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G. W. C. KAYE AND T. H. LABY

TABLES OF PHYSICAL AND CHEMICAL CONSTANTS

AND

SOME MATHEMATICAL FUNCTIONS

NINTH EDITION

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PHYSICAL AND CHEMICAL CONSTANTS

FOUR-FIGURE MATHEMATICAL TABLES.

By G. W. C. KAYE, O.B.E., M.A., D.SC., F.R.S., and T. H. LABY, M.A., SC.D., F.R.S. 8vo.

TABLES OF

PHYSICAL AND CHEMICAL CONSTANTS

AND SOME MATHEMATICAL FUNCTIONS

BY
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PREFACE TO NINTH EDITION.

THE geographical remoteness of the two authors, accentuated by the attendant difficulties of the war, has led to a scheme whereby each has accepted responsibility for the revision of certain sections in the present edition. Professor Laby has rewritten the following tables :—

Units and dimensions
Electrical units
Conversion factors
Mechanical equivalent of heat
Velocity of light
General and atomic constants
α-rays
Radioactivity
Isotopes
Arrangement of electrons in atoms

As regards "units," an attempt has been made to give an account of the principles underlying physical measurement and the choice of units. The electrical units include those which it was originally proposed by the International Electrotechnical Commission should come into force as "absolute" units on January 1, 1940, but the adoption of which has been deferred for the present. Much consideration has been given to selecting values of the general and atomic constants of physics (e, h and e/m) which appear to have the least error. Explanatory introductions have been added to the new tables of radioactive elements and isotopes.

In the revision of the above tables Professor Laby has received valuable assistance from Mr. V. D. Hopper, M.Sc., who has recently completed with him a determination of the electronic charge, Mr. R. D. Hill, M.Sc., who has kindly read the proofs, and from Miss Jean E. Laby, B.Sc. The initials of those responsible for a table are appended to it.

With reference to the remaining tables which have been subjected to revision or correction, these have been dealt with by Dr. Kaye, who has again had the valuable assistance of Mr. J. H. Awbery, B.A., B.Sc., to whom, and to others at the National Physical Laboratory who have made suggestions, grateful thanks are tendered.

PUBLISHERS' NOTE

THE lamented death of Dr. Kaye, which took place while the work was going through the press, accentuated still further the difficulties of production. In this misfortune the Physics Department of the National Physical Laboratory very kindly came to our assistance and gave a final inspection to the text of the volume and prepared the index, thus avoiding another considerable delay in publication. For this timely help we are most grateful.

EXTRACT FROM PREFACE TO FIRST EDITION.

THE need for a set of up-to-date English physical and chemical tables of convenient size and moderate price has repeatedly impressed us during our teaching and laboratory experience. We have accordingly attempted in this volume to collect the more reliable and recent determinations of some of the important physical and chemical constants.

To increase the utility of the book, we have inserted, in the case of many of the sections, a brief *résumé* containing references to such books and original papers as may profitably be consulted.

Attention has been paid to the setting and accuracy of the mathematical tables; these are included merely to facilitate calculations arising out of the use of the book, and limitations of space have cut out all but a few of the more essential functions.

We began this book while at the Cavendish Laboratory, Cambridge, and Dr. G. A. Carse shared in its inception. To Mr. G. F. C. Searle, F.R.S., we feel we owe much for his encouragement and suggestions when the scope of the book was under consideration . . .

G. W. C. K.
T. H. L.

September, 1911.

CONTENTS

THE ELEMENTS IN THE ORDER OF ATOMIC NUMBERS

INTERNATIONAL ATOMIC WEIGHTS 1938

Mean atomic weights of elements relative to atomic weight of oxygen (O ≡ 16), chemical composition being that found in nature.

