical officer are the effects produced on the constitution by climate; *i.e.*, by the sum of the influences connected with the sun, the soil, the air, or the water of a place. These influences are in the highest degree complex, and impossible as yet to be traced fully out. Different views have been adopted as to the general effect of climate on human life; but provided food is sufficient and suitable, the human frame has a wonderful power of adaptation. It is no doubt a commonly received opinion that a tropical climate is injurious to the constitution of a northern; but, in proportion to the supply of proper food, good water, pure air, the deadly effects attributed (somewhat vaguely) to "climate" have disappeared. Opportunities will not be found wanting in the naval service for removing sanitary defects, and improving the mode of living, so that men may not die faster in the tropics than at home.

In noting the climatic changes which are likely to affect health, there are not, it may be assumed, any great difficulties to be encountered in making instrumental observation; mathematical precision, at all events, is not so essential as when the results aimed at depend on the truth of a series of arithmetical sums. Nevertheless, in the mere registration of this kind of formulæ, accuracy is required, as one omission may invalidate a whole set of observations—such, for example, as the geographical position of the ship at the time the observations were made.

With regard to the air, the principal points to be observed are its temperature, degree of humidity, movement, weight, composition, microscopical impurities, and electrical condition. That the two first greatly influence health there is no reason to doubt; but, with regard to the others, it would be hazardous to offer any decided opinion. Amongst men who have devoted much time and attention to the subject there are, perhaps, a few who consider that at times they may have some influence on the mental and bodily functions.

Temperature.—Thermometrical observations by maximum, minimum, and common thermometers, with the view of noticing the effect of atmospherical heat on health, should be made several times a day, or even more frequently should there be a sudden rise or fall of the barometer. The minimum, medium, and maximum in the shade should be ascertained. In a ship under way it is hardly possible, in consequence of the great variety of aspects in which she may be placed with respect to the sun, and the various currents of air set in motion by her movements, to find a suitable place for these instruments; black* bulwarks and hammock-cloths rapidly absorb the heat of the sun's rays, and again throw it out by radiation for a considerable time after sunset. Should the instrument, therefore, be placed, as sometimes happens, contiguous to these, it will give an exaggerated view of the temperature. In the same manner the under surface of the deck radiates heat abundantly after the upper surface has been for some time exposed to the rays of the sun, consequently the temperature of the cabins and the space between decks is sometimes greatly increased; this, if continuous, should be placed on record, as well as the influence it may be supposed to have on the general health of a ship's company. In connexion with accumulated heat from these or other sources, it would also be proper to state the space allowed to each hammock, the number of hammocks berthed on one deck, and in a general way the dimensions of the deck, together with the size and disposition of the scuttles, ports, and windsails.

* Black not now (1886) in general use.

Acute inflammatory diseases have most unquestionably been induced by a current of external air rushing from the lower orifice of a windsail on men while asleep. Are we then to suppose, in the absence of all terrestrial miasmata, that these diseases are the result of the sudden abstraction of heat from the system? Simple immersion in the sea, or exposure to the external air in a state of nudity, has seldom an equally deleterious effect. So also the effects of intense radiant heat require investigation in the production of disease. The direct rays of the sun combined with excessive exertion have been known to induce a form of fever—the *causus* of some writers.

These, and subjects of a like nature, are well deserving the attention of every medical inquirer.

HUMIDITY.—The relative degree of humidity of the atmosphere, particularly within the tropics, seems to exercise a considerable influence over the health of Europeans; and hygrometrical observations are not less essential than thermometrical to a full investigation into the cause and nature of any of those diseases usually denominated climatorial. Various instruments have been used for these purposes; but those which denote with ordinary accuracy the state of the atmosphere, and are the least liable to go out of repair, are the best. It will naturally occur to the observer to guard against confounding the moisture arising from local causes, such as the damp state of the decks, or the halitus from the breath of a large body of men confined in a small space, with the natural moisture of the external air. Should the disparity, however, between the latter and the air between the decks on which the men generally congregate and sleep, be great, it will be incumbent on him when he uses an instrument to note the difference. From these data, viewed in connexion with the results of the thermometer, some better mode of ventilating vessels of war destined to remain for years within the humid regions of the tropics may be discovered.

According to their degree of humidity climates are divided into *moist* and *dry;* and as far as the body is concerned the chief effect of moist air is exerted on the amount of evaporation from the skin and lungs. The degree of dryness or moisture of an atmosphere should be expressed in terms of the relative (and not of the absolute) humidity, and should always be taken in connexion with the temperature, movement, and density of the air. As the temperature rises the evaporative power increases faster than the rise in the thermometer. The evaporating power of an atmosphere which contains 75 per cent. of saturation is very different according as the temperature of the air is 40° or 80°. The most agreeable relative amount of humidity to most healthy people is between 70 to 80 per cent.; and there is a general opinion that an atmosphere which permits free without excessive evaporation is the best. Air saturated with water (like moist hot siroccos) checks evaporation, and the temperature of the body rises.

To a dry air we are accustomed to attribute a bracing effect, to a moist air a relaxing; and there seems to be no reason to doubt the truth of the postulate, that—the one as a general rule conduces to health, the other to disease. How far these conditions modify morbid action it would be desirable to ascertain more definitely. Malarious diseases are peculiar to moist localities, and are said never to attain their fullest epidemic spread unless the humidity approaches saturation. The subject yet requires to be more fully examined, but facts are not wanting to lead to the supposition that dysentery, and diarrhœa approaching to dysentery, are more frequently the result of atmospheric changes (especially extreme and extensive ranges of temperature) in certain dry localities within the tropics, than they are in moist localities in similar parallels of latitude.

The relative degrees of health enjoyed in vessels differing in the hygrometrical condition of the air between decks, from whatever cause (exclusive of external causes) such differences may arise, is a subject which has long engaged the attention of all classes of naval officers. It is now generally allowed that a dry condition is the more healthy. As these hygrometrical conditions principally depend on the modes of cleaning the lower decks, it more especially belongs to the medical officers to watch with vigilance, and report (but not without due and ample experience) the effects of dampness, whether from accident, stress of weather, or artificially produced, as well as the effects of dryness artificially maintained by swinging stoves or other contrivances. "Warmth and great humidity are borne, on the whole, more easily than cold and great humidity." (Parkes.)

LIGHT.—The marked difference in the appearance of men employed in the bread-room and holds, compared with those who are freely exposed on deck, or in open boats, at all hours of the day, cannot escape the notice of the most superficial observer. It is, therefore, of importance to ascertain whether exclusion from the solar rays be not, to a greater extent than is generally believed, one reason why men who have acquired a pale waxy look from confinement below are more susceptible to disease, and less capable of sustaining its shocks, than are those whose blood is enriched and strengthened by the free exposure to light, heat, and air. The necessity of light for growth and perfect nutrition is a physiological axiom, and the influence of light is a most important part of climate. The force of these remarks, however, will be best understood by those who have had opportunities of witnessing the rapid change which takes place in the human constitution by exposure for only a short time to the direct rays of a tropical sun. Why, even in a state of perfect repose, the blood should acquire a brighter tinge, and an increased force of circulation, are inquiries, the value of which the observant physiologist will not fail to appreciate; neither will he fail, as often as opportunities occur, to follow up the investigation of these phenomena, should they terminate in disease, or unhappily produce death.

The electric light is now often in use between decks; and reports as to its influence as compared with sun light would be of value, such, for example, as would be analagous to those made by the late Mr. Ziemans on vegetable life.

Weight of the Air.—When the difference of pressure of air between two places is considerable, a marked effect is produced. In ascending mountains or in balloon ascents there is lessened pressure of air, by rarefaction, to this extent, that an ascent of 900 feet above the sea level takes off half a pound on an average from the 14 pounds weight of air at the sea level. The temperature is also lowered; and above 4,000 feet there is also lessened moisture. The movement of the air is greater, and there is an increased amount of light, and greater sun radiation if clouds are absent. The air is also freer from germs of all kinds.

The physiological effects of lessened pressure begin to be perceptible at 2,800 or 3,000 feet above sea level, *i.e.*, $= 2\frac{1}{2}$ to 3 inches descent of mercury. These effects are quickened pulse (by 15 to 20 beats per minute), augmenting in number with elevation, and best shown by balloon ascents. (Biot, Gay-Lussac, and Glaisher.)

Respiration is also increased by 10 to 15 per minute. Evaporation is increased from skin and lungs, and there is lessened urinary water. At greater heights there is increased pressure of the gases in the body against the containing parts, swelling of superficial blood-vessels, and occasionally bleeding from the nose and mouth.

The distance to which terrestrial miasmata may be borne by the external air has been so variously estimated, that correct information on the subject would tend not only to the benefit of the public service, but to the credit of the medical profession. In selecting a proper position for an encampment, or for the anchorage of vessels of war, the greatest discretion and judgment are required, particularly in those countries which abound in the aërial or telluric agencies inimical to man; and although these are matters on which the medical officer is not invariably consulted, and although necessity and the exigencies of the service may render the selection of the worst localities inevitable, still, dreading the suffering and loss of life which may be occasioned by a position badly chosen, the external geological features of any coast or island off which a squadron may require to be concentrated cannot fail to attract his attention. A microscopical examination of material collected on slides from the air ought to be carefully made as opportunities occur.

Movements of Air.—In connexion with terrestrial emanations, atmospherical currents depending on local causes, together with a description of land and sea breezes, are also subjects deeply interesting to all classes of men, whether employed in Her Majesty's naval service, or otherwise engaged in maritime pursuits. It is, therefore, much to be desired that the country contiguous to any unfrequented creek or bay, or the embouchures of tidal rivers which are likely to become the resort of shipping, should be examined, and, if found to contain lagoons or marshes, mapped so that those spots which are the most exposed to malarial currents may be known, and, if possible, avoided. The nature of the soil in the immediate neighbourhood, the kind and the depths of water in lagoons, the character, depth, and consistence of swamp, bog, or marsh land, the description of plants which surround or grow from them, would greatly enhance the value of such information. These being acknowledged sources of fever and ague, it should not escape the zeal of the inquirer to ascertain whether they were liable to irruptions from the sea, or floods from the interior; whether fogs arose from them, and, if so, at what time of the day or year they were most observable; and also whether they emitted noxious effluvia. Officers and men employed on boat service on the west coast of Africa have sometimes discovered within the mouths of tidal rivers particular places in which noxious effluvia were much more perceptible than in others.

There are few things of more importance to the naval medical officer than the origin and character of febrile diseases, as a knowledge of the facts connected with the former may greatly bias his judgment with regard to the latter; and, as the expression of his opinion thus influenced or formed, particularly with regard to their being of an infectious or of a non-infectious character, may endanger not only the health and the lives of the men in his own vessel, but the health and lives of men in other vessels, and even in communities residing on shore it will be admitted that these are not subjects, when opportunities occur, that ought to be superficially examined or inattentively reported.

Besides endemic and epidemic fevers which arise from general or terrestrial sources extraneous to a ship, there are others which originate in local or personal causes existing on board. To distinguish between these is a matter of greater difficulty than seems to be generally apprehended. For instance, fever may break out in a single vessel of a squadron, and attack not only the whole or the greater part of her crew, but visitors, though they remain on board for a few hours only. If these latter, after returning to their own ship or home, pass through the disease without communicating it to any other person, the opinion generally formed has been that the fever was the result of exposure to some local cause unconnected with the emanations from the sick; but if in either case the attendants or immediate neighbours of the visitors were subsequently, within two or three weeks, seized with fever similar to that of the latter and of the patients in the ship, and again other persons who had been in close communication with them were attacked, then the conclusion arrived at has been (as indeed it could not be otherwise), that, if it were not originally contagious, the disease had acquired in the course of its progress the power of propagating itself, and that in all probability it would through a series of subjects retain that power for an indefinite time. But even admitting that the origin of the fever may be clearly traced to some cause within the ship, it will yet remain to be determined whether that was of a local or of a personal nature, or of some peculiar combination of the two. In many cases it most unquestionably will be difficult, if not impossible, to decide ; nevertheless, a concise narrative of the events as they occur should be committed to paper, in order that it may be made available, should it be required for any investigation in connexion with the re-appearance of the fever at a future period either in the same or in a different locality.

When a fever has broken out in a vessel at sea, from a foul state of her holds, and continues to make progress, attacking man after man, how, it may be asked, is it possible to ascertain whether it has acquired a contagious character or not? The space is small, and the whole of the men being equally exposed to the original exciting cause, and, if such has been generated, to the personal cause also, are there any means of distinguishing the effects of the one from those of the other with that degree of certainty which would warrant the medical officer giving a conscientious opinion, if required by the arrival of the vessel in a port? The great similarity of all continued and remittent fevers, from whatever source they may arise, and the utter impossibility of complete segregation, even in the most roomy vessel, will, it is apprehended, render it extremely difficult to make such a distinction ; and the delivery of any opinion, beyond that which may be hypothetically formed, impracticable. Still, on the appearance of any epidemic in a ship of war, it will be necessary to come to some determination as to its origin ; for on this will depend the propriety of removing the cause, or removing from the cause, viz., clearing out the vessel or quitting the locality. If it arise from causes within the vessel, these should be stated, and also the means taken to remove them. It should also be noted if the disease was confined to, or was most prevalent among, those berthed in any special part of the ship. If from causes extraneous to the ship, they also, if possible, should be described, as well as the manner in which the men were exposed to their influence. The treatment of the disease will naturally rivet attention to the symptoms ; these again should lead to a more useful nosography than is generally adopted ; but unless diseases are completely identified all inquiry into causes is hopeless. As means of diagnosis advance, causes will become more fully investigated, and methods of prevention more obvious and precise. The following GENERAL diseases should be clearly identified and diagnosed from each other :—

GROUP A.—DISEASES BELIEVED TO BE DEPENDENT ON MORBID POISONS (SPECIFIC FEBRILE DISEASES).

Sub-group (1).

1. Small-pox; 2. Cow-pox; 3. Chicken-pox; 4. Measles; 5. Epidemic rose-rash, Rötheln or German measles; 6. Scarlet fever; 7. Dengue; 8. Typhus; 9. Plague; 10. Relapsing or Famine fever; 11. Influenza or Epidemic Catarrh; 12. Whooping cough; 13. Mumps; 14. Diphtheria; 15. Cerebro-spinal fever or Epidemic cerebro-spinal Meningitis; 16. Simple Continued fever—a febricula having no obvious distinguishing character; 17. Enteric, typhoid or Pythogenic fever, and typho-malarial fever, occurring in some countries where malaria and Enteric fever form a combination; 18. Yellow fever, as distinguished from severe forms of malarial fever with yellowness of skin or jaundice; 19. Cholera, Asiatic or Epidemic, as distinguished from 20. Sporadic or Simple Cholera or Cholera nostras; 21. Epidemic Diarrhœa; 22. Dysentery.

Sub-group (2).

23. Malarial Fevers (*a*) Intermittent or ague, (*b*) Remittent, (*c*) Malarial Cachexia; 24. Beriberi.

Sub-group (3).

25. Phagedæna (*a*) sloughing phagedæna, (*b*) Hospital gangrene; 26. Erysipelas (*a*) simple, (*b*) phlegmanous; 27. Pyæmia; 28. Septicæmia.

Sub-group (4).

29. Syphilis (*a*) Primary—Hard Chancre or infecting sore, (*b*) Secondary or Constitutional; 30. Gonorrhœa.

Sub-group (5).

31. Hydrophobia; 32. Glanders; 33. Horse-pox; 34. Splenic fever, Charbon or Wool-sorters' disease, variety, *malignant pustule.*

Group B.—Diseases dependent on External Agents other than Morbid Poisons.

Sub-group (1).

Diseases dependent on Parasites.

35. Animal parasites; 36. Vegetable parasites.

Sub-group (2).

Effects of Poisons.

37. Animal poisons; 38. Vegetable poisons; 39. Inorganic poisons.

Sub-group (3).

Effects of Injuries and Climate.

40. Effects of presence of foreign bodies; 41. Effects of mechanical injuries (*a*) general, (*b*) local; 42. Effects of excessive exertion and strain; 43. Effects of excessive venery; 44. Effects of heat; 45. Effects of cold; 46. Effects of electricity; 47. Effects of chemical agents; 48. Effects of climate.

Sub-group (4).

Diseases produced by Errors of Diet.

49. Surfeit; 50. Starvation; 51. Scurvy; 52. Alcohol, variety, *Delirium Tremens.*

Group C.—Developmental Diseases.

53. Immaturity at Birth; 54. Malformations; 55. Debility; 56. Old age.

Group D.—Not Classified.

57. Rheumatic fever or acute rheumatism; 58. Sub-acute and chronic rheumatism; 59. Gout; 60. Osteo-arthritis or rheumatoid arthritis; 61. Cysts; 62. Non-malignant new growth; 63. Malignant new growths, *e.g.*, cancer, sarcoma, &c.; 64. Tubercle; 65. Scrofula; 66. Rickets; 67. Cretinism; 68. Myxœdema; 69. Leprosy (*a*) Tubercular, (*b*) Anæsthetic; 70. Yaws; 71. Parangi; 72. Purpura; 73. Anæmia; 74. Chlorosis or Green sickness; 75. Idiopathic or Pernicious Anæmia; 76. Leucocythæmia; 77. Hæmophilia; 78. Diabetes Mellitus or Persistent glycosuria; 79. Glycosuria.

Local Diseases include all the important morbid states and processes which affect the various organs or parts of the body.

In naming and identifying disease the nomenclature recently (1885) issued by the College of Physicians, and sent to every medical man whose name appears on the Medical Register, is that which ought to be followed, as it is now adopted in all the services as well as in the hospitals of civil life.

As long as there is a British squadron on the sea, yellow fever, as it is called, must claim a large share of attention; and as it is seldom brought to these shores, he who encounters it on its own domain will do well, while it is under his eye, to examine carefully into its origin and character. When it occurs as an epidemic its source should be looked for, its course traced, and its disappearance noted; and whether yellow suffusion be present in all the cases, or only in some of them; whether, when black vomit occurs, the disease acquires a greater degree of virulence; and whether, in consequence of such aggravation, marked by deep yellow suffusion, dark coloured blood, hæmorrhage, and, in the fatal cases, black vomit, it becomes more contagious. As it does not appear by the records in the office of the Medical Director-General, that yellow fever ever broke out in a ship of war, unless she communicated with an infected ship, or entered a port where it was, or recently had been prevalent; and as it has never been observed in the tropical regions of India, along the eastern coast of Africa, or in any island, with the exception of Ascension and Bermuda, north of the equator, information respecting its spontaneous origin would be highly interesting. The existence of accumulations of felled timber floating in river creeks should be noted, and its relation to the Slave Trade.

Whether the common remitting fever of the tropics has ever changed or been converted into true yellow fever is a question on which medical authorities are still at issue, although the non-appearance of the latter on the swampy shores of Zanzibar, in India, Malacca, Borneo, and China, on the broad swamps which bound the Niger, where the worst forms of remitting fever prevail, would lead to the inference that these two diseases depend on totally different causes; and the evidence is becoming more and more conclusive that there is a *malarious* form of yellow fever and a *specific* form of yellow fever, distinct in their causes, course, and modes of propagation.

Whether the yellow suffusion depends on degeneration of the blood, or on the absorption of bile into the system, has not yet been determined. Two pieces of skin taken from the same body were examined by two of the most eminent physiologists in London; one thought the yellow colour was due to altered blood, though there was no evidence to prove the absence of bile; the other thought that the colouring matter was derived from bile, and that, "curious enough, it was chiefly seated in the "epidermis and epithelium of the tegumentary follicles." Here then, particularly if taken in connexion with the remedial measures which would require to be adopted were either of these conditions established, is a wide field for inquiry and observation.

In the treatment of yellow fever there is assuredly much to observe, and much to learn. The effects of remedies should be watched and compared. Blood-letting, and the nature of the blood abstracted, still offer a fair field for observation, whilst the empirical modes in which we have been taught to exhibit mercury will perhaps induce the younger physician, when he begins to think for himself, to reinvestigate the grounds on which his seniors recommended these questionable practices, and to compare them with the results obtained from other remedies in the present day. Though quinine, or quinine wine, as it is now employed in the naval service, has been found to be extremely useful in preventing the evolution of periodic fevers, there is no reason to suppose it will prove equally efficacious in preventing yellow fever.

The course of febrile diseases is now measured by accurate thermometric observations, characteristic of different types of fever. (Consult Aitken's "Science and Practice of Medicine:" *Seventh Edition.* Subject, Fever. Vol. I.)

In the naval service, more frequently, perhaps, than in any other, there are opportunities of ascertaining to a day, and even to an hour, the exact period of incubation in certain endemic and contagious diseases. A number of men, a boat's crew, for instance, may enter a vessel, a house, or a village in which a contagious disease is raging; or they may land, expose themselves to the influence of a "homicidal marsh," and then return on board, having inhaled a sufficiency of the poison to establish a certain specific morbid action, bearing, if of a personal nature, the exact similitude of its parent; and if of a terrestrial, that type of fever peculiar to the climate or locality, or to the prevailing epidemic—it will of course follow that, in proportion to the length of time the patients have been exposed to the exciting miasm, so in an inverse degree will be the value of the information, as during a protracted exposure there is no means of even approximately ascertaining when the system had acquired the requisite charge necessary to the evolution of the disease. The latent period of endemic fevers is a subject which is both curious and interesting; but with regard to contagious diseases it is infinitely more so, as it is principally on a correct knowledge of these periods that measures to prevent their spread may be advantageously adopted. Quarantine both by land and sea has been found to be inefficient and impracticable.

Exanthematous diseases are still an interesting study: information respecting their incubative periods, as well as information relative to the time the exciting poison of each will retain its specific action after it has escaped from the body; proof of their spontaneous origin where communication with an infectious source was impossible, would, in connexion with their total extinction, also be of value. There are few who do not believe in the communicability of these maladies, but of late attempts have been made to depreciate the great boon conferred on mankind by the discovery of the immortal Jenner. It has been stated, but on what grounds it would be difficult to discover, that vaccination has rendered the population more susceptible to other diseases, or, in other words, when small-pox is prevented or forestalled by cow-pox, that a large amount of rudimental disease is left in the system, which ultimately explodes in various other forms of morbid action. Evidence for or against these doctrines should not be permitted to pass unnoticed. Second attacks should be placed on record, and the medical officer ought not to omit mentioning whether the patient attacked with small-pox had or had not been vaccinated.

Of all the diseases which attack the human race there is not one respecting which sound information ought at the present moment to be more coveted than Asiatic cholera. Its contagious character is by no means generally admitted; and there are many who deny that it possesses this property, who endeavour to trace its origin and spread to filth putrifaction, to peculiar states of the weather, to changes in the atmosphere, and to various other causes. Hence, any apparently isolated outbreak of this disease should be carefully investigated. Its incubative period,—the time which the hypothetical germs* when separated from their source will retain their productiveness,—whether they adhere to inani-

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* The influence of such precise and definite objects seen or imagined as have received more or less definite names, such as "germs," "bacilli," "bacteria," have now been associated with numerous specific diseases as their specific cause, and announced as the bases of varied hypotheses which involve many points of speculation and contention. "While some of the points of contention appear to be "proven, others are only probable, and they are neither universally "nor unconditionally accepted. The exclusively causal agency of "bacilli in the diseases with which they have been associated, "although extremely plausable, is not conclusively proved; and a "greater number and variety of experiments of control are yet "needed to satisfy a just scepticism (Sir Andrew Clark, Bart., in "Luml. Lectures, *Lancet*, April 4, 1885)." To study on broad biological principles, and to find out, if possible, the real relation of such so-called "germs" or "bacteria" to any given disease, the cycle of their lives and their behaviour under a variety of super-induced changes, is the task with which the pathologist is now charged. But completeness, and, therefore, accuracy of final results, cannot be certainly obtained without a comprehensive knowledge of the entire group of *bacteria;* and the absence of this knowledge is a serious impediment to understanding the complete morphology of such forms as may *prove* "specific" in the *pathogenic* and in the *septic* series. To have their life histories, and especially the variations to which they may be subject under altered surroundings, is of the utmost importance to the truth. Minute and prolific as these organisms are, *time* must be an essential element in their vital mutations; and they may yet prove to be subject to variation of an important kind "under domestication" [or "cultivation"]. The law of variation is as operative to-day as ever, and the rapidity with which generation succeeds generation in these lowly and minute forms, certainly promotes the chance of variation and survival. It is, therefore, conceivable that changes may happen which it is of the utmost importance for us to know. As yet, however, we have no complete knowledge of the "life history" of any of these organisms; and, therefore, the complete specificity of anyone of them is not yet established. Those we know most about appear to be merely putrefactive organisms, like the so-called cholera "comma" bacillus of Koch and his so-called tubercle-bacillus also, both of which appear to be merely incidentally present in the diseases with which they have been associated (Dr. W. H. Dallanger, March 1885, *Contemporary Review*, p. 450). Unity, differentiaton, and evolution in disease are doctrines which are in need of revision; for it is beginning to be seen that the evolution of epidemics and the alliances of diseases hitherto believed to be distinct and different have a much more important place in nature than they have hitherto held or than their seeming differences have permitted them to hold ("Evolution in Pathology," *Glasgow Medical Journal*, August 1885, by Dr. W. Aitken, F.R.S.)

mate substances,—and whether secondary attacks of cholera are frequent, or whether one attack renders a person less liable to a second, are all questions of vital importance.

The incubative period of plague, and, if it rage epidemically, proof of its having been transmitted from one person to another, either simply through the medium of the atmosphere, or by means of fomites, are still questions of paramount interest to every nation which has any communication with the districts where it has been endemic.

To the medical officers of the army and navy we must look for information relative to the geographical distribution of diseases. Why yellow fever has been gradually extending for many years now along the east and west coasts of South America, one of the most healthy regions in the world, and why cholera has not yet reached the western coast of Africa, one of the most unhealthy regions in the world, are questions that will be answered differently by different persons according as they believe in the contagious or non-contagious character of these diseases. To mark, therefore, the introduction and the progress of these two maladies over regions where they are still unknown, is the bounden duty of every man who has the welfare of the human race at heart. Information relative to the cause or origin of endemic maladies is also much required. Why, for instance, Europeans suffer so much from bowel complaints on the coast of China, and not on the west coast of Africa; why on the former they should be infested with intestinal round worms, and on the latter with tape worms; why the dracunculus should be met with on the west coast of Africa and the chigoe in the West Indies, we are unable to explain; but, by patient investigation, and by following the paths where science leads, we may yet hope to discover many of nature's hidden secrets.

Some curious information may be obtained in distant countries relative to the modes of treating diseases amongst uncivilised tribes; not that it is likely to prove of much value, but as a matter of history it may be worth recording. It would even be interesting to know the virtues attached to charms and amulets, as well as the manner in which they are obtained, of what they consist, and how they are worn; nor would the native methods of performing surgical operations be of less interest. The Albanians, it is reported, with but slight knowledge of anatomy, perform the operation of lithotomy with dexterity and success. The Marabouts of Africa, with a fallen tree for their table, may be seen, with little display, performing the initiatory rites of Mahomedanism on the assembled youths of an entire village; while the Fetish man, on another part of the continent, ministering to the pride of caste, makes such fearful gashes on the cheeks of his patients as would astonish our boldest practitioners. How these wounds are cured might be worth knowing, as the scars sufficiently attest the extent and success of the surgery.

In the central parts of Africa, and in some of the islands, of the Indian Archipelago, there is reason to believe that the natives are in possession of narcotic poisons with which we are still unacquainted. An account of these, and of the modes in which they are prepared, would be interesting. And on all occasions the diseases most prevalent in the various foreign countries visited, and the most approved methods of treating them, together with an account of the medicinal plants, and other means in general use as remedies, should (in conformity with the public instructions) be invariably reported.

In preserving medical plants or seeds, and other objects of natural history, for the purpose of bringing them to this country, it will be found no easy matter to protect them from the ravages of insects, and in damp countries from the effects of mildew. The tin cases now used for certain articles of dress are well adapted for the safe keeping of perishable substances; but when they cannot be procured, a deal box made to fit snugly between the beams of the cabins allotted to officers, with its seams closed up by pasting paper inside, is the best substitute; but bottles would be preferable in most cases. Predatory insects may be excluded by scattering amongst the contents pieces of camphor, and rags sprinkled with turpentine, to which a few drops of the oil of petroleum or benzole will be a useful addition. Into a box so protected neither ants nor cockroaches will enter; and without some contrivance of the kind it will be in vain to attempt to preserve almost any object of natural history of an animal or vegetable substance; unless it be placed in spirits. Chloride of zinc has been successfully used for preserving animal tissues in the proportion of one part of the concentrated solution in 20 of water, for preserving fish and reptiles, and, when in good condition, specimens of morbid anatomy; but when the latter are very putrid they require at first a much stronger mixture, namely, about equal parts of each. In this the preparation is allowed to remain until it is free from smell, when it may be finally put up in a solution of the first-mentioned strength, but not in alcohol.

In the first edition of the Admiralty Manual of Scientific Inquiry several suggestions were made with reference to the improvement of the medical returns, which have since been adopted, so that the statistical information required is now more available, and it is to be presumed more correct, than it was formerly.

In the official journals supplied to each medical officer full instructions are given for dealing with the medical returns which he is called upon to prepare. This was not the case when the previous editions of this manual were published; and now that such full instructions are supplied, the concluding paragraphs of the previous editions of this Article are rendered unnecessary.

Works recommended:—"Practical Hygiene," by Dr. Parkes, 6th edition, edited by Professor de Chaumont; "Science and Practice of Medicine," 7th edition, by Dr. Aitken; "Influence of Tropical Climates in producing acute Endemic Diseases of Europeans," by Sir James Ranald Martin, London, 1861; "Reports of the Medical Officer of Privy Council." Handbook of "Geographical and Historical Pathology," by Professor Hirsch, translated for the Sydenham Society by Dr. Creighton. Darwin's voyage of the "Beagle." "Vital Statistics," in the collected works of William Farr, M.D., D.C.L., F.R.S., published by Edward Stanford, Charing Cross, London, 1885. "The collected works of John Simon, C.B.," edited by Dr. Edward Seaton, published by Sanitary Institution of Great Britain.

ARTICLE X.

GEOLOGY.

By the late CHARLES DARWIN, F.R.S., F.G.S.

(*Revised for this Edition by Professor A. Geikie, F.R.S.*)

A PERSON embarked on a naval expedition, who wishes to attend to geology, is placed in a position in some respects highly advantageous, and in others as much to the contrary. He can hardly expect, during his comparatively short visits at one place, to map out the area and sequence of widely extended formations, and the most important inferences of geology must ever depend on this having been carefully executed; he must generally confine himself to isolated sections and small areas, in which, however, without doubt, many interesting facts may be collected. On the other hand, he is admirably situated for studying the still active causes of those changes, which, accumulated during long-continued ages, it is the object of geology to record and explain. He is borne on the ocean, from which most sedimentary formations have been deposited. During the soundings which are so frequently carried on, he is excellently placed for studying the nature of the bottom, and the distribution of the living organisms and dead remains strewed over it. Again, on sea shores, he can watch the breakers slowly eating into the coast cliffs, and he can examine their action under various circumstances. In the wasting operations of air, rain, frost, rivers, waves, and the other denuding agents on the surface of the globe, he sees the processes which have planed down whole continents, levelled mountain ranges, hollowed out great valleys, and exposed over wide areas rocks which must have been formed or modified under the enormous pressure of an overlying mass of rock since removed. Again, as almost every active volcano is situated close to, or within a few leagues of, the sea, he is admirably situated for investigating volcanic phenomena, which, in their striking aspect and simplicity, are well adapted to encourage him in his studies.

In the present state of the science it may be doubted whether the mere collecting of fragments of rock, without some detailed observations on the district whence they are brought, is worthy of the time consumed and the cost of carriage of the specimens. The simple statement that one part of a coast consists of granite, and another of sandstone or clay-slate, can hardly be considered of much service to geology, and the labour thus thrown away might have been more profitably spent, and the collector saved much ultimate disappointment. It is now generally recognised that both the sedimentary rocks, and those which have come from below in a softened state, are nearly of the same character and composition over the whole world. A mere fragment, with no other information than the name of the place where found, tells little more than this fact. These remarks do not apply at all to the collection of fossil remains, on which subject some remarks will presently be made, nor do they apply to an observer collecting suites of rock specimens, with the intention of himself subsequently drawing up an account of the structure and succession of the rocks in the countries visited. For this end, he can hardly collect too copiously, for errors in the naming of the rocks may thus be corrected, and the careful comparison of such specimens will often reveal to him curious relations which at the time he did not suspect. He must record, on the spot, such observations as may give a permanent interest to the specimens, accompanying them by sketches when useful, and *not trusting to memory*.

In order to make observations of value, some reading and much careful thought are necessary; but perhaps no science requires so little preparatory study as geology, and none so readily yields, especially in foreign countries, new and striking points of interest. Some of the highest problems in geology wait on the observer in distant regions for explanation—such as, whether the successive formations, as judged of by the character of their fossil remains, correspond in distant parts of the world to those of Europe and North America, or whether some of them may not correspond to intervals of time, during which sedimentary beds were not accumulated in the latter regions, or, having been accumulated there, have been subsequently destroyed; and again, whether the lowest formations everywhere are the same with those in which the most ancient forms of life have been recognised in the countries best known to geologists. These and many other wide views in the history of the world are open to any one who, applying thought and labour to his subject, has the good fortune to geologise in countries little frequented.

A person wishing to commence geology is often deterred by not knowing the names of the rocks; nor is this difficulty to be altogether removed by reading descriptions, however well composed; it is best met by frequent inspection and handling of rightly named specimens. It is, however, more important and more easy to acquire by observation right ideas of the aspect, character, and composition of rocks. By patiently familiarising his eye (aided by a lens) with the aspect of the feldspar, quartz, and mica in granite, he will be able to recognise three important ingredients in igneous rocks, and where the mica is replaced by a dark, black-green mineral, less hard than the feldspar and quartz, he will know a fourth important mineral, hornblende. The sedimentary rocks can hardly be described, except by the terms in common use; impure limestone, which cannot be readily recognised by the eye, can be distinguished by its effervescence with acids. By the repeated comparison of freshly fractured sedimentary and igneous rocks, such as sand-stone and clay-slate on the one hand, and granite and lava on the other, he will learn the difference between crystalline and mechanical texture and aggregation; and this is a very necessary point. No department of geology has in recent years made such remarkable progress as petrography, or the study of rocks. The advance has mainly been due to the application of the microscope to investigate the minute structures of rock masses. Thin slices of rocks and minerals are ground smooth, polished and cemented with Canada balsam to glass, and are then reduced to such a degree of thinness as may be required to render them transparent. Even if the observer cannot himself undertake such researches, he should let no opportunity slip of collecting samples of every remarkable variety of rock which, with the requisite information regarding manner of occurrence, &c., he can hand over to some professed petrographer.

Let no one be deterred from geology by the want of mineralogical knowledge; many excellent geologists have acquired but little, and from this reason its value has undoubtedly been underrated, for many of the obscurer points in geology, such as the nature of the metamorphic changes in rocks, and the phenomena of metallic and other veins, always require such knowledge.

The appearances presented by the different forms of stratification (that is, the original planes of deposition) may be soon learnt in the field; though no doubt the beginner would be aided by the diagrams given in many elementary works.

Tools and Instruments.—A list of useful books is given at the end of this article. The geologist fortunately requires but little apparatus: a heavy hammer, with one end wedge-formed and the other truncated; a light hammer for trimming specimens; some chisels and a pickaxe for fossils; a pocket lens with three glasses (to be incessantly used); a compass and a clinometer, compose his essential tools. Clinometers are now usually fitted with a small compass. Some of these useful instruments are furnished with a spirit level, others with some pendulum or plumb-line arrangement, and all have graduated arcs. The observer must choose the form best suited to his habits—only taking care that the instrument be strong, of sufficient size, and protected as to the level or plumb-line. The instrument used by the members of the National Survey answers very well. In an uneven country it is not easy without the clinometer to judge which is the line of greatest inclination of a stratum; and it is always more satisfactory to observe the angle than to estimate it. A flat piece of rock representing the general slope can usually be found, and by placing a note-book on it the measurement can be facilitated. It is best to determine and record the "*strike*"—that is, the direction of a horizontal line on the surface of the stratum—first; then at right angles to this line measure the "*dip*," or angle of inclination, and note its direction. In a country where slaty cleavage occurs precautions are needed which will be noticed as we proceed.

A mouth blow-pipe with its apparatus, and a book with instructions for its use, teaches a little mineralogy in a pleasant manner. Besides the above instruments, a mountain barometer or its modern rival, the convenient aneroid, is often very necessary. Abney's pocket level is a portable and useful instrument. An observer, having previously ascertained the exact height of his eye when standing upright, can measure the altitude of any point with some degree of accuracy; he has only to mark by the level a recognisable stone or plant, and then to walk to it, repeat the process, and keep an account how many times the levelling has been repeated in ascending to the point the height of which he wishes to ascertain.

Rules for Collecting.—A few cautions may be here inserted on the method of collecting. Every single specimen ought to be numbered with a printed number (*those which can be read upside down having a stop after them*), and a book kept exclusively for their entry. As the value of many specimens entirely depends on the stratum or locality whence they were procured being known, it is highly necessary that every specimen should be ticketed on the same day when collected. If this be not done, the collector will never in after years feel sure that his tickets and references are correct. The ticketing of every separate fossil from the same stratum is very troublesome, yet it is particularly desirable that this should be done for the prevention of mistakes which so easily arise when the species are subsequently compared by naturalists; and it should always be borne in mind that misplaced fossils are far worse than none at all. Pill boxes are very useful for packing fossils. Masses of clay or any soft rock may be brought home if small fossil shells are abundant in them. A convenient size for rock specimens is 4 inches long by 3 inches broad, and half an inch thick; they should be folded up in paper. To save subsequent trouble, it will be found convenient to pack separately, and mark sets of specimens which came from different localities. These details may appear trifling; but few are aware of the labour of opening and arranging a large collection, and such have seldom been brought home without some errors and confusion having crept in.

Methods for Observing.—To a person not familiar with geological inquiry, who has the privilege of landing on a new coast, probably the simplest way of setting to work is for him to imagine a great trench cut across the country in a straight line, and that he has to describe the position (that is, the direction of the "strike" and angle of the "dip") and nature of the different strata or masses of rock on either side. As, however, he has not this trench or section before him, he must observe the dip and nature of the rocks on the surface, and take advantage of every river bank or cliff where the land is broken, and of every quarry or well, always carrying the beds and masses in his mind's eye to his imaginary section. In every case this section ought to be laid down on paper, on as nearly as possible the real proportional scale, copious notes should be made, and a large suite of specimens collected for *the observer's own* future examination. The value of sections, with their horizontal and vertical scales *true to nature*, cannot be exaggerated, and their importance has only lately been appreciated to the full extent. The habit of making even in the rudest manner sectional diagrams is of great importance, and ought never to be omitted; it often shows the observer palpably, and before it is too late (a grief to which every sea-voyager is particularly liable), where his knowledge is defective. Partly for the same reason, and partly from never knowing, when first examining a district, what points will turn out the most important, he ought to acquire the habit of writing very copious notes, not all for publication, but as a guide for himself. He ought to remember Bacon's aphorism, that "reading maketh a full "man, conference a ready man, and *writing an exact man*," and no follower of science has greater need of taking precautions to attain accuracy, for the imagination is apt to run riot when dealing with masses of vast dimensions, and with time almost infinite. After the observer has made a few traverses of the country, and drawn his section (and the coast cliffs often afford him an invaluable one), he will be himself astonished to find how, in a troubled region, over which the surface has, perhaps, been broken up and recemented almost like the fragments of ice on a great river, all the parts may sometimes be found to fall into intelligible order. He will in his mind see the beds first horizontally stretched out one over the other in a fixed order, and he may then perceive that the disturbance has arisen from a few nearly straight cracks, on the edges of which the beds have been upturned, and between which he will sometimes find great wedges of once heat-softened, but now crystalline rocks. He will find that large masses of strata have been removed and denuded, that is, ground down into pebbles and mud, and long ago drifted away to form in some other area newer strata.

In examining a district to make a section, many minor points of detail will occur for observation, which can hardly be specified ; such as the nature and cause of the transitions and alternations of the different strata, the source of the sediment and pebbles, the alterations in chemical nature, either of the whole mass, or of parts, as in concretions; the presence, and grouping and state of the fossil remains; the depth and condition of the old sea bottom when the beds were deposited, and an infinity of similar points. Probably the best method of obtaining this power of observation is to acquire the habit of always seeking an explanation of every geological point met with; for one mental query leads on to another, and this will at the same time give interest to the observer's researches, and induce him to compare what is before his eyes with all that he has read of or seen. With his increasing knowledge he will daily find his powers of observation, his very vision, become deeper and clearer. He must not, however, expect at once to solve the many difficulties which will be encountered, and which for a long time will remain to perplex geologists; but a ray of light will occasionally be his reward, and the reward is ample.

Organic Remains.—In the sectional diagram which we have supposed to be made, the simple superposition of the beds gives their relative antiquity; but the best section which a sea-voyager can hope to make will seldom include more than a small portion of the long sequence of known geological formations. And as such a voyager seldom passes over large districts, he will rarely succeed in placing in proper order, by the aid of superposition alone, the formations which he successively meets with even in the same country. Hence he must, more than any other geologist, rely on the characters of the embedded organic remains, and must sedulously collect every specimen and fragment of a specimen. By means of fossil remains, not only will he be enabled to arrange (with the help of naturalists on his return home) the formations in the same country according to their age, but their relations to the deposits of the most distant parts of the world can thus, and by no other method, be determined. It is now well known that the general order of appearance of animals and plants has been broadly the same all over the world. We cannot assert that each stage in the progress of life has everywhere been reached during the same period of time. But without claiming them as contemporaneous we can affirm that all the great sections of the geological record appear in every country in the same relative order. Hence we can compare the Jurassic rocks of Europe with those of India, or the Carboniferous rocks of Spitzbergen with those of New Zealand, being assured that whether or not they were coeval as to the time of their formation they belong to the same epoch in the progress of plant and animal life upon the globe.