Symbol.	At. No.	Atomic Weight (1938).	First isolated by	Date.	Symbol.	At. No.	Atomic Weight (1938).	First isolated by	Date.
H	1	1·0081	Cavendish	1766	**Pd**	46	106·7	Wollaston	1803
He	2	4·003	Ramsay & Cleve*	1895	**Ag**	47	107·880	—	P.
Li	3	6·940	Arfvedson	1817	**Cd**	48	112·41	Stromeyer	1817
Be§	4	9·02	Wöhler and Bussy	1828	**In**	49	114·76	Reich and Richter	1863
B	5	10·82	Gay-Lussac & Thénard	1808	**Sn**	50	118·70	—	P.
C	6	12·010	—	P.	**Sb**	51	121·76	Basil Valentine	15 centy.
N	7	14·008	Rutherford	1772	**Te**	52	127·61	v. Richenstein	1782
O	8	**16·000**	Priestley and Scheele	1774	**I**	53	126·92	Courtois	1811
F	9	19·00	Moissan	1886	**Xe**	54	131·3	Ramsay and Travers	1898
Ne	10	20·183	Ramsay and Travers	1898	**Cs**	55	132·91	Bunsen and Kirchhoff	1861
Na	11	22·997	Davy	1807	**Ba**	56	137·36	Davy	1808
Mg	12	24·32	Liebig and Bussy	1830	**La**	57	138·92	Mosander	1839
Al	13	26·97	Wöhler	1827	**Ce**	58	140·13	Mosander	1839
Si	14	28·06	Berzelius	1823	**Pr**	59	140·92	Auer von Welsbach	1885
P	15	31·02	Brand	1674	**Nd**	60	144·27	Auer von Welsbach	1885
S	16	32·06	—	P.	**Sm**	62	150·43	L. de Boisbaudran	1879
Cl	17	35·457	Scheele	1774	**Eu**	63	152·0	Demarçay	1901
A	18	39·944	Rayleigh & Ramsay	1894	**Gd**	64	156·9	Marignac	1886
K	19	39·096	Davy	1807	**Tb**	65	159·2	Mosander	1843
Ca	20	40·08	Davy	1808	**Dy**	66	162·46	U. & D.	1907
Sc	21	45·10	Nilson and Cleve	1879	**Ho**	67	163·5	L. de Boisbaudran	1886
Ti	22	47·90	Gregor	1789	**Er**	68	167·2	Mosander	1843
V	23	50·95	Berzelius	1831	**Tm**	69	169·4	Cleve	1879
Cr	24	52·01	Vauquelin	1797	**Yb**	70	173·04	Marignac	1878
Mn	25	54·93	Gahn	1774	**Lu**	71	175·0	Urbain	1908
Fe	26	55·84	—	P.	**Hf**	72	178·6	Coster & von Hevesy	1923
Co	27	58·94	Brand	1735	**Ta**	73	180·88	Eckeberg	1802
Ni	28	58·69	Cronstedt	1751	**W**	74	183·92	Bros. d'Elhujar	1783
Cu	29	63·57	—	P.	**Re**	75	186·31	Noddack & Taske	1925
Zn	30	65·38	Ment. by B. Valentine	15 centy.	**Os**	76	190·2	Smithson Tennant	1804
Ga	31	69·72	L. de Boisbaudran	1875	**Ir**	77	193·1	Smithson Tennant	1804
Ge	32	72·60	Winkler	1886	**Pt**	78	195·23	—	16 centy.
As	33	74·91	Albertus Magnus	13 centy.	**Au**	79	197·2	—	P.
Se	34	78·96	Berzelius	1817	**Hg**	80	200·61	Md. by Theophrastus	300 B.C.
Br	35	79·916	Balard	1826	**Tl**	81	204·39	Crookes	1861
Kr	36	83·7	Ramsay and Travers	1898	**Pb**	82	207·21	Mentd. by Pliny	P.
Rb	37	85·48	Bunsen and Kirchhoff	1861	**Bi**	83	209·00	Mtd. by B. Valentine	15 centy.
Sr	38	87·63	Davy	1808	**Po**	84	210	M. & Mme. Curie	1898
Y	39	88·92	Wöhler	1828	**Rn**	86	222	M. & Mme. Curie	1900
Zr	40	91·22	Berzelius	1825	**Ra**	88	226·05	Curies and Bémont	1898
Nb‡	41	92·91	Hatchett	1801	**Ac**	89	226–7	Debierne	1898
Mo	42	95·95	Hjelm	1790	**Th**	90	232·12	Berzelius	1828
Ru	44	101·7	Claus	1845	**Pa**	91	231	Piccard & Stahel	1921
Rh	45	102·91	Wollaston	1803	**U**	92	238·07	Peligot	1841