It is highly necessary carefully to keep separate the fossils found in different strata. In passing upwards from one bed to another, and occasionally even without any great change in the character of the rock, the fossils are often found to be wholly different; and if such distinct sets of fossils are mingled together, as if they had been found actually together, undoubtedly it would have been better for the progress of science that they had never been collected. As there is some inconvenience in keeping separate the fossils collected on the same day, this caution is the more requisite. The collector, if he be not an experienced naturalist, should be cautious in rejecting specimens, in the belief that they are the same with what he has already got; for it requires years of practice to perceive at once the small but constant distinctions which often separate species; the same species, moreover, if collected in different localities, or in beds, one placed far above the other, are generally more valuable in reasoning on ancient conditions of land and sea than new species.

In a group of strata or formations a few hundred to a thousand feet and upwards in thickness, the whole of which, characterised by the same fossils, may be regarded as belonging to the same geological period, most curious and important results may be sometimes deduced, if the positions or relative heights at which the groups of fossils are embedded be noted; and this is a point not sufficiently attended to. The depth of water under which a group of marine mollusca lived can often be approximately told; and thus the movement of the crust of the earth, whilst the strata, including the shells, were deposited, can be inferred. For instance, if in the bottom layers of a cliff, say 800 feet in height, a set of shells is buried, which must have lived under water only 50 or 100 feet in depth, it is clear that the bottom of the sea must have sunk to have allowed of the deposition of the 700 feet of superincumbent sub-marine strata; subsequently the whole 800 feet must have been upraised. For this same purpose, and for other ends, it is desirable to note which species are the most numerous, and whether layers are composed exclusively of single kinds. It should be also remarked, whether the more delicate bivalve shells retain their two valves united, and whether the burrowing kinds are embedded in their natural positions, as these facts show that the shells in one case have not been displaced, and in the other have not been drifted from afar. Where there are fossil corals, it should be observed whether the greater number or any of the specimens are upright, in the positions in which they grew.

The remark formerly made, that the collection of mere fragments of rock is of little or no use to geology is far from applicable to fossil remains. Every single fossil species, bones, shells, crustacea, corals, impressions of leaves, petrified wood, &c., should be collected, and it is scarcely possible to collect too many specimens. Even a single species without any information of any kind, if it prove a quite new form, will be valuable to the zoologist; if it prove identical with, or closely allied to a known species, it will interest the geologist. A set of fossils, however, and still more several sets, with their superposition known, cannot fail to be of the highest value; they will tell the relative geological age of the deposit, and perhaps give the key to the geology of the whole country; some of the most interesting problems in this science will be solved only when large collections have been carefully made in distant regions of world.

A collection of recent shells (both those living on the coast and those to be procured by the dredge off it) from the same country or island at which a collection of tertiary fossil shells is made, is generally of very great service to the palæontologist who undertakes the description of the fossils. The collecting of recent shells will, moreover, with the aid of a little study, teach the geologist some conchology, and this is an acquirement yearly becoming more necessary: the geologist should exert himself to learn some general zoology.

The bones of vertebrated animals are much more rarely found than the remains of the lower marine animals, and they are almost in proportion more valuable. A person not acquainted with the science will hardly be able to imagine the deep interest which the discovery of a skeleton, if of higher organisation than a fish, in any of the oldest formations, would most justly create. The age of such a formation would have to be judged of by the co-embedded shells, and, therefore, if possible, part of the slab containing the bones should include one or two shells to demonstrate their contemporaneity. Bones, however, from any formation are sure to be valuable; even a single tooth, in the hands of a Cuvier or Owen, will unfold a whole history: the head, jaws, and articular surfaces are the most valuable; but every fragment should be brought home. Where bones are found close together, and especially if some of the parts lie in their natural positions, they should be packed together. Every bone, if found even six inches beneath the black vegetable mould, should be collected; there can be no doubt that many most valuable relics have been neglected, from the supposition that they belonged to still living animals. Low cliffs of mud, gravel, and clay on the banks of streams and on seashores (as well as in bared reefs extending from them), old lake bottoms, deposits of calcareous springs, and the stalagmite of caverns are likely places for the discovery of the remains of quadrupeds. Gravel beds under streams of lava; fissures in volcanic rocks; peat-beds, and the clay or marl underlying peat, are all favourable places. Fishes' bones are found occasionally in all sedimentary strata, and are highly interesting from the suggestions they offer of varied and characteristic conditions of life, and causes of death.

Caverns. — These most frequently occur in limestone rocks, and they have yielded a truly wonderful harvest of remains in Europe, South America, and Australia. The bones generally occur in a reddish earth or loam under a stalagmitic crust produced by the dripping of the lime-charged water, which requires being broken up by a pickaxe. As caverns have often been used by wild races of man for places of habitation and burial, a most careful examination should be made to detect any signs of the surface having been anciently broken up near where the bones are found. Even small islands, not now inhabited by any land quadruped, if not very distant from a continent, are almost as likely to contain osseous remains as larger tracts of land. The interest of the discovery of the remains of land quadrupeds in an oceanic island would be extreme: for instance, it has been stated that the tooth of a mastodon has been found in one of the Azores; if this were confirmed, few geologists would doubt that these islands had once been united to Europe, thus enlarging our ideas of the ancient geography of the Atlantic. Nor should the sea-bed be neglected, for in some cases, as in part of the German Ocean, there was dry land while great extinct races of quadrupeds were abundant, and some of their bones are found upon its bed.

Fossil Footprints.—As allied to organic remains, fossil footprints may be here referred to. They have been observed in Europe and North America, in strata of Mesozoic age. These curious vestiges not only proclaim the former existence of reptiles and birds at very remote periods, and in rocks often not containing a fragment of bone, but they generally prove that the level of the land subsided, after the animal had left its impress on the ancient seabeach, thus allowing thousands of feet of marine strata to be thrown down over them. The best place for searching for footprints is in quarries of sandstone, in which the strata are separated by seams of shale. The best indication of their probable occurrence is the rock being "rippled," that is, marked with narrow little wavy ridges, such as occur on most sandy shores when the tide is down, and which indicate that the now rocky surface was once either a tidal beach or a lake-margin, over which the ancient animals walked. In the case of fossil footprints being found, the largest slab which could possibly be removed ought to be brought away, and accurate drawings, or, still better, casts, made of several of the footprints. A plan from accurate measurement ought to be taken of any row of prints. The value of such fossil footprints would be in a manifold degree increased, if the age of the deposit could be determined by shells found in the same stratum or above it.

Coal Deposits. — The origin of coal presents a most curious and difficult problem in geology, and though a vast amount of information has been accumulated on the subject, yet good observations in distant countries would be of the highest value. A very brief statement of the most prominent difficulties in the theory of its origin will, perhaps, be the best guide for further inquiries. If we look first to the coal itself, the frequency with which, both in Europe and North America, upright vegetables have been found in and on the coal, and the curious relation between the presence of coal and the nature of the clayey bed (abounding with roots) on which it rests, can leave no doubt that in these so frequent instances the vegetation whence the coal has been derived grew on the spot where now it is embedded. The regularity and wide extent of the beds of coal, and especially of certain subordinate seams in them, the stratification and fineness of the deposits alternating with the coal, and the rarity of channels (such as would have been formed by a stream or river) cutting through the associated strata, all seem pretty clearly to indicate that the coal was not formed on the surface, like a mass of peat, but under water. What, then, was the nature of those vast expanses of shallow water under which the coal was accumulated? The character of the upright fossil plants, according to our present knowledge, absolutely contradicts the idea of their having been marine forms of vegetation; yet undoubted marine shells and other remains are not infrequently associated with the coal-seams. It is difficult to believe that lakes, allowing, of course, their beds slowly to sink, could contain the vast expanse (sometimes several thousand square miles) and the enormous thickness, amounting in some instances to several thousand yards, of the coal-bearing strata. Nor is it easy to understand how, whilst a broad belt of low land with extensive lagoons near the mouth of some great river very gradually subsided, mud and sand should have been deposited at such a rate on the sinking surface as to keep up the level. On this view, or indeed on any such view, whence, it may be asked, after long-continued subsidence, sufficient to bury even a lofty mountain chain, was derived the sediment which formed the great pile of strata alternating with the coal? Must not an adjoining area have gone on rising, whilst the coal-bearing strata continued to sink? Each seam of coal undoubtedly marks a former surface of growing vegetation. In a coal-field containing thousands of feet of strata there may be dozens of coal-seams, one above another, separated by strata of sandstone shale and other sedimentary strata. Are we to regard the whole succession of strata as pointing to a prolonged depression and the coal-seams as indicating pauses in or reversals of the downward movement? From these few remarks it will be seen how many points deserve careful examination in any new coal district; the chief points being, the presence of upright vegetables and trunks of trees (of the position of which careful drawings should be made), and whether furnished with roots; the nature of the beds on which the coal rests, and generally of all the strata; the continuousness and form of the strata, and whether ripple-marked; the existence of marine animal remains, and whether such lived on the spot, or were drifted into their present positions; and many other similar points. It is superfluous to observe that all fossil plants should be collected; those found upright should be carefully distinguished from those embedded horizontally. The contents of any upright stems and of the roots should be examined, as it appears they have sometimes first become hollow from decay, and then been filled up with mud, which, in some instances, is charged with seeds and leaves, small shells, and bones of reptiles. The last-mentioned case occurs in Nova Scotia.

Salt Deposits.—Information is much required on this subject, and this is a case in which good suites of specimens, illustrating the nature of the rocks beneath and above the salt, would possess much interest. What is the nature and order of sequence of the saliferous strata? Are there layers of calcium-sulphate (gypsum, anhydrite), and are there other chlorides besides common salt, *e.g.*, chlorides of potassium and magnesium? Do the rocks contain any organic remains? Did such live on the spot where now buried? Are the strata regular, or are they crossed by oblique layers, showing the probable action of currents? Are there ripple marks, or beds of coarse pebbles, or other indications of the strata having been deposited in shallow water? What are the thickness, form, and dimensions of the beds of salt? Specimens of the salt and of any associated saline substances ought to be brought home in bottles for analysis. The origin of beds of salt, found in formations of very different ages in different parts of the world, is still somewhat obscure, though in general it would seem to have been due to the evaporation of sea water periodically overflowing extensive shallow basins or low sandy tracts like parts of the Run of Cutch. In some countries there are large lakes of brine often covering thick beds of salt; these deserve examination. On what does such salt or brine rest, whether on the bared underlying strata or on sand or gravel, such as cover the surrounding country? Does the salt contain the remains of animals or plants?

Cleavage.—The slaty structure or cleavage of rocks at first perplexes the young geologist; for, in proportion as it becomes well developed, the planes of stratification or of original deposition become obscure, and are often quite obliterated. As the sea voyager, and especially the surveyor, often visits numerous points on the same line of coast, he possesses some great advantages for studying this subject, and numerous observations made with care would probably give results of general value. The range or strike of the cleavage is uniform over surprisingly large areas, whereas both the angle and point of dip vary much; but there is reason to believe that the planes of inclination, examined across a wide tract transversely to the range, will fall into order and show that they are the truncated edges of a few great curves or domes. The relation of the cleavage-planes to the stratification or axes of elevation, should be carefully noted, and likewise to the general outline of the whole country. Long sections at right angles to the strike of the cleavage, with the dip carefully protracted on paper, would be highly interesting. When two chains of hills, each having its independent cleavage, cross each other careful observations should be made. In all cases any mineralogical difference, however slight, in the parallel cleavage-planes deserves attention, but observations on this head would be hardly trustworthy, unless the planes of stratification were so distinct that there could be no possibility of confounding (as has often happened) cleavage and stratification. Where a stratum of sandstone or of any other rock without cleavage is interstratified with a slaty rock, the surface of junction ought to be minutely examined to see if the slate has slipped along the planes of cleavage, or whether again the mass has not been either stretched or compressed at right angles to these same planes. Fossil shells have been found in slaty rocks, which have had their shapes greatly altered, and all in the same direction. Here, then, we have a guide to judge of the amount and direction of the mechanical displacement which the particles of the surrounding slate rocks have undergone. Observations on cleavage to be useful must be numerous and very accurately made, and should be accompanied by careful measures of the direction and dip of the joints and fissures.

The *foliation* of the metamorphic schists, that is, the origin of the layers of quartz, mica, feldspar, and other minerals, of which gneiss, micaceous, chloritic, and hornblendic schists are composed, is intimately connected with the cleavage of homogenous slaty rocks. Nearly all the proposed observations on cleavage are applicable to foliation. *Wherever large districts of foliated and ordinary slaty rocks unite, observations would be most desirable.* These foliated rocks have all undergone metamorphic action, that is, they have been mineralogically altered and rendered crystalline. Cleavage and foliation are probably essentially due to mechanical movements. Rocks subject to intense lateral pressure have undergone a process of shearing, and their component minerals, crushed into powder, have assumed new crystalline and chemical re-arrangements. But this is a most obscure subject, and one on which it would appear that much further light will not be thrown without the aid of a profound knowledge of mineralogy, petrography, and structural geology. It is now known that granitic rocks, which have been softened or liquefied (as may be told by their sending great veins into, and including fragments of, the overlying rocks), are here and there foliated in a more or less perfect degree. In these cases, we may conceive that the movements which induced foliation took place after the intrusion of these eruptive masses. There is reason to think that much gneiss is really granite which has had a foliated structure super-induced upon it.

Nature of the Sea Bottom.—As every sedimentary stratum has once formed the bed of the sea or of a lake, the importance of observations on the nature and condition of modern subaqueous surfaces is obvions, and no one is so favourably circumstanced for making them as a naval officer on a surveying expedition. The *limits of depth under different latitudes at which the various marine animals live* is an important point for investigation. Not only the shells, corals, sea-urchins, crabs, &c. brought up from different stated depths should be preserved, but the proportionate numbers of each kind should be carefully noted, as well as the nature of the sea-bottom. An observer could not labour too much in this line, and especially if he would subsequently himself undertake to tabulate and work out the results.*

There is another point of view under which the bed of the sea would amply repay long-continued observations. It is well known that the nature of the bottom often changes very regularly in approaching a coast; the pebbles, for instance, increasing in size in a steady ratio with the de-

* The observer who would devote himself to this most interesting and important branch of inquiry should study the methods employed and results obtained in the recent deep-sea exploring expeditions fitted out by the British and other Governments. *See*, in particular, "Narrative of the 'Challenger,'" 1885; Wyville Thomson's "Depths of the Sea," 1873, and "The Atlantic," 1877.

creasing depth. But the means by which the pebbles are thus sorted is not sufficiently known: is it by the oscillation of the waves at ordinary periods, or only during gales; or is it by the action of currents? *A chart, with the nature of the bottom carefully noted on it and the currents laid down,* would by itself throw some light on this question. The nature of the pebbles being observed, perhaps a point would be found whence they radiated. Excellent observations have been made by engineers on the travelling of shingle-beaches, but scarcely anything is known of their movement under water. In what condition are the pebbles?—are they encrusted (as often happens) with delicate corallines?—after a heavy gale are the spines of such corallines found broken? In narrow channels where there are rapid currents, and in the open sea in front of straits, where the water often deepens suddenly, what is the nature of the bottom? To what depth does the sea in a storm render the water muddy? How far from the beach, and to what depth, does the recoil of the waves, or the "undertow," act, for instance, on light anchors? At what depth can the sea wear solid rock? This may sometimes be judged of by the nature of the bottom; thus, when soft mud overlies at all times, even after gales of wind, a submarine rocky surface, which from the nature of the adjoining coast-strata we may feel sure has been worn down, we may infer that the sea at its present level, and under existing circumstances, is not a destroying but a depositing and protecting agent. Is it at the line of high or low water, or between them, that the breakers most vigorously eat into coast-cliffs? Gigantic fragments of rock, much too large to be themselves rolled about, may be seen at the foot of almost every line of high cliffs; by what means in the course of time will these be removed, as must have happened with their innumerable predecessors? Are they slowly worn away or broken up? It may be well to recollect that in the tropics the powerful action of frost in splitting stones is entirely eliminated; but its place is in some measure supplied by the influence of great and rapid changes in temperature between day and night and also of saturation by rain and desiccation by the baking action of solar heat. Our observations, moreover, on the alluvial and sub-littoral deposits of tropical latitudes are not perplexed by the ancient effects of floating ice. The spray of salt water, above the line of breakers, corrodes by chemical decomposition calcareous rocks; does this play any important part on other rocks? Most bold coasts are fronted by sharp promontories and even isolated pinnacles; are these *exclusively* due to the greater hardness of the rocks composing them, or do not the breakers act more efficiently when eddying round any slight projection, or gradually penetrating into fissures?

Rocks rising steeply out of the open ocean, and exposed to the incessant wash of the heaviest surf, are often thickly coated over with various marine animals, and this would seem to indicate that water alone does not wear away hard rocks, though the waves may occasionally tear off large fragments. Is the washing to and fro of pebbles, or of sand, a necessary element in the eroding power of waves on hard rocks? but how comes it that small, land-locked harbours, where the waves can hardly have force to move the shingle, should ever be surrounded by cliffs, which, in most cases, clearly prove that considerable masses of rock have been worn down into mud and removed? Again, at a moderate depth, where the bottom is covered with shingle, does the rolling to and fro of the pebbles wear away solid rock? if so, the pebbles would be clean, and the submarine rocky surface probably worn into furrows or channels at right angles to the beach. Where there are violent currents and eddies, are deep round holes worn in the bottom below low-water mark, like those produced by eddies in river channels and along rocky sea-shores? This, perhaps, might be ascertained by a long pole at the turn of the tide: deep round holes have been observed on rocks formerly covered by the sea, and their origin has perplexed geologists. Any person steadily attending to these subjects will occasionally be enabled to form an opinion on points at first appearing hopelessly obscure to him. The common deep-sea lead, especially if made a little bell-shaped and well armed, gives a surprisingly good picture of the bottom. There can be no doubt that whoever will for a long period collect and compare observations, made over wide areas and under different circumstances, will arrive at many curious, novel, and important results.

An observer occasionally may come to a district where lately some great aqueous catastrophe has occurred, such as the bursting of a lake temporarily formed by a landslip, or the rush of a great earthquake-wave over low land. In such cases all the effects produced, such as the thickness and nature of any deposit left — whether stratified irregularly or continuously — whether any rocky surface, over which the debacle has passed, be scored or smooth; all such points should be minutely described, and measurements taken of any great blocks which may have been transported: the great desideratum is accuracy and minuteness.

Ice Action.—The voyager in the Polar Seas would render an excellent service to geology by observing all the effects which icebergs produce in rounding, polishing, scoring, and shattering solid rocks, and likewise in transporting gravel and boulders. Floating ice under two forms is known to transport fragments; namely, coast-ice, in which the stranded boulders are frozen, and icebergs detached from the seaward ends of glaciers, on the surface of which masses of rock may have previously fallen from surrounding precipices. It is obvious that in the latter case the fragments will generally be quite angular, and they cannot be landed in water shallower than the thickness of the submerged ice, requisite to float the berg. On the other hand, the boulders frozen in coast-ice will generally be previously water-worn, and may be landed on an ordinary beach, or be driven by the force of the pack high and dry, and perhaps left piled in strange positions. All facts illustrating the difference in the results produced by coast-ice and true icebergs would be very valuable. Do the boulders fixed on coast-ice, when driven over rocky shoals, become themselves scored? Wherever there is reason to believe that a surface has been scored by recent ice-action, a minute description and drawings ought to be made of the depth, length, width, and direction of the grooves; and even large slabs brought home. On true icebergs, are the fragments of rock generally fixed or loose; when icebergs turn over, are fragments frequently seen embedded in that part which was under water; and how were they fixed there? The nature, number, size, form, and frequency of occurrence ot all fragments of rock seen on floating ice ought to be recorded, and the distance from their probable source. A polar shore, known from upraised organic remains to have been lately elevated, would be eminently instructive. Do great icebergs force up the mud and gravel at the bottom of the sea in ridges like the moraines of glaciers? Can shells or marine animals exist in a shallow sea often ploughed up and rendered turbid by the stranding of icebergs? The dredge alone could answer this. The means of distinguishing the effects of ancient floating ice from those produced by ancient glaciers, especially where, as now in Spitzbergen and Greenland, they entered the sea, are, at present, a great desideratum in geology.

Erratic boulders occur in Europe, North America, and in the southern parts of South America, which were transported by ice-sheets, glaciers, or floating ice. Erratic boulders, when not of gigantic size, may be confounded with rounded stones, transported by occasional great floods or by the coast action of the surf during slow changes of level of the land. Masses of granite, from often disintegrating into large, apparently water-worn boulders, and then rolling downwards, have several times been erroneously described as belonging to the erratic class. Where the nature of all the rocks in the vicinity is not perfectly known, great size and the angularity of the fragments (though by no means a constant concomitant) are the most obvious distinctive characters; but even when the surrounding country is not at all known, the composition of a single isolated hill or small island may easily be ascertained, and, if large fragments of foreign rock lie strewed on its surface, these may be assumed almost certainly to be erratic boulders. Here, however, a caution has been found necessary; for in the case of fragments of *sedimentary* rocks, they may be the last remnant of a denuded overlying formation. Wherever erratic boulders are found, their composition, form—especially observing whether they are angular, water-worn, or scored, —and their size, from actual, though rude measurements, should be given.

Both in the north and south of Britain, in Northern Europe, and in Canada and the northern parts of the United States, a peculiar formation, called "till," or boulder clay, has been found connected with erratic boulders; it consists generally of stiff, earthy clay, containing angular and rounded stones of all sizes up to the largest boulders, mingled in utter confusion, and generally without any distinct stratification. Such deposits should be examined. Sometimes the upper beds, when they are stratified, have been found violently contorted, whilst the lower ones are undisturbed, showing that the violence has not proceeded from below, as in ordinary geological cases. As Lyell suggested, this effect has probably been produced by the stranding of great icebergs or heavy sheets of floe-ice.

As far as our present knowledge goes, the above enumerated phenomena—such as scored, mammillated, and polished rocks, moraines, erratic boulders, and beds of "till,"—though occurring in latitudes where glaciers do not now occur, where the sea is never frozen, and where icebergs are never drifted—yet have not been observed in low countries, in either hemisphere, farther from the pole than about latitude 40°. Hence, on whatever coast ancient ice action may be discovered, *the limit of latitude towards the tropics at which it ceases ought to be carefully investigated.* Observations are much wanted on the west coast of North America and the east coast of Asia. The period of the ice-action is pretty well ascertained in Europe and North America, and a great service would be rendered to geology if the same point could be clearly made out in the southern hemisphere. Much information on this subject has now been obtained in New Zealand.

Distribution of Organic Beings.—As geology includes the history of the organic inhabitants, as well as of the inorganic materials, of the world, facts on distribution come under its scope. Earth has been observed on icebergs in the open ocean; portions of such earth ought to be collected, washed with fresh water, filtered, gently dried, wrapped up in brown paper, and sent home by the first opportunity, to be tried, with due precautions, whether any seeds still alive are included in it. Again, the roots of any tree cast up on an island in the open ocean should be split open, to see if any earth or stones are included (as often happens), and this earth ought to be treated like that from icebergs; it is truly surprising how many seeds are often contained in extremely small portions of earth. The earthy crust enclosing the teeth in fossil jaw-bones should be carefully examined; numerous seeds have in this way been obtained from the interstices of the teeth of mammoths buried in boulder-clay. Any graminivorous bird, caught far out at sea, ought to have the contents of its intestines dried for examination. The zoologist who, with a towing-net, fishes for floating minute animals ought to observe whether seeds are thus taken. These experiments, though troublesome, undoubtedly, would be well worth trying. All facts or traditional statements by the inhabitants of any island or coral reef, on the first arrival of any bird, reptile, insect, or remarkable plant, ought to be collected. In those rare cases in which showers of fish, reptiles, shells, earth, seeds, confervæ, &c., have fallen from the sky, every fact should be recorded, and specimens collected.

Volcanic Phenomena.—The voyager will probably have ample opportunities of examining volcanic islands, and perhaps volcanoes in eruption. With respect to the latter, he ought to record all that he sees; should the exact position of the orifice be known, he might, perhaps, by observing some point in a cloud, measure with a sextant to what height the fragments were shot forth, and the height of the often flat-topped column of ashes. Having surveying instruments, he ought to map, as carefully as time will permit, any crater remarkable for its size, depth, or peculiar form. The size, composition, thickness, degree of cellularity, and angle of slope, of any lava stream ought to be described wherever its internal structure can be made out.

Round many active and extinct volcanoes, both on continents and on islands, there is a circle of mountains, steep on their inner, and gently inclined on their outer flanks. The volcanic strata, of which they are composed, everywhere dip away from the central space. These mountains form the so-called "craters of elevation," the origin of which formerly excited much controversy. There is a grand range of mountains of this class at the Mauritius and at St. Jago in the Cape de Verdes, parts only of which have been described. The chief points to attend to are, the *inclination* of the lava-streams by actual measurement, their thickness, compactness, and composition; the *form and height of the mountains*, and whether they have suffered much wear and tear from sub-aërial denudation, and from the ancient action of the sea when the land stood at a lower level; *whether the mountains are traversed by many dikes*, of which the common direction ought to be recorded; *how far the mountains stand apart, and the diameter and outline of the rude circle which they together form.* In fact, a most useful service would be rendered by mapping any of these "craters of elevation," or what would be more feasible, drawing from actual measurements two sections at right angles to each other, across the circle.

Some streams of lava, especially those belonging to the trachytic series (harsh, generally rather pale-coloured lavas, with crystals of glassy feldspar), are laminated. The course of the layers with respect to the course of the stream ought to be minutely studied, both on the surface, at the termination, and on the flanks of the stream; and, if by a most fortunate chance there should have been formed a transverse section, throughout its entire thickness, this would be a very interesting subject for investigation. A series of specimens ought to be brought away to illustrate the nature of the lamination. It is desirable also to collect a sample of every distinct kind of lava, for subsequent microscopic examination and comparison with the known lavas of other regions. Attention of the same kind should be paid to the more remarkable varieties of ashes or tuffs.*

Aërial Dust.—Fine brown-coloured dust has often fallen on vessels far out at sea, more especially in the middle of the Atlantic. This should be collected; the direction and force of the wind (and the course of any upper current, as shown by the movement of the clouds) on the same day, and for some previous days, ought to be recorded, as well as the date, and the position of the ship. Such dust has been shown by Ehrenberg to consist, in many cases, almost entirely of the siliceous envelopes of infusoria. Most of it in the eastern Atlantic and Mediterranean regions appears to come from the African deserts, borne away by dust-storms. The distance to which real volcanic dust is blown is, likewise, in some respects well worth determining. Much attention has been given in recent years to the fall of "meteoric dust." Small granules of metallic iron and minute mineral spheres (*chondres*) dredged up in the mud of the deepest parts of the ocean remotest from land, have been recognised as probably derived from the fall of meteoric matter upon the surface of the ocean. The rate of accumulation of sediment in these oceanic abysses is so slow that the iron grains, which would otherwise be lost in fast gathering mud, can be detected.

Elevation of the Land.—The changes of level, often accompanying earthquakes, are treated of at p. 320, but a few remarks on the nature of the evidence to be sought on changes of level not actually witnessed by man, may be here inserted. Many appearances, such as lines of inland cliffs, of sand hillocks, eroded rocks, and banks of shingle, often indicate the former effects of the sea on the land when the latter stood at a lower level. But the best evidence, and the only kind by which the period can be ascertained (for the

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* Students who desire further details regarding volcanic phenomena should consult Scrope's "Volcanoes," 2nd edit., 1872, or "Vulkane und Erdbeben," by K. Fuchs, 1875. But for most ordinary observers the information supplied in the general text-books cited at the close of this article will be sufficient.

appearances above enumerated, though well preserved, may sometimes be of considerable antiquity), is the presence of upraised recent marine remains. On land which has been elevated within a geologically recent time, sea-shells are often found, either embedded in thin layers of sand and mould, or scattered on the bare surface. In these cases, and especially in the latter case, great caution is requisite in testing the evidence ; for man, birds, and hermit-crabs often transport, in the course of ages, an extraordinary number of shells. In the case of man, the shells generally occur in heaps, and there is reason to believe that this character is long preserved. To distinguish the shells transported by animals from those uplifted by terrestrial movement, the following characters may be used :—Whether the shells seem to have long lain dead under water, as indicated by barnacles, serpulæ, corallines adhering to their *insides;* whether the shells, either from not being full grown or from their kind, are too small for food; remembering that certain shells, as mussels, may be unintentionally transported by man or other animals in their young state while adhering to larger shells ; and lastly, whether all the specimens have the same appearance of antiquity. Some shells, which have been exposed for many ages, yet retain their colours in a surprising manner. The very best evidence is afforded by barnacles and boring shells being found attached to or buried in the rock, in the same positions in which they had lived; these may be sometimes found by removing the earth or birds' dung covering points of rock. Where shells are embedded in a superficial layer of soil, though it may appear exactly like vegetable mould, specimens of it should be preserved, for the microscope will sometimes reveal minute fragments of marine animals. In all these cases specimens of the shells, though broken and weathered, and having a wretched appearance, must be carefully preserved; for a mere statement that such upraised shells resembled those still living on the beach is absolutely of no value. It should be noticed whether the proportional numbers between the different kinds appear to be nearly the same in the upraised shells and in those now cast on the beach. The height at which the marine remains occur above the level of the sea should be measured. In confined situations, where the change of level appears to have been small, much caution must be exercised in receiving any evidence ; as a change in the direction of the currents (resulting from alterations in neighbouring submarine banks) may cause the tide to flow to a somewhat less height, and thus give the appearance of the land having been upraised.

Wherever a tract of country can be proved to have been recently elevated, its surface, as exhibiting the late action of the sea, is a fertile field for observation. On such coasts, terraces rising like steps, one above another, often occur. Their outline and composition should be studied, diagrams made of them, and their height measured at many and distant parts of the coast. There is reason to believe that in some instances such terraces range for surprisingly long distances at the same height. Where several occur on opposite sides of a valley a spirit level is almost indispensable in order to recognise the corresponding stages. Where ranges of cliffs exist, the marks of the erosion of the waves may sometimes be expected to occur, and as these generally present a defined line, it is particularly desirable that their horizontality should be ascertained by good levelling instruments, and, if they be not horizontal, that their inclination should be measured. Where more than one zone of erosion can be detected all should be levelled, for it does not necessarily follow that the several lines are parallel. Along extensive coasts, and round islands which have been uplifted to a considerable height, and where we now walk over what was, within a late geological period, the bed of the sea, it would be well to observe whether extensive sedimentary deposits have been upraised, for it has often been tacitly assumed that sedimentary deposits are in process of formation on all coasts.

Subsidence of the Land.—This movement is more difficult to detect than elevation, for it tends to hide under water the surface affected by it. Evidence, therefore, of subsidence is very valuable, and this movement, moreover, has probably played a more important part in the history of the world than elevation, for there is reason to believe that most great formations have been accumulated whilst the bed of the sea was sinking. Subsidence may sometimes be inferred from the form of the coast land; for instance, where a line of cliffs plunges precipitously into a sea so profoundly deep that it cannot be supposed that the now deeply submerged portions of the cliff have been simply worn away by currents. The direct evidence of subsidence, if not witnessed by man, is almost confined to the presence of stumps of trees, peat beds, and ruins of ancient buildings partly submerged on tidal beaches. Ancient buildings may sometimes afford such evidence in unlikely situations; it has been asserted that in one of the volcanic islands in the Caroline archipelago there are ruins with the steps covered by the sea. Again, at Terceira, at the Azores, there is an old church or monastery said to be similarly circumstanced.

*Coral-Reefs.**—The most important points with respect to coral reefs, which can be investigated, are the depth at which the bottom of the sea, outside the reef, ceases to be covered with a continuous bed of living corals, the nature of the slope below the lower limit of the outer edge of the reef, whether owing to the action of the breakers large masses of the coral rock are piled up on that slope, whether any evidence can be found that the reef advances seaward on the summit of such a talus, and whether any proof can be obtained that the sea-water, either outside or within the lagoon, exercises a solvent action on the dead coral. To obtain such information repeated soundings should be taken with a heavy and very broad bell-shaped lead, armed with tallow, which will break off minute portions of the corals or take an exact impression of them, and also instantly show how soon the bottom becomes covered with sand. These questions ought to be investigated in different seas, under different latitudes, and under different exposures. For collecting specimens of the corals it is to be feared that the dredge would become entangled, but chains and hooks may be lowered for this purpose. There is reason to suspect that different species of corals grow in different zones of depth, so that, in collecting specimens, the depth at which each kind is found, and at which it is most abundant, should be carefully noted. It ought always to be recorded whether the specimen came from the tranquil waters of a lagoon or protected channel, or from the exposed outside of the reef. The small reefs within the lagoons of certain atolls (or lagoon islands) in the Indian Ocean all rise to the surface, whereas in other atolls not a single reef rises within several fathoms of the same level. It would be a curious point to ascertain whether the corals in these cases

* The most complete works on this subject are "The Structure and Distribution of Coral Reefs," by Mr. Darwin, and "Corals and Coral Islands," by Prof. Dana.

consisted of the same species, and if so, on what possible circumstance this singular difference in the amount of their upward growth has depended.

Any facts should be collected which can elucidate the conditions under which a coral-reef first starts up and the rate at which corals can grow under favourable circumstances, nor should negative facts, showing that within a given period reefs have not increased either laterally or vertically upwards, be neglected. In a full-grown forest, to judge of its rate of growth, a part must be first cut down; so is it probably with reefs of corals. The aborigines of some of the many coral-islands in the great oceans might perhaps adduce positive facts on this head; for instance, the date might be known when a channel, since closed by the growth of the coral, had been cut to float out a large canoe.

For the classification of coral-reefs the most important point to be attended to is the inclination of the bed of the adjoining sea, and, secondly, the depth of the interior lagoon in the case of atolls, and of the channel between the land and the reef, in encircling or barrier, and in fringing reefs. Whenever it is practicable soundings ought to be taken at short ascertained distances, from close to the breakers in a straight line out to sea, so that a sectional outline may be protracted on paper. In those cases in which the bottom descends by a set of ledges or steps, their form ought to be particularly attended to, and whether they are covered with sand or with dead or living coral, and whether the corals differ on the different ledges. The same points should be attended to within the lagoon, wherever its bed or shore is step-formed; the origin of these steps or ledges is at present obscure. In the Indian and Pacific Oceans there are entire reefs, having the outline of atolls or lagoon islands, lying several fathoms submerged; there are likewise defined portions of reefs both in atolls and in encircling reefs similarly submerged. It would be particularly desirable to ascertain what is the nature of these submerged surfaces, whether formed of sand or rock or of living or dead corals. In some cases two or more atolls are united by a linear reef; the form of the bottom on each side of this connecting line ought to be examined. Where two atolls or reef-encircled islands stand very near each other the depth between them might be attempted by deep soundings; the bottom has been struck between some of the Maldiva atolls. Generally the form and nature of the reefs encircling islands ought to be compared in every respect with the annular reefs forming atolls.

On the shores of every kind of reef, especially of atolls and of land encircled by barrier reefs, *evidence of any change of level of the land* should be particularly sought for ; stumps of trees, the foundation posts of sheds, and wells, graves or other works of human origin now standing beneath the level of high-water mark, and which there was good reason to believe must have once stood above its level, would serve to mark subsidence, while, on the other hand, sheets of dead coral rising high above sea-level would afford proof of elevation. The observer must bear in mind, however, that cocoa-nut trees and mangroves will grow in salt water. If evidence of change of level be found, inquiry ought to be made whether earthquakes have been felt, or if volcanic eruptions have occurred. All masses of coral standing so much above the level of the sea that they could not have been thrown up by the breakers during gales of wind at a period when the reef had not grown so far out seaward should be investigated and their heights measured. There is reason to believe that some coral-reefs have been thought to have been upraised, owing to the effect of the lateral or horizontal extension of the reefs having been overlooked; for the necessary result of this outward growth is gradually to break the force of the waves, so that the rocks, now further removed from the outer breakers, become worn to a less height than formerly, and the more inland corals, not being any longer constantly washed by the surf, cease to live at a level at which they once flourished. It is indispensable that specimens of all upraised corals, and especially of the shells generally associated with them, should be collected, for there can be no doubt that ancient strata containing corals have in some instances been confounded with recent coral rock. It was Mr. Darwin's belief that all the characteristic differences between atolls and encircling reefs on the one hand, and fringing reefs on the other, depend on the effect produced on the upward-growing corals by the slow sinking of their foundations. More recently another view has been proposed, according to which coral-reefs begin on the tops of submarine peaks or banks, and after building up to low-water line proceed to grow outward upon the talus of loose blocks and fine detritus torn off from their sea-fronts by breakers. Subsidence would not in this case be necessary, and instances of elevation in a region of atolls (so hard to account for on the theory of subsidence) offer no difficulty. Hence the importance of obtaining more information regarding this most interesting question.

A thick and widely extended mass of upraised recent coral-rock has never yet been accurately examined, and a careful description of such a mass—especially if the area included a central depression, showing that it originally existed as an atoll—is a great desideratum. Of what nature is the coral rock; is it regularly stratified or crossed by oblique layers; does it consist of consolidated fine detritus or of coarse fragments, or is it formed of upright corals embedded as they grew; and to what extent is the structure of the corals obliterated by the crystalline texture superinduced by infiltrating water, which carries carbonate of lime in solution and allows it to crystalline in the minute pores and interstices of the rock? Are many shells or the bones of fish and turtle included in the mass, and are the boring kinds still in their proper positions? The thickness of the entire mass and of the principal strata should be measured, and a large suite of specimens collected.

In conclusion, it may be re-urged that the young geologist must bear in mind that *to collect specimens* is the least part of his labour. If he collects *fossils* he can hardly go wrong; if he be so fortunate as to find the *bones of any of the higher animals*, he will, in all probability, make an important discovery. Let him, however, remember that he will add greatly to the value of his fossils by *labelling* every single specimen, by never *mingling* those from *two formations*, and by describing the *succession of the strata* whence they are disinterred. But let his aim be higher: by making sectional diagrams as accurately as possible of every district which he visits (nor let him suppose that accuracy is a quality to be acquired at will), by collecting for his own use, or for subsequent microscopic study and comparison, well-selected rock-specimens, and by acquiring the habit of patiently seeking the cause of everything which meets his eye, and by comparing it with all that he has himself seen or read of, he may, even without any previous knowledge, become a good geologist, and will enjoy the high satisfaction of contributing to the completion of the history of this wonderful world.

BOOKS ON GEOLOGY AND ALLIED SUBJECTS.

PRACTICAL INSTRUCTION:

The Geological Observer. H. T. De la Beche. 1855.
Outlines of Field Geology. A. Geikie. 3rd edition. 1884.
Führer für Forschungsreisende. F. von Richthofen. 1886.

GENERAL TEXT BOOKS:

Principles of Geology. C. Lyell.
La Terre. E. Reclus.
Physische Erdkunde. Oscar Peschel. 1885.
Text-book of Geology. A. Geikie. 2nd edition. 1885.
Geology. A. H. Green. (Part I., Physical Geology.) 1882.
Manual of Geology. J. D. Dana.
Traité de Géologie. A. De Lapparent.
Elemente der Geologie. H. Credner.

MINERALOGY (but *see* the Article on this subject at p.):

Elemente der Mineralogie. Naumann-Zirkel.
Text-book of Descriptive Mineralogy. H. Bauerman. 1884.
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Manual of Determinative Mineralogy. G. J. Brush.
Elderhorst's Manual of Qualitative Blow-pipe Analysis. Nason and Chandler.

PETROGRAPHY:

The Study of Rocks. F. Rutley. 1879.
Mikroskopische Physiographie der petrographisch wichtigen Mineralien. H. Rosenbusch. 1885.
Lehrbuch der Petrographie. F. Zirkel. 1866.
Mikroskopische Beschaffenheit der Mineralien und Gesteine. F. Zirkel.

PALÆONTOLOGY:

Manual of Palæontology. H. A. Nicholson. 2nd edition. 1879.
Palæontology. R. Owen. 2nd edition. 1861.
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ARTICLE XI.

Fourth Division, Section 2.

MINERALOGY.

By the late Sir HENRY DE LA BECHE, C.B., F.R.S., &c.

(*Revised for this Edition by Professor W. J. Sollas, LL.D., D.Sc.*)

A glance at the best treatises on mineralogy, even those wherein the matter is most condensed, is sufficient to show that a profound acquaintance with this science can only be acquired by careful study, and by means of a competent knowledge of certain other sciences, the aid of which must be obtained properly to comprehend the internal and external structure and chemical composition of minerals. The naval man may nevertheless accomplish much, more especially respecting the mode of occurrence and probable origin of minerals under certain conditions, and he may also add by his researches to the catalogue of known substances of this class, and may discover new varieties of known minerals.

To classify the natural substances described under the head of mineralogy, very various methods have been adopted, chiefly, however, divisible into those based upon their external characters or chemical composition.

About 800 mineral substances are supposed to differ sufficiently to entitle them to be regarded as distinct species, independently of many merely considered as varieties, or accidental. It will be obvious that a voyager, especially when his general time may be occupied with other duties (only a portion of it applicable to mineralogy, and that irregularly), cannot expect to make himself familiar with all these substances. With many of those more commonly found he will have little difficulty, and by practice he will readily detect them when presented to his attention. Those which form the constituents of rocks it is especially necessary to learn and distinguish, since so much of geological importance often turns upon their proper determination. Those which are referable to the useful class should engage his attention, since while, on the one hand, valuable ores of the useful metals and other important substances are often neglected (even in our mining districts unusual though valuable ores have been thrown away at no very remote times); on the other, many a mineral, commercially worthless, is treasured up, often even to the neglect of those of high value, some particular brilliancy of appearance or fancied resemblance to precious or metallic substances having misled the collector.

The voyager, if he possessed no other means of distinguishing minerals from each other than chemistry afforded him, would in many instances, from the want of the needful space and appliances on board ship, have the extent of his mineralogical labours greatly abridged. At the same time, with a box containing certain chemical substances, a small stock of apparatus, and a blow-pipe, he will, after a little practice, find his power to distinguish minerals chemically far greater than he might at first anticipate.

For an account of the characters of minerals, and the methods of observing them, the voyager is referred to the following treatises:—Adam, "Tableau mineralogique: Paris, 1869." Bauerman, "Text-book of Descriptive Mineralogy, London, 1884." Bombicci, "Corso di Mineralogia, Bologna, 1875." Blum, "Lehrbuch der Oryktognosie, Stuttgart, 1854." Dana, "System of Mineralogy, New York, 1883." Des Cloizeaux, "Manuel de Mineralogie, Paris, 1874." Greg and Lettsom, "Manual of the Mineralogy of Great Britain and Ireland, London, 1858." Haidinger, "Handbuch der bestimmenden Mineralogie, Wien, 1851." Kengott, "Tabellarischer Leitfaden der Mineralogie, Zürich, 1859." Naumann-Zirkel, "Elemente der Mineralogie, Leipzig, 1881." Phillips, "Elementary Introduction to Mineralogy, London, 1852." Quenstedt, Handbuch der Mineralogie, Tübingen, 1877."

The characters of greatest importance in the discrimination of mineral species are—form, cleavage, fracture, lustre, colour, streak, hardness, specific gravity, and the chemical reactions. Hardness, lustre, colour, and streak are easily observed, yet, being frequently alike in different minerals. and not admitting of being measured with much accuracy, they cannot be considered as exact determinative characters. Specific gravity is one of the most important distinctive characters, and admits of being observed with exactness. It may be readily determined, and with quite sufficient accuracy for all practical purposes, by Jolly's spiral spring balance (made by Berberich of Munich), or Walker's balance, described in the Geological Magazine, Decade 2, vol. 10, p. 109. More exact results are obtainable by the method of immersion in heavy liquids. The reader should consult a valuable article by Prof. Judd, "On the methods "which have been devised for the rapid determination of "minerals and rocks" (Proc. Geol. Assoc., vol. viii., p. 278).

A useful list of specific gravities is given in the "Annuaire" published by the Bureau des Longitudes, Paris. Other characters most to be relied on for the determination of species are—form, cleavage, and the chemical reactions.

On breaking a crystallized mineral, it generally exhibits a tendency to split in the direction of one or more planes, called cleavages. In many cases the blow of a small hammer is sufficient to produce the cleavage: in others, especially when the direction of cleavage is previously unknown, the mineral should be supported upon a block of wood, and the point of a needle, or that of a sharp punch, hammered into it. When the direction of the cleavage is approximately known, the mineral may be struck by the edge of a small chisel driven by a hammer, or pressed between the edges of a pair of wire-nippers, the edge or edges being nearly in the direction of the cleavage. It is found that in the same mineral the cleavages are always disposed in the same manner, forming constant angles with each other, and with the faces of the crystal.

Instruments called *goniometers* have been invented for measuring the angles which the faces (including the cleavage planes under that term) make with each other. By comparing the observed angles with the angles recorded in books on Mineralogy, we either arrive at once at a knowledge of the species of the mineral, or else ascertain that it belongs to one of a more or less limited number of species. For this purpose the cleavages are usually more useful than the natural faces, because being frequently brighter, the angles they make with each other can be more easily and more accurately measured, and also because, being fewer in number, there is little difficulty in identifying them with the cleavages recorded in the descriptions of mineral species.

Carengeot's goniometer, used by Haüy, is incapable of affording results sufficiently accurate; Wollaston's reflective goniometer is consequently the only instrument the use of which can be recommended. A full description of the method of observing with it is given in Phillips's "Mineralogy," edition of 1852, and in Mallard's "Crystallographie," vol. I., 1879. It is a common mistake to suppose that crystals seldom occur with faces sufficiently bright for measurement with this instrument. When a small screen, at a distance of from 10 to 20 feet from the observer, having in it a hole of a square inch in area, through which the light of the sun is reflected from a plane mirror, is used for the bright signal, it is difficult to find crystals which have not faces bright enough to allow the angles they make with each other to be measured with very tolerable accuracy. The flame of a good lamp or candle serves very well for the bright signal, but is much inferior to sunlight. The crystal should be attached to the branch of the goniometer with a cement composed of bees-wax, a little olive oil, and a very small quantity of honey, melted together and stirred till nearly cold. The consistence of the cement should be such as to admit of its being moulded between the fingers. It is important also that the crystal should be more distant from the circle than any part of the branch which carries it. For otherwise, in one position, the branch comes between the bright signal and the crystal, it conceals the faint signal in another, and the crystal itself in a third position.

A description, by Mitscherlich, of a very portable form of reflective goniometer occurs in the Transactions of the Academy of Sciences of Berlin for 1843.

A knowledge of elementary crystallography sufficient for the observer's purpose may be gained from the chapter on that subject usually given in mineralogical treatises, or from either of the following works, with the assistance, if possible, of a small collection of models of crystals:— Bauerman's "Systematic Mineralogy," London, 1882. Kopp's "Einleitung in die Krystallographie, Braunschweig, 1862." Rammelsberg's "Krystallkunde, Berlin, 1852." Regnault's "Crystallography." Rose's "Elemente der Krystallographie, Berlin, 1838." Mathematical Crystallography is treated of in:—"A tract on Crystallography, by W. H. Miller, Cambridge, 1863." "Lehrbuch der Krystallographie von Viktor v. Lang, Wien, 1866." "Lehrbuch der Krystallographie und Mineral-Morphologie von Albrecht Schrauf, Wien, 1866." "Traité de Crystallographie, Mallard, vol. i., Paris, 1879." An excellent exposition of Miller's system is given in Gurney's Crystallography (Manuals of Elementary Science, Crystallography, published by the Society for the Promotion of Christian Knowledge). The student would do well to purchase a good set of models of crystals. Models in wood can be obtained from Dr. Krantz of Bonn; J. R. Gregory, 15, Russell Street, Covent Garden, and, in earthenware, from Messrs. J. J. Griffin & Son, 22, Garrick Street, Covent Garden.

Care must be taken not to confound true crystals with pseudomorphous minerals, which in form resemble certain known minerals, but have a different chemical constitution. Some of these appear to have been produced by the filling of a mould, left by the disappearance of one mineral, with the matter of another of dissimilar chemical composition. Thus at St. Agnes and St. Just, in Cornwall, cavities left by crystals of feldspar are found to be filled up with a mixture of grains of cassiterite and quartz sand. Others would appear to have been formed in a different manner, there being little reason to suppose that, like the pseudomorphous minerals before mentioned, they have merely filled up moulds left by the disappearance of the original minerals. On the contrary, the elements of the new mineral seem gradually to have replaced the old mineral, so that the original form is always retained. Now and then specimens are found wherein parts of the original crystals still occur, the remainder being replaced by another substance.

Further information on the subject of pseudomorphous minerals is to be found in Haidinger's papers in Poggendorff's "Annalen," vol. ii., pp. 173, 366; vol. lxii., p. 161; and in Blum's "Die Pseudomorphosen des Mineralreichs, Stuttgart and Heidelberg, 1843–79." An abstract of Blum's treatise and first supplement is given by Dana in "Silliman's Journal" for 1845, vol. xlviii., p. 66, and 1848, vol. vi., p. 267.

It is probable that to chemical composition the voyager will chiefly look for aid, more especially if he be a medical officer, and therefore likely to have become sufficiently acquainted with chemistry for the purpose. The following works will be found useful:—Will's "Outlines of Qualitative Analysis," Fresenius's "Qualitative and Quantitative Analysis," Parnell's "Qualitative and Quantitative Analysis," Rammelsberg's "Leitfaden für die qualitative chemische Analyse," Rammelsberg's "Anfangsgründe der quantitativen mineralogisch und metallurgisch-analytischen Chemie," Rammelsberg's "Handbuch der Mineralchemie, Leipzig, 1875," and Rose's "Analysis," translated by Normandy. We would suggest that no surveying voyage should be sent, more particularly to distant countries, without one of those little chests of needful things for chemical research which are prepared for the purpose.* The determination of the chemical composition of a mineral by the wet method is not likely to succeed, except in the hands of a person tolerably well versed in practical chemistry; but by a little practice much knowledge of the constituents of a mineral may be acquired by the blowpipe, or what may be termed the dry method. Works especially dedicated to this mode of investigation, are,—Berzelius, "Die Anwendung des Lothrohr, &c.," Nurnberg, 1846. Translated by J. D. Whitney, Boston, U.S., 1845. Brush, "Manual of Determinative Mineralogy with an Introduction on Blowpipe Analysis," New York, 1878. Elderhorst, "Manual of

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* J. J. Griffin & Sons (of 22, Garrick Street, Covent Garden) and others fit up very compact and useful chests of this kind. They necessarily vary in price according to their contents. For about 8*l.*, a chest of about $1\frac{1}{2}$ cubic feet, not a cumbrous size for a cabin, may be obtained. It would contain apparatus and substances sufficient for discriminating all well-known ores and minerals, including a blowpipe apparatus with the necessary fluxes and re-agents, as also a selection of the most useful instruments for testing in the wet way, with a collection of tests in the dry state, and stoppered bottles to contain solutions; also a set of bottles with pure acids.

More complete chests may be obtained for about 15*l.* or 16*l.*—far more valuable for long voyages, during which deficiencies cannot be expected to be supplied. These are divided into two chests, one containing the things needful for more constant, the other large articles for occasional use, as well as duplicates of apparatus liable to be broken, with an extra stock of chemicals. These chests usually occupy about 4 cubic feet, and contain apparatus and chemicals sufficient for the complete quantitative analyses of minerals, or the separation of the component parts of a mineral, in quantities sufficient for an accurate analysis. They include platinum crucibles, Bohemian test tubes, Berlin porcelain crucibles and capsules, complete blowpipe apparatus, &c., &c.

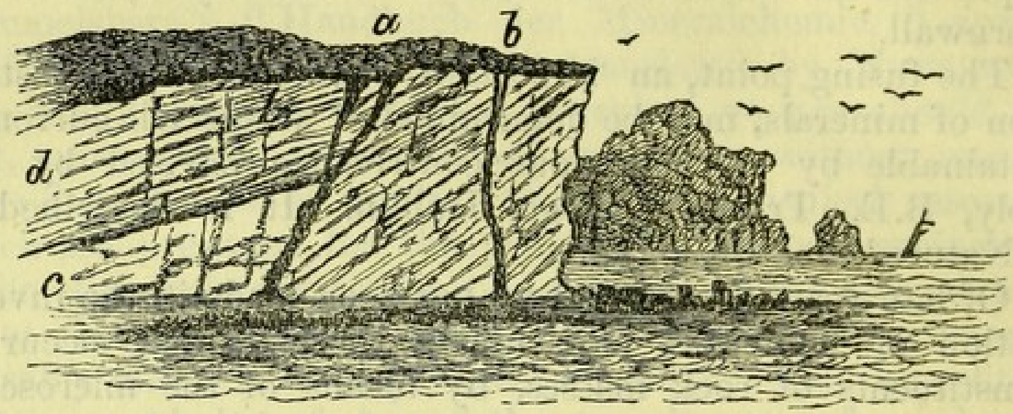
Blowpipe Analysis," Philadelphia, 1866. Landauer, "Blowpipe Analysis"; translated by Taylor and Kay, London, 1879. Plattner, "Die Proberkunst mit dem Lothrohr, &c., 1865;" translated by Muspratt, London. Von Kobell, "Tafeln zur Bestimmung der Mineralien," Munich, 1883; translated by R. Campbell. Compact sets of blowpipe apparatus can be obtained from Mr. W. A. Taylor, Penzance, Cornwall.

The fusing point, an important character in the distinction of minerals, may be determined if an electric current is obtainable by an ingenious contrivance devised by Mr. Joly, B.E., Trinity College, Dublin. It is described in "Nature," vol. 33, p. 15.

Of late years great progress has been made in the investigation of minerals, particularly those which occur as constituents of rock masses, by means of the microscope. This is an extensive branch of mineralogical inquiry to which the following works may serve as an introduction :—Boricky, "Elemente einen neuen Chemisch-mikroskopischen Mineral und Gestiens-Analyse." Prag, 1877. Fouqué et Lévy, "Introduction a l'étude des Roches éruptives Francaises, Mineralogie Micrographique." Paris, 1879. Rosenousch, "Mikroskopische Physiographie des petrographish wichtiegin Mineralien," Stuttgart, 1873. Rutley, "The Study of Rocks," London, 1879. Zirkel, "Mikroskopische Beschaffenheit des Mineralien und Gesteine," Leipzig, 1873; and "Microscopic Petrography," U.S. Geol. Exploration of Fortieth Parallel, Washington, 1876.

The voyager should be provided with hammers of different sizes, stone-cutters' chisels for breaking off crystals, and a watchmaker's forceps for picking the detached crystals out of cavities in which they cannot be reached with the fingers. Tools for blasting are serviceable in cases where it is possible to obtain the assistance of workmen acquainted with their use. Means should be provided for packing the minerals collected in such a manner that they may be transported without shaking or rubbing against each other.

We will now suppose the voyager landing upon some coast, and desirous, among other things, either of adding to our knowledge of minerals or their localities, or of discovering ores of the useful metals or coals. With respect to many minerals and the ores of the metals, it fortunately so happens that precisely the same places may be searched, and these are cracks and fissures, or those dislocations of rocks known as faults, either partially or wholly filled with mineral matter. Should he see before him such veins as *a* and *b* traversing the rocks of a cliff, he should not neglect to land there. If any hollow spaces present themselves, let him there search for the crystalline minerals. The vein *a*



is represented as filling a fault, the dislocation having brought different rocks into contact; and we may suppose, for illustration, that *c* is basalt, and *d* some schistose rock. The fissure *b* is intended to be a mere crack. Often when dissimilar rocks are brought into contact, mineral substances are found in the fissures, and this is a point which the voyager should not neglect. In certain countries the occurrence of the ores of the useful metals is not unfrequent under such conditions. On tidal coasts should a vein of this kind be found productive, it may be desirable to wait for low water to trace the direction of the vein among any ledges or rocks which may be then laid bare. This may give the run of the vein inland, but not with certainty; for though fissures or faults may take general lines on the large scale, they, as would be expected, are very irregular for short distances.

Should crystals be found in any such vein, it is often desirable to ascertain how they occur relatively to other bodies, crystalline or otherwise.

Although, when exposed to the action of weather, the minerals which may be found in veins or fissures, open on the faces of cliffs, are not very often (except when of substances not easily injured) in a good state of preservation; they show that such minerals are found in the vein, so that, if time and opportunity permit, some unexposed part of the vein may be broken into. In such cases the process of blasting may often be employed with advantage. Success may not, certainly, always attend such a search, for it is curious to observe how very local, even in the same vein, the occurrence of a particular mineral may be.

In collecting minerals in a vein, should a boat be at hand, so that they may be readily taken to the ship, it is better not to limit the specimen to some mere crystal itself, but to break off some of the body (either part of the vein or of the rock, as the case may be) upon which it has been formed, so that, when more leisure may be obtained, any illustration the whole specimen may afford of the manner in which the mineral may have been formed should be preserved. By such specimens we often learn the history, as it were, of the mineral accumulations which, taken together, may, wholly or in part, have filled up a fissure. In this way it may often be seen that crystalline coatings of many substances have successively covered each other up towards the centre of the fissures.

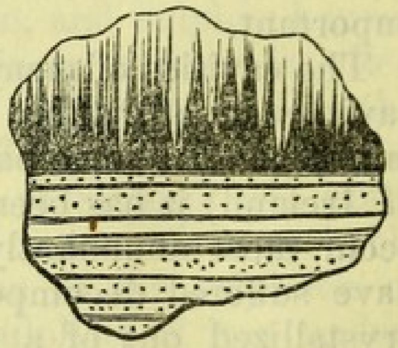
The contents of veins are often far from being definitely crystallised : thus quartz and other mineral substances, such as the ores of many metals, have an amorphous appearance, their deposit having been effected under conditions which did not permit them to crystallize. Again, we find that, during the filling up of veins, fragments of rocks from the sides or upper parts of the fissure have dropped in ; by their want of contact and by their isolation in many parts of the vein showing that this happened when the mineral or minerals thrown down from solutions were accumulating. In other cases fragments from the adjoining rocks have accumulated in the fissure before any deposit of mineral matter from solutions was effected. Ores of the useful metals, such as sulphide of lead, copper pyrites, and peroxide of tin may, and often do, form the cementing matter of such fragments as quartz, carbonite of lime, or other minerals. In collecting some minerals which have covered others it may be frequently desirable to obtain enough of the first to show how the latter may have occurred. Rock crystals are thus often seen investing other minerals, the most delicate threads of the latter being preserved in them. By a little care we may take out enough of the crystals to show completely how these threads may have radiated from a centre or have been otherwise disposed.

As with other mineral substances, we find that ores of the useful metals have been sometimes thrown down in a fissure at one time and not at another, the deposit of one ore sometimes repeated, at others not. Thus there may have been a coating of a zinc ore at one time, of copper ore at another, and a covering of tin ore upon these, sometimes separated by other mineral substances, at others in deposits one above the other. Again, we find in the successive dislocations which are sometimes seen to have effected the lines of fissures, that while the lines of least resistance to the applied force have been chiefly through the contents of the original fissure, occasionally a new fissure has been made through portions of the adjoining rock; so that the minerals which may have been subsequently deposited in the new crack or fissure will be partly in the old line, and partly amid the newly broken and adjacent rocks.

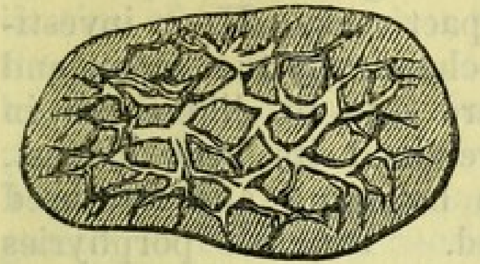
It would be out of place to attempt a general notice of those veins which, because they contain the ores of the useful metals, are commonly termed *mineral:* it will be sufficient to observe that from decomposition the upper or exposed parts of many do not show the ores in the manner they occur beneath. Thus, above veins wherein the ore from which the largest amount of copper is produced, namely, the compound of copper, iron, and sulphur known as *copper pyrites*, a mass of ferruginous matter is often found, known by many of our miners as *gossan*, and by the French miners as *chapeau de fer*. This is the result of a decomposition arising from exposure to atmospheric influences of various kinds, chiefly air and water. It is probable that the first step was the conversion of the sulphides of iron and copper into sulphates; the sulphate of iron undergoing further oxidation and other changes thus produced the reddish iron oxide of the gossan; while the sulphate of copper filtering downwards gave rise, when it came in contact with the unaltered lode, to a deposit of metallic copper. Thus we find this metal in a pure state gathered together in chinks and cavities between the main mass of gossan and the body of the undecomposed copper pyrites, mingling, perhaps, occasionally with the lower part of the former. Sometimes this *native copper*, as it is called, may retain its metallic character, but at others it becomes converted into an oxide, and this again into a carbonate by the percolation of waters containing common air and carbonic acid. The iron seems in a great measure to have been left behind and this forms the rusty substance above mentioned. It will be readily understood that, the needful conditions obtaining, other parts of a mineral vein than the mere upper portion may become decomposed in the same manner. In fact, the changes which have been effected in the fissures containing mineral veins, the mode of throwing down a mineral substance, its subsequent removal, its reappearance or apparent transport elsewhere, the pseudomorphous filling up of crystalline cavities, the substitution of one substance for another, the evident alterations produced by new fissures, particularly when these have traversed the original fissures at right angles, the differences of contents of fissures when they take different directions traversing the same country and association of rocks, are objects of high interest; and though no doubt best studied in mining countries, where opportunities are so numerous, and veins are so extensively laid open, a voyager, with some little time on a favourable portion of coast, may often nevertheless acquire much information on these heads. To do so, and procure illustrative specimens and a highly valuable collection, interesting in many respects, it is not necessary that the vein should be one containing the ores of the useful metals—the contents of those fissures and dislocations, termed common faults, are often in a scientific point of view equally important.

The cavities of many igneous rocks, and indeed holes and cavities in all, afford good places wherein to search for minerals. In some parts of Iceland (and also in the north of Ireland) it has been observed that crystallized minerals occur most abundantly in the cavities of the rocks which have suffered decomposition, the minerals having probably crystallized out of a solution of some of the constituents of the rock. In Iceland they are found sparingly in the cavities near the summit of the mountain Bulandstind, consisting of igneous rock, but very abundantly in those at its base (Sartorius v. Waltershausen, Skizze von Island, page 91). The traveller is recommended to observe the manner in which minerals are distributed at different heights in similar situations.

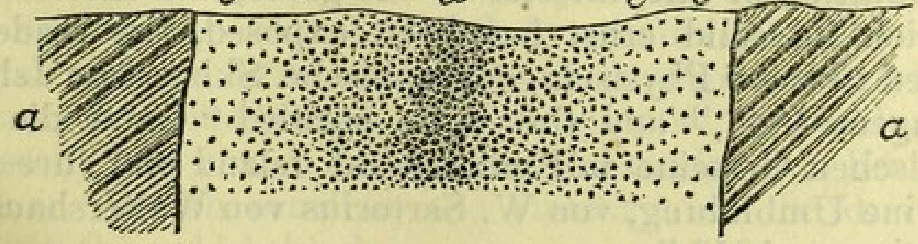
Minerals of the zeolite family are very common in the vesicular cavities of some igneous rocks; and at one time, before their mode of occurrence was properly understood, the quantity of water found in many of them was thought to militate against the igneous origin of the containing rock. They form an interesting class of minerals, and, opportunities offering, should always be collected. They come under the head of hydrated aluminous silicates, with potash, soda, lime, and their isomorphous substances. The great proportion of them contain from 8 to 18 per cent. of water in combination. In the same kind of vesicles, silicious deposits in the form of agates are not uncommon. In these and in cavities of various rocks, even those of aqueous origin, such, for example, as the dolomitic rocks of the new red sandstone series, in Somerset and Gloucestershire, the agate linings of the cavities have continued only for certain distances, after which the elements of other minerals have entered the hollows, and various crystallized substances have been the result. Cavities, therefore, in all rocks may be searched. With respect to the successive silicious coatings forming agates, while some kinds of coatings show an adjustment to the walls of the cavity, others have accumulated in flat layers, generally considered to have been formed horizontally. Sometimes part of a cavity has been filled in one way, and the remaining portion in the other. Occasionally, from cavities left after a part of the hollow had been filled horizontally, stalactites of the matter of the agate have descended from above, as in the annexed figure. It is desirable always to ascertain how far such flat layers correspond with the present horizon; and, if the vesicles or hollows are almond-shaped (elongated more in one direction than another), how far these are constant in the same direction, thus pointing out that in which the molten viscous rock moved.



Many nodules in rocks, those which have clearly not been formed as gravel or boulders by attrition, afford examples of the aggregation of similar matter from a mass, such as one of clay, in which that matter has once been more generally diffused. In this way we have silicious nodules, calcareous nodules, and those valuable nodules, the clay ironstones. These last are fundamentally carbonates of iron, with a variable addition of the matter of the mud or silt amid which the carbonate of iron has once been more generally diffused. In many such nodules there has been a shrinking from the centre to the sides, causing cracks, that have been variously filled with mineral matter, as in the subjoined figure. Occasionally in the cracks so formed, and not quite filled up, various mineral substances are obtained well crystallized. It may be here observed, as regards the titanium frequently discovered in iron furnaces when blown out, that we have found the oxide of titanium crystallized in the cavities of clay ironstones. Taken as a whole, the observer will do well to look into any cavities or cracks he may discover in rocks, even in the hollows among organic remains, for various mineral substances. Many a crystallized body will thus be frequently found, and the replacement of one substance by another be well seen.



Not only in cracks or hollows, but in the body of the rocks themselves, minerals may be observed well crystallized. That is well seen in the class of igneous rocks known as porphyries—that is, where a general paste or base, confusedly crystalline, compact or earthy, may happen to contain isolated and well formed minerals of different kinds. From experiments in the laboratory, and the results of metallurgical and chemical operations carried on upon the large scale, we know that this isolation of crystals may readily be obtained. In the igneous *dykes*, as they are termed—that is, where igneous matter in fusion has been forced up, filling cracks formed in the rocks which they traverse—we sometimes see good illustrations of the mode in which isolated mineral crystals may be produced. Let us take as an example some of the granitic dykes known as *elvans* by the miners of Cornwall, and let the annexed figure represent a section of one of them, *a a* being some



schistose rock broken through or fractured (it may be any rock previously consolidated; granite is thus frequently fractured and the fissure filled by an elvan). We find that, while the central portion *d* may be a granite, the parts *c c* are porphyritic, and *b b* some compact rock. Upon investigation, we see that all parts are chemically the same, and that these various characters are due to differences in cooling. The central portion retained its heat longest, while the portions adjoining the bounding and fractured rocks were more speedily cooled. In such porphyries various minerals are found, those of the feldspar family being very common. Such results from differences of cooling can be imitated artificially with substances under our control. In this way crystals of silicate of lime may be beautifully obtained, isolated in transparent glass.

Whole mountain masses are occasionally composed of porphyritic rocks, including the porphyritic granites among them; and it is desirable to obtain specimens of these, selecting portions where the crystals may be well formed, and observing, should more than one kind of isolated mineral be present, how far when one kind becomes common another may disappear, and if different kinds continue mixed through the general mass, or only in patches. It is equally desirable to obtain good characteristic specimens of the base or paste, and from situations where they have been uninjured by exposure to the weather, and have lost little of the soluble substances which may have once been contained in the rock. The minute study of the whole of such igneous rocks is every day becoming more interesting.

It is not only among the igneous rocks which have once been in a molten state that the observer should look for minerals, but also, in volcanic regions, for those evidently sublimed upon the faces of craters, or in cracks or chinks of their sides, or of lava currents. For an example of the kind of observations to be made in volcanic districts, and the method of drawing conclusions from them respecting the condition of the interior of the globe, and the changes to which its solid crust has been exposed, the reader is referred to the "Physisch-geographische Skizze von Island, Göttingen, 1847," and the work entitled "Ueber die vul-
"kanischen Gesteine in Sicilien und Island und ihre sub-
"marine Umbildung, von W. Sartorius von Waltershausen:
"Göttingen, 1853."

The minerals often seen isolated in those rocks which have been termed metamorphic, or altered in consequence of the upburst or protrusion of some rock in a state of igneous fusion near them, constitute a class of much interest. Here again we see conditions highly favourable to the crystallization of minerals ; but this case so far differs from that of the porphyries, that, whereas in the latter the whole mass has evidently been in a fluid or viscous state, in the former the stratified character of the rocks of that class is preserved. The manner of observing this order of rocks belongs to geology. It is only necessary here to call attention to the kind of isolated minerals found. Among them staurolites, andalusites, and garnets are frequent under certain conditions, which it may be advisable to guard the observer from supposing merely those of temperature. The freedom with which the isolated minerals thus formed, have crystallized, the main mass retaining its general structure, is highly interesting. We have seen crystals of garnet, perfectly formed, amid the grains of a sandstone, close in contact with granite, the beds of the sandstone retaining their original shape, and the mechanically-produced grains well distinguishable. In many districts the order in which some of these minerals occur, as we recede from the igneous rock, is said to be invariable. In order, if possible, to discover how far such an order of succession either exists, or is the same, for different localities, the relative distances from the igneous rock, at which the different species are found to occur most abundantly, should be carefully recorded.

Minerals from inaccessible localities are often found in the moraines, ancient as well as recent, brought down by glaciers, and also in watercourses. The rubbish heaps in the neighbourhood of mines frequently contain rare crystallized minerals resulting from the decomposition of metallic ores by exposure to the atmosphere, as well as unaltered minerals.

Gold occurs sometimes disseminated in rocks and sand, in particles too minute to be easily detected by the eye. If the sand or the rock reduced to powder, be rubbed in a mortar with a little mercury, an amalgam of gold and mercury is formed which may be separated by washing away the stony powder. On exposing the amalgam to heat in an iron or earthen crucible, the mercury will be driven off, leaving the gold behind.

We have chiefly referred hitherto to minerals found crystallized, either alone or entangling some other substances. Many important mineral substances occur, so that they appear to us in mass, sometimes forming beds mingling with others, or occupying clefts in rocks; occasionally constituting portions which have separated out from the body of the rock, as in the instances of the nodules previously mentioned. In these various forms many minerals are found, some being ores of the useful metals, such as iron ores, including bog-iron among them, and iron pyrites, valuable for the sulphur in it; as filling clefts in rocks, mingled with other matter, many ores of lead, tin, copper, &c. Other substances, also employed for various purposes, are obtained in the massive state, such as rock-salt, gypsum, and coal. For these minerals qualitative chemical researches will be found valuable, it being desirable to test the composition of many substances, which may offer certain general resemblances in appearance, before some given locality may be quitted.

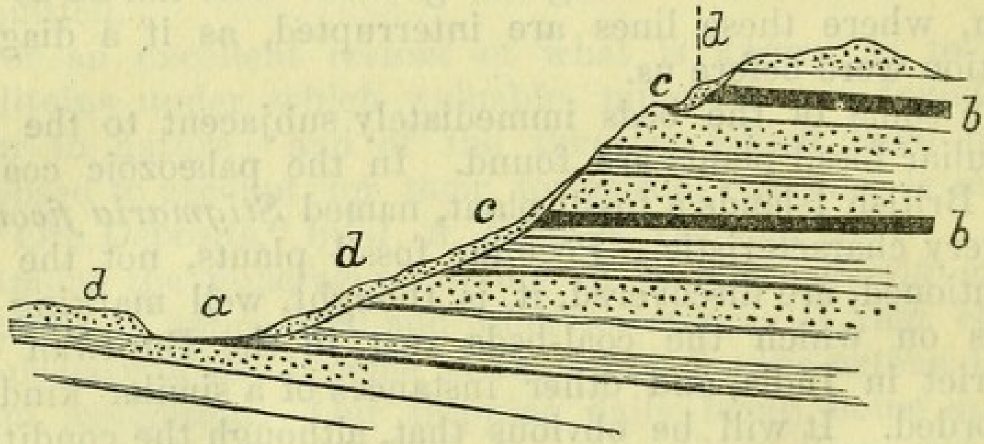
For an excellent *resumé* of what is known as to the conditoins under which valuable minerals are found to occur in nature; and of the theories which have been proposed to account for their formation, reference is made to "Ore Deposits," by J. A. Phillips, London, 1884.

Among the minerals occurring in beds, we should more particularly notice coal and other substances of that class, which have of late become so important for the extension of steam navigation. Our shipping daily bring home specimens of coal or lignite from localities where they were not previously known to occur. And it may be here needful to state, as now well known to geologists, that good coal is not confined to rocks of a particular geological date, but that, the needful physical conditions having obtained, it has been produced from vegetable matter accumulated at different geological times. When we have a cliff before us, there is little difficulty in seeing that a coal-bed occurs among others of sandstone, shale, or other substances. Not unfrequently coal-beds are based upon clays, or argillaceous strata which have a clayey character from exposure, and then it sometimes happens, from the slipping and falling of the general mass, that the real thickness and importance of a coal-bed may not appear on a cliff. Thus it was at Labuan, where now a valuable coal-bed about nine feet thick is worked: when first seen on the coast it did not appear more than 18 inches thick.

Of whatever geological age an accumulation of mud, silts, sands, and gravels, now more or less consolidated as shales, sandstones, and conglomerates, and containing interstratified coal, may happen to have been, it rarely occurs that the bed upon which the coal itself reposes has not some peculiar character, easily observed. In many cases we feel assured that this has arisen from those beds having formed the ground, often perhaps marshy or with a slight covering of water, on which the plants, now converted into coal, have grown. Should these marked deposits be found, they often form valuable aids in tracing coal beds, where the outcrop of the latter may not be very apparent, and they are especially serviceable, as in many of the hilly coal-measure districts of the British Islands, where these beds throw out springs of water. Whole lines of such springs coinciding with the bottom of coal-beds can be traced in the hilly coal districts of South Wales and Monmouthshire, and often on a hill-side faults traversing the general mass can be as well seen, where these lines are interrupted, as if a diagram section were before us.

In some of the beds immediately subjacent to the coal peculiar fossil plants are found. In the palæozoic coal of the British Islands a fossil plant, named *Stigmaria ficoides*, is very characteristic. Peculiar fossil plants, not the one mentioned, are discovered, it is thought, well marking the beds on which the coal-beds rest in the Burdwan coal district in India, and other instances of a similar kind are recorded. It will be obvious that, although the conditions for the production of marked accumulations may have preceded the growth of most of the coal-vegetables themselves, the latter may not have sometimes grown, so that no coal rests upon such beds. Still these beds, when any such occur, are useful to trace, since, while we find in one locality no vegetable accumulation to have taken place upon them, or, if effected, the vegetable matter to have been subsequently removed, upon an extension of the same beds we may often see good workable coal.

Though in cliffs, either on the shore on on the sides of rivers, hills, and mountains, we commonly find the most direct evidence of the existence of coal, it may be often traced to its beds, where such occur, by means of the detritus brought down by brooks and rivers. By following rolled pebbles up such watercourses they may be often seen to end near some bed or beds whence they have been derived. If these cross the stream, a good opportunity may be afforded for examining their quality and thickness. The pebbles may, however, come from the sides of some adjacent hills sloping towards the streams, the beds of coal not crossing them, fragments only of their outcrop being mingled with any others of associated beds. The thickness of such coal-beds may be thus concealed, as will be readily seen by the annexed section, in which *a* represents the river course, up which pebbles of coal may be traced; *b b* beds of coal, the outcrops of which, *c c*, may be much concealed by fragments of rock descended from above and mingled in a fragmentary covering *d d*. The best should be done to obtain a knowledge of the associated beds by tracing up the rills of water descending the sides of the hills. Excellent evidence may thus be often obtained, and the true position of the coal-beds found. In selecting specimens of coal in such cases, it rarely happens that a portion of it can be procured



fairly exhibiting its qualities, injury having arisen from atmospheric influences. If the outcrop of the coal can be attained, it is always desirable to penetrate as far as circumstances will permit into the body of the bed, thence selecting a fair specimen. When this cannot be done (and a voyager often has but little time for his researches), fragments lying about should be selected which may appear the least decomposed; and if these be of different qualities, as if of portions of different beds, they also should receive attention. In all cases where fossil plants are mingled with the coal or associated beds, specimens as various as can be obtained should be secured. These have a geological bearing which may often turn out of great practical importance in some given region.

It scarcely requires remark that the foregoing observations are but hints which it is hoped may be useful to those engaged in voyages of discovery and survey, or who, on more general service, may feel inclined, whenever fitting opportunities may present themselves, to devote some portion of the time not occupied by their professional duties to the study of minerals, either for purely scientific purposes, for their useful employment, or for both combined. That these opportunities do present themselves we well know, or, rather, if sought, will be found more frequently than might be imagined. Many a walk along a coast may thus be advantageously turned to account, and an interest be excited not at first thought probable. Not only may a naval man thus add to his own stock of knowledge, but he may most materially by his exertions promote the advance of science and its applications generally, minerals being objects of great interest, whether we regard them with reference to their importance to man, and the aid many of them afford to the spread of civilization, or as connected with several sciences, even those of the highest order.

ARTICLE XII.

SEISMOLOGY.

By THOMAS GRAY, B.Sc., F.R.S.E.

The part of terrestrial physics which treats of the more or less violent oscillatory movements that occasionally take place in portions of the earth's surface strata has been distinguished by the name Seismology. These movements, especially when they are of such violence as to endanger, or cause damage to, structures on the earth's surface, are familiarly known as earthquakes. The science of seismology, however, properly includes not only the investigation of the laws of earthquakes, but also those of the oscillations of small amplitude and short period known as earth tremors, and those of the oscillations of long period and sometimes of large amplitude which have been called earth pulsations.

Seismology cannot be said to have passed the stage of observation and classification, as few, if any, laws can be said to be satisfactorily established. The object of the present article is to indicate the nature of the facts that may be accumulated, and the observations or experiments that may be made, by persons who in the ordinary course of their profession visit different localities, but who seldom remain at any one place long enough to allow them to undertake systematic series of investigations. The methods of observation and the apparatus described are of the simplest kind, because it is desirable that the methods should be readily applied, and that the apparatus should be easily made without the aid of skilled instrument makers.

Earthquakes and earth tremors are no doubt identical in their nature and probably in most cases originate in the same way. They are manifested at any place by a more or less rapid backward and forward movement of the earth's surface. The question at once suggests itself: How and where do these disturbances originate? An answer to this question has been the object of a great amount of laborious research, the results of which have for the most part only served to reveal the great inherent difficulty of the subject. The solution of the problem as to how an earthquake originates has generally been attempted by endeavouring, in the first place, to establish the position of the centre of disturbance, or the " centrum."

This in its turn brings in a great variety of considerations as to the mode and rate of propagation of such a disturbance through the earth's mass, and these lead directly to the investigation of the formation and the propagation of waves of compression and distortion in elastic solids.

If we imagine a portion of the earth's mass to be suddenly subjected to intense stresses of any kind whatever, the immediate consequence will be the transmission outwards, from this part of the earth's mass as centre, of waves of distortion and of combined compression and distortion. These waves will generally be propagated in different directions with different and with varying velocities on account of the heterogenous character of the strata through which they pass. It will simplify matters considerably, and will be sufficient to give a general idea of the nature of the problem, if we suppose the strata through which the waves are propagated to be isotropic.

DEFINITION.—A substance is said to be isotropic when a spherical portion cut from any part of it is undistinguishable from another spherical portion of the same size cut from any other part of it; that is to say, the rate of variation of any physical property of the substance along any line in it is everywhere zero.

Transmission of waves in an isotropic solid.—If we imagine a comparatively small portion of this medium to be subjected to violent stresses, which, to fix our ideas, we may suppose to be produced by an explosion in a cavity, there will be, in the most general case, two sets of waves propagated outwards from the cavity. One of these sets of waves will, by its transit over any place, produce an oscillatory movement, the direction of motion in which is along a line passing through the place and the origin of disturbance. This wave is generally called the normal wave; it is analogous to a sound wave in air, and is propagated with a velocity which depends partly on the resistance which the substance offers to change of bulk or compression and partly on the resistance it offers to change of shape or distortion. If the ratio of the compressive force applied per unit area, to the compression produced per unit volume of the substance, be called k, and the ratio of the distorting force applied per unit area to the distortion produced be called n, and if v_0 be put for the velocity of propagation, and ρ for the density of the substance, we have the following relation—

$$v_0^2 = \frac{k + \frac{4}{3} n}{\rho} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

The quantity k is commonly called the bulk modulus or the modulus of compression, while n is called the rigidity modulus of the substance.

The other set of waves produces, by its transit over any place, an oscillatory movement the direction of motion in which is at right angles to a straight line joining the place and the origin. The velocity of propagation of this set of waves depends solely upon the rigidity of the material, that is, on the modulus n, and if we call this velocity v, we have the relation—

$$v_1^2 = \frac{n}{\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From equations (1) and (2) it is clear that—

$$\frac{v_0^2}{v_1^2} = \frac{k + \frac{4}{3} n}{n} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

and as k and n are both essentially positive quantities we conclude that v_0 must always be greater than v_1. An observer, then, situated on the surface of such a medium as we have here supposed, and at a sufficient distance from the origin of disturbance, would observe both sets of waves separately the one after the other. The earth would, therefore, first oscillate in one direction and a short time afterwards in a direction at right angles to that. At places nearer the origin the earth would begin to oscillate in obedience to the normal wave alone, it would afterwards oscillate in obedience to the resultant of the normal and the transverse waves simultaneously, and lastly, it would oscillate in obedience to the transverse wave alone.

Variation of Amplitude.—Consider next the rate at which the amplitude of the backward and forward motion diminishes as the wave radiates from the centre. It is to be remembered that, since k and n are constant, the velocity of propagation must be constant, and hence if we suppose that the front of the wave has reached any distance d from the centre before the matter there comes to rest, the thickness of the spherical shell which is disturbed at any time must continue equal to d no matter what the radius of the shell may be. Again, it is clear that the period of oscillation of any part of the complex wave which makes up the whole disturbance will remain constant. Now the total energy, kinetic and potential, in the disturbed shell must remain constant, if we assume no absorption. We therefore have for any two disturbed shells at the same phase of the motion, the energies of any pair of corresponding particles of equal mass inversely as the volumes of spherical shells of different radii but constant thickness, that is, inversely as the squares of the radii of the shells. Taking that phase of the motion of the pair of particles in which the energy is wholly kinetic energy, and suppose a_0 and a_1 to be their respective amplitudes of oscillation, and M and T their common mass and period of vibration respectively, we have for two shells of radii R_0 and R_1 the equation—

$$\frac{M\,\frac{4\pi^2}{T^2}\,a_0^2}{M\,\frac{4\pi^2}{T^2}\,a_1^2} = \frac{R_1^2}{R_0^2},\ \text{or}\ \frac{a_0}{a_1} = \frac{R_1}{R_2} \qquad \ldots\ldots\ldots\ldots (4.)$$

That is to say, the amplitudes of the motions of the different particles of the medium will be inversely as the distances of these particles from the centre of disturbance.