P., Prehistoric; * Lockyer (in sun), 1868; U. & D., Urbain & Demenitroux; § Be or Gl; ‡ Nb or Cb.
Atomic Numbers 43, 61, 85 and 87 are still unrepresented. See Isotopes, pp. 169–71

INTERNATIONAL ATOMIC WEIGHTS FOR 1938 (O ≡ 16)

(See "Eighth Report of the Committee on Atomic Weights" of the International Union of Chemistry; also F. W. Clarke, "A Recalculation of the Atomic Weights." Mean atomic weights of the elements relative to the atomic weight of oxygen, O ≡ 16, the isotopic composition of the elements being that found in nature. For isotopes, see p. 169–71.)

Element.	Symbol.	Atomic Weight.	Element.	Symbol.	Atomic Weight.
Aluminium	**Al**	26·97	**Neodymium**	**Nd**	144·27
Antimony	**Sb**	121·76	**Neon**	**Ne**	20·183
Argon	**A**	39·944	**Nickel**	**Ni**	58·69
Arsenic	**As**	74·91	**Niobium** †	**Nb**	92·91
Barium	**Ba**	137·36	**Nitrogen**	**N**	14·008
Beryllium *	**Be**	9·02	**Osmium**	**Os**	190·2
Bismuth	**Bi**	209·00	**Oxygen**	**O**	**16·000**
Boron	**B**	10·82	**Palladium**	**Pd**	106·7
Bromine	**Br**	79·916	**Phosphorus**	**P**	31·02
Cadmium	**Cd**	112·41	**Platinum**	**Pt**	195·23
Cæsium	**Cs**	132·91	**Potassium**	**K**	39·096
Calcium	**Ca**	40·08	**Praseodymium**	**Pr**	140·92
Carbon	**C**	12·010	**Protoactinium**	**Pa**	231
Cerium	**Ce**	140·13	**Radium**	**Ra**	226·05
Chlorine	**Cl**	35·457	**Radon**	**Rn**	222
Chromium	**Cr**	52·01	**Rhenium**	**Re**	186·31
Cobalt	**Co**	58·94	**Rhodium**	**Rh**	102·91
Copper	**Cu**	63·57	**Rubidium**	**Rb**	85·48
Dysprosium	**Dy**	162·46	**Ruthenium**	**Ru**	101·7
Erbium	**Er**	167·2	**Samarium**	**Sm**	150·43
Europium	**Eu**	152·0	**Scandium**	**Sc**	45·10
Fluorine	**F**	19·00	**Selenium**	**Se**	78·96
Gadolinium	**Gd**	156·9	**Silicon**	**Si**	28·06
Gallium	**Ga**	69·72	**Silver**	**Ag**	107·880
Germanium	**Ge**	72·60	**Sodium**	**Na**	22·997
Gold	**Au**	197·2	**Strontium**	**Sr**	87·63
Hafnium	**Hf**	178·6	**Sulphur**	**S**	32·06
Helium	**He**	4·003	**Tantalum**	**Ta**	180·88
Holmium	**Ho**	163·5	**Tellurium**	**Te**	127·61
Hydrogen	**H**	1·0081	**Terbium**	**Tb**	159·2
Indium	**In**	114·76	**Thallium**	**Tl**	204·39
Iodine	**I**	126·92	**Thorium**	**Th**	232·12
Iridium	**Ir**	193·1	**Thulium**	**Tm**	169·4
Iron	**Fe**	55·84	**Tin**	**Sn**	118·70
Krypton	**Kr**	83·7	**Titanium**	**Ti**	47·90
Lanthanum	**La**	138·92	**Tungsten**	**W**	183·92
Lead	**Pb**	207·21	**Uranium**	**U**	238·07
Lithium	**Li**	6·940	**Vanadium**	**V**	50·95
Lutecium	**Lu**	175·0	**Xenon**	**Xe**	131·3
Magnesium	**Mg**	24·32	**Ytterbium**	**Yb**	173·04
Manganese	**Mn**	54·93	**Yttrium**	**Y**	88·92
Mercury	**Hg**	200·61	**Zinc**	**Zn**	65·38
Molybdenum	**Mo**	95·95	**Zirconium**	**Zr**	91·22

* Beryllium or Glucinum (Gl). † Niobium or Columbium (Cb).

C.G.S. UNITS AND DIMENSIONS

The metric standards of length and mass are kept at the International Bureau of Weights and Measures in the Pavillon de Breteuil, Sèvres, near Paris. The Bureau is jointly maintained by the principal civilized governments as members of the Metric Convention. The use of metric weights and measures was legalized in the United Kingdom in 1897.

LENGTH

Unit—the **centimetre**, 1/100 of the international metre, which is the distance, at the melting-point of ice, between the centres of two lines engraved upon the polished " neutral web " surface of a platinum-iridium bar of a nearly **X**-shaped section, called the **International Prototype Metre**.

The alloy of 90 Pt, 10 Ir used (also for the International Kilogramme) has not a large expansion coefficient (see p. 63), is hard and durable, and was artificially aged. Pt-Ir copies of this metre, called **National Prototype Metres,** were made at the same time, and distributed by lot about 1889 to the different governments. The international metre is a copy of the original Borda platinum standard—the mètre des archives. This was intended to be one ten-millionth of the quadrant from the equator to the pole through Paris, and was legalized in 1795 by the French Republic. But as the value of a quadrant came to be more accurately determined, and moreover is changing, the actual bar constructed was made the standard.*

The international prototype metre has been measured several times in terms of the wave-lengths of the red cadmium ray (see p. 86).

See Michelson's " Light Waves," 1903. Guillaume, " La Convention du Mètre."

1 metre = 1,553,164·13 wave-lengths in dry CO_2 free air at 15° C. and 76 cm. of Hg.
= 1,552,734·81 wave-lengths in vacuum (Sears and Barrell, *Phil. Trans.*, 1934).

MASS

Unit—the **gramme**, 1/1000 of the **International Prototype Kilogramme**, which is the mass of a cylinder of platinum-iridium.

The international kilogramme is a copy of the original Borda platinum kilogramme—the kilogramme des archives—which was intended to have the same mass as that of a cubic decimetre of pure water at the temperature of its maximum density. More exact measurements revealed the incorrectness of the relation (see p. 17), and so the kilogramme was subsequently defined as above.

As with the metre, Pt-Ir copies of the international standard—**National Prototype Kilogrammes**—have been distributed to the different governments.

TIME

Unit—the **second** is defined to be 1/86,164·100 of a **sidereal day.** The sidereal day is the period of rotation of the earth with respect to an equatorial star without proper motion.†

The second is often defined as 1/(24×60×60) of a **mean solar day,** *i.e.* 1/86,400 of the **average** value of the somewhat variable interval (the apparent solar day) between two successive returns of the sun to the meridian (see p. 24).

In actual practice the sidereal day is the interval between two successive transits of the first point of Aries ‡ across any selected meridian. The sidereal day so measured is shorter than the period of rotation of the earth relative to a fixed star by 0·009 second; the difference arises from the precession of the earth's axis, which causes an annual retrograde motion of 50 seconds of arc of the first point of Aries along the ecliptic.

In the accurate determination of time by astronomical observations of the earth's rotation relative to fixed stars, the observations need to be corrected for **nutation** in right ascension. The earth's axis is subject to precession, and to a periodic motion called nutation due to the sun and moon's gravitational action on the rotating earth. See " Nautical Almanac, 1940."

A **tropical or solar year** is the average interval between two successive returns of the sun to the first point of Aries; it is found to equal 365·2422 mean solar days. Our modern

---

* The *mean* meridian quadrant pole to the equator = $1{\cdot}000228.10^9$ cm. (see p. 22).

† Tidal friction is retarding the rotation of the earth, so that the above (sidereal) definition of the second, while practically justified, is theoretically not quite perfect.

‡ The first point of Aries is that one of the two nodes of intersection of the ecliptic and the celestial equator where the sun (moving in the ecliptic) crosses the equator from south to north (at about March 21). The ecliptic is the apparent yearly track of the sun in a great circle on the celestial sphere.

T. H. L.

(Julian) calendar assumes that in 4 successive civil years, 3 consist of 365 days, and 1 of 366; the average thus being 365·25 days. The Gregorian correction (that century years are not to count as leap years unless divisible by 400) reduces this value to 365·2425 mean solar days, and thus the **average civil year** is a close approximation to a tropical year.