In actual experience this minimum rate of decrease of amplitude will always be exceeded on account of the imperfect elasticity of the materials forming the earth's strata, in consequence of the giving up of energy, in the form of heat, to the medium as the disturbance is propagated through it. Besides this cause of variation we must not forget that in actual rock masses the condition on which the constancy of the thickness of the disturbed shell is stated to depend does not generally hold. When the disturbance passes from one stratum to another having higher elasticity moduli, the density remaining the same, the velocity of propagation is increased, and consequently the thickness of the disturbed shell is also increased, and hence the amplitude of the motion of each individual particle is smaller than would be given by equation (4). On the other hand, when the disturbance passes from a medium in which the velocity is high to one in which the velocity is low the amplitude is increased. This is a most important case and its verification in the serious effects produced on buildings standing on foundations of low elastic moduli is matter of common experience in regions affected by earthquakes. Similarly variations in the density of the medium, affect the amplitude. Let v_0 be the velocity of propagation and ρ_0 the density in the first medium, v_1 and ρ_1 the corresponding quantities in the second medium, and θ be the angle of incidence from the first to the second medium. Then if a_0 be the amplitude in the first, and a_1 that in the second medium—

$$\frac{a_1}{a_0} = \frac{2v_0\,\rho_0}{\rho_1 v_1 + \rho_0 \{v_0^2 - (v_1^2 - v_0^2)\tan^2\theta\}^{\frac{1}{2}}} \ldots (5.)$$

Intensity as affected by position and amplitude.—Again, the maximum acceleration, and therefore also the intensity, of shock is, on the supposition of simple harmonic motion, proportional to the amplitude when the period is constant. Let d be the depth of the centrum, R the length along any radius vector to the surface, ϵ the angle of emergence, or the acute angle which the radius vector makes with the surface, and a the amplitude at the surface. The horizontal amplitude is $a \cos \epsilon$. But $\sin \epsilon = \frac{d}{\mathrm{R}}$, and $a = \frac{\text{constant}}{\mathrm{R}} = \frac{c}{\mathrm{R}}$ say. Hence we have horizontal acceleration $= \frac{mc}{d} \sin \epsilon \cos \epsilon = \frac{mc}{2d} \sin 2\epsilon$ where m is a constant. Now $\sin 2\epsilon$ is evidently a maximum when ϵ is 45°, and therefore we have the horizontal intensity a maximum along a circle the radius of which is equal to the depth of the centrum below the surface, and the centre of which is the point on the surface vertically above the centrum commonly called the epicentrum.

It should be noted that the depth d is here assumed so small compared with the radius of the earth that the surface of the earth may be considered plane. The application of this line of maximum intensity to the determination of the depth of the centrum is evident and will be again referred to below.

Apparent velocity of propagation on the surface.—Let E be the epicentrum, P any point on the surface, C the centrum, and let the angle E C P. be θ. Then if v be the velocity of propagation through the medium, and V the apparent velocity on the surface, we have—

$$\frac{CP}{v} - \frac{CE}{v} = \frac{EP}{V}, \text{ or}$$

$$\frac{V}{v} = \frac{\sin\theta}{1-\cos\theta} = \cot\tfrac{1}{2}\theta \ldots\ldots\ldots\ldots (6.)$$

That is to say, the horizontal velocity V is infinite at the epicentrum and is equal to v at an infinite distance from it. This conclusion will be found of considerable importance in the determination of the position of the epicentrum. It must also be carefully kept in mind when any deductions are being made as to the nature of the underlying rocks from the velocity of propagation of earthquake waves as observed on the surface.

Direction of motion at the surface.—With regard to the direction of the motion at the surface it may be remarked that, in so far as it depends on the normal wave, the motion in a uniform medium will be vertical at the epicentrum and will become more and more nearly horizontal as we recede from that point, the direction is in all cases along the radius vector from the centrum.

With regard to the transverse wave, the direction of motion is, at any point, normal to the radius vector from the centrum to that point. At the surface this wave will generally, but not necessarily, have a horizontal component at right angles to the horizontal component of the normal wave. This component will, however, at all points where the radius vector from the centrum is not nearly parallel to the surface, be combined with a component parallel to the horizontal component of the normal wave. The resultant horizontal direction of motion of the transverse wave, therefore, will not, as a rule, be at right angles to that of the normal wave.

When observations are made on the surface of the earth the angle of emergence ϵ is modified by the effect of the free surface. The velocity of propagation at the surface is somewhat less than in the substance of the medium on account of the diminution in the elastic modulus due to the free lateral expansion of the substance. This tends to make the direction of motion more nearly vertical at the surface, and this tendency is augmented by the lateral expansion and contraction, and hence the observed value of ϵ is too great. If the observations be made at a point a few feet below the surface, and if possible in the solid rock, this difficulty will be to a great extent avoided.

In so far, then, as we can look upon the problem from the point of view of the propagation of waves in an isotropic medium we find the following important elements for observation, namely:—(a.) *The direction of motion;* (b.) *The constancy of that direction;* (c.) *The amplitude, or extent, of the motion to one side or other of the position of equilibrium;* (d.) *The period of oscillation;* (e.) *The time and duration of the transit of the normal and of the transverse waves;* (f.) *The velocity of propagation;* (g.) *The line of maximum intensity;* (h.) *The position of maximum horizontal velocity of propagation.*

The rock formations near the surface of the earth cannot be considered as even approximately isotropic, but still the different elements above enumerated should be carefully observed. A comparison of what actually takes place with what would be expected in an isotropic medium is indeed one of the ways in which we can form an estimate of how nearly uniform or how nearly continuous these rock formations are. The amplitude and the period of oscillation give the means of estimating the stresses and strains to which structures resting on the surface are subject. The constancy or inconstancy of the direction of motion in the normal wave is an important element as throwing light on the number of reflections and refractions the wave has experienced in its passage outward from the origin of disturbance. It is probable that the nearest approach to a simple arrangement in the structure of the earth's strata which we can conceive is that of successive layers of different materials. Now, consider a wave passing in the direction *a b* through the medium below the line A B, fig. 1, and suppose that at A B it passes into a layer of different material and becomes refracted into the direction *b c*, and at C is again refracted into the direction *c d*. At each surface of separation between the different layers, as A B and C D, the wave is partly reflected back into the stratum through which it approaches the surfaces, and partly passes

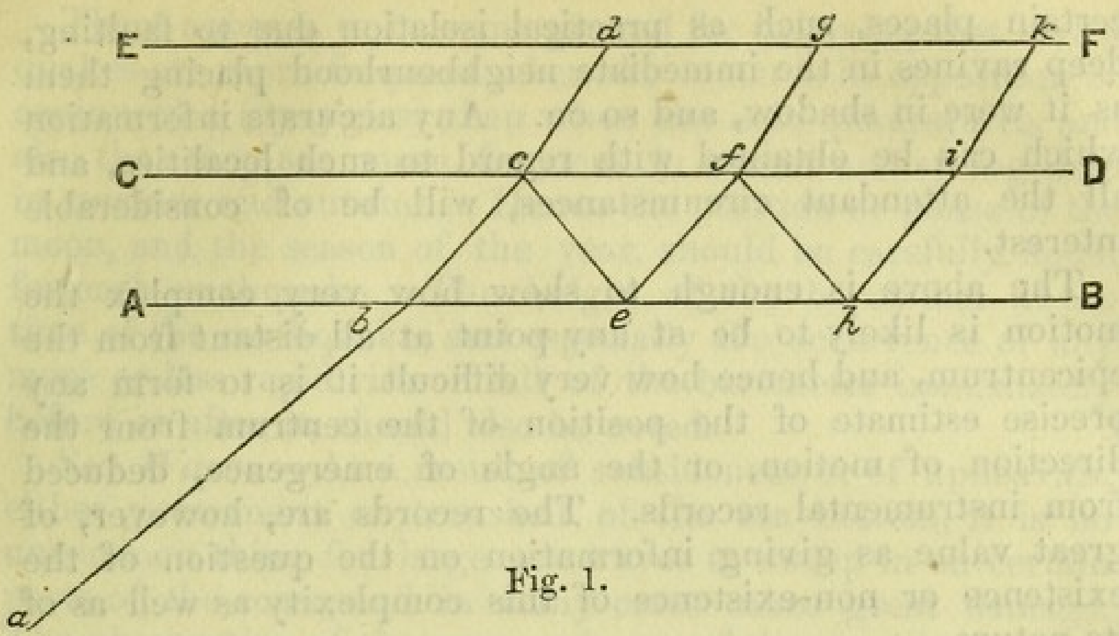


Fig. 1.

forward along a line somewhat inclined to its former direction, as illustrated at *b c*, *c d*, &c., where the velocity of propagation in the successive layers is supposed to be getting less and less. It is clear that at any point on the surface, such as *k*, there will be, in such a case, a succession of small motions which are not due to the direct wave, but are due to waves which reached directly points nearer the epicentrum.

The angle of emergence for these secondary waves will be greater than for the direct wave, and will generally be very variable. Again, it will generally be found that the surfaces of separation between successive strata are not parallel, and a very little consideration will show that the reflected and refracted waves will then tend either to become more nearly vertical or more nearly horizontal. We may readily imagine a very interesting case of this problem. Suppose, for example, the wave after it passes through the stratum above A B to be totally reflected from the surface C D, in consequence of the inclination of the two surfaces. The wave may then pass for a considerable distance along the stratum between A B and C D, until by folding or contortion of the underlying strata the inclination becomes such as to throw the wave upwards to the surface. This is a simple explanation of the phenomena, not at all uncommon in earthquake countries, known as "earthquake bridges." These bridges are small parts of the country which are not affected by the earthquakes, that in the surrounding districts often produce great damage. There are, of course, other explanations of this immunity from earthquakes in certain places, such as practical isolation due to faulting, deep ravines in the immediate neighbourhood placing them as it were in shadow, and so on. Any accurate information which can be obtained with regard to such localities, and all the attendant circumstances, will be of considerable interest.

The above is enough to show how very complex the motion is likely to be at any point at all distant from the epicentrum, and hence how very difficult it is to form any precise estimate of the position of the centrum from the direction of motion, or the angle of emergence, deduced from instrumental records. The records are, however, of great value as giving information on the question of the existence or non-existence of this complexity as well as of its nature.

Perhaps the most valuable observations on actual earthquakes are those connected with the velocity of propagation of the disturbance. This involves the determination of the time of transit at different places, and these times are the only reliable means of getting at the position of the centrum. When the times at which the disturbance passed a number of places, not in one line, and also the distances between these places are known, it is an easy mathematical problem to deduce very nearly the locality from which the disturbance emanated. One or two examples will be given further on when we are treating more particularly of the interpretation and application of the results of observation. When the approximate position of the centrum or epicentrum is known the physical characteristics of the district should not be neglected, as they may prove of great value in determining what caused the disturbance. The points more immediately connected with velocity which should be observed are: first, its actual amount, as giving information as to the value of the elastic moduli of the rocks through which the disturbance is passing; and second, the variation of the horizontal velocity as the wave recedes from the epicentrum as a means of determining the position of that point. It has been asserted that the actual velocity of propagation is, in some cases, greater near the centrum than at a distance from it. This would either imply a change of the elastic moduli due to intense stress, or less loss of effective velocity due to discontinuity of the strata near the centrum than at a distance from it. Evidence bearing on this point would be valuable.

There appears to be some ground for believing that earthquakes are more frequent when the moon is in opposition or conjunction (syzygies) than when she is in quadratures, and also that they are more frequent in winter and spring than in summer and autumn. Hence the position or phase of the moon, and the season of the year, should be carefully noted for each earthquake. The height of the barometer at the time of the earthquake, and especially the occurrence of any more or less rapid rise or fall of the barometer immediately before or after it, should also be noted.

Sea Waves.—As a result of subsidences or of upheavals, either permanent or transient, of the sea bottom, it is no uncommon thing for large sea waves to sweep in on certain parts of the coast, and in many cases cause great damage. The observation of these waves is one of the most instructive parts of seismological investigation.

The points which should be most particularly attended to are (1) the height of the wave, (2) the length of the wave, (3) the velocity of propagation, and (4) the period of the wave. The height of the wave can be best obtained from tide gauge records* on the coast line. It may be approximated to at sea when the wave is short by running up the rigging far enough to get the top of the wave in line with the horizon. The wave is, however, in general too long for even approximate measurement at sea. The period can also be best obtained from the tide gauge records. The tide gauges must be situated on a steep coast where the water is deep close in shore, and they must be arranged so as to be little affected by breakers. The velocity of propagation can be best derived from the time of arrival at different places whose distance apart are known. The length of the wave can then be deduced from the period and the velocity. The great length of the wave will in most cases form an insuperable obstacle in the way of observations at sea. In some cases, however, as when the wave approaches with a steep front some idea of its velocity and height may be obtained on board ship. It may be sufficient, for instance, to note the time taken for the wave to pass from one end to the other of the ship, its direction of propagation relatively to that of the ship being as nearly as possible estimated and allowed for, or a float may be veered out astern and the time taken for the wave to pass from the

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* On this point *see also* page 12.

ship to the float noted. In such a case the compass bearing of the direction of propagation should also be taken.

It may be well to state the following facts regarding the propagation of waves in water :—

1. When the height of the wave above mean water level is small compared with the depth of the water, and at the same time the depth of the water small compared with the length of the wave, the velocity of propagation is given by the equation—

$$v^2 = gh \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where g is the accelerating force of gravity on unit mass, or the number of units of velocity acquired by a body in one second when falling freely under the action of gravity, and h is the depth of the water.

2. When the depth of the water is great compared both with the height and the length of the wave, the velocity of propagation is given by the equation—

$$v^2 = gr = \frac{gl}{2\pi} \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

where g has the same meaning as before, r is the radius of a circle whose circumference is the length of the wave, l is the wave length, and π is the ratio of the circumference to the diameter of a circle.

It will generally be found that even in deep water the velocity given by equation (7) most nearly agrees with the actual velocity of earthquake waves. This is due to the very long period, often exceeding 20 minutes, which these waves generally have.

Consider what the length of a wave which has a period of 20 minutes will be when the water is 2,000 fathoms deep.

The length of the wave is the same as the distance through which it is propagated in the period of the wave. That is, in this case, assuming equation (7).

$1{,}200 \times \sqrt{32 \times 12{,}000} \doteq 740{,}000$ feet, or more than 60 times the depth of the water.

It is well to remark also that the form of the wave surface is of considerable service as indicating the nature of the disturbance which produced it. Thus a wave with a gentle front slope has probably been produced by gentle rise or fall of a part of the sea bottom, while a wave with a steep front has probably been due to a somewhat sudden elevation or depression. Waves of complicated surface form again would indicate violent oscillations of the bottom. Neither the form nor the velocity of propagation of these waves can be satisfactorily observed near a shore which shoals gradually, because the shallow water has the effect of retarding the velocity, and hence of raising the waves to great height, causing them to assume gradually steeper and steeper fronts, and finally to rush in shore as enormous breakers.

When an earthquake precedes the arrival of a sea wave, the interval between the two may be of considerable service in forming an estimate of the distance of the origin of the disturbance which caused the wave.

Effects of Earthquakes on Buildings.—Another source of information lies in the permanent effect of earthquakes on buildings. These often stand for a considerable time as records of the intensity and direction of the stresses to which they have been subjected. Information with regard to the structure of the buildings which suffered most, and also with regard to those which did not suffer, during an earthquake is of great value. The points which should be particularly attended to are, the general form of the building, the form and construction of the openings, such as windows, doors, &c., the material and strength of the walls, and the nature and weight of the roof. The nature of the underlying strata, the general contour of the surrounding country, and the kind of foundation on which the building stood should be carefully noted. When making observations in a town which lies partly on high and partly on low ground the relative effect of the earthquake on similar buildings built on the top or slope of the hill, and on those built on the low ground, is of great interest.

If the disturbance has been of a superficial character it will generally be found that excavations either in the site of the building itself, or surrounding the building, have exercised considerable influence in warding off the destructive effects. Again, when parts of buildings such as chimneys, coping stones of gate posts, monuments, and so on, have been twisted round on their bases, the original directions of the edges of the base, the form of the part twisted, and the direction and amount of the twist should be observed. It is well to observe also, when there have been several examples of twisting, whether all the objects of similar form found facing in the same direction have turned in the same direction. Numbers of excellent examples of twisting are often to be found in graveyards on account of the number, similarity, and general coincidence in the bearings of the tombstones.

Buildings of a strong and rigid construction are well adapted to withstand shocks of long period even if the amplitude be considerable, but they are not well adapted to withstand shocks of short period and considerable amplitude because of the enormous stresses to which they are then subjected, due mainly to the unyielding nature of their structure. On the other hand, light, frail structures carrying moderately heavy roofs, such as are to be found in great numbers in almost all Asiatic countries, are very apt to collapse when the period is long and the amplitude considerable. They have, in fact, time to fall in such circumstances. They will, however, on account of the general flexibility of their structure, withstand violent earthquakes of short period, becoming little, if at all, damaged.

Instruments.

It is impossible in the space at our disposal to describe nearly all the different forms of apparatus which have been devised for the purpose of recording earthquakes, and indeed, the more elaborate forms would here be out of place. It is desirable, however, that a few of the simpler forms of apparatus, such, for example, as can with comparatively little trouble be made by the observer himself, should be described.

Instruments for Direction of Motion.—An approximation to the direction of the principal part of an earthquake shock can be obtained in a variety of ways. If the shock be severe, its general direction may be obtained from the position of bodies which have been overturned, and for the observation of such shocks it is well to set up bodies of convenient shape for the purpose. This is the old column seismoscope. A convenient form of this apparatus consists of a set of round columns of diameters varying from a quarter of an inch to an inch and of a uniform height, say three inches, each resting on a round base a little larger than itself fixed firmly to the ground. The distance between the columns should be sufficient to prevent any chance of their touching each other when they fall, that is to say, the distance between the columns should be more than twice their height. The columns should be surrounded by a bed of fine sand or similar substance so that they shall lie where they fall. The direction in which the columns fall will in some, but not in all, cases coincide with the direction of motion. They may be overturned by successive impulses causing them to oscillate backwards and forwards until the amplitude becomes sufficient for them to go over altogether. In this case the direction of the length of the column will not be any reliable indication of the direction of motion, as a column under such circumstances generally acquires a conical motion round its base before it is overturned which completely prevents any accurate deductions being made from it. This method of observation is only valuable when the shock is so sudden and violent as to shoot the column right over at the first impulse. Many earthquakes are preceded by a trembling motion of gradually increasing amplitude, which is apt to interfere greatly with the indications of columns.

It may be well to state the problem for the case of a sudden impulse. A round column of height, $2h$, and radius, r, stands upon one end, the plane of which is at right angles to the axis of the cylinder, on a level plane. The plane suddenly acquires a velocity, v, find the minimum value of v which will overturn the column. For simplicity imagine the plane and column to have a common velocity, v, and the plane to become suddenly fixed. Let k be the radius of gyration of the column round a tangent to its base and ω the angular velocity generated. Then equating moments of momenta we have—

$$hv=k^2\omega \qquad \ldots\ldots\ldots\ldots\ldots\ldots (9.)$$

and equating the kinetic energy of rotation to the energy required to overturn the column we get—

$$k^2\omega^2=2gh\,\frac{1-\cos\theta}{\cos\theta} \qquad \ldots\ldots\ldots\ldots (10.)$$

where $\cos\theta=\frac{h}{\sqrt{r^2+h^2}}$. Eliminating ω between equations (9) and (10) we readily obtain—

$$v^2=2g\,\frac{k^2}{\sqrt{h^2+r^2}},\ \frac{-\cos\theta}{\cos^2\theta}=2gl\frac{1-\cos\theta}{\cos^2\theta} \qquad \ldots (11.)$$

where l is the length of the simple pendulum which has the same period as the column would have if hung up as a pendulum by the point round which it overturned.

A more satisfactory seismoscope for showing that an earthquake has occurred, and for giving its approximate direction of motion consists of two flat disks, of the same diameter, one of them toothed like a wheel by means of triangular notches of somewhat obtuse angle cut all round its edge. One notch for every 10° or 15° of arc will make a convenient arrangement. The notched is fixed to the unnotched disk so as to form a short cylinder notched all round its upper edge; fix this cylinder with its end planes level, firmly to, but a few inches above, the bottom of a shallow tray containing sand, and fix the tray firmly to the ground. Now place into each notch a ball of such a size that it just rests stably (glass marbles answer the purpose perfectly). During even a very small earthquake the balls at and near the two ends of the diameter which coincides with the direction of motion will be shot off and caught in the sand. Deductions must not, however, be rashly made as to the intensity of the shock from the positions of the balls in the sand, although in some cases valuable information may be obtained from those positions. The balls will be carried along with the plane until the acceleration becomes greater than the stability which the ball has on the plane can produce, when it will roll off. The advantage is that the stability can be made excessively small, and hence the balls are projected by a very slight motion of the ground. When the shock arrives as a sudden impulse the balls drop close to the edge of the planes on one side, and are projected to some distance on the other. This does not, however, tell from which side the shock came unless it is known whether the first impulse is due to compression or rarefaction of the medium.

A simpler and more effective instrument than a set of columns for giving an idea of the maximum velocity of a shock may be made as follows: In a strip of metal, punch, by means of a sharp centre punch, a row of small conical holes. Along the edge of a similar strip of thin metal or wood cut at the proper distances apart a series of triangular notches. Fix the two strips to a block of wood in such a way that the first notch shall be nearly vertically over, but a little behind, the first hole, the second notch a little further behind the second hole, and so on. Take two such arrangements and fasten them to something which has a rigid hold of the ground in such a way that the line of holes in the one set is at right angles to the line of holes in the other, both lines being horizontal. Now take a number of thin, stiff rods, like large sewing needles, and place on the top of each a small mass of lead like a large gun shot. Place the point of one of these in each hole, and allow the needle to rest against the corresponding notch, and a step-by-step arrangement is obtained which, according to the greatest inclination of the needles shot over, will give a means of estimating the greatest horizontal velocity acquired at a point on the earth's surface during the shock. The lead mass may be fixed to the top of the needle, but it is better to make a conical hole in one side and place it with the bottom of the hole resting on the top of the needle.

Let θ be the inclination of any one of these rods to the vertical, and suppose the point of support to acquire suddenly a horizontal velocity v in the vertical plane through the needle, then the least value of v which will overturn the rod is given by the equation—

$$v^2 = 2\,gr.\frac{1-\cos\theta}{\cos^2\theta} \quad \ldots\ldots\ldots\ldots\ldots(12)$$

where r is the length of the rod. When θ is small this agrees very nearly with the maximum velocity of the bob of a simple pendulum of length r when it is made to vibrate through an arc equal to the horizontal trace of the rod.

Another instrument which has always been in favour, because of its simplicity, is a pendulum. The simplest form of pendulum seismometer consists of a heavy mass suspended by a thin wire or cord, and having a thin stile projecting below the bob and touching the surface of a bed of sand. At the time of an earthquake the bob of the pendulum is expected to remain either nearly stationary or to swing in the direction of the shock. These instruments generally fail on account of a slight want of symmetry in the suspension, and in the position of the marking stile. This causes the pendulum, which always swings a little, to change its plane of motion, and hence to produce a complicated network of lines from which nothing of value can be learned. If such an instrument be used at all provision must be made to prevent the free swinging which obliterates the records. This may be easily done by applying a little friction to the bob through the marking point. Let the bob be made in the form of a flat disc or ring, and suspend it like a scale pan by three wires meeting at some distance above the bob, and from thence continued to the point of support by a single wire. Smoke a small piece of glass by holding it over a smoky flame, and place it with the smoked side up over the centre of the bob. Now hinge to any convenient support outside of the bob a light lever, carrying a needle point fixed in a flat flexible spring, and so arranged that when the lever is folded down the point rests on the glass plate as nearly as possible above the centre of the bob. By weight added to the lever, or by a spring, or by any other convenient means, let the pressure of the needle point on the glass be adjusted until when the pendulum is deflected through a short distance, say a quarter of an inch, it simply swings back to its normal position and stops. This pendulum will then indicate the direction of oscillation with considerable accuracy, and except for very small and slow motions, it will also give a good indication of the maximum amount of motion which has taken place when that is not excessive. For a district where the earthquakes partake more of the character of tremors this pendulum arrangement, with some modifications, will be found a convenient and useful instrument. In such a case the extent of the motion is very small, and hence the friction of the needle point may be made small. It will be necessary also to add some magnifying arrangement to indicate with greater accuracy the direction and amount of motion. An index of the form shown in Fig. 2 will be found to answer the purpose well. It consists of a small pulley *p* fixed to the vertical axis *a*, which is fitted between the prongs of a fork of wood *w*, with just enough of friction to keep it at any desired place. From the

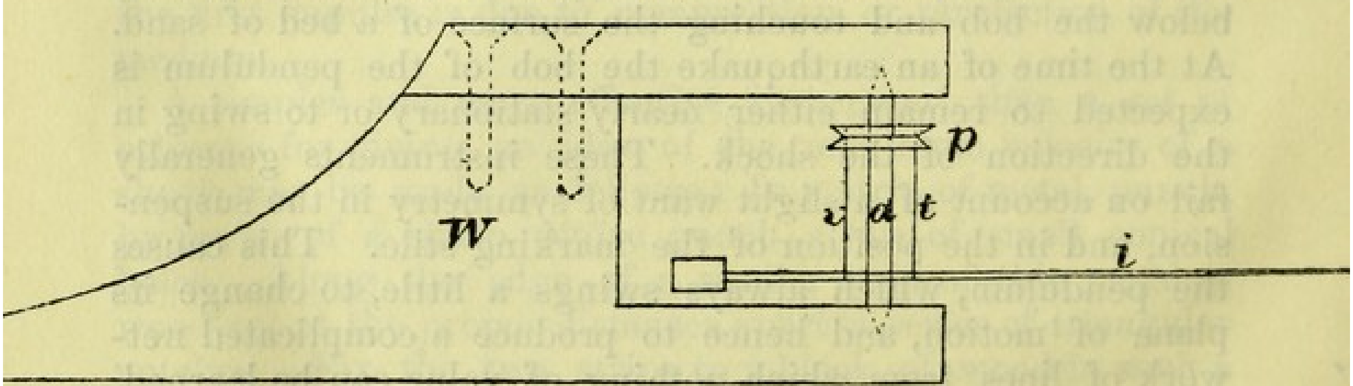


Fig. 2.

pulley *p* an index *i* is hung by two threads *t t*. A fine wire, or a thread well oiled to prevent it from changing its length with moisture, is fixed to a thin stiff wire projecting below the bob of the pendulum, and one end is taken round and made fast to the pulley *p*, so that if the pendulum bob moves away from the pulley the pulley is turned round. The index *i* is hung from the pulley, because if it be rigidly attached, its considerable moment of inertia tends to make the pulley turn too far round when it receives a sudden jerk from the thread. Two such indices should be arranged and and actuated by threads attached to the same wire under the pendulum, but taken out along lines at right angles to each other, so that the two indices may register two rectangular components of the motion.

A simple modification of the Zöllner horizontal pendulum (*see* Pogg. Ann. for 1873, p. 131, and the Phil. Mag. for 1872, p. 491, or the Brit. Ass. Rep. for 1881, p. 112) makes a very convenient instrument for measuring the horizontal component of the motion during an earthquake. The Zöllner pendulum consists of a rigid rod carrying at one end a heavy mass and held in a horizontal position by two pieces of thin spring steel, fixed one above and the other below the horizontal rod. The points at which the sustaining steel strips are attached to the framework of the stand are nearly in the same vertical line, while the strip which is fixed to the lower point is attached to the horizontal rod at a point a little further from the heavy mass than the strip which is fixed to the higher point. It is clear that if the steel strips have little torsional rigidity the period of horizontal oscillation of the heavy mass may be made long, and hence the mass might be used as a steady body from which to record earthquakes, after the manner of the bob of the ordinary pendulum described above. It is more convenient in practice, however, to dispense with the steel strip suspension, and either to substitute a simple vertical axis round which the mass can turn like a door on its hinges, or to put a vertical knife edge on the end of the horizontal rod and allow it to rest in the bottom of a flat vertical V, while the weight of the mass is supported by a cord or fine wire, attached at one end to the mass, and at the other to a fixed point nearly vertically above the V in which the knife edge rests. The line of the supporting wire should be arranged to pass through the centre of gravity of the mass This second modification is easily made in a rough form, and it offers very little frictional resistance to the free horizontal oscillation of the mass. One great advantage of the horizontal over the vertical pendulum is the ease with which a long period can be obtained with an instrument of small dimensions. For earthquakes in which the amplitude does not exceed half an inch, the distance from the knife edge to the centre of gravity of the mass need not exceed two or three inches. A moderate magnification of the motion may be obtained with such an instrument by simply adding a light index in the form of a continuation of the horizontal rod which carries the mass. *See* Prof. J. A. Ewing on "A New Seismograph," Proc. R. S., No. 210, 1881, p. 440. This index may be made to record its motion on a piece of smoked glass placed under its sharpened point. These horizontal pendulums, to give both horizontal components of the motion, have to be used in pairs, as they only indicate motions at right angles to their own plane. They are, when adjusted for a long period of free oscillation, better adapted for giving continuous records on moving record receivers than for giving static records, as their near approach to neutral equilibrium, which is so valuable for continuous records, renders them very liable to be permanently displaced by the shaking, especially if the vertical axis has a little friction.

For the observation of earth tremors these instruments may be very easily arranged to have great magnifying power, especially if they be not required to register, or are made to register, by photography. This magnification is best obtained by attaching one thread of the bifilar suspension of a small mirror to the outer end of the horizontal rod, and the other thread to a closely adjacent fixed point. The mirror may then be made to reflect a beam of light to a scale, or to a strip of photographic paper, and will either show to an observer, or give a permanent record of, the minute motions under investigation. If the period of these small motions be long, it is better to use the Zöllner form of the pendulum, because even a very minute amount of friction may then prevent the instrument giving the proper indications.

A little consideration will show that this horizontal pendulum is extremely sensitive to change of level. This is rather an objection from the earthquake point of view, but it is of great value as rendering the instrument suitable for the observation of slow changes of level of the earth's surface. For this purpose the position of the spot of light on a suitably placed scale may be observed from time to time, or, what is much better, the distance between a photographic record obtained from the suspended mirror, and another similar record obtained on the same band of paper from a fixed mirror, may be observed.

An ordinary pendulum can, by a similar arrangement of mirrors for magnifying the displacement of the bob relatively to the earth, due to small changes of level, be made to act in the same way as that just described, the only disadvantage being the much greater size of the instrument for the same sensibility, thus rendering it much more difficult to set up and use with certainty as to the results.

Attempts have, with some success, been made to observe the change of angle between the planes of a fixed mirror and the surface of a basin of mercury due to changes of level in the earth's surface, but this method is in a higher degree insensitive, and can only be carried out by elaborate means and continual personal observation.

Interesting results are sometimes obtained by simply fixing two very sensitive spirit levels securely to the surface of the rock near the earth's surface, and observing the fluctuations in the position of the bubble, and at the same time noting all such attendant phenomena as height of the barometer, atmospheric, and rock temperatures, rainfall, state of the tide at the nearest coast, position of the sun and moon, and so on.

In order to obtain results of value in this part of seismology, the instruments ought to be fixed to the solid rock and at some distance below its surface, so as to avoid so much as possible the effects of surface temperature and other conditions. It should also be remembered that the weight of the observor may have great effect on instruments of sufficient sensibility to show these very minute changes of level. For further information on this important and highly interesting branch of seismology, the reader is referred to the Reports on the Measurement of the Lunar Disturbance of Gravity, by Professor George H. Darwin and Mr. Horace Darwin in the British Association Proceedings for 1881 and 1882, where a very full summary of the work which has been done in the subject is given.

The prevailing direction of motion in an earthquake shock may be approximately obtained by placing a number of rectangular prisms on end, on a rigid level base, with their faces in different azimuths. If the direction of motion is not either exactly parallel to a diagonal or a side of the prism, it will tend to turn round until one pair of sides comes parallel to it. Hence, if the shock be sufficiently severe, or last long enough, the prisms will be found to have set their sides parallel, and from the direction in which, and the corners round which, they have severally turned the direction of shock may be obtained. This will be understood by considering that the effect of the shock is to tilt the prism on one corner, while the angular momentum generated makes it turn round this corner as a pivot. (*See* Milne's " Earthquakes," p. 196.

The whole of the arrangements yet described have for their object the determination of the horizontal motion, and this they do either directly or through two components which have to be combined in order to get the actual horizontal motion. There yet remains to be described the method of determining the vertical component. This component has hitherto proved by far the most troublesome to determine with an approach to accuracy. Attempts have generally been made by means of springs, either spirals of wire stretched by a heavy weight, or flat springs fixed at one end and bent by hanging a weight on the other, and thus in both cases made to form, as it were, vertical motion pendulums. These appliances are of course open to all the objections brought against the ordinary pendulums described above, with the addition that the free period cannot be conveniently made long, especially in the case of spiral springs, and that the position of the weight is apt to change slowly in consequence of imperfect elasticity of the material. To obviate these difficulties the present writer designed the arrangement shown in Fig. 3. This consists of a lever L, carrying at one end a mass M, and furnished at the other with a knife edge K, fixed with its length at right to that of the lever. The lever is held in position by two flat springs S, bent as shown nearly into circles. The circular form is got by cutting the springs in such a way that the breadth is at every point proportional to the cross bending moment at that point in the bent spring. The thickness then being taken as nearly constant the curvature becomes uniform. This prevents one part of the spring being more bent than another, and care is taken that the curvature is not greater than the elastic limit of the material will admit of, so as to obviate as much as possible the difficulty above referred to, as to imperfect elasticity. The lever arrangement has in itself considerable advantage in the way of length of period, but its chief advantage lies in the facility which it offers to the addition of negative stability. If, for example, the lever be imagined to be a trough containing liquid, when the lever is depressed the liquid will flow

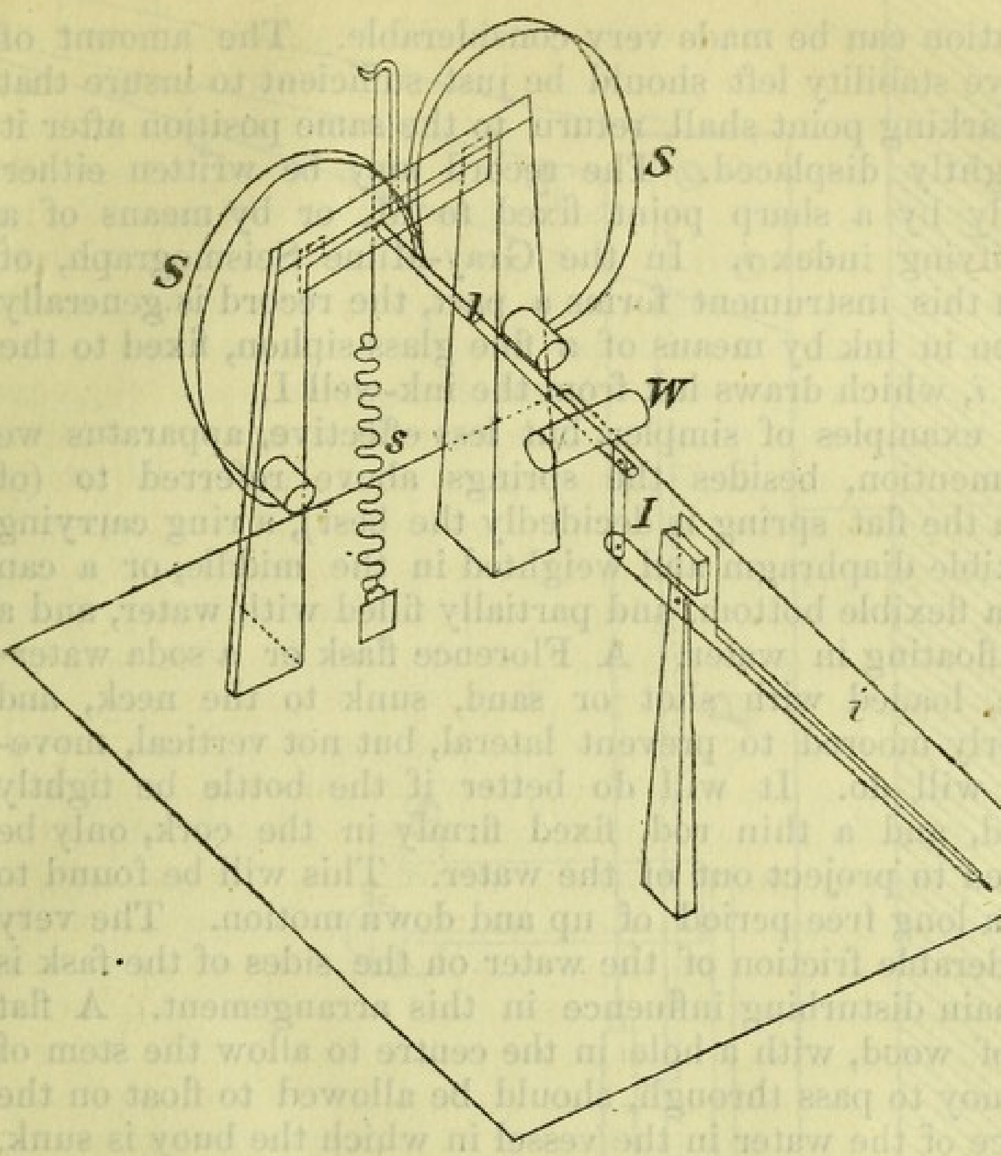


Fig. 3.

forward, and thus gain leverage to keep it depressed. Or take the case actually shown, that of a second spring pulling down and having its point of attachment above the knife edge. As the lever C moves up and down, the couple applied by this second spring changes, and can be arranged to produce complete compensation for the increased or diminished couple applied by the spring S. Another obvious, but much less effective, mode of compensation is to make the point of attachment of the spring S, under the line joining the knife edge and the centre of gravity of the mass M. The second spring S is used both to produce the required negative stability, and as a fine adjustment for bringing the lever *l* to the horizontal position. A certain amount of positive stability must be left so as to insure approximate constancy in the position of the lever, but as the friction of the arrangement is small, the period of free oscillation can be made very considerable. The amount of positive stability left should be just sufficient to insure that the marking point shall return to the same position after it is slightly displaced. The record may be written either directly by a sharp point fixed to M, or by means of a magnifying index *i*. In the Gray-Milne Seismograph, of which this instrument forms a part, the record is generally written in ink by means of a fine glass siphon, fixed to the index *i*, which draws ink from the ink-well I.

As examples of simpler, but less effective, apparatus we may mention, besides the springs above referred to (of which the flat spring is decidedly the best), a ring carrying a flexible diaphragm and weighted in the middle, or a can with a flexible bottom, and partially filled with water, and a buoy floating in water. A Florence flask or a soda water-bottle, loaded with shot or sand, sunk to the neck, and properly moored to prevent lateral, but not vertical, movement will do. It will do better if the bottle be tightly corked, and a thin rod, fixed firmly in the cork, only be allowed to project out of the water. This will be found to have a long free period of up and down motion. The very considerable friction of the water on the sides of the fask is the main disturbing influence in this arrangement. A flat disc of wood, with a hole in the centre to allow the stem of the buoy to pass through, should be allowed to float on the surface of the water in the vessel in which the buoy is sunk, so as to prevent the water getting up a state of oscillation. *See* T. Gray on "Instruments for Measuring and Recording Earthquake Motion," Phil. Mag., Sept. 1881. Also Milne and Gray on "Earthquake Observations and Experiments," Phil. Mag., Nov. 1881.

Graphic Records.—The following simple methods of obtaining graphic records of the motion of the earth during an earthquake will be found to give good results. Fix a plank P, Fig. 4, firmly to the ground by means of stakes driven to a considerable depth, or by any other convenient means. Mount on the plank a small carriage C, made from a strip of board about 2 feet long and 6 inches broad, and provided with three round-ended plugs to act as feet. Cut a **V** groove along the length of the plank, and place the carriage on it with two of its feet in the groove. Now attach to one end of the carriage a cord, and take it under a pulley *a* at the end of the plank, and again over a similar pulley *b* fixed to the top of the vertical frame *f*, and attach

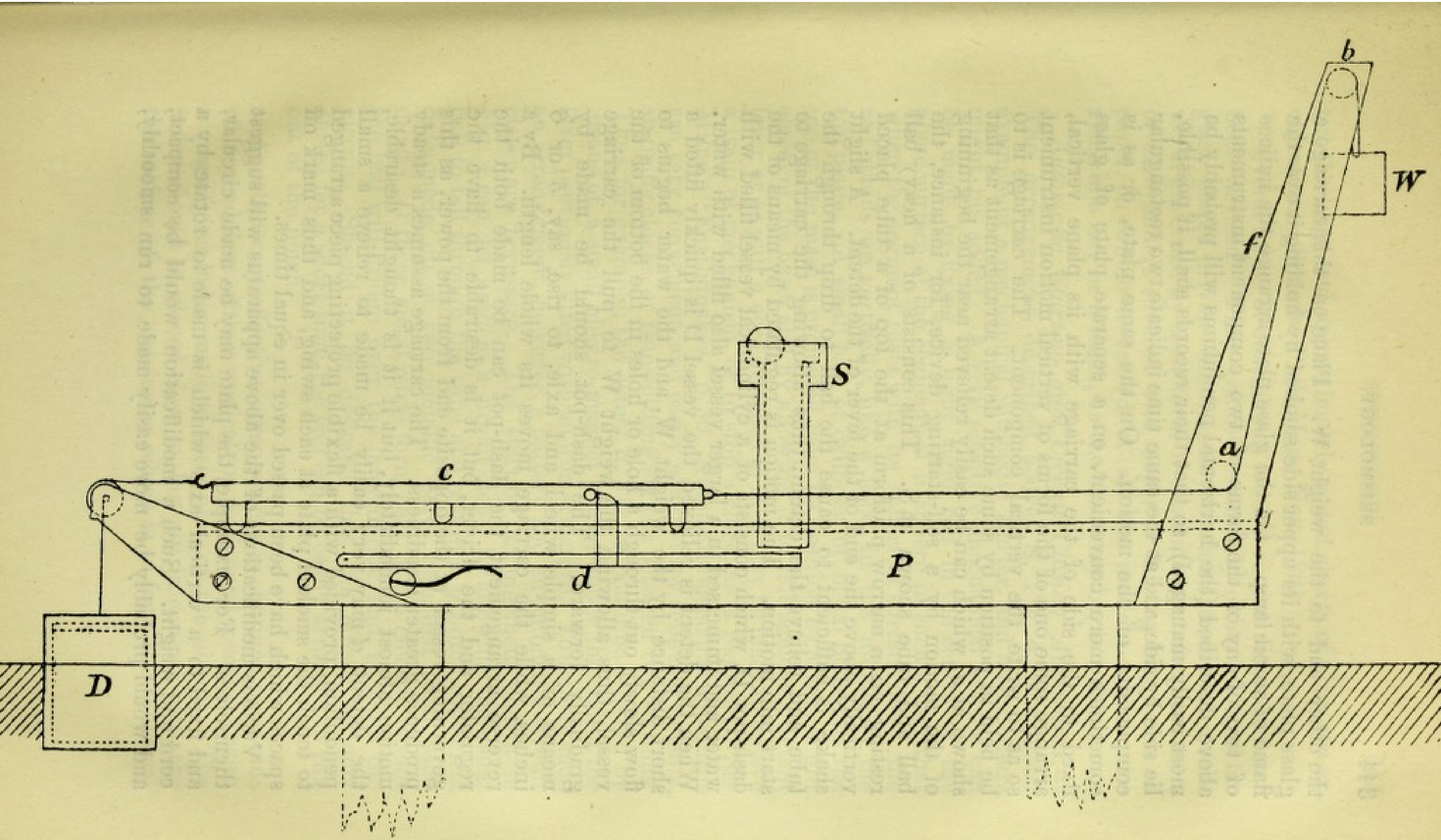


Fig. 4.

the other end to the weight W. Place on this carriage a glass plate, with its upper side smoked by holding it over the flame of an oil lamp. On the glass plate arrange the indices of two of any of the forms of two component instruments above described (the horizontal pendulums will probably be most easily managed), so that their records shall, if possible, lie side by side, and at the same time indicate two rectangular components of the motion. On the same plate, or as is sometimes more convenient, on a separate plate of glass fixed to the side of the carriage with its plane vertical, arrange some one of the forms of vertical motion instrument so as to write the vertical component. The carriage is to be held in position by some such detent arrangement as that shown at *d*, which can be easily relieved near the beginning of the motion by a self-starting device, for instance, the ball and tube shown at S. This consists of a heavy ball resting on a narrow platform at the top of a tube placed vertically above the end of the lever of the detent. A slight shake is sufficient to cause the ball to drop through the tube and relieve the detent, thus allowing the carriage to start into motion. The motion is regulated by means of the dash-pot D, which consists of a cylindrical vessel filled with water and immersed in a larger vessel also filled with water. When the detent is relieved the vessel D is quickly lifted a short distance by the weight W, and the water begins to flow slowly out through a hole or holes in the bottom of the vessel, thus allowing the weight W to pull the carriage gradually forward. The dash-pot should be made by means of a simple wheel and axle, to rise, say, 5 or 6 inches, while the carriage moves its whole length. By a reverse arrangement the dash-pot can be made both the regulator and the driver, but it is desirable to have the governing vessel at the opposite end from the power, as this produces greater steadiness. The carriage assumes a steady motion almost immediately, but if it is thought desirable, the detent *d* may very easily be made to relieve a small pendulum, provided with a flexible projecting piece arranged to touch the smoked plate at each swing, and thus mark off spaces which have been passed over in equal times.

Various modifications of the above apparatus will suggest themselves. For example, the plate may be made circular, and fixed to a vertical axis which is made to rotate by a cord and weight. Such a modification would be compact, and would probably be more easily made to run smoothly, but the large and approximately round sheets of glass are an objection. *See also* Phil. Mag., Nov. 1881.

Several forms of continuous motion record receivers have been devised. They consist essentially either of circular glass plates driven continuously by long trains of clock-work, governed by some form of continuous motion governor, or of cylinders covered with paper or driving long bands of paper, on which a record of all the motions which take place in a day or a week, as the case may be, is written.

Automatic Starting and Circuit Closing Apparatus.—The arrangement described above, S, Fig. 4, is a good example of a mechanical automatic starter, and many others might be added. A very sensitive mechanical starter can be made by fixing a light rigid rod in the centre of the plane surface of the segment of a sphere in such a way that when the segment rests with its spherical surface down the rod stands up vertically, like a mast, in the middle of the top plane. A small ball or cylinder of metal placed on the top of the mast is projected from its position by a very slight shake of the base, and by allowing it to fall against a detent lever or to pull a cord attached to it, it may be made to relieve a train of mechanism, or to stop a clock, as is required. *See* Milne's "Earthquakes," p. 36. Automatic electrical apparatus are very convenient, and easily adapted for relieving detents, stopping clocks, or transmitting signals between two stations. Thus, for example, the detent *d*, Fig. 4, could be relieved by means of a small electro-magnet placed under the end of the lever previously fitted with an iron armature. To actuate such an arrangement, however, a battery and an automatic circuit closer are necessary. The starting arrangement shown in Fig. 4 can be used as a circuit closer by allowing the metal ball to fall through the tube and rest in a V notch or conical hole made up of two metallic parts insulated from each other. If these metal parts form part of an electric circuit the ball will bridge over the interruption, and so close the circuit. Should it be desirable that the circuit be only closed for a short time, the ball can be easily arranged to run out of the notch.

Another very effective arrangement is obtained by means of a pendulum, either vertical or horizontal, provided with a magnifying index made to form part of the circuit. The index should be placed close to, but not in contact with, the the surface of the conductor which is to form the continuation of the circuit, and thus a slight motion of the pendulum brings the two into contact and closes the circuit.

One of the best ways of closing the circuit is to fix an iron pin *p*, Fig. 5, in the bottom of an iron or wooden cup *c*, and pour mercury into the cup until the surface of the mercury is a little higher than the pin. If now the mercury

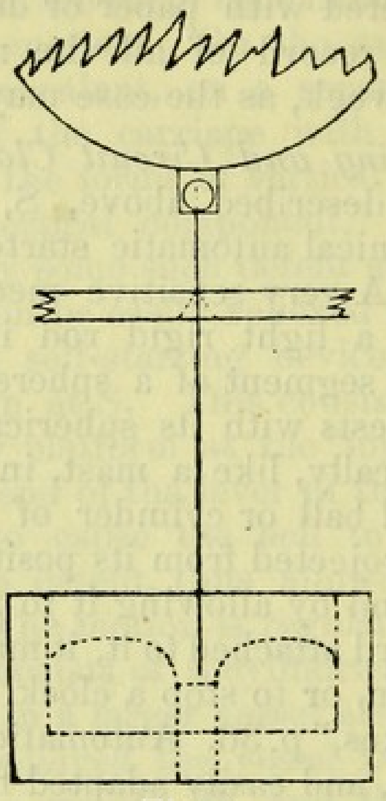


Fig. 5.

be pushed off the pin by the finger or the end of a pencil, it will stand up round it and form a sharp depression, into which the end of the index *i* can be placed. At the time of an earthquake the index *i* is pushed into the mercury, which generally closes round it, thus making a very secure contact. In a similar way, if two pins be fixed near together in the bottom of a cup and a small quantity of acidulated water be poured in round them, the surface of the liquid will rise by capillary attraction between the pins and form a sharp elevation, through which the index *i* may be made to pass and repass during a shock, and in this way close an electric circuit. The liquid in both these cases must be put in contact with one pole of the battery.

Clock Stopping.—Two contrivances for stopping the pendulum of a clock at the time of an earthquake shock are shown in Figs. 6 and 7. In both figures B is the bob of the pendulum, *a b c*, Fig. 6, is a crank lever, which may be either hinged or allowed to rest on a knife edge at *b*; *b c* is a light

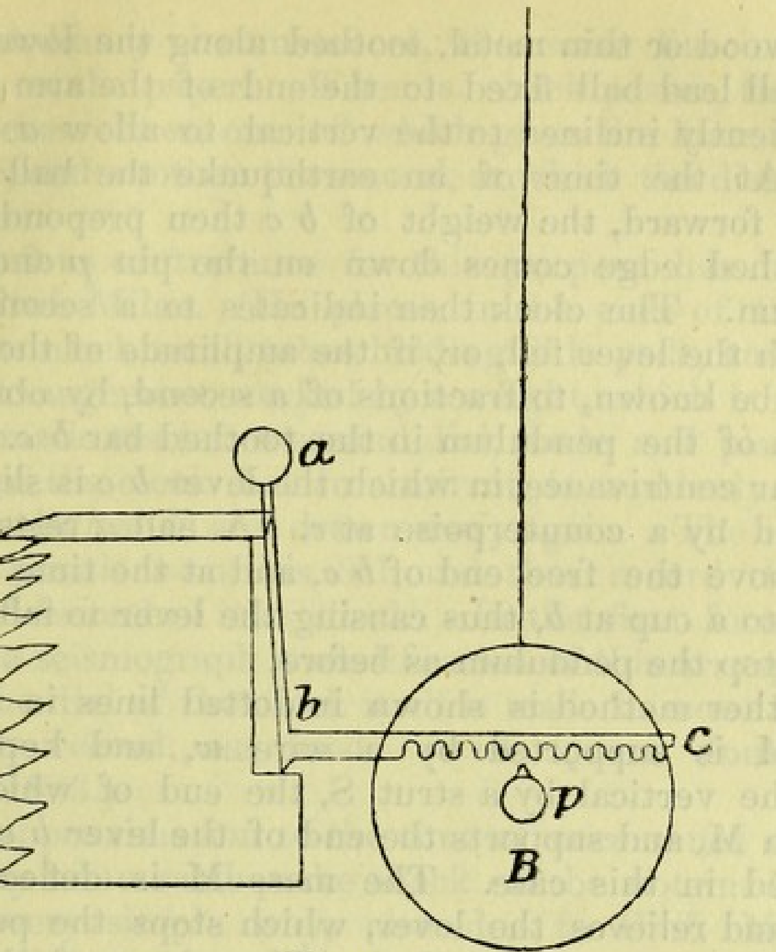


Fig. 6.

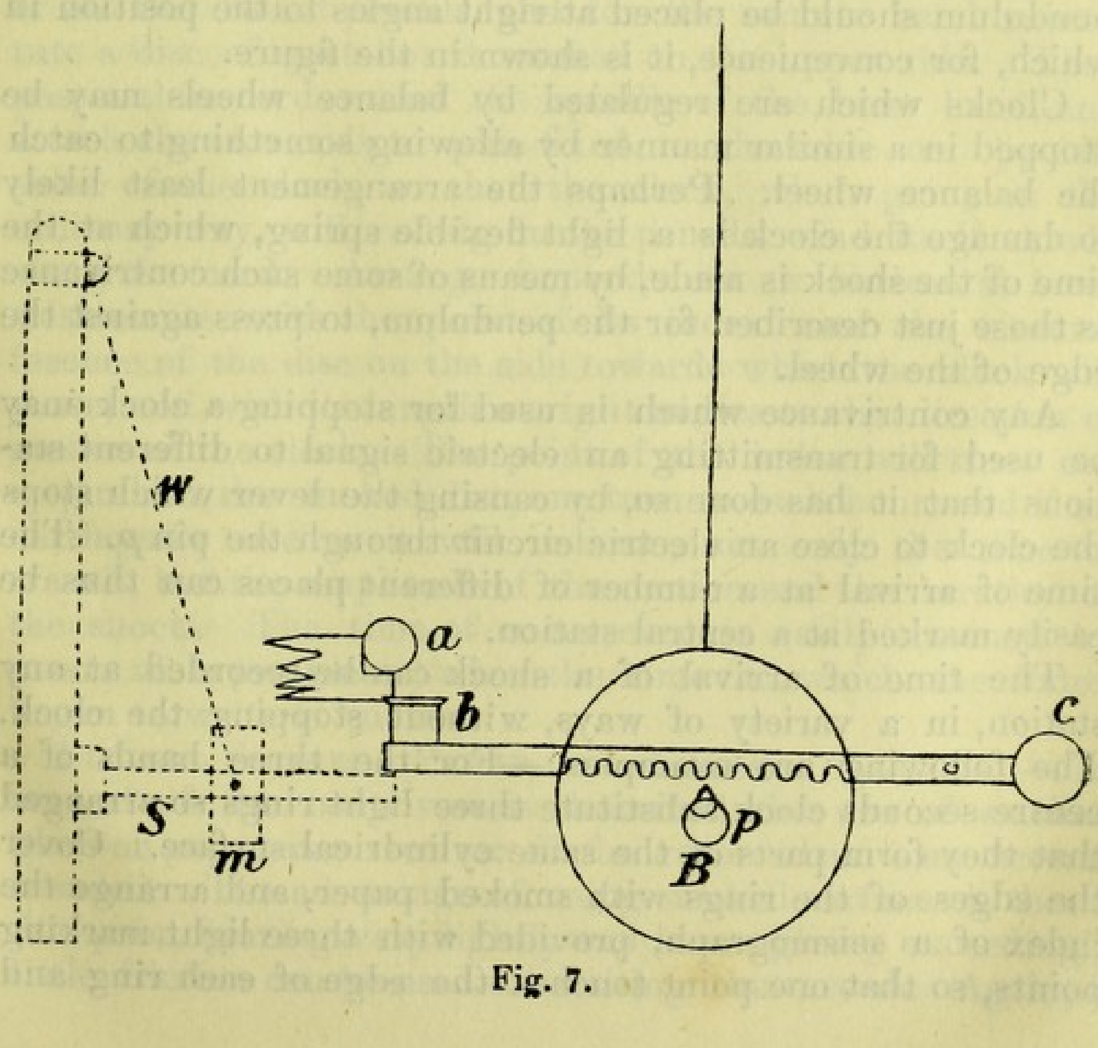


Fig. 7.

rod of wood or thin metal, toothed along the lower edge; *a* is a small lead ball fixed to the end of the arm *b a*, which is sufficiently inclined to the vertical to allow *a* to balance *b c*. At the time of an earthquake the ball is thrown slightly forward, the weight of *b c* then preponderates, and the toothed edge comes down on the pin *p* and stops the pendulum. The clock then indicates to a second the time at which the lever fell, or, if the amplitude of the pendulum motion be known, to fractions of a second, by observing the position of the pendulum in the toothed bar *b c*. Fig. 7 is a similar contrivance, in which the lever *b c* is slightly over-balanced by a counterpoise at *c*. A ball *a* rests in a notch just above the free end of *b c*, and at the time of a shock rolls into a cup at *b*, thus causing the lever to fall on the pin *p* and stop the pendulum as before.

Another method is shown in dotted lines in Fig. 7. A mass M is supported by a wire *w*, and kept deflected from the vertical by a strut S, the end of which projects through M, and supports the end of the lever *b c*, not counterpoised in this case. The mass M is deflected by the shock and relieves the lever, which stops the pendulum in the manner above described. The plane of the deflected pendulum should be placed at right angles to the position in which, for convenience, it is shown in the figure.

Clocks which are regulated by balance wheels may be stopped in a similar manner by allowing something to catch the balance wheel. Perhaps the arrangement least likely to damage the clock is a light flexible spring, which at the time of the shock is made, by means of some such contrivance as those just described for the pendulum, to press against the edge of the wheel.

Any contrivance which is used for stopping a clock may be used for transmitting an electric signal to different stations that it has done so, by causing the lever which stops the clock to close an electric circuit through the pin *p*. The time of arrival at a number of different places can thus be easily marked at a central station.

The time of arrival of a shock can be recorded at any station, in a variety of ways, without stopping the clock. The following are examples:—For the three hands of a centre seconds clock substitute three light rings so arranged that they form parts of the same cylindrical surface. Cover the edges of the rings with smoked paper, and arrange the index of a seismograph, provided with three light marking points, so that one point touches the edge of each ring and draws, in ordinary circumstances, the same line over and over again on the paper. When a shock passes, the points will mark cross lines, one of which gives the hour, another the minute, and another the second, at which the disturbance was felt.

An ingenious contrivance for this purpose has been devised for Prof. Milne. He places in the ends of the three hands of the clock small tubes holding ink pads, and by an excentric arrangement worked by a weight, which is relieved by an automatic starter, a second dial, made and placed like the image of the clock dial in a mirror, is suddenly thrown forward on the hands and drawn away again. The ink pads mark their positions on this dial, and thus record the hour, minute, and second of the shock. In the first form of the Gray-Milne seismograph a modification of this arrangement, in which the dial of the clock itself is made to move forward and take the record, was used. (*Vide* Quart. Jour. Geol. Soc., May 1883.)

A good approximation to the time of occurrence and also the intensity of an earthquake shock can be obtained in the following very simple way, also due to Prof. Milne:— Place a small American clock on its back resting on wheels, or on two round pencils, and for the minute hand substitute a disc of pasteboard smoked on the upper side. Then pass a thin cord round the spindle of the hour hand, and attach the two ends to pins fixed to the table on opposite sides of the clock, so that the clock, when going in the ordinary way, will, rolling on the pencils, wind itself slowly along the cord. Arrange a pendulum or horizontal lever seismometer with the point of its index near the circumference of the disc on the side towards which the clock will move, and with its length at right angles to the direction of motion of the clock. The point of the index will trace out a spiral on the smoked disc, one turn to each hour, and if an earthquake occurs it will indicate, not only the time of transit, but the amplitude of the motion and the duration of the shock. The time of occurrence is easily obtained by means of a protractor, when the time at which the index began to write is known.

Fixing Smoked Paper or Glass Diagrams. — In several of the contrivances described the use of smoked glass or paper as a receiver of the record has been recommended. The advantage of using smoked surfaces is that a fine point bearing very lightly and hence giving exceedingly little friction can be used for writing the record. Again, if glass or transparent paper be used the sheet may be used as a negative, and photographic prints taken of the diagrams.

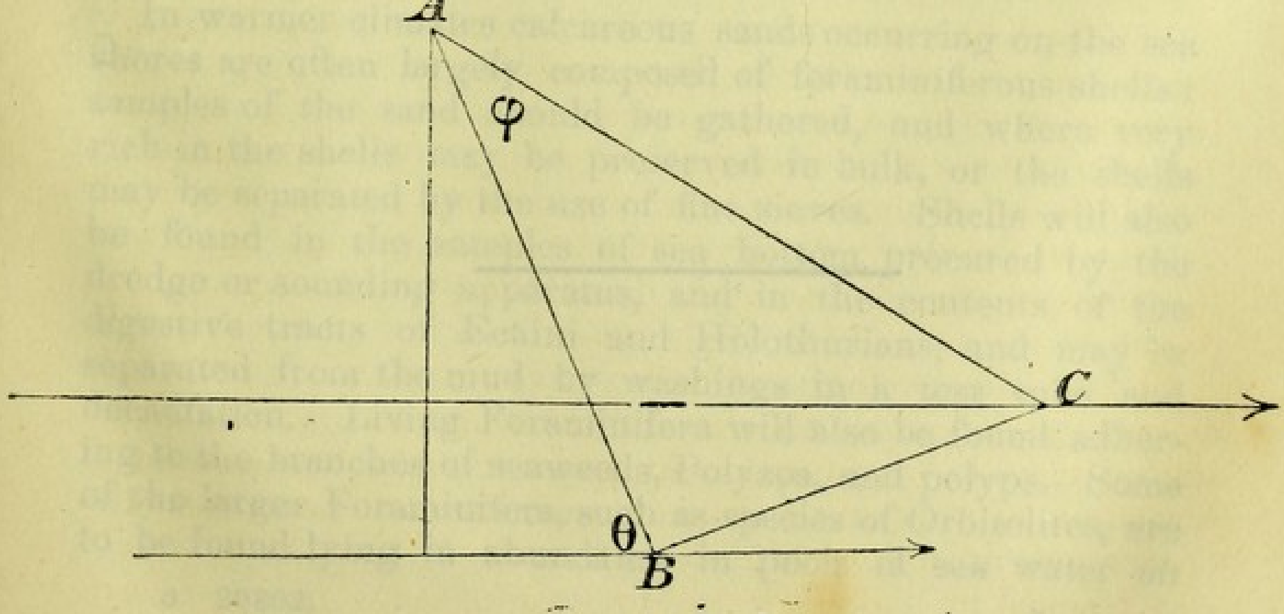
To fix the soot after the diagram is written photographers' varnish may be run carefully over the sheet previously warmed, or better, a spray jet, like that used by artists for fixing chalk sketches, may be used to coat the sheet with varnish.

DETERMINATION OF CENTRUM.—The determination of the centre of disturbance or the point where an earthquake originated may be advantageously attacked in the following manner:—First obtain as much information as possible as to the area over which the earthquake was felt and the intensity at different places. This may be done by writing to persons holding prominent positions in the various towns and villages surrounding the most disturbed region. Having obtained this information, mark, following some plan which will indicate the intensity, according to the different reports, the positions of the different places on a map. This will give an area within which the centrum must be situated, unless, as often happens, the intensity seems to increase towards the seacoast when the centrum is probably beneath the sea. Next add to this the times of occurrence at as many places as possible, obtained from clocks which were stopped, or from personal observation received from persons who can be relied on to observe accurately. These times will probably be too inexact to found any calculation on, but they will assist in forming a rough idea of the position to be determined. It may then be advisable to visit several places where information is likely to be gathered from the damage done to houses or other structures. In making comparisons care should be taken to choose similar structures similarly situated with regard to foundation, surrounding country, and so forth. By some such means endeavour to make out as nearly as possible lines of equal intensity and also the curve of maximum intensity. The epicentrum will then be somewhere near the central portion of this curve, and the depth of the centrum approximately equal to the mean radius of the curve. (*See* Milne's "Earthquakes," p. 188.)

Should the earthquake under investigation occur in a district where small shocks are frequent, an instrumental survey may be instituted, and from it more accurate information as to relative intensity and the relative times of occurrence at different places obtained. Having in this way reached by successive approximations to a fairly accurate knowledge of the point or points from which earthquakes are likely to emanate, special observations on carefully selected sites should be made for the purpose of discovering the degree of verticality of the disturbance, and the rate at which it diminishes as the distance increases. The times of occurrence should also be attended to very carefully, and the horizontal velocity of propagation at different places determined. The principles already explained will then lead to valuable conclusions as to the position of the epicentrum, the depth of the centrum, and the nature of the underlying rock formations.

DIRECTION OF MOTION AND DIRECTION OF PROPAGATION.—The direction of motion at any point during an earthquake shock may be determined by one or other of the instruments above described, or it may be inferred from the direction in which elevated bodies have been projected. It may also be roughly inferred from the relative damage done to similar buildings which were standing in different azimuths. Walls that are overturned will generally have their planes across the direction of motion, while walls which are cracked will generally have their planes more or less nearly along the direction of motion.

The direction of propagation, as has already been pointed out, cannot with any certainty be inferred from the direction of motion at any one point, and for this element, as well as for the velocity of propagation we have to fall back on the times of arrival of the shock at different places. The following may be taken as an example of the application of this method (*see* Mallet on "The Facts and Theory of Earthquake Phenomena," Brit. Ass. Rep., 1858, p. 95) :—



Let ABC be three points on the earth's surface, say, two or three miles, or more, apart. Let the earthquake wave approach these points in the direction of the arrows, and let the interval between its arrival at A and at B be t_0 and between its arrival at A and at C, t_1. Let the angle which the direction of propagation makes with AB be θ, the angle BAC be φ, and the velocity of propagation v. Then we have—

$$vt_0 = \mathrm{AB} \cos \theta \text{ and}$$

$$vt_1 = \mathrm{AC} \cos (\theta - \varphi)$$

$$\text{Hence } \tan \theta = \frac{t_1 \mathrm{AB}}{t_0 \mathrm{AC} \sin \varphi} - \cot \varphi \ldots\ldots (13.)$$

and

$$v = \frac{\mathrm{AB}}{t_0(1) + \tan^2 \theta)} \ldots\ldots\ldots\ldots (14.)$$

Many interesting modifications of this problem will readily suggest themselves, which it is unnecessary to state here in detail. *See* Milne's "Earthquakes," Chap. X. When the times of arrival at more than three points are known it will generally be found advisable to divide them into groups of three, as on account of unavoidable errors of observation no one direction or velocity will satisfy all the conditions. When graphic records are taken of the shock the direction and velocity can be obtained from three points only a very short distance apart by marking electrically a definite instant on all three diagrams, and observing the interval between this mark and any prominent feature common to all the records.

ARTICLE XIII.

ZOOLOGY.

The article on Zoology in the former editions, by Professor Owen, has been here essentially re-written.

BY PROFESSOR H. N. MOSELEY, F.R.S.

Instructions for observing, collecting, and preserving animals.

PART I.—INVERTEBRATA.

PROTOZOA.

RHIZOPODA.

Foraminifera.

The Foraminifera will well repay special attention, because of the importance of their relations to geological questions of paramount interest. In forming their shells, those in which these are calcareous, separate from the ocean water the calcareous matter held in solution by it as the result of denudation. The shells form vast deep sea and extensive shore deposits, and contribute largely to the formation of many coral islands.

In warmer climates calcareous sands occurring on the sea shores are often largely composed of foraminiferous shells; samples of the sand should be gathered, and where very rich in the shells may be preserved in bulk, or the shells may be separated by the use of fine sieves. Shells will also be found in the samples of sea bottom procured by the dredge or sounding apparatus, and in the contents of the digestive tracts of Echini and Holothurians, and may be separated from the mud by washings in a test tube and decantation. Living Foraminifera will also be found adhering to the branches of seaweeds, Polyzoa, and polyps. Some of the larger Foraminifera, such as species of Orbitolites, are to be found lying in abundance in pools of sea water on coral reefs. Attempts should be made to study the mode of protrusion of the pseudopodia and general habits of the living Orbitolites, a supply of specimens of the larger Foraminifera when obtained living should be preserved in strong spirit. A certain number of species of Foraminifera are pelagic in habits, and are of special importance as forming the main part of the deep sea Globigerina mud. Many of these forms possess shells covered by long radiating spines of extreme fineness, which support fine pseudopodial threads of sarcode. These pelagic Foraminifera should be assiduously sought for in the contents of the tow net whenever used at sea; they should be carefully preserved, and the circumstances and localities of their occurrences accurately noted. For information as to pelagic and deep sea Foraminifera the Report on the scientific results of the voyage of H.M.S. "Challenger" should be consulted. Dr. G. S. Brady's report of the Foraminifera composes Vol. IX. Mr. John Murray's summaries of his important results will be found in the "Narrative," Vol. I.

Radiolaria.

The Radiolaria are entirely pelagic. Constant attention to the frequency of their occurrence at the sea surface may be paid with great advantage during any long voyage in warmer seas. Occasionally they occur in enormous abundance, the whole sea surface for several days' voyage being found filled with them. On such occasions the main bulk of the animals present is usually made up of a very few species, possibly one or two only. Specimens of these should be identified and preserved. Radiolaria may be preserved by being placed directly in strong spirit, or they may be first treated with $\frac{1}{10}$th per cent. solution of osmic acid for about five minutes as explained under the general account of the treatment of animals caught in the tow net.* In certain regions the deep sea bottom is composed of the silicious skeletons of Radiolaria, and termed radiolarian ooze. In the Arctic and Antarctic regions pelagic organisms both of animal and vegetable nature become washed up on to the

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* *See* p. 411. For special details as to the preservation of Radiolarian, *see* K. Brandt. Fauna u. Flora des Golpes von Neapel, XIII., Monographie, s. 7.

surface of floating ice. Where this has become honeycombed by decay the pores and irregularities act as strainers, and the ice may become completely filled with the organisms so as to be conspicuously discoloured by them. These organisms may become frozen in, and by subsequent vicissitudes the discoloured portion of ice may reach all kinds of elevated or other positions on icebergs or iceblocks. Portions of such discoloured ice should be collected and the deposit melted out from them carefully preserved. In a deposit from melted pancake ice, from the barrier in 78° 10′ S. lat., 162° W. long., collected by Sir Joseph Hooker during Ross's Antarctic voyage, Ehrenberg found the skeletons of 51 Radiolaria, and the calcareous shells of four species of Foraminifera, besides abundance of diatoms. The "Challenger" found the Antarctic ice similarly stained of an ochreous tint by diatoms.

CŒLENTERATA.

Spongida.

Sponges are bodies usually adherent in irregular or amorphous masses, rarely in the form of hollow reticulate cones; they are composed of a soft jelly-like tissue, in most cases supported by a skeleton composed of silicious or calcareous spiculæ or of horny filaments. They are divided accordingly into calcareous sponges, flinty or silicious sponges, and horny or keratose sponges. Their soft tissues are commonly diffluent, and begin to drop from the skeleton almost immediately they are removed from the water, and even when this is not actually the case decomposition sets in with extreme rapidity. It is important, therefore, that when their soft tissues are intended to be preserved the sponges should be plunged into very strong alcohol instantaneously after their removal from the water, so that they may not be allowed a moment to deliquesce. It is most important that portions at least of all sponges collected should thus be preserved entire in alcohol. In the case of large solitary and compound sponges, when spirit is scanty, portions may be cut out for preservation in spirit, and the remainder dried. The portions selected for hardening in spirit should include part of the surface, a portion of the margin of one of the principal apertures or ostia, and a small block of the deep-seated tissues near the base, as likely to contain generative organs. They should be cut out with a sharp knife or razor, all squeezing being carefully avoided. When sponges are dried they should be soaked for some hours previously in fresh water. When different species are packed in the same vessels, whether in spirit or dry, they should be first wrapped in paper to prevent their spicules getting mixed together. For special histological examination portions of any sponges of special interest should be preserved in absolute alcohol.

Marine sponges are to be found exposed at low tide and at all depths attached to the bottom mud or rocks, sea-weeds, shells of mollusks, or even those of living crabs. They are often of very brilliant colours. Every opportunity should be taken in unexplored regions to search for freshwater sponges in rivers, lakes, and ponds, and they should be preserved in spirits, if possible, when found. They are usually of a brilliant green colour, and being coloured by chlorophyll may easily be mistaken for water weeds at first sight.

Hydrozoa.

Hydromedusæ (*Hydroid Polyps and Hydroid Corals*).

The sessile branching colonial Hydroid polyps occur at all depths attached to all available objects of support; some can only be obtained by dredging. Those inhabiting the shores are best to be found by searching in tide pools, since they are more easily recognised when their branches are expanded in the water.

In the tide pools they should be sought on the under sides of stones and rocky ledges, and beneath the hanging weed. Mr. Hincks recommends that the collector "should "lie down beside a likely pool with overhanging ledges "and clefts well draperied with weed, that he may be able "to peer into it patiently and intensely without the fatigue "and distraction of stooping," he should then scan the whole pool inch by inch, raising the curtain of hanging weed and allowing the sunlight to pierce the chinks and crannies.

Special care should be taken to collect specimens with the sexual organs or gonads, whether medusoid or not, present in all stages of development. In most forms the sexes are separate on different stocks, certain stocks bearing only male gonophores, and others only female, and in selecting specimens it is advisable that whenever time permits the attempt should be made to secure examples of both. Amongst the Calyptoblastea or Thecaphora, in which the gonophores are enclosed in horny capsules or gonothecæ often large and conspicuous, the male capsules are frequently smaller than the female, and of a different shape. As a rule the stocks are diœcious, but sometimes in species usually diœcious both male and female capsules are found on the same branch of a stock.

Of the Hydroid Corals or Hydrocorallinæ, the Milleporidæ occur in shallow water as important components of coral reefs, whilst of the Stylasteridæ only two of the genera Stylaster and Distichopora occur on reefs in shallow water, most representatives being found in considerable depths down to 1,500 fathoms, or deeper. Fragments of these latter may be obtained on sounding lines.

Whenever opportunity occurs attempts should be made to investigate the sexual organs and mode of development of the Milleporidæ which are not known. In the Stylasteridæ, which are mostly very brilliantly coloured, the gonophores are contained in chambers within the substance of the calcareous skeletons of the stocks termed ampullæ, the outer walls of which project more or less from the surfaces of the branches. The male stocks are often clearly distinguishable from the female in consequence of the greater size and prominence of the ampullæ, and care should be taken to secure specimens of both sexes.

All the Hydromedusoid stocks are best preserved in strong spirits. It is best to try and secure specimens with the polyps preserved in the expanded condition. The attempt should be made in the case of all specially interesting forms This may be effected by placing the living specimens in a tall jar half full of sea water, which has been thoroughly aerated by being shaken up with air, and as soon as the polyps are seen to be expanded, suddenly pouring into the jar a hot, even almost boiling, saturated solution of corrosive sublimate in water sufficient to fill the jar completely.

If the operation is successful the polyps will be instantly killed in the expanded condition. After the lapse of four or five minutes, the sublimate solution should be poured off and fresh water substituted, to be followed by weak and then strong spirit. A certain amount of spirit may sometimes be added to the solution of corrosive sublimate in water, in order to render it more concentrated and rapid in its action. The less the quantity of sea water in which the polyps can be induced to expand the better for the process. It would be especially valuable if preparations of Millepora, or any of the Stylasteridæ, could be thus obtained with expanded polyps. No opportunity should be lost of studying the forms and movements of the living polyps of any of the Hydroid corals.

When spirit is not available, or when sufficient spirit material has already been gathered, the horny skeletons of many Hydroid stocks may be dried with very good results. A novel process for drying these has lately been introduced with very beautiful results, which consists in steeping them, previously to drying, in some viscid solution, which keeps them flexible and prevents shrinkage.*

Representatives of the fresh water polyp of the genus Hydra should be sought for in fresh waters in any unexplored regions visited.

Hydroid stocks also occur in brackish water, and should be sought for in such places as harbours, at the mouths of rivers, attached to piles and other supports. Cordylophora lacustris, a British species, occurs abundantly in the Victoria docks.

Free Craspedote Medusæ, Siphonophora (Portuguese men-of-war), Scyphomedusæ (Blubbers, Jellyfish), and Ctenophora.

These free swimming forms, although the Craspedote Medusæ and Siphonophora actually belong to the Hydromedusæ already considered, may be conveniently here treated of together. They offer an excellent field to the collector which has been much neglected owing to the difficulties attending successful preservation, and one, therefore, likely to yield many valuable novelties.

In all cases these free swimming Hydrozoa pass through a number of successive changes in structure and form in the process of growth and development. It is most important

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* For further information on methods of collecting Hydroida, *see* a History of the British Hydroid Zoophytes by G. T. Hincks, London, 1868. Introduction p. xlviii. and p. 298.

to collect as complete a series of these forms in the case of each species as possible.

The free Craspedote Medusæ will be obtained in abundance in the towing net, especially when this is used, at no great distance from land. They may be either the Medusiform sexual persons detached from Hydromedusoid stocks, or allied Medusæ which have no attached polyplike form in the cycle of their existence. Some of the latter may be of considerable size.

Special search should be made for free Craspedote Medusæ in fresh water ponds in tropical regions, especially in tropical South America and the West Indies. Two fresh water medusæ only are at present known, one of which, Limnocodium Sowerbii, occurs in the Victoria Regia tank in the Royal Botanic Gardens, Regent's Park, having evidently been conveyed thither with some tropical water-plant from some locality unknown, whilst the other has been observed in a lake in the island of Trinidad.

Of the Siphonophora the Portuguese men-of-war and Velella and Porpita, are found floating at the actual surface of the ocean, and in common with all the larger pelagic Hydroid colonies should, if possible, when wanted for preservation, be dipped up together with plenty of surrounding water with bailers or buckets rather than lifted free of the water with a net of any kind. When caught in a towing net they will usually be found more or less broken and injured. The other forms which are actively moving colonies provided with swimming bells, such as Diphyes and Physophora, are usually only to be obtained with the net. The Siphonophora are mostly very difficult to preserve, but especially if collected in the Pacific or Indian Oceans, anywhere but in the North Atlantic or Mediterranean, are well worth collecting. All stages in the growth and development of the colonies should be sought for, especially very young ones.

Efforts should also be made to collect specimens of all the larger jelly-fish or blubbers (Scyphomedusæ) met with in other than the home seas, and to preserve a few specimens of each in as good condition as possible. Any occurrences of these at great distances from land should be especially noted and specimens of such procured if possible.

Of the geographical distribution of the Ctenophora comparatively little is as yet known, and they should be always preserved when obtained in remote localities. They are to be obtained mostly with the towing net only, but sometimes may be found cast up freshly on the shore in tolerably good condition.

Mode of Preservation of the free swimming Hydrozoa.

Professor Haeckel in his splendid monograph of the Medusæ* gives the following advice to all naturalists who may be willing to collect Medusæ for him of which he especially desires to increase his collection of larval and young forms.

In the preservation of all Medusæ, but most necessarily of all in the case of the large forms, the most important precaution always to be observed is that they must be placed for from 12 to 24 hours in a saline solution before they are transferred to very strong alcohol. This saline solution may be a concentrated one of alum, one part to 10 or 15 of sea water, or the well known Goadby's or Owen's Solution,† or a solution which is roughly composed as follows: four table-spoonsful of alum, eight table-spoonsful of common salt, and three wine bottles full of rain water (for large Medusæ add to this a trace of corrosive sublimate). Very effectual for some Medusæ (but not for all) is to place them from 10 to 12 hours in concentrated solution of picric acid in water before placing them in strong alcohol. The best method of all is to treat them for from 10 to 20 minutes with a very weak solution of osmic acid in water from $\frac{1}{10}$th to $\frac{1}{5}$th per cent., and then to stain them with carmine solution. Further, it is most important to fill the vessels in which the Medusæ, especially the large ones, are packed completely with alcohol, so as to prevent shaking about as much as possible.

Objects treated with picric acid or osmic acids should be washed with fresh water before being placed in spirits.

Dr. Paul Mayer, of the Naples Zoological station, specially

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* E. Haeckel, System der Medusen, 2 Hälfte Vorwort, s. xix.

† *Goadby's Solution.*

Bay salt - - - - - -	4 oz.
Alum - - - - - -	2 oz.
Corrosive sublimate - - - -	2 grains.
Rain water - - - - -	2 quarts.

recommends for Medusæ the use of Kleinenberg's picro sulphuric acid solution.*

PICRO-SULPHURIC ACID.

Picric acid (saturated solution in distilled water)	- 100 vols.
Sulphuric acid concentrated - - -	2 vols.

Filter the mixture and dilute it with three times its bulk of water, finally add as much creosote as will mix.

Objects are left in the fluid three, four, or more hours, and are then in order to harden them and remove the acid transferred to 70 per cent. alcohol, where they remain from five to six hours. They are next placed in 90 per cent. alcohol, which must be changed till the yellow tint has disappeared.

This is one of the best solutions for killing all kinds of marine invertebrates previously to placing them in alcohol, especially when they are intended to be used for anatomical and histological purposes afterwards. In the case of large specimens the periods of action of the fluids used may be prolonged.

The smaller Medusæ and Ctenophora may be treated with very good results with several drops of 1 per cent. osmic acid solution whilst lying in a small quantity of sea water in a test tube or watch glass. After four or five minutes action of the acid they must be transferred to fresh water and thoroughly washed and then placed in strong spirits.

Dr. W. Haacke† has found the following method extremely successful in the preservation of fine specimens of large Medusæ for museum purposes in life-like and unshrunken form. He adds some drops of a concentrated solution of chromic acid to the sea water containing the living Medusæ, regulating the amount by guess, according to the size and consistence of the animals, and leaving them in the solution a varying period on the same grounds. He then transfers the Medusæ to fresh sea water, and changes this till all the chromic acid is extracted that can be removed. He then takes a mixture of concentrated glycerine and very strong alcohol, so combined as to have as nearly the same specific gravity as sea water, as tested by means of a Hydrometer, and transfers the Medusæ

* Whitman, Methods of Research, p. 19.

† Zoologischer Anzeiger, 31st August 1885, s. 515.

by gradual changes into successively stronger solution of the mixture with sea water till it finally rests in the pure mixture itself. He recommends this process only for specially fine museum specimens for exhibition not for histological purposes.

Some further remarks on methods suitable for application to free swimming Hydroids will be found under the heading "towing net."

Actinozoa.

Zoantharia (*Sea Anemones and the majority of the reef and deep sea Corals*).

Actiniaria Sea Anemonies.

The sea anemones of tropical regions should be carefully observed, and aberrant forms should be looked for, especially those placed in the sub-family Phymanthidæ, the discs of which are provided with pinnate and leaf-like appendages resembling tentacles. Every opportunity should be taken to collect examples of these forms as their anatomy has not been properly investigated. The pelagic sea anemones, the Minyadinæ, which may be found in the tow-net, and which enclose in their bases a pneumatic apparatus, should, whenever met with, be preserved with great care, being rare and as yet little known. Their mode of floating and movements whilst living should be carefully watched and noted.

Attempts should be made to kill Actinozoa in the expanded condition. This with small specimens can be effected by suddenly pouring a hot solution of corrosive sublimate over them whilst in as small quantity of sea water as possible as in the case of the Hydroids, but in the case of large specimens the hot solution must be injected forcibly with a syringe into the mouth of the animal whilst expanded in a small quantity of sea water, more hot solution being at the same moment poured round and over the animal. After from 5 to 15 minutes the animal is washed in fresh water and placed for 12 hours in 50 per cent. alcohol before being transferred to stronger alcohol.*

* Andres' Method from Whitman's Methods of Research, p. 204.

Zoantharian Corals or Madreporaria.