A **sidereal year** is the time interval in which the sun appears to perform a complete revolution with reference to the fixed stars; *i.e.* it is the time in which the earth describes one sidereal revolution round the sun. Owing to precession, a sidereal year is longer than a tropical year.

Epoch 1900.
Tropical year = 365·2422 mean solar days.
Sidereal year = 365·2564 ,, ,, ,, = 366·2564 sidereal days.

Reference: Newcomb, "Astronomy," or Russell, Dugan, and Stewart, "Astronomy."

BRITISH IMPERIAL STANDARDS

(From information supplied by Major MacMahon, F.R.S., Board of Trade, Standards Office.)

According to the Weights and Measures Act, 1878, the **yard** is the distance, at 62° F., between the central transverse lines in two gold plugs in the bronze bar, called the **Imperial Standard Yard**, when supported on bronze rollers in such manner as best to avoid flexure of the bar.

The defining lines are situated at the bottom of each of two holes, so as to be in the median plane of the bar, which is of 1 inch square section and 38 inches long. Its composition is 32 Cu, 5 Sn, 2 Zn. Copper alloys are now known not to be suitable for standards of length, and in 1902 a Pt-Ir X-shaped copy of the yard was made.

The **pound** is the **weight** in vacuo of a platinum cylinder called the **imperial standard pound**.

The imperial standard yard and pound are preserved at the Standards Office of the Board of Trade, Old Palace Yard. A number of official copies have been prepared, and are in the custody of the Royal Society, the Mint, Greenwich Observatory, and the Houses of Parliament.

The **gallon** contains 10 lbs. weight of distilled water weighed in air against brass weights at a pressure of 30 inches, and with the water and the air at 62° F.

[NOTE.—No mention is made in the Act of the density of the brass weights, or of the humidity of the air.]

BRITISH AND METRIC EQUIVALENTS

The present legal equivalents are those legalized by the Order in Council of May 19, 1898, and derived at the International Bureau of Weights and Measures, by Benoît in 1895 in the case of the yard and the metre, and by Broch in 1883 for the pound and the kilogramme. (See *Trav. et Mém. du Bur. Intl.*, tomes iv., 1885, and xii., 1902.)

Imperial Standard.		**International Prototype.**	**(Reciprocal.)**
1 yard	=	·914399 metre	1·093614
1 pound	=	·45359243 kilogramme	2·2046223

Compare Sears and Barrell, *Phil. Trans.*, 1934.

UNITED STATES AND METRIC EQUIVALENTS

The metric system was legalized in the United States in 1866. By Executive order, April 1893, the U.S. yard is defined as—

1 U.S. yard = 3600/3937 metre = 0·914402 m.
1 U.S. inch = 2·540006 cm.
1 U.S. pound = 1/2·20462 kgm. (legal definition).
1 U.S. gallon = 3·785332 litre.

See Circular 47 of the U.S. National Bureau of Standards, 1915.

NOTE.—1 U.S. inch = 1·000003 imperial inch.
1 U.S. gallon = 0·8327 imperial gallon. 1·201 = 1/0·8327.

T. H. L.

GENERAL PRINCIPLES OF MEASUREMENT. UNITS AND STANDARDS

The magnitude of a given physical quantity is its ratio to the magnitude of **unit quantity**, a quantity of the same kind. This ratio (magnitude of a given quantity/magnitude of unit) $= n$, is a number which in general is not integral. It is called the **numeric** in the expression for the magnitude of a physical quantity. For the application of this principle it is necessary to have a unit of each of the quantities of physics.

The introduction of the **metric** and the **C.G.S. systems** reduced the number of redundant units and rationalized physical units and standards. Any system of units is based on a physical theory (*e.g.* the C.G.S. system on Newtonian mechanics). The **standards** of a system are chosen to be permanent and reproducible with precision (*e.g.* the metre and sidereal day as standards of length and time have these characteristics). Finally, convenience of magnitude in a unit is sought, but is unattainable for those quantities which as known to science have a large range of magnitude. Length is such a magnitude, and lengths from 10^{-13} to 10^{+20} cm. are recorded in these pages.

In Newtonian mechanics a fundamental relation is the second law of motion, and it is one between four quantities: mass, length, time, and force. In the C.G.S. system of units three of these, the centimetre, gram, and second, are chosen as **fundamental units**, and the units of the other quantities of general physics (including force) are derived from them.

In the **engineering system** of certain English-speaking countries length, time, and force are taken as fundamental quantities. The **foot, second,** and the **weight of one pound** (lbwt.) are the units of these quantities. The units of a number of other quantities are derived from them (see table below). Since the weight of one pound produces an acceleration of g ft.sec.$^{-2}$ in 1 pound mass, it produces unit acceleration in a mass of g pound, and therefore the latter has unit mass. At latitude 45°, at sea-level, $g = 32{\cdot}1725$ in this system.

In the **metric** (gravitational) **engineering system** the **metre, second,** and **weight of one kgm.** (kgmwt.) are the fundamental units. (Units derived from them are given below.)

The unit of mass is g kgm., g being 9·80616 for lat. 45° at sea-level.

DERIVED C.G.S. UNITS AND STANDARDS

GENERAL AND MECHANICAL UNITS

Angle:—*Units*—radian, right angle, degree, minute, second.

$$1 \text{ radian} = 180/\pi \text{ deg.} = 57^\circ{\cdot}29578.$$

Solid Angle:—*Unit*—the stereradian is the solid angle which unit area of the surface of sphere of unit radius subtends at the centre of the sphere. Complete solid angle at centre of a sphere $= 4\pi$ stereradian.

Area:—*Unit*—the square centimetre.

Volume:—*Unit*—the cubic centimetre (c.c.). The metric unit is the **litre,** now defined as the volume of a kilogramme of pure, air-free water at the temperature of maximum density (see p. 31) and 760 mm. pressure (*Procès Verbaux,* 1901, p. 175). The litre was originally intended to be 1 cubic decimetre or 1000 c.cs.; the present accepted experimental relation is that 1 kilogramme of water at 4° C. and 760 mm. pressure measures 1000·028 c.cs. (see p. 17).

Density:—*Unit*—1 gm. per c.c. **Specific gravity** expresses the density of a substance relative to that of water, and is objectionable in requiring two temperatures to be stated.

Velocity:—*Unit*—1 cm. per second. **Angular Velocity**:—*Units*—1 radian per sec.; 1 revolution per sec.

Acceleration:—Time rate of alteration of velocity. *Unit*—(1 cm. per sec.) per sec. **Angular Acceleration**:—*Units*—1 radian per sec.^{2}; 1 revolution per sec.^{2}.

T. H. L.

Momentum :—*Unit*—1 gm. cm. sec.$^{-1}$.

Moment of a Force :—The moment of a force about a given axis is proportional to the force, and to the distance of its line of action from the axis. *Unit* —1 cm.^{2} gm. sec.$^{-2}$.

Moment of Inertia of a body about a given axis is Σmr^2, where m gm. is the mass of one of the elementary particles into which the body can be divided, and r cm. is its perpendicular distance from the axis of rotation. *Unit*—1 cm.^{2} gm. (see p. 25).

Angular Momentum about a given axis :—*Unit*—a rigid body of unit moment of inertia (1 cm.^{2} gm.) about an axis which rotates with unit angular velocity (1 rad. sec.$^{-1}$) about that axis has 1 cm.^{2} gm. sec.$^{-1}$ angular momentum.

Force :—*Unit*—the dyne is that force which produces an acceleration of 1 cm. sec.$^{-2}$ in a particle of 1 gm. mass.

Couple, Torque, Turning Moment :—*Unit*—two equal opposite parallel forces each of 1 dyne, 1 cm. apart, produce unit couple 1 dyne cm.

Work :—*Unit*—unit work, 1 dyne cm., is done by a force of 1 dyne when its point of application is displaced 1 cm. in the direction in which it acts. 1 dyne cm. = 1 erg. 1 joule = 10^7 erg.

Energy :—Kinetic, Potential, Chemical, Thermal, Electric, Magnetic and other forms of energy are distinguished. A *unit* for the measurement of all forms of energy is the unit of work, the **erg**. The calorie is a unit of thermal energy (see below). The watt. sec. is a unit of electrical energy (see electrical units).