These are the Zoantharia which are provided with a continuous calcareous skeleton. The greater part of the genera and species of these corals are compound forms, and are confined to comparatively shallow water from low tide mark to about a depth of 20 fathoms, and most of them, since they enter into the composition of reefs, are termed reef corals. Certain reef corals extend down to a depth of 30 fathoms and somewhat deeper. Nearly all reef corals are unable to tolerate an exposure to the air and sun at low tide, but certain East Indian corals at Banda have been observed to be constantly so exposed at each tide, apparently suffering no more than the common sea anemones so exposed. Observations on the occurrence of the phenomenon elsewhere, and the duration of the exposure of the various species tolerating it would be interesting. Other Zoantharian corals occur in deep water in all depths from 30 to 3,000 fathoms. They are mostly simple forms, single individuals only.

In collecting reef corals, in the present state of our knowledge and of the series already in museums, two objects should be especially kept in view, *firstly*, to attempt to gather as complete series as possible of all the younger stages of the growth of as many species as possible, tracing these stages downward from one to the other until, if possible, the very young solitary parent polyp of each species of colony is obtained ; *secondly*, to endeavour to obtain specimens of as many of the adult corals as possible, well preserved in spirits with their polyps killed as nearly as possible in the expanded condition. Even quite small pieces of branches of various species thus preserved with expanded polyps are very much wanted for anatomical examination. The polyps should be treated with corrosive sublimate as already described for sea anemonies.

A complete collection of specimens of all the species of corals occurring in any particular district or island is always very valuable, even if the specimens are only small, so long as they are sufficient for the determination of the species, and a list of the coral fauna can be compiled from them.

On many reefs, especially in the Malay Polynesian region, various species of the genus Fungia, which are the largest representatives of simple corals existing, are to be found in quite shallow water in enormous abundance. On the reefs of Banda Island, and at Tahiti, a cartload could easily be gathered. Good specimens of the adults preserved in spirits with the tentacles expanded are much required, and also series of all the stages of development from the parent fixed stock. This stock is small and cup-shaped, and provided with a stem, and throws off a succession of buds. Specimens of the buds and stock are much wanted, either in spirits or dried, but especially in the former state.

Corals which are being prepared for drying, or as it is ordinarily termed "to be bleached," though in reality what is done is merely to remove thoroughly the flesh from the skeleton, are often exposed for some time in the sun to the rain or to running water. This method is a bad one except for preparing large specimens which cannot be otherwise treated, and in which the preservation of the finer details is not of great importance. The very finest details of the skeleton are liable to be dissolved away to some extent by the action of the carbonic acid in the rain water, and the specimens may thus be injured for scientific use. The most perfect specimens of the skeleton are to be obtained by immersing the corals in strong solutions of caustic soda, and then thoroughly washing them in fresh water. The skeletons of the deep sea corals of the "Challenger" expedition were thus prepared.

Corals may also be dried in the sun with much of the flesh on, and so packed to be cleaned with strong alkalis when they arrive at their destination. Although sawdust is very troublesome to remove from the interstices of dried corals, it is, perhaps, the safest substance to pack them in.

Specially careful notes should be taken as to the range in position and depth of the various species of corals occurring on each coral island or each system of reefs, the relative abundance of each species, and the extent to which fragments of particular species are seen to enter into the composition of the coral debris and calcareous sand present. The dimensions of the largest and average sized specimens of the larger compound forms too large for removal may with advantage be measured and recorded.

With regard to observations to be made on the zoology of coral reefs, Mr. Charles Darwin's well-known work on the Structure and Distribution of Coral Reefs, 8vo., 1842, should be consulted; also Mr. Alexander Agassiz, the Tortugas and Florida reefs: Memoirs of the American Academy of Arts and Sciences, Vol. xi., Part I., No. 1; also J. D. Dana, Corals and Coral Islands.

Alcyonaria.

These are the Actinozoa provided with eight feathered tentacles; nearly all are compound. One living form has a continuous skeleton like the Madreporaria. It is of a deep blue colour (Heliopora cærulea). The developmental history of this coral should, if possible, be determined, as it is of special interest as representing numerous extinct palæozoic allies.

Other Alcyonarian colonies are branched and tree-like in growth, and have a stony (Red or precious coral of commerce) or horny axis (Gorgonidæ or Sea Fans), or semicalcareous flexible axis (Sea Fans, Pennatulidæ); others, again, are devoid of continuous skeleton, and are more or less soft-bodied masses (Alcyonidæ, Dead men's fingers). These may be preserved in the same manner as the Zoantharia with the tentacles protruded, if possible, or placed direct in spirits. Many also may be dried, either entire or as it is termed with the bark on, or the skeletons of them alone after maceration in water. The former mode is to be preferred.

ECHINODERMATA.

CRINOIDEA, ASTEROIDEA (STAR FISH), OPHIUROIDEA (BRITTLE STARS), ECHINOIDEA (SEA URCHINS), HOLOTHUROIDEA (SEA CUCUMBERS, OR TREPANG).

Of the Crinoidea many species of the free swimming kinds without stalks (Feather stars) are often to be found in shallow water at low tide, others are only to be obtained with the dredge. Species of very large size with large discs, such as occur in the East Indian region, are especially valuable when well preserved for museum purposes and dissection, but examples of all met with at distant localities should be secured. Their young stalked stages of development should be sought for attached to weeds and other objects wherever the adults occur abundantly, the weeds being carefully examined with a lens. Series of well preserved specimens of stages in the development of any exotic feather star would be most valuable. The stalked Crinoids, Pentacrini or Lily stars, which remain stalked in the adult condition, occur only in water of considerable depth. They are frequently brought up attached to deep sea cables when raised after long rest on the bottom, and sometimes by means of deep sea fishing lines. They are very valuable and interesting, and should be always secured and preserved with especial care in plenty of strong spirits whenever opportunity occurs. Certain species occur in a depth of only 65 fathoms, and successful dredgings for such might well be made by means of boats. A light triangular iron framework armed with fishhooks along its sides, and with swabs attached behind and weighted sufficiently to sink it, might be found more successful than the dredge. With a view to opportunities occurring for attempts to be made to secure some of these valuable Crinoids, the following localities at which they have been obtained in comparatively shallow water are given:—

Pentacrinus decorus and P. Mülleri, Rhizocrinus Rawsoni, off Barbados, 84 fathoms. P. Asterias, off Guadoluope, 80 fathoms. Metacrinus, Bay of Yedo, 65 fathoms; also lat. 10° 14′ N., long. 123° 54′ E., 95 fathoms. Three or four species of Metacrinus in abundance; a most favourable spot for further dredging, Arafura Sea, off the Ke Islands. Lat. 5° 49′ S., long. 132° 14′ E., 140 fathoms.

The especially rare and remarkable aberrant Crinoid Holopus, hitherto found only in the Carribean Sea, off Martinique and Barbados, off Bahia Honda and Montserrat, should be always remembered. For further information on the Crinoids, *see* Dr. P. H. Carpenter's Report on the Crinoidea, Report on the Scientific Results of the "Challenger" Expedition, Vol. XI.

As in the case of the Crinoidea certain species of the star-fish, brittle stars, sea urchins, and Holothurians are to be found in shallow water, and others in greater or less depths ranging to the extreme deep sea. Many of the sea urchins are to be found inhabiting cavities in rocks and coral reefs. It is best to preserve some specimens at least of all Echinoderms in strong spirit. The Holothurians have the habit of ejecting their viscera when handled. The best method, according to Prof. K. Möbius, of preserving as many as possible in the complete condition, is to throw them as soon as possible into strong alcohol. Sea urchins contain a large quantity of water in their body cavities. This should be allowed to run out before they are placed in spirit by piercing the membrane intervening between the mouth and the oral margin of the shell with a penknife. After the water has escaped the specimens should be held under the spirit one by one till they are sufficiently filled to sink. When more than one are packed in the same vessel each should be wrapped round with calico or muslin, so as to retain in connexion with it any spines which may be loosened and protect these from injury. Star-fishes and brittle stars should be separated from one another by paper when many are packed in spirit together.

Special preparations of both Crinoids and other Echinoderms, especially for histological purposes, may be made by killing them with corrosive sublimate solution before placing them in alcohol. A modification of the picro sulphuric acid solution containing nitric acid instead of sulphuric is also used with excellent results for killing all marine animals, such as Echinoderms and stony corals, which contain much carbonate of lime, which if acted on by sulphuric acid is deposited as sulphate of lime and spoils the preparation.

PICRO NITRIC ACID.

Water - - - - - -	95 parts.
Nitric acid (25 per cent. $N_2 . O_5$.) - - -	5 parts.
Picric acid as much as will dissolve.	

The fluid is used undiluted and in the same way as the picro sulphuric. It must be remembered that any specimens thus treated will be to some extent decalcified, and it should, therefore, only be applied to one or more out of several specimens, since the structure of the spicules and skeletons could not be made out in specimens acted on by acid. All Echini and starfish should be examined for small molluscan shells (Stylifer) which nestle in and among the rays and at the roots of the spines, and for other parasites. In the cloacal cavities of certain starfish (Culcita, e. g.), and more commonly in those of Holothurians, may be found small parasitic fish of the genus Fierasfer. Attached to the discs of the feather stars will be found small disc-shaped parasitic worms of the remarkable genus Myzostoma. They may often be seen to drop off when a specimen is immersed in spirit. Specimens of these should be carefully preserved. In the cases of the stalked Crinoids other Myzostomidæ may be found in gall-like capsules on the arms of the hosts.

All Echinoderms except Holothurians may also be dried, a method especially useful for large and bulky examples of star-fishes and sea urchins. These should be emptied of their viscera by the mouth or larger (lower) aperture, and should then be soaked in fresh water, changed two or three times to extract the salt contained before they are dried in the shade, or slowly by artificial heat. If spirit is abundant enough to permit it their drying may be much facilitated by soaking them first a short time in spirit. The jaw apparatus of the Echini should be preserved and dried, and that of each specimen packed inside it. The dried Echini should be wrapped up in cotton and sewed up each in its separate bag, in order to preserve the spines which are apt to become detached. Brittle stars may be dried without removal of the viscera after soaking as above.

WORMS.

TURBELLARIA.

Planarians.

Marine Planarians are to be found on the under sides of rocks turned over on reefs, and crawling on sea weeds and corals. They resemble extremely flattened slugs in appearance, and move with a peculiar gliding motion due to the action of cilia. Many are very brightly coloured, and though most are small some attain, especially in the tropics, a length of many inches. In order to kill them in an uncontracted condition the following method may be adopted. The animal is laid * on its back in some small vessel, and the sea water removed from it with a pipette; corrosive sublimate solution in water, heated almost to boiling, is then suddenly poured over it. It dies expanded. After half an hour it is washed by placing it in water, and then placed first in weak and then in strong spirit.

Land Planarians occur in most parts of the world, and are to be found in damp places, under the bark of trees, or amongst decayed vegetable matter. They are nocturnal in habits and should be sought at night and at daybreak. They should be preserved in strong spirits.

Nemertines.

Nemertines are to be found in positions similar to those in which marine planarians occur, and should be similarly killed

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* *See* Whitman methods of Research, p. 27.

with corrosive sublimate or placed direct in spirit. Terrestrial Nemertines are to be found in some localities inhabiting moist earth near the sea-shores, and should receive special attention. One pelagic transparent Nemertine Pelagonemertes with a ramified digestive tract occurs in the Pacific Ocean. It is excessively rare, and specimens are much required.

Intestinal and other internal Parasitic Worms, Trematoda (Flukes), Cestoidea (Tape Worms), Nematoda (Round Worms), Acanthocephala.

Almost every vertebrate animal that is opened and dissected, especially fishes, may contain rare or undescribed parasites belonging to some one of the above groups. The eyes of fishes are often the seat of such ; the noses of sharks are frequently infested by them. They may be found not only in the alimentary canal, but in the tissues of most of the organs. When the parasite is attached the part to which it adheres should be removed with it, care being taken to secure the whole mouth or proboscis of the parasite. When it is encysted in an organ the cyst is to be removed entire with the surrounding tissue of the organ. Portions of muscle or other tissue which appear speckled with minute white spots should be preserved, as these may be occasioned by the cysts of Trichinæ or allied Nematoids. In seeking for parasitic worms the entire digestive tract should be slit up and its contents washed out with a stream of water into a vessel, and washed over gradually into another vessel and thus thoroughly examined. The washed surface of the intestine should be also examined for attached parasites, especially Acanthocephala. Some of the Trematoda occur as external parasites on the gills of fishes. All these parasites may be treated with advantage with picro-sulphuric acid or corrosive sublimate solution before being preserved in strong alcohol. Special care must be taken that the host on which each parasite collected occurs is clearly identified by the label.

ANNELIDA.

Leeches, Earth Worms, Sea Mice, Nereids, Tube Worms, Gephyrea.

Certain interesting leeches, some of them provided with tufted gills, occur as parasites on the outer surfaces of marine fishes and turtles, and some smaller leeches on freshwater fishes. In tropical and also some temperate regions land leeches occur on bushes and trees, and amongst the grass. Specimens should be collected, and also specimens of all freshwater leeches in remote localities. In such localities also, and especially in uninhabited oceanic islands, earth worms should be collected, as they are as yet little known and their geographical distribution very interesting. In Australia, in Ceylon, at the Cape of Good Hope, and elsewhere very interesting, gigantic earth worms, several feet in length and thick in proportion, occur, which form very large heaps of castings. They should be inquired after and perfect specimens secured if possible. Their burrows should be excavated to search for their large egg-capsules. Freshwater annelids should also be collected. They are to be found in the mud of rivers and ponds by washing it in glass vessels.

Many of the marine annelids inhabit tubes of various construction, which should be preserved with their inhabitants. Special preparations of the tube inhabiting forms may be prepared with their tentacular apparatus expanded, by treating them with hot corrosive sublimate as already described. These annelids as well as Gephyrea should be preserved in spirits.

Balanoglossus.—A marine worm-like animal of special zoological interest named Balanoglossus, in reality not at all allied to the Annelids, but forming the type of a special class Enteropneusta; should be constantly looked for. Species of it occur both in shallow and deep water buried in mud. It is worm-like in appearance, soft, fleshy, and orange-coloured when alive, and has an acorn-shaped proboscis at its anterior extremity with a collar behind it, succeeded by a series of respiratory slits on either side. All specimens of it or any allied form should be carefully preserved.

CRUSTACEA.

Cirripedia.

Barnacles and Acorn Shells.

The Barnacles or pedunculated Cirripeds, with soft stalks, should be preserved in spirit; they are commonly attached to floating timber, and the smaller species to seaweed and shells. The sessile kinds (acorn-shells), which encrust the coast-rocks all over the world, and are found parasitic on turtles and whales, should likewise be preserved in spirit. The colours of the pedunculated kinds should be noted whilst they are fresh. If the sessile kinds are preserved dry, the included parts of the animal ought never to be taken out. In removing all the kinds from their points of attachment, care must be taken that, in some specimens at least, the base, which is either membranous or calcareous, be preserved. It is particularly desirable that some young, in all stages, as well as large specimens should be collected. In the tropical seas certain corals and shells contain embedded in them singular forms of cirripeds, which, presenting externally little more than a simple aperture, are easily overlooked; such kinds had better be preserved in the coral. Others live embedded in sponges; two genera live on whale's skin (Coronula and Tubicinella). The development of these needs to be studied by specimens of the ova and young. Another less known genus (Chelonobia) lives partly embedded in the skin of turtles ; a third attaches itself to the manatee or sea-cow ; and some small and interesting species of barnacle are parasitic on sea-snakes. Some small forms (Alcippe) inhabit cavities excavated in the shells of Buccinum and other molluscs. These cavities have narrow, minute, keyhole-shaped apertures. Another (Cryptophialus) inhabits cavities bored in the shells of another cirriped. Lobsters, crabs, bivalve and other shells, as well as floating pieces of wood, or even net-corks, become the habitat of animals of the class Cirripedia. It should always be noted to what animals or objects such cirripedes are attached, as well as any circumstances that may determine the period during which they have remained attached.

Copepoda, Branchiopoda, Stomatopoda, Decapoda, Gigantostraca.

Lerneæ or Fish Lice.

The mouth and gills of fishes, and their external surfaces, and also the external surfaces of cetacea should be examined for crustacean parasites of all kinds. When these parasites adhere firmly to the part they should be cut out with the adhering organ entire. It sometimes, as in the case of Penella, penetrates to a great depth in the flesh, and even in some cases coils itself amongst the viscera, so that it is necessary to preserve the whole fish in order to show its entire extent adequately.

Free swimming Copepods, Water Fleas, Branchiopoda.

Numerous pelagic Copepods and Ostracods will be caught with the towing net, and will best be preserved with the general catch taken with that net. The gorgeous colours of the male Sapphirrinidæ may be preserved by treating these animals with osmic acid solution. Freshwater Copepods and Ostracods and Branchiopoda should be taken with a towing or hand net in freshwater lakes, ponds, and rivers in all remote regions and in oceanic islands. Water fleas (Cladocera) and such forms as Branchipus, Apus, and Estheria should be similarly always collected in fresh waters in the same regions.

Shrimps, Lobsters, Crabs, and King Crabs.

Crustacea are best preserved in strong spirit. A great many of them, especially the delicate small ones, may with advantage be first killed in picro-sulphuric acid, especially when required for histological purposes. The larger and middle-sized specimens should be kept by themselves, or when packed in spirit together should each be wrapped in calico or other fabric of some kind. A very important subject of investigation is the development of the crustacea from the earliest period at which they can be observed to the assumption of the mature or parent form. The eggs, usually of some bright colour, attached beneath the tail of the female crab, lobster, or shrimp, should be examined for this purpose; the embryo, if in course of development, may be readily seen by opening the egg under a moderate magnifying power. Drawings of the different forms or stages of the embryo should be made, if possible, and a full series of the eggs and embryos preserved in tubes in spirit, after being treated with picro-sulphuric acid. Special efforts should be made, if opportunity occur, to obtain series of preserved eggs, embryos, and larvæ, illustrating the development of the Moluccan or Chinese species of the King-crab (Limulus), and of any land crab, with observations on the exact habits of the mother and of the stages gone through whilst the ova remain attached under the mother's abdomen, and the stage at which they are set free. The nature of the breeding habits of the cocoanut-climing crab (Birgus latro) and the history of its development are also important matters for research. Sets of embryological and larval material or drawings illustrating the development of almost any exotic crustacea would be valuable.

The larger crustacea, shrimps, crayfish, or crabs, inhabiting fresh waters should be collected in every region explored. They have as yet been much neglected, and should at least always be caught and inspected. Several different kinds may occur together in one range of fresh water. They, as well as marine crustacea, may be caught with basket-work cages or circular nets, baited with meat or fish. The various species of wood lice should not be omitted in collecting.

The larger crustacea may be preserved by drying, especially when spirit is scarce. In preparing them for drying care is to be taken to preserve all their external parts as perfect as possible. The abdomen or tail is detached from the front part of the body or thorax, and all the viscera removed. The claws and thicker joints of the limbs must be separated at the joints and all the contained muscle removed from them. The parts must be soaked in fresh water and washed out with it, then smeared over inside with arsenical soap or arsenical solution, put together again, and dried. When dried the specimens should be wrapped in very soft paper and then packed in cotton wool, so as not to allow of their being displaced in the case nor to touch one another. It is desirable with regard to brilliantly-coloured crabs to wash them over, after they are dried, with a thin coat of the following varnish :—

VARNISH FOR CRABS, EGGS, AND SIMILAR OBJECTS.

Common gum - - - -	4 oz.
Gum tragacanth - - - -	½ oz.

Dissolve these in three pints of water, add to the solution 20 grains of corrosive sublimate, and 20 drops of oil of thyme, dissolved in 4 oz. of spirit of wine; mix it well, and let it stand for a few days to separate: the clearer part is to be used as varnish; the thicker part forms an excellent cement.

Smaller crabs, shrimps, &c. can be dried without the removal of anything but the viscera, especially if they are soaked a short time in spirits. Ordinary spirit varnish or dried Canada balsam dissolved in chloroform may be used with effect if the above cannot be procured.

MYRIAPODA, INSECTA, ARACHNIDA.

Myriapoda.

Centipedes and Millipedes.

It is hardly necessary to warn collectors that Centipedes, especially the large tropical forms, should be handled with forceps, in order to avoid their poisonous bite. Both these and the Millipedes Iulidæ should be put in bottles when caught and killed by a few drops of chloroform or by the vapour of cyanide of potassium, so that they may die in an extended condition before being put into spirit, as otherwise they become coiled up by contraction and useless. They may be further prevented from doing this by being placed in tubes of glass or bamboo before being plunged into the spirit. Certain Millipedes (*Siphonophora*) are provided with a snout-like, slender, suctorial mouth ; these are especially rare and valuable. Eggs and very young stages of growth of any species are well worth preserving, and observations on the developmental stages of all forms are much wanted.

The genus Scolopendra is viviparous, and females containing young are very scarce ; possibly they hide themselves when pregnant. Large numbers should be opened to seek for embryos. Eggs and embryos should be treated with picro-sulphuric acid.

Certain large myriapods of the genus Sphærotherium, allied to the Millipedes, but with short, broad bodies, looking like enormous woodlice, have a stridulating organ on one of the pairs of appendages on the hinder end of the abdomen in the males. They occur at the Cape of Good Hope. Observations on their habits and on the nature of the sound they make are much required. *See* G. C. Bourne on the Anatomy of Sphærotherium, Linnæan Soc. Journal, Vol. XIX.

Peripatus.

Peripatus is a distant ally of the Myriapoda, as being a very primitive tracheate, with tracheal openings all over its skin surface. It looks like a dark brown or blackish lepidopterous caterpillar with numerous stumpy legs, each provided with a minute pair of claws. It emits, when touched, fine jets of extremely viscid slime from two small papillæ near its mouth. It will be immediately recognised by this peculiarity. It occurs under dead logs of trees in damp places, and is to be found by turning them over. It occurs in the West Indies and tropical America in the cooler mountain regions; also at the Cape of Good Hope, in Australia, and New Zealand, and in Chili. Specimens are especially required from the West Indies, Australia, and Chili, but it may be expected to be found in fresh localities. It is best to kill specimens by drowning them in a bottle full of water, when they die extended and may be put in strong spirit.

Insecta.

Butterflies and Moths.

Some specimens of all kinds of insects collected and their larvæ in all stages should be preserved in spirit for anatomical examination. Whenever it is possible it is best to treat them first with picro sulphuric acid, and when their bodies are at all large to open the abdomen and fill it with the fluid with a pipette. Many of the softer kinds of insects and spiders can only be profitably preserved in spirits. Care must be taken that the softer kinds of insects are not put into the same bottle with the harder kinds without careful packing with paper. Gauze nets must be used for catching the Lepidoptera (butterflies and moths) on the wing. It is most important to kill these insects, and preserve them without the loss of any of the delicate down with which they are covered, and which may only too easily be rubbed off.

The smaller butterflies should be killed within the net by being nipped with a small pair of forceps, or the finger nails, beneath the thorax, the wings during the process being turned up over the head. The larger butterflies may be paralysed by this method, but must be subsequently killed by being placed in a wide-mouthed bottle with a perforated false bottom, beneath which is a lump of cyanide of potassium, or better still, by means of a steel pen, dipped into strong solution of the cyanide, and inserted into the thorax beneath between the bases of the legs. Small moths may with skill be similarly nipped and afterwards poisoned; but all large bodied and very hairy moths are best passed direct from the net into the poison bottle, or into chip boxes, to be poisoned on arrival at home till quiescent and pricked with the pen to ensure against revival.

Both the butterflies and the moths should be packed with their wings very carefully turned upwards against one another, and their antennæ turned backwards in square pieces of white smooth paper. A stock of these pieces of paper are to be kept cut, of various sizes, for the purpose. Ordinary printing paper does very well. Each square is folded across diagonally to form a right-angled triangle, and the free margins are secured by being folded over. The insect is to be enclosed with its legs towards the diagonal fold. In the case of large-bodied moths, a small cushion of cotton wool wrapped in tissue paper should be gummed on to the paper receptacle inside, so as to prevent crushing. The paper triangles may conveniently be packed side by side edgewise in small tin boxes for transport. Lepidoptera should not be pinned. Those with very large bodies should have the abdomen opened by a slit beneath, the contents removed, and a little cotton substituted after the abdomen has been brushed inside with arsenical solution.

Larvæ preserved in spirits lose their colour, and in order to retain these a specimen or two of the larger ones, and of their pupæ, may be opened, the viscera removed, and the inside, after it has been brushed with arsenical solution, stuffed with cotton.

Flies, Dragon Flies, and Wasps.

The insects with delicate membranous wings, such as Ephemeridæ (May-flies), Hymenoptera (wasps, bees, ants), Diptera (flies, gnats, daddy-long-legs), Dragon flies, some delicate locusts and mantises, and also minute moths (Microlepidoptera), ought to be pinned at once when caught, after being rapidly stupefied, with entomological pins of suitable size, the pin being passed right through the centre of the thorax. These insects should be packed for transport in boxes lined with cork. Their wings and legs should be kept close to the body to save space and prevent collision. Each pin should be made fast in the box so as to secure its not being shaken loose during a journey, and it is best when such boxes are finally packed for transmission to spread a very thin layer of cotton wool all over the heads of the pins before the box is closed. This layer entangles any specimen which may come loose, and prevents its damaging all the rest in the box by shaking about. The wool is easily removed with care without breaking antennæ or other delicate parts when the box is unpacked.

Beetles, Bugs, and Cockroaches.

All other insects are well and easily preserved in spirit. They should be killed before being immersed in it. This may be effected by the cyanide bottle, or when large locusts or beetles are to be dealt with by placing them in a corked bottle and immersing it a moment in hot water.

A ready mode of preserving beetles (Coleoptera) when found in abundance on any foreign coast is to put them, when dried, in a box, on the bottom of which a layer of fine dry sand has been strewed. When the layer is overspread with beetles they must be covered with another layer of sand, and the packer must proceed with layers of beetles and sand alternately, till the box, which should be water-tight, is quite full, when the lid should be screwed down and the seams pitched. Sawdust is often used instead of sand, but it is necessary that it should be perfectly clean and dry, and that all the fine powder should be sifted out of it.

Mr. Darwin preserved all his dry specimens of insects, excepting the Lepidoptera, between layers of rag in pill boxes, placing at the bottom a bit of camphor, and they arrived in an excellent state.

General Directions concerning Insects.

Many insects may be taken by beating trees or bushes over an expanded umbrella held beneath, others by sweeping herbage and flowers with a butterfly net with a heavy ring, and of rather stouter gauze than usual. Nocturnal moths may be caught by exposing a strong light at a window in suitable places, and also by placing a mixture of treacle, sugar, and beer on the trunks of trees in woods and gardens at nightfall, and visiting them at short intervals with a lantern. The moths may often be caught directly from the tree trunks into chip boxes without the use of a net. Many moths may also be caught by examining beds of flowers with a lantern at night, by searching each flower separately for moths feeding on it.

Freshwater insects should not be neglected, a fine muslin net like a landing net should be used to gather them.

Species of the pelagic genus Halobates, insects of the bug family, will also be met with in the tow nets all over the ocean, very far from land as well as near it. They are small black insects with long legs. All specimens obtained should be carefully preserved in spirits and labelled with their locality. Their geographical distribution is of great interest and only partially known. Any information as to their mode of breeding, development, and habits would be most valuable. See on this subject P. Buchanan White, Pelagic Hemiptera. "Challenger" Report, Zoology, Vol. VII.

For further information about the collection of insects *see* A. S. Packard, Directions for Collecting and Preserving Insects. Washington: Smithsonian Institution. 1873. (Includes Arachnida and Myriapoda.)

A. Harrach, Der Käfersammler. Practische Anleitung zum fangen, präpariren aubewahren und zur Aufzucht der Käfer. Weimar, 1884.

Arachnida.

Scorpions, Spiders, Ticks, Mites.

All forms of Arachnida are to be preserved in spirits. If, however, eggs and embryos in stages of development, and very young specimens are obtained, they should be treated with picro sulphuric acid before being placed in spirits. It would be well also to prepare specially for anatomical use any very large adult specimens obtained by placing them in picro sulphuric acid, and injecting this fluid also into their body cavities to preserve the viscera, before placing them in spirit. Scorpions are viviparous as far as known. All species met with should be collected, great care being taken to denote their locality.

The Pedipalpi (Thelyphonus and Phrynus), allies of the scorpions, with the first pairs of legs extremely long and thin, and looking like antennæ, occurring in the tropics of both old and new world, should be especially sought for and their embryology investigated if possible. The Solifugidæ (Galeodes), like spiders but with head and thorax distinct and long abdomen, should be preserved whenever met with. In collecting spiders from their webs it is important, if possible, to note and sketch the structure of the web and its situation, and, if possible, to secure and identify as such the male and female of each species. The males are usually much, sometimes exceedingly, smaller than the females, and may be found on the same web with the female, often coloured differently, and to be recognised by the club shaped enlargements at the ends of the palpi.

MOLLUSCA.

CHITONS, LIMPETS, WHELKS, SNAILS, SLUGS, DENTALIUM, PTEROPODS, CUTTLES, PEARLY NAUTILUS, OYSTERS, MUSSELS.

"A superficial towing-net, another so constructed as to be kept a fathom or two below the surface, and the deep-sea trawl, are the principal agents for capturing these animals. But when the tide is at the lowest, the collector should wade among the rocks and pools near the shore, and search under overhanging ledges of rock as far as his arms can reach. An iron rake, with long close-set teeth, will be a useful implement on such occasions. He should turn over all loose stones and growing seaweeds, taking care to protect his hands with gloves, and his feet with shoes* and stockings, against the sharp spines of echini, the back fins of weevers (sting-fishes), and the stings of medusæ (sea-nettles). In detaching chitons and patellæ (limpets), which are all to be sought for on rocky coasts, the surgeon's spatula will prove a valuable assistant. Those who have paid particular attention to preserving chitons have found it necessary to suffer them to die under pressure between two boards. Haliotis (sea-ears) may be removed from the rocks to which they adhere by throwing a little warm water over them, and then giving them a sharp push with the foot sideways, when mere violence would be of no avail without injuring the shell. Rolled madrepores and loose fragments of rock should be turned over. Cypræa (cowries) and other testacea are frequently harboured under them. Numbers of mollusca conchifera are generally to be found about coral reefs."—*Broderip.*

A very successful method of obtaining mollusca as well as other shore animals which are often otherwise entirely

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* Leather soles become softened, and afford a very poor protection to the feet. A pair of wooden shoes, such as those used by dyers, might be kept expressly for wading about reefs.

missed is to drive an ordinary shrimping net along the sea bottom at night near the shore, where the nature of the coast permits it, wading in to the knees or middle for the purpose.

Holes in the coral rocks should be narrowly searched for Cephalopods, which frequently lurk in them, and are often betrayed by the little heaps of shells about the entrance of their dens.

Among the floating mollusca possibly to be met with in tropical latitudes is Spirula, a small cuttle-fish with a chambered shell embedded at the end of the body and covered by the skin. An entire specimen of this rare mollusk is a great desideratum; and if it should be captured alive, its movements should be watched in a vessel of sea-water, with reference more especially to the power of rising and sinking at will, and the position of the shell during those actions. The chambered part of the shell should be opened under water, in order to determine whether it contains a gas; the nature of this gas should likewise, if possible, be ascertained. As a part of the shell of the spirula projects externally at the posterior part of the animal, this part should be laid open in the living spirula, in order to ascertain how far such mutilation would affect its power of rising or sinking in the water.

Living Spirulas may, perhaps, be caught in the tow net, especially if it be used at a considerable depth, or by the trawl net in deep water; but specimens with soft parts present are more likely to be found in the stomachs of sharks and pelagic teleostean fish. Most so obtained are more or less injured by digestion, but should nevertheless be preserved in spirits, if any of the soft parts remain attached to the shell. Sometimes a perfect specimen may be obtained in this way.

Young shells of the Pearly Nautilus are often found in fishes stomachs although seldom elsewhere. They are very rare in collections and should always be kept. Very small ones have never been found. No greater zoological prize could be obtained than the egg capsules of Spirula or Nautilus pompilius with embryos in stages of development. All Cephalopod egg masses met with in regions inhabited by these remarkable forms should therefore be carefully examined and preserved. The appearance of the egg masses in these two cases is entirely unknown. And it differs very much amongst other kind of Cephalopods.

In the event of a living Pearly Nautilus being captured, the same observations and experiments should be made on that species as on spirula. They would be attended with more precision and facility, as the species is much larger than the *spirula*, and its shell external.

Before, however, the living specimen is injured it should be allowed to rest in a large bucket of water and its mode of motion and attitude carefully watched and recorded. An accurate drawing should also, if possible, be made on a large scale showing the position of each tentacle, and all the soft parts in the extended condition and this might with advantage be compared with the figure given in Woodward's manual of the Mollusca, 3rd edition, p. 188. No such accurate finished drawing as yet exists. Nautilus pompilius is caught by the natives in shallow water amongst the reefs in some places by means of traps baited with the flesh of crabs. It is eaten by the natives of Fiji and New Caledonia. It might, perhaps, be taken by crab-pot like traps baited with crabs' flesh and set in rather deep water. Rumphius describes it as taken sometimes near Amboyna in crab or fish traps.

A sketch or drawing of mollusca, of which the form and colour are liable to be altered by death, or when put in spirit, will aid materially in rendering the description of the species useful and intelligible.

Some specimens of each species should be preserved in spirit. If they have died with their soft parts protruded, they should be suspended so as to prevent distortion from pressure. If the shell be of the spiral form, the whorls should be perforated with a fine awl or partly crushed so as to allow the spirit or solution to enter; otherwise, as the main body of the animal fills up the whole mouth of the shell, the deeper-seated and softer parts would become putrid before the preserving liquor could get to them.

Where the animal has been detached from its shell, the soft parts and the shell should be marked with corresponding numbers. When the animal is furnished with an operculum (the little door which closes the mouth of many turbinated shells), it should be carefully preserved; and, if detached from the animal, should be so numbered as to prevent the possibility of its being attributed to the wrong species. Shells should never be cleaned, but should be preserved as they come from the sea, taking care only to fill the mouths of those which are turbinated with tow or cotton to prevent fracture. It may be sometimes requisite to put a live shell into hot water, and boil it a minute or two, in order to dislodge the animal, which may then be removed with a small hoop or forceps.

Observations should be made on those genera of Chitons, the shells of which are provided on their surfaces with immense numbers of minute eyes, in order to ascertain how far they are sensitive to light, whether, for example, when kept in a vessel of sea water with one end dark and the other light they fail to find their way to the dark end when the eyes are painted over with some opaque substance, and whether when the eyes on one side of one shell only are kept free, they still find their way away from the light. Specimens of chitons with well marked eyes should be treated with picro nitric acid solution and preserved in strong alcohol in order that the histological structure of the eyes may be properly investigated in them. *See* H. N. Moseley on the presence of eyes on the shells of certain Chitonidæ, Quart. Journal of Microsc. Science, January 1885.

Land shells are found in various situations, as in humid spots covered by herbage and rank grass; beneath the bark or within the hollows of old trees, crevices of rocks, walls and bones; about the drainage of houses, or in the dry season by digging near the roots of trees. Early in the morning, especially in rainy weather, is the best time for taking them. The freshwater kinds may be sought for in quiet inlets on the sides of lakes, rivers, and brooks. The greater number of gastropods occur at or near the surface, under the leaves of aquatic plants, and among decayed vegetables; whilst the lamellibranchs and certain gastropods keep at the bottom, and are often more or less imbedded in the sand or mud from which they must be raked into a landing net.

With regard to the marine bivalves, rocks, submarine clay-banks, piles, stones, and indurated sand should be carefully inspected for Pholas, Lithodomus, and other boring species.

By digging with a wide-pronged fork in sand-banks, at low water, many bivalves, such as Solen, Cardium and Tellina, will be procured alive; and, if the inhabitants of the coast be accustomed to diving, their services should be secured for deeper water. Care must be taken not to separate the ligament which binds the hinge of the bivalve shells. When the animal is dead the shell will gape, and the soft parts may then be removed without injury. Attempts to open bivalves, while the animals are alive, generally terminate in great injury to the shells.

Natica, Terebra, and various other arenicolous mollusks, may be discovered by the curious and characteristic tracks which they leave visible upon the smooth surface of the sand at low water. Various Echinoderms may be detected in the same manner.

For deep-sea shells the dredge is indispensable.

Various pelagic mollusca, Heteropods, Cephalopods, and Pteropods, mostly with soft and gelatinous transparent bodies, will be obtained in the tow-net. Those devoid of a shell should be treated with picro sulphuric acid, or other saline solutions before being preserved in spirit, in the same way as described for Medusæ. If large Carinarias be obtained the shell may be carefully removed in order that the animal may be treated with a solution without injury to it. Pteropods with or without a shell may be killed expanded by the action of hot corrosive sublimate solution. Which solution may also be used with advantage for killing pelagic Cephalopods.

For further information on the Mollusca, *see* S. P. Woodward's Manual of the Mollusca, 3rd edition, with Appendix by R. Tate, London, 1875.

POLYZOA, OR BRYOZOA.

Polyzoa are usually colonial animals, forming masses composed of numerous microscopic cells, either gelatinous, horny, or calcareous, in the shape of moss-like tufts or encrusting investments on stones or seaweeds. Some form branching, arborescent or otherwise shaped growths of hard calcareous matter resembling the skeletons of stony corals, and others gelatinous growths of various shapes. These are all best preserved in strong spirits, but some may be simply dried, provided small parts of them are put in spirits. By the use of hot corrosive sublimate solution the zooids can, especially in the case of freshwater species, be killed in the expanded condition. Freshwater species should especially be sought for in remote localities. One freshwater form, Plumatella, creeps about on a flat base like a slug, the whole colony moving together. The only solitary and at the same time the largest known form Loxosoma inhabits the surfaces of compound Ascidians, horny sponges and Sipunculids. Specimens should be sought for and collected. The animal should be treated with osmic acid followed by spirits. Most interesting and aberrant and worth collecting is Rhabdopleura, the creeping stem of the colonies of which adhere to the tunics of Ascidians; and Cephalodiscus, in which the horny cells form a spongy sort of mass in cavities in which the zooids, which each bear an eye, lie free. The former occurs off the coast of Scandinavia and elsewhere in the North Sea, and the latter in the Straits of Magellan, both in a depth of 60 fathoms or so.

BRACHIOPODA.

In some parts of the world, especially in the Australian seas, for example, in Port Jackson harbour, Brachiopods with hinged shells can be obtained in considerable number in comparatively shallow water. They should always be preserved in strong spirit in as large quantities as possible, being of great value for dissection and difficult to obtain. Care should be taken that the spirit penetrates fully into the shells after the water has escaped from their cavities; they may else remain partly filled with air. Of the unhinged Brachiopods Lingula is most abundant on some coasts in shallow water, and may be gathered, as, for example, at Zamboangan, Philippine Islands, in great quantities at low tide in the mud. Large stores of them should be gathered if opportunity occurs, and preserved in strong spirits.

TUNICATA.

Appendicularia, Ascidians, Pyrosoma, Salpa, Doliolum.

Appendicularia is often met with in very great abundance in the tow-net. It is, though very minute, easily recognised by its jerky intermittent motion. It is very difficult to preserve at all satisfactorily. It may be treated with picro sulphuric or osmic acid before being placed in strong spirits. Pyrosoma, Salpa, and Dioliolum may also be with advantage soaked in picro sulphuric acid before being gradually transferred to strong spirits. Very large specimens of Pyrosoma, as long as 4 feet, sometimes occur. An entire specimen of such a size would be well worth preserving with care. Ascidians should always be preserved in spirits.

PART II.—VERTEBRATA.

CEPHALOCHORDA.

LEPTOCARDIA.

Amphioxus.

Species of Amphioxus have been met with in various parts of the world. Dr. Günther in his "Study of Fishes" gives many parts of the British and of the European coasts, North America, the West Indies, Brazil, Peru, Tasmania, Australia, and Borneo, as localities for the Lancelet. Specimens should be constantly watched for amongst the contents of dredges used in comparatively small depths, and always preserved if taken at any remote localities. They should be treated with corrosive sublimate before being placed in strong spirit. If any observations can be made on the embryonic development of exotic representatives of the animal it would be well worth while to ascertain whether the stages passed through correspond exactly with those exhibited by the Mediterranean one.

CRANIATA.

CYCLOSTOMATA.

Lampreys.

Lampreys and their allies should be carefully sought for in all regions little explored, both in the sea and in fresh waters. Care should be taken to note any evidence bearing on their migrations up rivers for purposes of spawning, and, if possible, to identify and obtain specimens of the adult and larval (Ammodytes form) of any species collected.

The Myxinidæ, or "Hag Fish" are exclusively marine. They bore their way into the bodies of dead cod and other fish to feed on their flesh. The history of their embryonic development is entirely unknown, and would certainly be of the greatest scientific interest if elucidated. Their eggs are large and ovoid in form, provided with a number of trumpet-shaped tubular processes at each end for attachment to objects on the sea bottom. Such eggs might at any time be brought up by the dredge in regions where the various species of Myxine exist, and any showing stages in the development of the embryo should be most carefully preserved. Species of Myxine are known from the North Atlantic, Japan, and Magellan Straits. A large Myxinoid of the genus Bdellostoma, reaching a length of nearly 3 feet, occurs at the Cape of Good Hope, and is often caught with a line and bait from ships anchored at Simon's Bay. It gives off immense quantities of slime when drawn on board. The eggs are much like those of Myxine. It would be well to use a dredge or some apparatus provided with hooks over the anchorage ground on the chance of obtaining egg capsules of this species with the contents in stages of development.

PISCES. FISHES.

Methods and Localities for Collection.

One of the readiest methods of obtaining specimens of fish for natural history purposes is by means of a trammel net, which, if put down overnight in any locality where the tides are not too strong, is sure to contain in the morning a fair sample of the fish of the district, since it entangles all kinds which run against it both large and small. Trammel nets made by Mr. Hearder, of Plymouth, were used with excellent results during the "Challenger" voyage. Small cartridges of dynamite are also very serviceable for killing specimens of fish, especially those which will not take a bait, in cases where the cartridges can be thrown amongst small shoals of fish from the stern of a ship, or into basins between the pinnacles of coral reefs or into river pools. The cartridges must be fitted with a piece of safety match tipped with a percussion cap and weighted with small stones, the weight and length of the safety match being adjusted so as to allow of the requisite sinking before the explosion. The stunned fish can be gathered with a landing net. Deep sea fish are caught by the Japanese fishermen by means of long lines and baited hooks in depths of over 200 fathoms, and Dr. Günther, in his excellent instructions for the collection of fish and reptiles (Anleitung zu wissenschaft lichen Beobachtungen auf Reisen, p. 600), describes how the fishermen of Portugal and Madeira use a very stout line as long as 800 fathoms with a heavy weight and hooks attached at intervals for catching deep sea fish. He also recommends the use of fish traps made on the same principle as lobster pots, in depths down to 400 fathoms. Experiments of these kinds are especially likely to procure important novelties. Any pelagic fish obtained with the towing-net should be carefully preserved apart from the general contents of the net, and the utmost care should be taken to record the locality of such specimens. Especially valuable are the young stages of pelagic fish of all kinds and sizes obtained by the tow-net. The contents of the stomachs of any sharks ,dolphins, or albacores, caught at sea, should always be examined for small fish or cephalopods. Ova and embryos of the Holocephali (*Callorhynchus* and *Chimæra*) are very much required for investigation.

Certain rivers in Africa (*e.g.*, the Gambia) contain a peculiar eel-like fish, the "Mud Fish" (Protopterus) or Lepidosiren with filaments for fins, which burrows and becomes torpid in the mud during the dry season. This fish sometimes attains an immense size, growing to a length of 6 feet. Such large specimens are much wanted for museums, or the separated heads of such would be of great value. The ova, or young in stages of development are entirely unknown and of special importance.

Dr. Günther in his above-cited memoir, to which the reader is referred for further information, cites as especially important grounds for the collection of fish, certain to yield valuable, new, and rare forms, the Arctic seas, all coasts south of lat. 30° S., the Persian Gulf, the northern coasts of Australia, New Guinea, the Pacific Islands, the west coasts of North and South America, the coast of north-east Asia, north of lat. 36° N. The fresh waters should everywhere be examined as to their fish fauna. It is possible that the rivers of New Guinea may yield allies of the remarkable Ceratodus or barramundi of the Queensland rivers.

Methods of Preservation in Alcohol.

Specimens of all fish of moderate size should be preserved in spirits. Dr. Günther (lc. s. 389, 391–397) advises the collector to take with him the best and strongest spirit to be had. Methylated spirit is next best, but should be avoided if possible. Arrac, cognac, or rum can be used when the others are not to be procured, provided they are strong enough ; that is to say, will ignite at once without previous warming on a flame being held to them. The collector should be provided with a hydrometer, such as is used by distillers for determining the strength of spirits.

Two similar vessels should be used for preserving the specimens. Rectangular boxes of sheet zinc, 18 inches high, 12 inches broad, and 6 inches deep, with a round opening on the top 4 inches in diameter, covered by a strong zinc cap secured by a screw. Each of these metal boxes is to be enclosed in a wooden case with a handle on each side. The cases are copied from ammunition boxes made for the British Army.

The fish to be preserved should have two deep cuts made in them, one in the region of the stomach so as to lay it open, and another in that just in front of the anus to let the contents of the digestive tract escape, and allow the spirit to penetrate amongst the viscera. In large fish (2 feet long) and very fleshy fish, a large number of cuts or stabs must besides be made with a scalpel into the muscles of the back and tail, to allow the spirit to penetrate.

The specimens thus prepared must be placed in one of the receptacles containing weaker spirit in order to remove the water. This spirit will rapidly become weaker with use. It should not be allowed to descend below 10° under proof. When it does so it should be filtered through powdered charcoal, and raised again to the proper strength by the addition of very strong spirit, or, if a still is available, re-distilled.

After a few days, one or two in hot climates, the specimens are transferred from the first to the second receptacle which has been filled with stronger spirits, and allowed to remain there 8 to 14 days, or, if they are earlier found to be well preserved, until they are packed for transmission. The spirit in this vessel should not be allowed to fall below a strength of 10° over proof. The specimens made use of should always be fresh. Specimens in a state of decomposition will affect the whole batch unfavourably. The specimens should be constantly examined during the hardening process. Some fish, especially deep sea forms, are much more liable to decomposition than others. If, therefore, valuable specimens are found to be soft and decomposing they should at once be removed and placed in the strongest spirit by themselves. In cases in which in tropical regions it is found impossible to prevent decomposition otherwise, corrosive sublimate may be dissolved in the spirit made use of. All fish bearing scales should be wrapped in a piece of calico before being placed in spirits.

Spirit used for packing fish for transmission should have a strength of from 15° to 20° over proof. The hardened specimens may best be packed for carriage in zinc boxes, which should not exceed in contents at most 18 cubic feet in order to avoid mutual appressure, and which should be contained within strong wooden packing cases. After the specimens are packed and the zinc lid soldered down, a small hole is to be made in the lid and spirit of 20° over proof to be poured in till the case is quite full. The hole is then closed by soldering a small piece of zinc over it.

Collectors often make the mistake of allowing their spirit to get too weak by putting far too many specimens in it without renewing its strength, and their specimens are consequently so badly preserved as to be of very little use. The preservation of organic structures in spirits depends on the removal from them of all the water which they contain, and the thorough permeation of all their tissues by the spirit. In order that this should be accomplished considerable time is required for the action of the spirits, especially where the structures are large and thick. Once the structures have been thoroughly permeated conservation is effected, and all that is necessary to preserve the specimen indefinitely is the presence of the smallest quantity of spirit with it in a closed receptacle so as to preclude evaporation. The important error to avoid is the packing of specimens before they have become completely permeated.

Other methods ; Stuffing.

Large fish which cannot be put in spirits may with advantage be preserved in salt with an admixture of corrosive sublimate, for the purpose of making skeletons. The viscera must be removed, and the fish must be thoroughly salted inside and out, and the muscles must be stabbed all over the back and sides to allow the salt to penetrate.

Large specimens of sharks or rays may be skinned, the head being severed from the trunk behind the pectoral fins and left attached to the skin. The whole preparation should be well salted, rolled up, and packed in a cask. The specimen can be stuffed at home, and will form a most valuable addition to a collection.

The jaws and teeth, together with the backbone or some of the vertebræ, of every large shark or large ray, which is not otherwise preserved, should be kept, care being taken to keep the teeth and vertebræ of each individual attached together. A section of the jaws and teeth, with part of the vertebral column, should be preserved in spirits.

For dry specimens the larger fishes may be skinned. The skin should be washed on the inner side with arsenical soap, and then loosely filled with cotton, wool, or tow. With regard to the smaller or moderate-sized specimens, the Curator of the Dublin University Museum states : "An excellent mode of preserving fishes, easily accomplished, may be thus described: Lay the fish on a table, with the side which you wish to preserve upward ; then with the scissors cut it so as to separate the fins and skin of one side, mouth and tail, from the body and viscera; spread the skin so obtained on a linen cloth, fold it over it, and subject it to some small pressure; remove the cloth, and take away any portions of flesh which may appear easily removable ; then fold it in a dry cloth and subject it again to pressure—a board and a few weights or stones will do if no other press be at hand; repeat the operation at intervals until the skin becomes quite dry, then wash it well on both sides with varnish (*see* p. 275). When dry, sew it on strong paper, and you will have as it were a coloured drawing of your fish. The great advantages of this plan are the ease with which it is done and the small space specimens occupy when finished; a large collection does not require more room than so many dried plants." However, this method should be adopted only when means are wanting of preserving the specimens entire in spirits.

Delicate embryos of fish and ova in stages of development and the soft, transparent, and fragile pelagic young of fish in the larval condition, such as the young of Pleuronectids, and Leptocephali, should be treated with saturated corrosive sublimate solution in water before being placed in alcohol.

AMPHIBIA AND REPTILIA.

Cæcilians, Newts, Salamanders, Frogs, Toads, Snakes, Lizards, Crocodiles, Tortoises, Turtles.

All these animals of moderate size should be preserved in spirits, the same methods of treatment being pursued as described above from Dr. Günther's instructions in the case of fish. Two similar incisions must be made in the ventral region, and similar precautions adopted as to the strength of the spirits; a piece of linen should be wrapped round each specimen to preserve the scales; this is requisite at least for the smaller lizards and snakes.

It may be necessary to skin larger reptiles. In skinning lizards the operator must be very careful not to break the tail. The larger snakes may require to be skinned, in which case care should be taken to preserve the head attached to the skin. The skins with the heads attached should be put into spirits. In flaying serpents great care must be taken not to damage the scales; and the operator should be cautious for his own sake when employed about the head of the poisonous species; a scratch from a fang of a rattle-snake or of a cobra soon after its death may be fatal. The heads of both poisonous and innocuous species should be preserved for the examination of their teeth.

Tortoises and turtles may be prepared in a dry state, the breastplate being separated by a knife or saw from the back, and after the viscera and fleshy parts have been removed, restored to its position. The skin of the head and neck must be turned inside out as far as the head, and the vertebræ and flesh of the neck thus detached from the head, which, after being freed from the flesh, the brain, and the tongue, may be preserved with the skin of the neck. In skinning the legs and the tail, the skin of these must be turned inside out, and, the flesh having been removed from the bones, these are to be returned to their places by redrawing the skin over them, first winding a little cotton or tow round the bones to prevent the skin adhering to them as it dries. The skin should be well rubbed with arsenical soap or painted with arsenical solution.

When turtles, tortoises, crocodiles, or alligators are too large to be preserved whole in spirits, some parts, as the head, heart, or certain of the other viscera should be put into spirit. The skeletons of such specimens are especially desirable. The bones should have the flesh roughly removed from them with knives, but should be kept together adhering by the ligaments as much as possible. Above all, the bones of the extremities should never be separated, but left with the skin on. When the bones have been roughly cleared from the flesh they may be soaked in water for a short time to remove the blood, but never on any account be boiled. Care should be taken that the hyoid bones in the base of the tongue are preserved. It is better to tie them to the skull in packing. The bones, after washing, may be packed in wooden cases or casks after being well salted with rough salt with some corrosive sublimate added to it. The limb bones and feet and head and tail may be conveniently packed inside the thorax. This method has the advantage over any one in which the bones are dried of preserving the cartilaginous parts of the skeleton, which are especially important in reptiles. If the bones are completely cleaned and dried they may be packed in a bag or box with bran, paper cuttings, hay, or dried seaweed. The drying of the bones in a hot sun is to be avoided, as they are apt to be thus much distorted by warping. If the bones of the feet are separated many of them are almost certain to be lost. Large reptiles can be killed by means of large doses of strong cyanide of potassium solution, if their jaws can be dragged open so that the poison can be poured into the gullet; or a long knife may be thrust into the body at the base of the neck so as to sever the great blood vessels of the heart.

The eggs, at different stages of development, of crocodiles, turtles, and tortoises, and also of the larger snakes, should be preserved, as also the young animals. As the colours of most reptiles are much altered by spirit, a coloured sketch of them should be made, when practicable, either during life or immediately after death.

The Amphibia should be obtained in the different stages of their metamorphoses. The different species of the burrowing snake-like genus called *Cæcilia* are especially desirable in the young state. The gravid oviducts of these and of the viviparous kinds of salamander should be preserved and also the young of the perennibranchiate amphibia of the United States, Menopoma, Amphiuma, Menobranchus, Siren, and their allies. Epicrium Glutinosum of Ceylon, lays its eggs in a mass in a burrow in the earth and incubates them to keep them moist.

The eggs of crocodiles, turtles, or snakes in early stages of development should be opened, and the embryos removed from the yolks and placed in picro-sulphuric acid for about five hours, and then transferred to weak and then to strong alcohol; or they may be hardened more rapidly by being placed in a warm saturated solution of corrosive sublimate in water for 20 minutes or half-an-hour, and then transferred to spirit. Larval and embryo Amphibia should be treated with the same reagents.

Dr. Günther recommends that embryos of all kinds which are enclosed in egg shells should be preserved in the strongest spirit, inside their shells, the latter having been first perforated in many places, so that the contained fluid can run out. This method is no doubt the best to be adopted by those who are unable to perform the delicate operation of the removal of the embryo. The perforated egg might with advantage, however, be soaked in corrosive sublimate solution before treatment with spirit.

For further information, see Dr. Günther's instructions already referred to.

BIRDS.

Methods of Collection.

Of the rarer kinds, especially the smaller species, specimens should be preserved in spirits for anatomical examination. Or if only a single specimen is obtained, the body removed from the skin should be so preserved. Of such as are too large to be preserved entire, the gullet, stomach, or gizzard, liver, intestines, ovary, oviduct or male organs should all be taken out as low down as the anus, and with the cloaca should be preserved in spirit. The tongue and trachea with the lower larynx (syrinx) should be preserved in spirit by themselves; and if more than two specimens of a rare bird are captured the head of one should be preserved in strong spirit, a small portion of the cranium being removed to allow the spirit to get to the brain.

The most common as well as convenient mode of preserving birds for zoological purposes is by removing and preparing the dry skin with the head and feet attached. Most specimens of birds collected will of course be shot.

Some birds, however, such as albatrosses and penguins, may be taken by the hand on shore on their breeding grounds, and petrels of various kinds may be procured in numbers by digging them out of their burrows. It is difficult to kill such birds, especially the large ones, in any way but by poisoning them, and a stout bottle full of small pieces of solid cyanide of potassium should be carried for this purpose on all expeditions where such birds are likely to be met with. A piece of the poison should be placed with forceps at the back of the fauces of the bird to be killed, and the beak then forcibly closed and held till death occurs. Penguins can hardly be killed in any other way without injury to their plumage. It is almost impossible to asphyxiate them. Other sea birds of strong flight, such as gulls and terns, can be readily procured by throwing overboard in a harbour or elsewhere where they are feeding small pieces of fat, each with a small piece of cyanide of potassium carefully enclosed inside it. The birds that swallow them drop at once on the water and may be picked up.

Immediately a bird is killed the blood spots should be dried up with blotting paper or cotton wool, and cotton wool should be stuffed with forceps into the throat and the nostrils and the anus, so as to plug them completely. The shot wounds should also be plugged with wool or blotting-paper. The crop, if it is very full, should be emptied. The blood spots or other impurities adhering to the feathers should be dusted with fine, dry sand, if possible, and gently rubbed till quite removed. The bird, with its feathers smoothed in the natural direction, should then be wrapped in a cone of paper and packed for carriage to the skinning place. A large botanical vasculum, with a strap for slinging it over the shoulder, is a very convenient receptacle for transporting birds shot for skinning. In warm climates a series of holes may be punched in it to allow the birds to cool. If time permits it is better to allow them to lie and cool before packing them.

Directions for skinning Birds.

Pass a thread with a needle through the nostrils of the bird, and tie the bill close under the lower mandible, allowing the ends of the thread to hang loose. Break the humerus in two with the fingers or a pair of pincers close to its head on either side. After parting the breast feathers, the incision for skinning should be made from the lower part of the sternum or breast bone to the tail, care being taken not to cut into the body so as to open the abdomen. Whilst removing the skin by means of the finger or the handle of a scalpel, thrust cotton wool between it and the body at the parts not being operated on to keep the feathers clean and prevent them from coming in contact with the moist parts, or, better, dust the parts freshly separated with fine dry sawdust or plaster of Paris to dry them. Having detached the skin of those parts on each side, the legs are next to be pushed through and cut off at the joint that protrudes, *i.e.*, leaving the thigh attached to the body, and then follows the more difficult process of separating the vertebræ near the tail. Having detached, however, the legs, and leaving the flesh upon them for the present, the operator must continue to separate the skin from the hind part of the body as well as he can, dusting the parts as before from time to time to dry them. He must then very carefully cut through the vertebral column near the tail above the coccyx, without injuring the skin of the back. The skin of the back is then detached with much ease. Further operations are now much facilitated by transfixing the hinder end of the body of the bird with a small steel hook, and thus suspending it by a string or small chain from a T-piece stand or other support at a convenient height above the skinning table. When the partly skinned bird is thus suspended head downwards, the pulling of the skin inside out over the shoulders and neck and separation of the wings is much aided. A little practice is necessary to keep back the feathers of the breast while the skin is drawn over the shoulders; the wings should now be separated at the fracture in the humerus, and a thread of some length should be tied to the broken end of each humerus and left hanging to it in order that it may readily be drawn out for subsequent treatment. The skin should then be pulled over the neck, and very gently and carefully over the head, especial caution being taken not to enlarge the auditory orifices or those of the eyes. With the majority of birds the skin may be drawn back over and from the head without much difficulty; but there are some, as woodpeckers and ducks, in which the head is larger than the neck, and consequently cannot be drawn through that part without stretching the skin. In these cases it is advisable to make an incision in the skin at one side of the head, and thus uncover the back of the skull. The fleshy parts must then be removed, as well as the tongue, eyeballs, and brain, the back of the skull being cut off with a knife in order to open the brain cavity behind. In small birds a quill cut in a slanting manner will be found useful to scoop out the brain; a little wool may afterwards be wound round it to remove any moisture that may remain in the hollow parts of the skull. Whilst skinning the head, upon reaching the eye it will be necessary to cut the tough membrane that surrounds that part. The brain and flesh being thoroughly removed, and the skull and skin of the neck anointed with arsenical soap,* the orbits should be filled with plugs of cotton of the size of the eyeballs removed, and some small shreds of cotton placed on the

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* *Receipt for Arsenical Soap.*

Camphor - - - -	5 oz.
Arsenic in powder - - -	2 lbs.
White soap - - -	2 lbs.
Salts of tartar - - -	12 oz.
Lime in powder - - -	4 oz.

Cut the soap in thin small slices, as thin as possible; put them in a pot over a gentle fire, with very little water, taking care to stir it often with a wooden spoon: when it is well melted, put in the salts of tartar and powdered chalk. Take it off the fire, add the arsenic, and triturate the whole gently. Lastly, put in the camphor, which must first be reduced to powder in a mortar by the help of a little spirits of wine; mix the whole well together. The paste ought then to have the consistence of flour paste. Put it into china or glazed earthen pots, taking care to put a ticket on each.

When it is to be used, put the necessary quantity into a jam pot, dilute it with a little cold water until it has the consistence of cream: cover this pot with a lid of pasteboard, in the middle of which bore a hole for the handle of the brush.

The three first ingredients in the above receipt may be used, if the whole cannot be readily obtained.

Arsenite of Soda.

Martin (Praxis der Naturgeschichte, 1 Th. 2te Auflage, s. 27) recommends saturated solution of arsenite of soda in cold water as better for the preservation of birds' and mammals' skins and all organic matters which are to be dried than arsenical soap. It can, moreover, be carried in the solid state in far less bulk and weight in proportion to its efficiency, It is especially recommended for curing fleshy parts which cannot be removed, such as the combs and wattles of birds, the legs and web feet of large birds, and the antlers of deer in velvet. Invertebrata to be dried may be soaked with this solution diluted with twice its bulk of water.

sides of the skull to replace the muscles. The cavity of the skull should be stuffed with tow so as to leave a string of tow depending to occupy the neck. The neck must now be restored to its normal position by pulling the head forth by means of the bill, which will be reached by means of the thread attached, an operation requiring much caution, so as not to tear the very tender skin of the sides of the neck. Bits of cotton should be freely used to prevent the feathers being anywhere soiled by adhering to the skinned body, as they are extremely apt to do, despite all care, unless some such precaution be resorted to. The skull having been returned within the skin, the feathers of the head should be properly arranged, which is best done with a large needle ; the eyelids should be neatly placed, and not stretched too large, the feathers covering the ears disposed as they originally were, and the orifices of the eyes contracted to their proper form ; the feathers in front of and over the eye should also be set naturally ; and, lastly, the skin of the crown and occiput should be loosened or lifted from the skull, and not be pulled too tightly backward. The flesh should now be removed from the severed ends of the limbs, which should be drawn out of the skin as far as they will come for the purpose. They should be treated with arsenical soap or solution, wrapped round with a little cotton, and returned within the skin. The two threads attached to the wing bones should be tied together over the stuffing placed in the body so as to secure the wings in a natural position, but not too closely. The arsenical soap is now to be sparingly applied to the inside of the skin, and the legs and beak brushed with a solution of arseniate of soda or corrosive sublimate. Where the legs are very large, as in cassowaries or ostriches, pelicans, or large birds of prey, Martin advises that the sole of the foot should be cut into, and a canal bored along the tarsi with a stiff wire, into which arsenite of soda solution should be at once injected.

The whole of the inside of the skin should now be sparingly brushed over with arsenical soap, and the legs and beak should be painted with a solution of arsenite of soda or corrosive sublimate. The skin should then be stuffed with tow or cotton, care being taken to avoid stretching the skin by putting in too much, especially to avoid puffing out the neck, in which it is enough to prevent the skin of its two sides from adhering together ; and, lastly, to mind that the bird is restored to its original length and proportions, and that the feathers are laid down as smooth as possible. In large birds, more especially, it will be found useful to put a reed or thin bit of stick up the neck, around which the stuffing of the neck may be wound; for this will prevent the tender skin of the neck from bursting, when dry, upon the specimen not being handled with sufficient care: and, in large birds, it is also necessary to make an incision above the elbow-joint of the wings extending along their under surface, and to remove from thence the muscles of that part, and rub in arsenical soap, or apply arsenite of soda solution. In general it will be found more easy to skin birds after one or two trials, to the complete satisfaction of the operator, than to put them nicely into shape afterwards, in the form they are to take on drying. When the skins have been thoroughly dried, they are to be rolled up in paper and tied round with a string, or pinned up in a paper cone.

Birds should be skinned as soon as they are cold; they cannot be kept so long as quadrupeds, and as soon as decomposition begins the feathers are affected; and, if the operation of skinning be deferred till it take place, they will drop off. The os coccygis, or rump bone, should be left with the skin, otherwise the tail feathers will be liable to fall out. In many aquatic birds, such as divers and penguins, the skin of the body bears a thick layer of fat which cannot well be removed with the scalpel. It can, however, be got rid of by successive applications of plaster of Paris in considerable quantity.

The nest, eggs, and young should be procured if possible.

To preserve the eggs of birds with their nests, each nest should be put into a round box just large enough to contain it.

Eggs should be blown from a single hole in the middle of the side by means of a blowpipe of brass or glass bent like a jeweller's blow-pipe. The hole should be perfectly round and made with a conical or rectangular egg drill made specially for the purpose. If a pipe is not available two holes may be made, but never at the actual ends of the egg. Valuable eggs containing chicks may be cleared through a large hole in the side by means of very fine scissors, fine hooks, and a syringe, the margin of the hole being first strengthened and prevented from splitting by pasting round it successive rings of paper one over another. The eggs when blown should be packed in chip or other boxes with cotton.

Large eggs, as those of the ostrich and cassowary, at different periods of incubation, should be preserved in spirit.

If in very early stages the embryos should be first soaked in corrosive sublimate solution. The complete series of the development of the embryos of any species of penguin are especially desirable, but series of embryos of any but the commonest birds are well worth preserving.

To each bird attach a note:—1. Colour of the bill, throat, tongue, cere, skin round the eye, iris, feet, and any other naked places before they fade. 2. The season of the year when killed and in what locality. 3. Whether male or female, after ascertaining the sex by dissection. 4. The nature of the contents of the stomach.

The skins of the domestic breeds of poultry and pigeons should be obtained from all parts of the world. A good collection of the races of our domestic birds might prove of more value than new or rare species.

The skeletons of birds may be prepared in a short time for sending home by removing the viscera, cutting away all the soft parts, breaking down the brain with a prcbe or stick, and washing it out by the "foramen magnum," or hole for the exit of the spinal cord, and drying the skeleton with its parts naturally connected, except the head, which may be packed in the thorax: and the whole, when dry, packed in bran or sawdust. The skeleton may with advantage be soaked in water before being dried, or may be packed in salt with a little corrosive sublimate instead of being dried at all as recommended for the skeletons of other vertebrata. Admit the bones of only one individual into each bag or box, taking care to label it with the same number as that attached to the skin. The viscera and any other soft part which appears curious should be preserved in spirit.

In case of opportunity occurring of observing the breeding habits of the King Penguin, Aptenodytes Pennantii, at the Crozet or Marion islands or elsewhere on a southern voyage, the mode in which the female holds her single egg supported above her webbed feet amongst the feathers of her rump, should be closely examined. The bird jumps along the breeding area of the rookery with the egg held supported as described and entirely hidden from view. No trace of nest is made. The egg is only dropped when the bird is maltreated. It appears to be held in a sort of pouch, but no trace of uch a pouch has been found in skinned specimens. The xact condition of the rump in incubating birds should be determined. The mode of incubation is probably the same in the giant penguin, Aptenodytes Fosteri.

For further information, *see* Dr. G. Hartlaub, Anleitungen zu Wissenschaftlichen Beobachtungen auf Reisen, s. 461.

T. M. Harting. Hints on Shore Shooting, with a chapter on skinning and preserving birds.

MAMMALS.

Hairy Quadrupeds, Sea Cows, Seals, Porpoises, Grampuses, Whales.

The smaller kinds of mammals, such as bats, shrews, mice, may be preserved entire in spirit. An opening should be made in the skin of the belly to give the spirit access to the viscera, and spirit should be injected through this with a syringe. Care should be taken not to crowd too many specimens in the same vessel. In all cases, since the spirit becomes diluted and deteriorated by the blood and other fluids of the recent specimens, such specimens should be removed after a few days, according to the temperature, into fresh spirit, in using which precautions similar to those described in the case of fishes should be adopted.

The larger mammals must be skinned, taking care that the head and feet remain attached to the skin, according to the directions subsequently given. The skins, if transmitted either in spirits or in a saturated solution of alum and salt, or in the following arsenical solution :—

Arsenical Solution.

Bay salt - - - -	$\frac{1}{2}$ lb.
Arsenious acid or white oxide of arsenic -	20 grains.
Corrosive sublimate - - -	2 grains.
Boiling rain water - - - -	1 quart.

—usually arrive in excellent condition, and may be mounted as well as if recently taken off the animal, which is never the case with such as have been dried.

If the circumstances under which an animal is taken will admit of the preservation of the skeleton, that ought to be done. The skeletons of wild animals are especially valuable, the examples usually found in museums being too frequently those of menagerie specimens, in which the bones are seldom so fully developed. The skeletons of the domestic quadrupeds from different parts of the world are highly desirable.

If want of space or other circumstances forbid the preservation of the entire skeleton, the skull is the most valuable part to select, and it should be preserved whenever the opportunity occurs.

The mode of preparing the skull of a mammal for the museum is to place the head, after the rough removal of the flesh, in a jar of water until the soft parts become detached by maceration and putrefaction. It is then washed clean, care being taken to prevent the loss of the small ear-bones, tongue-bone, or loose teeth, and should be placed in fresh water, and the water frequently changed, until the skull becomes free from offensive smell: it should then be exposed to the sun and air, and will in a few days become white. But this process is not requisite for the mere preservation and transmission of skulls; if the brain be broken down and extracted by means of a small flattened stick through the "foramen magnum," and the soft parts cut away, the skull may be simply dried, with the lower jaw and hyoid bone attached, and packed in bran, sawdust, or dried seaweed.

In preparing skeletons of mammals the direction given in the case of the preparation of skeletons of reptiles may be followed, *see* page 392; but as comparatively little of the skeletons is cartilaginous they may be dried, whenever that method is most convenient; although it is best to preserve the sternal cartilages in the moist condition if possible. The dried skeletons should be washed over with solution of arsenite of soda, especially at the joints and feet, to protect them from the attacks of insects and mites. Adult animals should be chosen for skeletons, but the skulls of young animals of all ages are especially valuable. In Cetacea two elongate rod-like bones lying free in the abdominal muscles close to the anus, one on each side the rudimentary pelvis, should be carefully sought for and extracted before further dissection is proceeded with. For further information, *see* Directions for the preparation of skeletons of animals, by Prof. W. H. Flower. Hints to Travellers, p. 211.

In any mammal dissected any of the viscera of special interest may be preserved in spirits.

If the female parts are in a state of impregnation, the whole are to be taken out and placed in very strong spirit, without opening the uterus, unless for the purpose of admitting the spirit for the preservation of its contents, where of large size. Whilst the embryos are in very early stages or very small they should be treated with corrosive sublimate solution before being placed in spirit. The early fœtuses of almost all wild mammals are worth preserving; those of all scarce or local forms extremely valuable; no chance of procuring them should be missed.

The fœtal young of very large animals, such as whales, seals, the walrus, and elephants, should be preserved entire: but if a young cetaceous animal be too large the tail may be cut off below the anus and the body put into spirit; and if this should be too big for one cask, the head may be taken off and preserved in another.

Of a full-grown whale or other large animal the following parts should be preserved :—

The eyes, with the surrounding external skin, their muscles and fat, in an entire mass. The internal organs of hearing. The brain. Sections of the spinal chord. The supra-renal glands. The ganglions of the sympathetic nerve system. The beginning of the aorta and pulmonary artery, for the valves.

The mammæ of the female, with part of the surrounding skin; also the ovaria and uterus. The fœtus, when found in the belly, to be taken out with the whole of the uterus, vagina, and ovaria. Very early fœtuses of any of the Cetacea or Sirenia are desiderata of first importance.

The penis of the male to be taken off as far back as to include the anus with it.

The internal organs of hearing of Ornithorhynchus and Echidnæ preserved for histological examination are very much required, their structure being quite unknown. They should be hardened in osmic acid before being placed in the strongest alchohol.

In skinning quadrupeds the skull and leg bones should always be retained. The first incision should be made from the breast along the middle of the abdomen ; the skin is then easily separated from the body by the finger, occasionally helped with the knife. Upon reaching the legs, they should be cut through, the fore-legs at the shoulder-joint, and the hind-legs at the base of the thigh-bone. The whole of the leg-bones are to be left in their places until the operation with the other part of the body is completed. In skinning the neck and head, the skin must be turned inside out, great care being taken in separating the skin from the head, that the ears and eyelids be not cut. The skin being drawn off the head as far as the ears, the head should be separated from the neck and then freed from every particle of flesh, the tongue being removed, and the brain scooped out by the foramen magnum without injuring the skull. The next thing is to skin the legs and the tail. In these parts, as in the neck, the skin must be turned inside out; all the flesh must then be removed from the bones, and they must be returned to their places by redrawing the skin over them. A little cotton or tow should first be wound round them to prevent the skin adhering to them when it dries.

In most colonies native assistants may be soon taught this process, and nothing more is necessary beyond washing and then wiping the skin tolerably dry, if it is to be put into spirit or solution; but if it is intended to be sent home dry, then the interior surface must be anointed with arsenical soap or painted with solution of arseniate of soda, with which the bones, and especially the skull, the nostrils, ears, lips, and the feet, should be thoroughly treated. The fur or hair also may be wetted with the same solution diluted with twice its volume of water. The skin should then be stuffed with tow or cotton, but not so tightly as to stretch it.

In warm climates it is necessary to skin the animal immediately after death, and it is very desirable that the skin be kept in the shade.

According to Martin it is expedient in the case of large quadrupeds to carry the primary incision from the anus the entire length of the body in the median ventral line to the tip of the chin. Similarly, the skin of the hind legs should be slit right up behind from the sole upwards, and that of the fore limbs also, the cut extending to the armpit and thence to join the longitudinal ventral incision. The skin can thus be properly spread out for treatment, and the skull easily cleaned.

The skins of large quadrupeds may, if it be intended to dry them, be cured with powdered alum well rubbed in dry all over them, or, far better, be immersed in a strong solution of alum, in which they may remain three or four days. When taken out of the solution, or after the rubbing process, they should be washed on the inner side with arsenical soap, or arseniate of soda solution, their hoofs and skulls being cured with the latter solution as in the smaller mammals.

Great care should be taken in packing dried skins that they are thoroughly dry. They should be packed in wooden boxes. When soldered up in tin boxes specimens often become mouldy and are sometimes quite destroyed by the imprisoned damp.

But, as already stated, by far the most satisfactory results are to be obtained by sending the skins of mammalia of any size home in fluid.

Martin. Praxis der Naturgeschichte, 1 Th. 2te Auflage, s. 20, s. 67, advises the use of a saturated solution of salt and alum in water for the preservation of the skins of large mammalia, and also those of large reptiles. The skins as soon as removed are to be thrown for a short time into cold water, to remove the blood and dirt, they should then be hung in the shade for some minutes and then spread out with the flesh side uppermost, and covered somewhat thickly all over with salt and alum in equal proportions. This mixture must be well rubbed in, especially about the ears, lips, feet, or hoofs. Afterwards the skin is to be folded together with the head, feet, and tail inside, and placed in a bath of a saturated solution of salt and alum, being weighted with stones so as to keep it well under the surface. An excess of the solid salts must always be maintained in the bath to ensure saturation, and as the alum is not easily soluble, its solution in preparing the bath should be assisted by boiling. During the first few days each skin under treatment must be taken out, turned over, refolded, and replaced, in order to ensure its uniform hardening by the salts. If decomposition commences then the bath certainly lacks sufficient salts. Skins when once uniformly hardened may be kept in perfect order for any length of time in this fluid. They may be packed together in layers in casks, care being taken to fill the interstices tightly with soft packing materials, and to fill the cask so full and completely that no slipping can occur during transmission. After the head of the cask is secured, the cask is to be filled up with the saturated solution through the bunghole.

Labelling specimens.

The labels or numbers should never be placed on the paper or wrapper in which a specimen is enclosed: in this case they often become accidentally transferred, especially in the examination which the specimens undergo at the custom-house. Small parchment labels with the locality of the specimens, should be securely tied to the legs or some other convenient part; a number corresponding with the collector's note-book should also be attached; this number may be stamped on a small piece of sheet-lead or trebly thick tin-foil; when specimens are preserved in spirit the latter must be used, since the former will corrode and injure the specimens. A set of steel dies, from 0 to 9, with a small punch, should be got, with these the numbers may at any time be stamped in a line, with a hole punched in front of each, and then cut off with a pair of scissors as wanted.

Notes.

The collector should note down the colour of the eyes or *iris*, and the form of the pupil, and the colours of those parts (the naked parts, *e.g.*) which are likely to be altered in drying: also the form of the head and muzzle, and the habitual position of the ears and tail. The exact locality in which the several specimens were procured is of great importance, and not only the country, but the nature of the country, its elevation and geological character, as nearly as can be ascertained. Also the degree of commonness of the animal and any of its known habits, and the native name.

Neither shape nor colour can be preserved in the dried skins of whales, porpoises, and similar animals, nor can they be ascertained from skins alone, without the aid of drawings taken from the specimens in a fresh state. Skins of Cetaceans (whale and porpoise tribe), and of seals, are, nevertheless, great desiderata for public museums, and, with the addition of sketches and notes of the recent animal, are especially recommended to the attention of the naturalist voyager. The skulls or skeletons of all the species of the southern cetaceans and seals should be preserved, the sex being noted.

As the greater portion of the smaller mammals are of nocturnal habits, they can seldom be procured without the aid of traps, which must be baited, some with flesh or a dead bird, some with cheese, bread, and fruits: small pits, widest at the bottom, and baited, often serve to entrap small quadrupeds. A small supply of strychnia is useful for poisoning carnivora and other mammals.

Necessary materials for determining Species.

In almost all cases the zoologist is desirous of examining more than one specimen—in fact, of having before him at least a specimen of the male, female, and young animal, and also one or two skulls, before he can give a satisfactory description of a new species, that is, such a description that the animal may be with tolerable certainty identified through its means. When one specimen only can be procured, the skull should not be injured; a little extra time is well spent in removing the brain through the occipital opening, the back part of the skull being of importance. When the species are small, and several specimens can be procured, one at least should always be preserved in spirit.

TRANSPORT OF LIVING ANIMALS.

Important aids to the advancement of zoology may be rendered by the transport of living animals, and more especially their transmission to the Menagerie of the Zoological Society of London, for which purpose the following remarks have been contributed by a former Vice-President of the Society, William John Broderip, Esq., F.R.S.:—

"In the endeavour to bring a captured animal home alive, it will be well to remember that the younger quadrupeds and birds are—provided they are of an age to be separated from the mother with safety—the greater will be the chance of success in bringing them home in a thriving state. There is hardly any young vertebrated animal which judicious kindness will not render familiar. The captive should be kept clean, and should be fed sparingly; that is, it should have only sufficient to sustain it in health; all trash should be kept out of its reach, and it should not be subjected to the capricious kindness or ill-treatment of strangers.

"Herbivorous quadrupeds, and hard-billed or seed-eating birds, are obviously most easily accommodated during a voyage; but carnivorous animals and insectivorous birds may be transported without much difficulty by paying attention to their food and habits.

"It would be far from impracticable for ingenuity to devise a mode of introducing even humming-birds alive into this country. A strict attention to temperature, and the aid of an artificial florist, might effect this. If it be found that the birds will not feed out of little troughs quills, or tubes of coloured paper,* the flowers which are observed to be their favourites might be imitated, and liquefied honey, or even sugar and water, might be placed in a little reservoir in the site of the nectarium. To take these brilliant creatures alive is not difficult, if the following method be adopted. Some plant (the aloe, for instance), the flowers of which are particularly attractive to the humming-birds, being selected, all the bunches of blossom, save one or two, should be broken off in the evening, after the birds have retired. These bunches should be enclosed in light bamboo trap-cages, with large open falling doors kept up by strings, to be held by a person in concealment. A little before the usual time of the appearance of the humming-birds, the bird-catcher must be in his hiding-place with the door-strings in his hand, and when he finds his prize busily employed about the enclosed flower, he must drop the door and secure his prey. Mr. Bullock tried this plan with great success; and, while on this subject, it may not be irrelevant (as connected with their diet) to state that he saw these birds frequently take insects out of the spiders' webs, where they lay entangled, and swallow them; and that Mr. George Loddiges has observed the remains of insects in the crops of some of those species which he has opened.

"Reptiles are so tolerant of hunger, and are gifted with such tenacity of life, that they bear a voyage extremely well. Turtles and alligators are brought over without difficulty, and tortoises and terrapenes may be imported almost without trouble. It is not uncommon for those who touch at the Gallapagos, where great land tortoises abound, to put them into dry casks, one over the other, without any provision; and, after many weeks, they are found not only alive, but in excellent condition for the table, where they are said to exceed turtle in delicacy of flavour.

"Guanas, chamæleons, together with others of the lizard tribe, and all serpents, bear abstinence from food for a long

* Captain Lyon, in his "Journal of a Residence, &c., in the Republic of Mexico," p. 212, states that he kept a humming-bird for nearly a month on sugar and water, slightly impregnated with saffron. It greedily sucked this mixture from a small quill; and the Captain adds, that he is sure that, with constant attention, these little creatures might be kept for a long time.

time, and are brought from their native countries with little trouble.

"Insects may be taken in the caterpillar stage when about to enter the chrysalis state, and in this manner may attain their imago, or perfect development, either on the voyage or after their arrival, by attention to their habits and to the temperature of their natural locality.

"The terrestrial or pulmoniferous Mollusca (land-shells) may be brought over alive with ease. When they show a disposition to hybernate, by sticking firmly to the side of the box or vessel wherein they may be, and at the same time throwing out the thick parchment-like secretion which serves many of the species instead of a true operculum, they should not be disturbed, but must be kept dry, and, if possible, excluded from the air. Many species have been thus accidentally imported. Bulimus undatus was brought sticking to timber from the West India islands into Liverpool, and is now naturalized in the woods near that town. Living specimens of Bulimus rosaceus, brought to England by Captain King and Lieutenant Graves, R.N., from Chiloe, were in full vigour, though the animals had been packed up in cotton, with the collection of shells, one for 18 months and another for two years. Testacella and other species had been imported previously.

"By strict attention to changing the sea-water, which very soon becomes unfit for respiration when put into a vessel, marine conchifera, mollusca, and crustacea might be brought home alive, and an opportunity given of studying their organization much more satisfactorily than can be done by a mere post-mortem examination.

"The land-crab of the West Indies has been brought over with success. A pair of them were exhibited, in full vigour, for a few weeks at the end of summer, in one of the enclosures open to the air at the Zoological Gardens."

GENERAL DIRECTIONS.

Dredging.

The value of the collections of marine animals made will largely depend on the constant use of the dredge. The mouth of the dredge should flare very little or it will fill itself full of mud and sand immediately and collect very little, as it drags on the bottom. Two or more swabs such as are used for drying decks should be attached to a cross-bar fastened to the bottom of the bag of the dredge. They entangle corals, starfish, and other animals which are often missed by the net itself. Attempts should be made to dredge in as deep water as possible, and where a dredge cannot be used in deep water because of its weight a light frame armed with fish hooks and weighted might be used with great success in very considerable depths. A triangular frame of bamboo armed with hooks and weighted with stones is used at Cebu in the Philippines by the local fishermen to procure Venus flower-basket sponges from a depth of 100 fathoms. Such an instrument might yield a rich harvest on one of the Pentacrinus grounds. A small, light trawl might also be used from a boat in considerable depths with much success.

Dredging requires experience to judge of the length of rope to be used; if there be too much on a sandy bottom the dredge will bury itself; if too little it will not scrape properly; on rocky bottoms the rope must be kept short as possible, and the towing line should not be directly made fast to the boat, but attached to it by a stop of fine twine which will break at once if a jerk occurs from the catching of the dredge in a rock, and thus set the line free. The end of the line should have a small buoy attached to it, which can be thrown overboard when a hitch occurs. The boat can then be rowed back to the buoy, and the dredge easily disentangled by being pulled up vertically.

In deep water the dredge can only be made to act effectually by placing a weight on the line at a certain distance from the dredge. In the deep sea dredging operations of the "Challenger" the weight slung on the line by means of a thimble was allowed to descend after the whole of the line employed had been paid out and brought up at a distance in front of the dredge by means of a toggle previously fixed.

The contents of the dredge are best examined by means of sieves, of which three should be used one over the other, first a riddle, next a wheat sieve, and third an oat sieve. They should fit into one another and have lateral handles for agitating them. The contents of the dredge being emptied into the riddle, and water being poured upon them, the mud will be washed off, and the contents separated so as to be very easily examined.

Towing Net.

The towing net should be used whenever it is practicable, both on long voyages and at short distances from shore, also at anchor whenever a tideway or current permit. Unfortunately, no method can be devised for using a tow-net from a vessel moving through the water with any considerable velocity; either the fine net is at once torn, or anything it catches is entirely destroyed by the wash. All that can be done on such occasions is to raise water in buckets and strain it through a fine net, or to hold the net under the spout of a sea-pump. It may thus be ascertained what a particular phosphorescence observed is due to, and a rough idea of the most abundant components of the pelagic fauna obtained. Whenever the vessel is moving slowly the tow-net should be used, and especially in calm weather and at night, when most of the pelagic animals come to the surface. The tow-net should also be used at considerable depths down to 20, 50, or even 100 fathoms, a lead being attached to the line to sink it. Mr. John Murray, of the "Challenger" Expedition, used it with great success in these and greater depths. It is well to use two or more nets at once at different depths. If no animals are found near the surface they are probably to be met with somewhere below. The tow-net is best made of bunting, being simply conical in form with the mouth distended by an iron ring. The bunting must not be too closely woven. It would be well to try a towing-net of some size with a very slight partial valve inside formed of a second cone of bunting inside the first, to prevent the escape of little fish, cephalopods, and other active animals which enter it. Possibly the reason why living Spirula is never caught in the tow-net in regions where it abounds is that no such precaution is adopted.

Ordinary fish globes of various sizes are especially useful for receiving the contents of the tow-net and examining them. The net when drawn on board should be at once turned inside out and washed in fresh sea water in such a globe. After the contents have been examined and any larger animals removed for special treatment, a solution of corrosive sublimate in water should be poured into the sea-water containing the remainder. This will in a short time kill the whole of the animals present and cause them to sink to the bottom of the vessel. The bulk of the sea-water should then be poured off and the dead animals well washed by additions of fresh water and stirring. The fresh water should then be poured off and some alcohol added to the residue so as to form a weak solution which should be gradually strengthened. The contents may be poured out into a glass dish and hunted over with a lens in order that particular specimens may be picked out for preservation apart in small glass tubes, or the whole catch may be transferred to a bottle or larger tube in strong spirit and labelled for future examination. The general contents of the tow-net, or any part of it, may also, with specially good results, be treated with a small quantity of Osmic acid solution, added to the sea water containing it. The pelagic animals when fallen to the bottom dead are to be washed with fresh water and transferred to strong spirit as in the case of those killed with corrosive sublimate. It is not advisable to add spirit to sea-water containing minute pelagic animals since an amorphous precipitate of sulphate of lime is formed which falls amongst them and cannot be got rid of. It is most important to obtain series of samples of the general pelagic fauna from all parts of the ocean, gathered at all times of the year and under various conditions of weather, and obtained at different specified depths at specified hours of the day or night. All these particulars should be stated on the label of each bottle. Possibly the use of a tow-net of some colour less conspicuous in the water than white might prove advantageous.

Store Bottles, Tubes, and Boxes.

The most economical wide-mouthed bottles for use for collecting on a voyage are those known in the trade as "rock bottles" and manufactured for holding sweetmeats. They are made in three sizes and sold packed in wooden cases in compartments padded with cork, and provided with handles at each end. The bottles are about the same height, 9 inches, with glass stoppers with cork rims. The diameters of the three sizes are 6, $4\frac{1}{2}$, and $3\frac{3}{4}$ inches, with mouths, $3\frac{3}{4}$, $2\frac{3}{4}$, and $2\frac{3}{4}$ inches respectively. They are very cheap ; 200 cases containing 2,300 jars were supplied to the "Challenger" Expedition by Messrs. E. Breffit & Co., Upper Thames Street, London, at a cost of 70*l*. Very serviceable also and cheap are white glass bottles $3\frac{1}{4}$ inches high, 2 inches in diameter, with mouths of about $1\frac{3}{4}$ inches with ground glass stoppers. They are made by machinery as pomatum bottles, and sold very cheaply by the gross. They were supplied to the

"Challenger" Expedition by Messrs. J. Powell and Sons of Whitefriars. A leather case to contain six of these bottles upright in compartments, with a leather lid to strap down over their stoppers, and a sling to suspend the case from the shoulder makes a most useful field collecting case for all kinds of purposes, and as the bottles are so cheap they can easily be replaced when they get broken.

A supply of glass tubes, like test tubes, but thicker, and without a bent lip, should be taken. They should be of various sizes nested within one another for convenience of package, and a supply of corks should accompany them. The tubes when full of specimens in spirits and corked up, should be packed with paper in rock bottles containing some spirit, and as soon as a rock bottle is packed as full as it will hold with them it should be filled up with spirit, and either bladdered over or tied over with some stout fabric like duck. The bladder or duck may finally receive a coat of paint, or several, for security. If tubes are packed dry they are apt to leak and their contents thus become spoiled.

A supply of sheet zinc and solder to make cases for packing objects preserved in spirits should be taken by the intending collector; or a series of rectangular cases, ready made, and nested one within the other, requiring only the soldering on of the lids, may be more expedient. The zinc receptacles, when full, should always be packed in stout wooden cases.

A supply of cigar boxes, and also chip boxes, pill boxes, seidlitz powder boxes, and respirator boxes, such as are manufactured for druggists' use, will be found most serviceable for dry things of all kinds. In damp climates, on board steam vessels, specimens may often be quickly and well dried by artificial heat in the funnel casings or engine room, or by using the ships' oven at night, when by mere exposure to the air they would only decompose.

Labels.

In most cases the entire interest of any specimens collected depends on their correct labelling, with full particulars of locality, date, and circumstances. It is always best to attach a label to each bottle of specimens with all essential particulars written upon it, if possible; not merely to affix a letter or number to be explained only by reference to a note book. It is an excellent plan to affix the number so as to refer to fuller details in a note-book, but the locality and date should be secured to every specimen. Parchment labels should be tied round the necks of all bottles besides, the labels pasted on their surfaces. Inside all bottles and tubes with specimens in spirits should be placed slips of parchment with the locality and date written on them with a dark lead pencil ; such a label is imperishable in spirit. Parchment or vellum clippings suitable for the purpose may be obtained in quantity at bookbinders.

Microscopes.

The best microscopes for use on board ship are such as have comparatively short, squat stands with broad, heavy, horseshoe-shaped bases, a simple sliding coarse adjustment of the tube without rackwork, and a roomy fixed stage without mechanical motion ; instruments, in fact, made on Hartnach's or Zeiss's models. Such instruments may most conveniently be secured to the table at which they are used by means of a brass holdfast made on the pattern of the iron ones used by cabinetmakers ; a hole is bored in the table to receive the upright of the holdfast, and a slight pressure on the angle of the holdfast tightens its grip on the foot of the microscope so securely that no rolling of the ship shakes it at all loose ; at the same time its hold can in a moment be relaxed and the position of the instrument round the hole be changed at will. The table should, of course, be screwed to the deck, and also the stool on which the observer sits, and if the height of the table and stool be so adjusted that the legs can keep a tight grip on the table underneath, it is possible, with practice, to use a magnifying power of even 1,100 diameters with success in very heavy weather. Microscope lamps with ring feet can also conveniently be secured to the table by means of a holdfast.

Modes of Killing Animals.

Animals should not as a rule be plunged alive into strong spirits ; if this be done they die in a state of extreme contraction and distortion. The object of the use of such solutions as picro-sulphuric acid is to kill them without the occurrence of such distortion or their disfigurement by deposits of hardened glandular deposits. Many marine and freshwater animals, especially marine annelids, may be killed in a relaxed condition often with tentacles and other appendages in a state of expansion by a method known as Eisig's. This consists in putting into a vessel containing in sea-water the animals to be killed a few drops of alcohol, and repeating this at short intervals until death ensues, after which the animal may be passed through the different grades of alcohol in the usual way. The gradual addition of the alcohol to kill the animal slowly may be perhaps best effected by allowing a mixture of alcohol and water to drip slowly into the sea-water from a bottle suspended above it.

The proper preservation of animals and their tissues for scientific purposes is now a very special art, which has been principally elaborated at the Naples Zoological Station. It possesses a special literature, and in the restricted compass of the present instructions it has been possible only to give directions as to methods most likely to be serviceable in general. But for preserving the embryos or adults of most groups of the animal kingdom special methods and reagents are found most serviceable in each case. Any collector, therefore, who wishes to excel in the preparation of his specimens and produce material suited for advanced microscopic research should study C. O. Whitman's "Methods of Research in Microscopical Anatomy and Physiology." Boston: Cassino & Co. 1885.

GENERAL DIRECTIONS TO BE OBSERVED DURING A VOYAGE.*

The towing-nets should be kept overboard whenever it is practicable, and the dredge should be used perseveringly in soundings.

The anchor should be inspected as soon as it arrives at the surface, especially if the holding ground be mud. The finest shells have been lifted on the flukes of anchors. The cable should also undergo an examination.

Let the arming of the lead be narrowly observed, and let the men have orders to preserve anything that may be sticking to the arming, the lead itself, or the lead-line.

Floating masses of seaweed, especially sargasso, should be carefully searched; and if one of those tangled natural rafts, which are often carried adrift from great rivers, should be seen, it should be examined minutely, and the animals, plants, and seeds, which it may be transporting to colonise

* From "Hints for Collecting," &c., by Wm. John Broderip, Esq., F.R.S.

some newly-formed island, should be preserved, if possible, or at all events, accurately noted.

Whenever a new marine species, or one whose habits are unknown, is obtained, it should be placed in sea-water, and, if practicable, a drawing should be made of it while yet alive, with a note stating whether it is gregarious or solitary — phosphorescent or not — and giving the locality, the temperature, the state of the weather, the depth of water, and the time, where and when it was captured. The sea-water in which living marine animals are confined should be often changed; for it speedily becomes unfit for life.

If a turtle be taken, the shell should be examined for parasitic barnacles (Chelonobia) and other adhesions. The specimens ought not to be scraped off, but the plate of shell to which they are affixed should be taken out, and the whole should be preserved together. Whales should be searched for Coronula, Tubicinella, and similar forms; they should be left, as they are found, in the skin and blubber of the animal, and the piece with its contents should be plunged in spirits.

The stomach and intestines of those fishes and birds which are killed during the voyage should be inspected before they are thrown away, not only for the purpose of noting their food, but for the chance of finding undigested shells, and in search of Entozoa. The feathers of birds should be examined with a view to ascertain whether any parasitic insects, any ova of fish or testacea, or any seeds of plants, adhere to their plumage. Their crops will often be found stored with fruits and seeds, which they disseminate in their flight.

Particular attention should be paid to the appearance of birds or insects, as well as to the direction whence they seem to come, with a view to the elucidation of their migration.

By placing in the sea clean planks of wood, the rate of growth of Teredo navalis, and of the Cirripedia, together with the ravages made by the former in a given time, may be ascertained. Serpulæ will probably be found on the board also, and perhaps other shells. This experiment should be repeated whenever an opportunity occurs, and in different localities and climates. Some of the planks should be painted, others covered with pitch, others studded closely with copper and other nails, and some should be in their natural state.

When on shore in search of land-shells the collector must not be content with a close examination of the trunks, leaves, and stems of trees and other plants, but must turn up all decayed vegetable substances, especially in moist places, and there dig into the earth, more particularly about the roots of trees, and under overshadowing bushes and shrubs. Stones must be lifted, herbaceous plants must be pulled up and their roots inspected, and if the boat's crew be at hand, fallen trunks of trees should be turned over with hand-spikes. The height above the level of the sea at which specimens are taken, and the plants on which any of them are observed to be feeding, must be noted. In the latter case the plants should be preserved in an herbarium, fully labelled.

No boggy places, especially where streamlets ooze out, should be passed without examining the rushes and other plants there growing for fresh water testacea. At the proper season their ova may be found adhering to living and dead stems of plants, and to leaves.

No bird, insect, shell, or any other zoological specimen, should be neglected because it does not strike the eye as beautiful, or because it is small and appears to be insignificant. Such objects are often the most interesting.

When a box or barrel of specimens is once securely packed, it should never be opened till it arrives at the place of its destination. If it is wished to have a few duplicates at hand, for the purpose of exchange with other collectors who may be met during the voyage, some specimens should be set aside for that purpose. All observations should be noted down while the impression is warm; and, if possible, with the subjects actually before the observer.

When an object is seen afloat, attracting notice by its magnitude or other peculiarity, and is not captured, its nearest approach to the ship, its mode, course, and rate of progression, and the parts actually recognisable, should be noted, at the time, with the utmost accuracy. If practicable a boat should be put off for close observation. If the observer has not the zoological knowledge, or the opportunity for exact inspection, requisite for determining the species from the phenomena, he should abstain from giving the object any special name. Supposing it to be an animal, a shot fired, if it do not hit, may so alarm the creature as to cause some sudden movement which may reveal more of its true nature.

WORKS TO BE CONSULTED.

Anleitungen zu Wisseuschaftlichen Beobachtungen auf Reisen mit besonderer, Rücksicht auf die Bedürfnisse der kaiserlichen Marine herausgegeben von Dr. C. Neumayer. Berlin, 1875. A new edition is to appear in 1887.

Hints to Travellers, Scientific and General. 5th editon. London. The Royal Geographical Society, 1883.

Methods in Microscopical Anatomy and Embryology, by C. O. Whitman. Boston, S. E. Cassino & Co. 1885.

Die Praxis der Naturgeschichte Ein vollständiges Lehrbuch über das Sammeln lebender und todter Naturkörper; deren Beobachtung Erhaltung und Pflege in freien und gefangenen Zustande; Konservation, Preparation und Aufstellung in Samlungen. Von P. L. Martin. Weimar, 1876–1882.

ARTICLE XIV.

BOTANY.

By Sir J. D. HOOKER, M.D., R.N., C.B., K.C.S.I., F.R.S., &c.

The advancement of botany, whether as a science or for ulterior purposes, by voyagers and travellers can only be accomplished by diligently observing and collecting plants, and exercising patience in preserving instructive specimens of them. It cannot be too strongly impressed on voyagers or travellers, when visiting little known regions of the globe, that the time devoted to observation and collection will be little profitable if satisfactorily preserved specimens are not obtained; and this, whether the object be to promote a knowledge of scientific botany or to make known the useful products yielded by plants.

As it may not be clear to those who have received no education in botany how mere collections can advance the science so greatly, they may be informed that our knowledge of the extent and varied forms of vegetable life in our planet (amounting, perhaps, to 150,000 known kinds of flowering plants alone) has been derived almost exclusively from the study at home of well-preserved specimens brought by voyagers and travellers within the last 150 years, supplemented by an examination of a mere fraction of them that have been cultivated in Europe. From the date of the voyages of Cook and Vancouver, England has been foremost amongst nations in advancing botany through the exertions of its naval officers; and it is the object of this portion of the Manual to indicate to them how the good work of their predecessors may be profitably extended.

It may further be an encouragement to know, that with the exception of the shores of our own island, of the Baltic, and of France and the United States, there is, perhaps, no coast on the globe from which botanical collections are not wanted; for though of many of these the flowering plants are more or less well known, this is not the case as regards the flowerless, that is to say, the mosses, lichens, seaweeds, and fungi, and the microscopical plants of fresh and salt water. It is true that to make good collections of many of these knowledge and skill are required; but this is not so with all, for any one with patience and industry can collect and preserve seaweeds and mosses.

The collector, then, may by devoting his attention to botany, promote not only the advancement of scientific botany, but of horticulture and gardening, and of arts, manufactures, and trade.

For the first object he will preserve specimens in a dry state *for the Herbarium*, or, as it used to be called, the *Hortus Siccus* (dried garden); for the second he will obtain living plants, roots, bulbs, cuttings, and seeds *for the garden;* for the third he will, by observation and inquiry, obtain for *the Museum of Economic Botany*, textile materials, gums, dyes, drugs, woods, &c., &c., together with information as to their uses, *accompanied by specimens for the herbarium of the plants that yield them.*

On the Collection and Preservation of Specimens for the Herbarium.

Materials and appliances for collecting and preserving.— The collector should be provided with a portfolio* with shoulder strap, containing a few quires of rather stout paper; a spud or digger, a stout knife to cut branches, or, better, a pair of pruning scissors (to be attached by a string to the button hole), a small tin box, and a few pill boxes in which to put fruit seeds or parts of plants that cannot be

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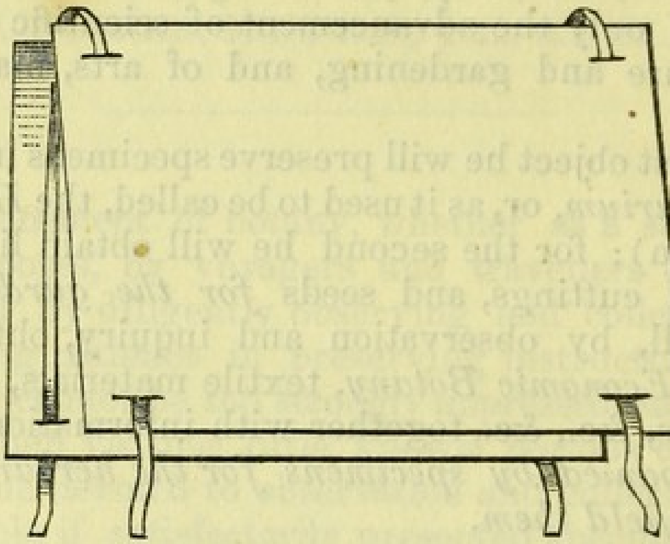
* The portfolio of a convenient size measures 16 to 18 by 10 to 12 in. It is made of two mill-boards covered with stout glazed cloth, with front and side flaps attached to one inner face, to cover the enclosed paper in wet weather. Two thin straps with buckles, which pass round the portfolio transversely, close it when shut, and a stout shoulder strap, which should also pass round both flaps, serves to suspend it from the shoulder. Small outside pockets may be added to hold the digger and pruning scissors. The amount of paper to be taken on an excursion must depend on the nature of the plants likely to be obtained and the length of the day's work. A collecting portfolio of a simple kind may be improvised out of two paste-boards and tapes as shown in the accompanying cut.

conveniently put in the portfolio. For short excursions the portfolio may be dispensed with, and a tin box, carried over the shoulder, of the form well known as a botanical box or vasculum. When possible an attendant should carry the portfolio or vasculum, leaving the collector free to take notes, either in a note-book, or on slips of paper (prepared paper such as is used for luggage is best in very wet climates) to be attached to the specimens.



Collecting Portfolio.

Small plants 12 to 16 inches high or less should, as a rule, be gathered whole, with the roots (which if too thick may be sliced) ; but of large herbs, shrubs, and trees, portions in as good a state of leaf, bud, flower, and fruit as can be obtained, of the same length, should be taken. Of some plants the flowers must be taken separately from the leaves ; of others with leaves of different forms, a selection of these is necessary. Long, slender herbs, grasses, ferns, and such like may be folded once or twice. When gathered lay them into the portfolio or vasculum, or if provided with both, put the delicate ones only in the former. In the case of certain plants, such as palms, screw pines, aloes, cacti, and trees with huge clusters of flowers, it is difficult to obtain anything but fragments ; these must be judiciously selected and accompanied with notes, and, if possible, by sketches, which even if rude and artistically bad are of the greatest value to the botanist. In countries abounding in such unmanageable plants, as the Brazils, Malayan Archipelago, and Pacific Islands, little can be done towards collecting these on a single visit, though even in such a case much aid can be had from settlers or natives. Many succulent plants may be preserved in a fit state for recognition by judiciously slicing the leaves, which should be roughly sketched on the spot.

Corallines and their allies, which are seaweeds coated with calcareous matter, thus resembling corals, are some of them branched and jointed, when they may be preserved flat like ordinary plants; others are crustaceous, like corals, and can be preserved like corals in soft paper or cotton wool.

Of mosses, tufts should be taken, to be spread out afterwards. The coarser seaweeds may be at once wrapped in paper or cloth and laid in the vasculum; but for some of the finer a water bottle is necessary. Fungi, except the harder kinds, are very difficult of collection, and still more of preservation, and cannot well be taken in hand with other plants; the soft ones should be drawn before changing colour.

Such are the best means of procuring good specimens; but the collector may find himself in a position to collect when unprovided with such appliances. Thus, a traveller has been known to improvise a portfolio out of a roll of paper (like a roll of music), tied round with a string, carried in his coat pocket*; and valuable specimens have been secured by enclosing them in the folds of a newspaper carried on the chest with the coat buttoned over it. In such cases the specimens are, on arrival at home or on board ship, put between flat papers and dried as follows :—

Preservation of Specimens.—For herbarium purposes the object is to absorb the moisture from the specimens as quickly as possible under such pressure as will prevent their shrivelling in drying. For this purpose provide a quantity of brown or stout grey, moderately absorbent paper of a folio size†, two light boards and several mill-boards of the same size, also three stout straps with buckles. Lay a few sheets of the paper on one of the boards, and on it place as many of the specimens from the portfolio or vasculum as the paper will take, side by side, as close as may be, but not over one another, putting the thicker ends of the specimens

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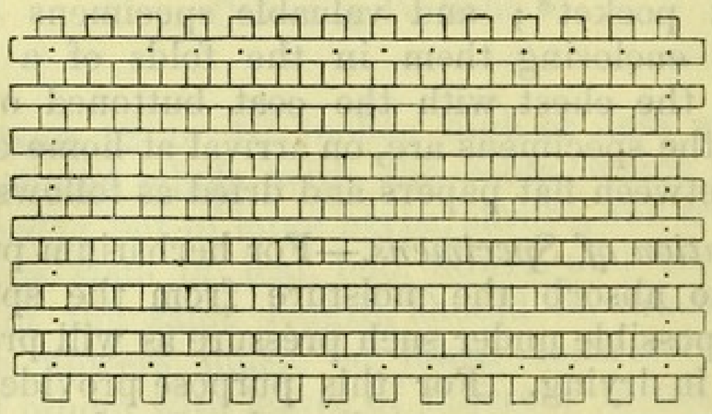
* The late Dr. Sinclair, R.N., an indefatigable collector, whose specimens were excellent, collected largely by this means.

† Bentall's botanical paper (16 by 10 inches or 20 by 12) is excellent, except for very damp climates, where stout brown is best.

towards the edge. Over this lay several sheets of paper according to the thickness and succulence of the specimens, and on these another layer of plants, till the whole collection is thus accommodated; then place the other board on the top and either put the whole under pressure, or strap up, once lengthways and twice across. If the specimens are thick, or the pile of plants and papers thick, some of the mill-boards introduced here and there will be very useful. After a day or two; according to the more or less succulent nature of the plants or the heat and dryness of the climate, remove the specimens into dry papers, and repeat this process till they are stiff and do not shrivel on exposure, drying the damp papers in the sun or by fire for future use. The bundles of plants in papers will dry sooner if hung in the sun, or in the engine room, or near the galley fire.

Instead of the wooden boards and mill-boards, ventilators of wire, split bamboo, or other wood may be used with great advantage, by which contrivance the air is admitted into the bundle and the process of drying accelerated (*see* cut). A saving of time and trouble may be effected



in transferring the plants from wet to dry sheets by placing them at first within a folded sheet of very thin paper, which is, with its contents, put between the dry sheets. For delicate plants, or where a number of small specimens are on a sheet, this is a great saving of trouble. Some plants with fine rigid leaves, as spruces, silver firs, and many heaths, throw off their leaves on drying, which may be in a great measure prevented by plunging them for a few seconds in boiling water before placing them in the drying paper. Succulent plants which long retain their vitality, as epiphytie orchids, may be similarly plunged (except the flowers) for a second into boiling water, or the whole plant may be put into a weak solution of carbolic acid or alcohol, or kept for several days in a basin of water with a muslin bag of corrosive sublimate in it. After such immersion (which kills them) they dry easily and well between papers, and are not attacked by insects afterwards. As before indicated, many succulent plants must have their leaves or stems sliced before drying. Mosses (to be spread out by the hand), ferns, lichens, and the coarse seaweeds are dried in the ordinary way.

For the more delicate seaweeds the following directions will suffice. The specimens are to be collected in the same manner as flowering plants, but it is well to be provided with a wide-mouthed bottle of water in which to bring home the most delicate specimens. The coarser olive brown kinds should be steeped for a day or two in fresh-water and dried under pressure like ordinary plants. The more delicate red or green kinds should be floated in a shallow basin of fresh water, one at a time, when a piece of white paper is immersed under them, and they are to be spread out upon it, the delicate branches being displayed with a pointed instrument; then, with a little dexterity, the paper is to be withdrawn with the specimen spread out upon it, placed between sheets of bibulous paper, and the whole pressed. A few especially delicate kinds decompose in fresh water and these must be treated in salt water.

Lastly, there are certain plants and flowers and fruits of plants which can only be preserved in alcohol or coarse spirits or dried without pressure. The intelligent collector will recognise these, and use his judgment as to their preservation.

When sufficiently dry, the specimens should be put upon single sheets of any kind of paper of tolerably uniform size, except when from being unusually woody they would injure the specimens on the sheets above or below them, when more paper or pads of paper must be used; care being taken so to distribute the specimens on the sheets that the pile is compact, for which purpose the thicker ends must be, as a rule, towards the margin. A ticket with notes of date, colour of flower, nature of plant, locality, &c. should accompany any specimen requiring it. Old newpapers are good for the purpose of receiving the dried specimens.

For packing and transmission to England, brown paper wraps, or oilcloth is, in some cases, sufficient, in other cases wooden or tin boxes are necessary, according to distance, climate, and means of transport, preservation from damp being in all cases imperative. Casks are capital packing cases, the rectangular bundles being placed in the middle, and dried fruits, woods, and other museum objects fill up the side spaces. A little camphor should be put in with the specimens, and where vermin abound a few drops of cajeput oil, poured in before closing the box, will start out ants, cock-roaches, &c. It is, of course, *imperative,* that the loose specimens packed into the interstices should be *thoroughly dry*, or they will ruin the herbarium specimens.

Living Plants for Cultivation.

Plants for cultivation in our European gardens may be introduced either as *seeds*, *bulbs*, *tubers*, *cuttings*, or *rooted plants.*

Seeds, *bulbs*, and *tubers* are easily collected, and as easily transmitted to Europe from very distant countries. The first, *seeds*, require to be gathered quite ripe ; to be wrapped, a quantity of each, in dry and not absorbent paper, done up in a parcel, and kept, if possible, while on board ship, in an airy part of the cabin. *Bulbs* and *tubers* should be taken up when their foliage has withered ; and, if well dried, they may be packed in the same way as seeds.

Cuttings.—Generally speaking, it is vain to attempt sending *cuttings of plants* to a distance, for they soon perish ; but this is not the case with the greater number of *succulent* plants—those with thick and firm fleshy stems and leaves. Such are many of the *Cactus tribe* in South America ; the various succulents of South Africa, as *Aloes*, *Euphorbias*, *Stapelias*, *Mesembryanthemums*, or *Fig-Marygolds*, the *Houseleek* kind, &c. Many of the *Bromelia*, or Pine-apple tribe, and the *Agaves* or *American Aloes*, will survive a long time as cuttings. The cuttings should be taken off, if possible, where there is a contraction or articulation of the stem, or at the setting on of a branch. The wound ought to be dried by exposure to the sun ; and the cuttings may be packed in a box, with paper wrapped about them, or any dry elastic substance to keep them steady.

Cuttings may often be brought from moderate distances (voyages of from 10 days to a month) stuck into a potato, or with the cut ends enveloped in damp moss or clay, or put in a phial of water, the upper part being exposed.

Rooted Plants.—Some few of these, namely, such as are of a succulent nature, small plants of *Cactus*, *Aloë*, *Bromelia*, *Tillandsia*, and *Zamia*, &c., and (which are now highly valued in European stoves) the various *Epiphytes* or *Air Plants*, those numerous *Orchideous Plants* and others of the *Arum Tribe*, which clothe the trunks and branches of trees in tropical countries :—all these will bear a long voyage, if removed with their roots and stowed in a box like the cuttings above described, the larger kinds surrounded with dry straw. But plants, in general, when taken up with their roots (and young ones should be preferred) can be securely transported, placed in earth, in Ward's plant cases. These cases are glazed at the top or roof, being, in fact, portable greenhouses. The plants should be established in the cases some days before sending them off, and the soil secured by cross battens firmly attached to the sides, so as to confine the roots in the soil in the event of the case being overturned. Epiphytic orchids, and so-called air plants, may be nailed to the sides of the case, or hung from the roof, as may many ferns (especially filmy ferns), if first established on pieces of wood or fragments of tree-fern trunks. After a moderate watering the lid is fastened on with putty and screws, and the case placed on the deck of the vessel, so as to be exposed to the light, which is indispensable. So long as the glass is unbroken no watering of the plant is required, or other attention than screening from the powerful rays of the sun. It must not, however, be supposed that the transmission of plants in Ward's cases is a simple or uniformly successful operation. The cases must be well made, and provided with very strong wire gratings over the glass; well-rooted plants of proper size and age must be selected; and the planting of these in proper soil, securing them in their places, watering, and treatment on the voyage in case of accidents, all require experience as well as skill and care.

There are many devices by which live plants may be brought home by those who exercise skill and ingenuity. A very valuable collection was brought to Kew in a sailing ship from New Zealand, round Cape Horn, by a gentleman whose resources were a wooden box and some pickle bottles. Very small plants were planted in the bottles which were loosely corked, hung in the rigging by day, and taken below at night. A piece of glass was let into the top of the box and plants placed in earth at the bottom; it was kept on deck, and in the cold nights rounding the Horn a nightlight was burnt in it to supply warmth. Great care was exercised in watering, in screening the plants, and in checking too rapid growth in the passage through the tropics. No doubt the green colour of the bottles was very advantageous.

On the Collection of Specimens for the Museum of Economic Botany.

The object here is to bring together and exhibit those interesting vegetable products from all parts of the world, which cannot be shown as living plants in a garden, or as preserved plants in an herbarium. The public may now see growing in our Botanic Gardens the rare *Lace Tree* of Jamaica, the yet rarer *Ivory Palm Nut* of the Magdalena, and the *Cow Tree* from the Caraccas. The interest of these is greatly enhanced, when, in the same establishment, the curious and beautiful lace of the first, the fruit and ivory-like seeds of the second, and the cream-like substance of the third, used as nourishment by the Indians, can be inspected.

Among the objects, therefore, which are to be collected for the museum are—

1. *Fruits and Seeds*, especially those which are of large size and possess any peculiarity of form and structure entitling them to notice, such as *Pine Cones*, the various fruits of *Palms*, &c., &c. Many of them are naturally dry, and require little care (except to be freed from moisture) previous to packing. Those which are about to burst open into valves, or to separate by their scales (as the *cones* of *Pines* and *Araucarias*), should be bound round with pack-thread, or with fine flexible iron or copper wire, which may easily be woven into a network over the cone. The soft and fleshy kinds can only be preserved in alcohol, coarse spirits, pyroligneous acid, or other preservative fluid.

Here, too, may be indicated the importance of collecting living plants, seeds, and fruits washed up on shores by tides, currents, or rivers, these being often thus brought from very distant countries, and showing not only the directions of currents, but the influence of them in distributing plants. With the same view the stomachs of grain-feeding birds shot at sea, and of migratory or wandering birds on small islands should be searched for seeds, as should the mud on the feet of aquatic birds.

2. *Flowers* which are very large or particularly fleshy, and, therefore, unsuited to the *Hortus Siccus*, should be preserved in alcohol or pyroligneous acid. Among those which would be much prized are, for instance, portions of the flowering branches of *Palms*, *Screw Pines* (*Pandani*), &c., &c., and the larger kinds of *Orchidaceæ*.

3. *Entire Plants* or parts of them.—Many have a very fleshy nature, and must be preserved whole in preservative fluid, or portions of the stem and branches, according to their size, with flower and fruit; such are the rare kinds of *Stapelia*, *Orchidaceæ*, *Rafflesia*, *Mesembryanthemum*, *Cactus*, *Aphyteia*, *Balanophora*, *soft Parasites*, and others of a similar sort.

4. *Trunks of Trees*, portions and sections, particularly when they exhibit any remarkable structure, or afford valuable wood used for construction or ornaments, *Tree Ferns*, *Zamia*, *Cycas*, and *parasitical* stems, when these latter display their union with the tree whereon they grow.

Trunks of tree-ferns from little visited tropical islands are much wanted. Specimens of moderate size should be selected, and the fronds, or some of them, be turned down on the trunk, when the whole may be sewn up in canvas.

5. *Woods*.—Specimens of the kinds employed in commerce for veneering, cabinet work, or other useful purposes, or such as recommend themselves by their beauty, hardness, or any other valuable quality. Specimens of wood should be truncheons, 5 or 6 inches long, and of a foot or a foot and a half diameter. In all cases it is advisable that a small branch dried and pressed, with leaves, flowers, (and fruit, if convenient), should accompany the specimen of wood, in proof of the *precise* tree or plant from which the latter is derived, and, if not the scientific, the native name should be written.

6. *Dye Stuffs* of various kinds.

7. *Medicinal Substances*, *Gums*, and *Resins* employed in the arts, *Oil Seeds*, and *Oils*, &c.—These are of very great importance, and merit the attention of travellers in every country. With respect to many well-known medicinal substances, it is remarkable that we are still in uncertainty as to the plants which yield them.

With regard to books, voyagers about to make prolonged visits to particular coasts or stations should apply to the authorities at Kew for information on this head. The most useful for general purposes are " Le Maout and Decaisne,

" Descriptive and Analytic Botany," translated by Mrs. Hooker, and " The Treasury of Botany," both published by Longmans & Co.

Countries from which Collections are wanted.

A question will naturally suggest itself to the traveller, not previously versed in the vegetable productions of different parts of the globe, " In what region can I most effectually serve the cause of botany ? " The answer is ready : In almost every portion of our world the inquiring mind will find objects for study, though assuredly the less the country has been tracked by Europeans and men of science, the more fertile it may be expected to prove in novelty. But even where the coast has been visited and tolerably accurately investigated, the interior, especially if mountainous (and the loftier the mountains the more varied their vegetation), will afford an ample field for research. Even with regard to many frequented spots, it has been truly observed, that few persons visit them " with their eyes open." Thus, while some travellers assert that Aden is utterly destitute of vegetation, others have detected plants of very peculiar structure, and admirably adapted to such a locality; and one naturalist, Pakenham Edgeworth, Esq., actually published a *Florula* entitled " Half an Hour's Botanizing Excursion at Aden," giving an account of 40 species gathered during that brief time, 11 of which were considered new to science.

One has only to glance at a map of the world, and it will be instantly seen that much of it is unknown alike to the botanist and the geographer. The extensive interior of South America, particularly towards the sources of the great rivers, the deserts and mountain chains of Africa, the table lands of Tibet, with the northern declivities of the Himalayan Mountains, the Chinese dominions, little visited parts of Japan, and many of the numerous islands of the the Malayan Archipelago, are still almost a *terra incognita* to the naturalist. But it is not to such little traversed realms alone that we need look for new and interesting vegetable productions, particularly of the more useful kinds, those of many of our own colonies being still very imperfectly known.

Europe.—The coasts of Greece and the islands of the archipelago, Rhodes, Crete, and Cyprus, abound in beautiful plants not yet brought into cultivation in Europe, and the uses to which vegetable products are put in these countries is far from satisfactorily known. The same may be said of coasts of the Levant, Ægean, and Black Seas, the seaweeds of which have never been carefully collected, nor have their mosses and other flowerless plants. The discovery of the cedar of Lebanon in the mountain region of Cyprus, by Sir Samuel Baker, only a few years ago, is a striking proof of our ignorance of the vegetation of often visited and supposed well known floras within easy reach of England.

Africa.—Morocco, Tunis, Barca, and Tripoli are only partially explored, whether on the coast or inland. The long stretch of Atlantic coast from Morocco at Cape Agadhir to Cape de Verd (the western seaboard of the Sahara) is botanically utterly unknown, and though in a sense desert, yet being exposed to the moist winds of the ocean, it doubtless maintains a very curious, though not luxuriant, vegetation. From the Senegal River to the tropic of Capricorn there is no land from which collections of all kinds would not be valuable, but especially that extending from Loanda to Damara Land.

On the east coast of Africa, the western shores of the Red Sea, and Somali land are particularly interesting as the home of the Myrrh tribe, which are botanically very imperfectly known. Even of the botany of Suakim there are but imperfect data. From Somali land to Delagoa bay a rich and very scantily explored flora extends along the whole coast, especially on the coast ranges of hills. In Africa, south of the tropics, Namaqua land on the west, and the Transvaal on the east, are but partially botanized, and the intervening desert country is full of curious plants.

Of the Western African islands, the mountains of the Cape de Verd islands, Fernando Po, Princes, St. Thomas, are all rich fields for the botanist (of Annabon nothing is known), as are on the east side Bourbon, the Amirante, Providence, Aldabra, and the Comoro, whilst Madagascar is still to a great extent a virgin field, its west coast especially.

Asia.—The vegetation of the coasts and interior of Arabia is very little known, as is that of Omar, the Persian Gulf, and Southern Persia, and the coast of Beluchistan eastward to Kurrachee. The flora of British India offers little novelty to casual visitors, though large tracts of the Deccan peninsula and of the eastern and north-eastern portion are unexplored. The Malay peninsula and islands, including the Moluccas, the Phillippines and Borneo, again present perhaps the richest flora in the world in point of abundant and beautiful vegetation and innumerable vegetable products useful in the arts, trades, and professions of Europe, whilst their orchids, palms, ferns, and flowering plants are the choicest in cultivation. Northward of them, the coasts and islands of Eastern Asia from Siam to Corea, offer an even more interesting field from so many of their vegetable products having been in use for ages, of which only a small proportion are as yet scientifically investigated. A botanizing excursion up the Yang-tse-kiang in one of the steamers that habitually ascend that noble stream would, by simply collecting at the stopping places, return laden with a harvest of interest, and the same may be said of all the other Chinese rivers. The neighbourhoods of the Japan ports are comparatively well known, but not so the interior, nor Bonin, the Loo-choo islands and Formosa, whilst of the Pelew and Caroline islands absolutely nothing is known. New Guinea is a terra incognita except a few points near the coast, and the same may be said of the islands north and east of it, the Louiside Archipelago, Admiralty Islands, New Britain, New Ireland, and the Solomon Islands.

Australia.—The southern and eastern colonies offer little novelty to the casual visitor, but North Australia and the coast from Torres Straits westwards and southwards to Shark's Bay will amply repay the collector.

North America.—Lower California and the east and west coasts of Mexico (especially north-western) and Central America, Honduras, Nicaragua, Costa Rica, Panama, and Darien, are very little known. No collections have been made on some small islands on the west coast, as the Revillagigados, nor in Cooper island, in lat. 26° N. and long 132° W.

The West Indies.—St. Domingo, including the republic of Hayti, is absolutely virgin ground. A very small portion of Cuba has been explored, and except Trinidad and Jamaica, every island wants more botanical visits. Barbados alone presents no indigenous vegetation of interest. The higher parts of all the mountainous islets, and of Dominica especially, no doubt, teem with novelties.

South America.—There is no point along the whole stretch of coast on the west from Panama to Valparaiso from which novelty may not be expected, whether from the coast, or from the flanks of the Andes. Western Chili is comparatively well known botanically, but not Chiloe, and the mosses, seaweeds, and other flowerless plants of South Chili, Western Patagonia, and Fuegia offer an inexhaustible field to the cryptogamic botanist. The Galapagos Islands possess a flora of especial interest, the different islands having to a great extent different plants, which should be carefully collected with a view of contrasting the vegetation of the several islets. Juan Fernandez, though better explored, contains a kind of sandal wood of which flowering specimens are very much wanted. Masa fuera has never been botanically explored. To the north of these islands are Ambrose and Felix Islands, from which collections are much wanted.

On the east side of South America the Patagonian flora is not well known, nor is that of Western Brazil, Tucuman, and Paraguay. On the coasts of tropical Brazil collections have been made, chiefly at Rio, Bahia, Pernambuco, and Para. Of the American islands in the South Atlantic the Falklands alone are explored. Great interest would attach to collections from the islands of Trinidad (in 20° S. lat.) and from Fernando Noronha.

In America, north of Brazil, British Guiana has been visited by collectors, but collections from French and Dutch Guiana are wanting in our herbaria. Venezuela has been only partially exployed.

Pacific Ocean.—The Sandwich Islands and New Zealand and Norfolk Island are the best known botanically, next the Fiji Islands and Tahiti; but there is a great more to be done in both these latter, whilst the New Hebrides, New Ireland, New Britain, the Navigators and Marquesas Islands, Bounty, Antipodes, and a host of lesser islets have never been collected upon by a botanist. Of these latter, Pitcairn's and Easter Islands are amongst the most desirable to visit and explore botanically.

Southern Ocean.—The desolate islands of this region contain a scanty flora of very great interest. Tristan d'Acunha probably contains little novelty, but Gough Island is quite unknown. Kerguelen Island, Hood's Island, Lord Auckland's group, and Campbell's Island have all been approximately explored botanically, but Bouvet, Marion, the Crozets and Prince Edward Islands, the Royal Company's and Macquarie Islands are almost unknown, and collections from these would have extraordinary interest in view of the geographical distribution of the plants of the Southern Ocean.

INDEX.

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Plate C.

CHART ILLUSTRATING

THE MEAN DIRECTION OF OCEANIC CURRENTS.

(Reduced from Admiralty Current Chart.)