Power :—*Unit*—erg per sec. A system which does work at the rate of 1 erg per second has unit power.

1 joule sec.$^{-1}$ = 10^7 erg. sec.$^{-1}$ = 1 watt.
1 international watt = 1·00020 . 10^7 erg sec.$^{-1}$.

Pressure (hydrostatic) :—The force produced by a fluid normal to a surface per unit of area. *Unit* pressure is 1 dyne per cm.^{2}.

1 bar = 1 dyne cm.$^{-2}$ (As used to express small pressures.)
1 bar = 10^6 dyne cm.$^{-2}$ (As used in meteorology.)

For gravitational units of pressure, see below.

Stress, Modulus of Elasticity, Young's Modulus, Rigidity, Bulk Modulus or **Incompressibility** :—Stress is the force per unit area normal (or tangential) to a specified surface. Unit stress is 1 dyne per cm.^{2}.

The constant of proportionality in Hooke's law (Stress/strain) = constant, is a modulus of elasticity, and it has the dimensions of stress, since strain is of zero dimensions. Thus unit stress, 1 dyne per cm.^{2}, is the unit of the above elastic constants.

Surface Tension :—*Unit*—dyne cm.

Gravitation Universal Constant :—*Unit*—gm.$^{-1}$ cm.$^{-3}$ sec.$^{-2}$.

Viscosity :—*Unit*—gm. cm.$^{-1}$ sec.$^{-1}$.

HEAT UNITS

The Dimensions of Temperature :—There are no generally accepted dimensions for the quantity temperature. One procedure is to ignore the inter-relation of temperature and heat, but to assign to heat the dimensions of energy (ML^2T^{-2}). The dimensions of temperature are then written simply as θ. With these conventions those of other thermal quantities can be derived, *e.g.* those of entropy are $ML^2T^{-2}\theta^{-1}$.

In the table of dimensions of heat units which follows, dimensions are given on this system.

An alternative procedure is to calculate the dimensions of temperature from the principle that the kinetic energy per gm.-mol. of the molecules of an ideal gas is proportional to its absolute temperature. They are then L^2T^{-2}, and entropy has the dimensions of mass, M.

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Temperature:—The melting-point of pure ice under 1 atmosphere is defined as 0° C., and the boiling-point of water under 1 atmosphere as 100° C. This fundamental interval is divided into 100 parts by use of an agreed thermometric procedure (see p. 53); each part is a degree Centigrade.

Heat:—*Dynamical unit*—the erg.
Thermal unit—The calorie, the heat required to raise the temperature of 1 gm. of water by 1° C. at a stated temperature.

1 15° C. calorie = 4·1852 . 10^7 erg.
1 20° C. calorie = 4·1813 . 10^7 erg.
1 British thermal unit = 1 lb. water 1° F. = 252 cal. at 17° C.

In the data of thermo-chemistry, "Calorie" may mean "large calorie," *i.e.* kilocalorie. 860 international kilocalories = 1 kilowatt hour.

Gas Constant R in $pv = \mathrm{RT}$, the equation for an ideal gas. R in erg deg.$^{-1}$ mol.$^{-1}$ has the value:

$$\mathrm{R} = \frac{pv}{\mathrm{T}} = \frac{1{\cdot}01320 \times 10^6 \times 22415{\cdot}2}{273{\cdot}16} = 8{\cdot}3142 \times 10^7 \; (g = 980{\cdot}616).$$

R in other units has the values:

82·059 cm.^{3} atmos. deg.$^{-1}$ mol.$^{-1}$ = 0·08206 litre atmos. deg.$^{-1}$ mol.$^{-1}$ = 1·9865 cal.$_{15°}$ deg.$^{-1}$ mol.$^{-1}$.

(See Birge, "General Physical Constants," 1929.)

Boltzmann's constant k:—k = R/number of molecules per gm.-mol. = 1·3709 . 10^{-16} erg deg.$^{-1}$.

Entropy:—When in a reversible change a substance takes in a quantity of heat dQ at a temperature T, its increase of entropy is dQ/T. *Units*—mean calorie gm.$^{-1}$ deg.$^{-1}$, joule gm.$^{-1}$ deg.$^{-1}$, international joule gm. $^{-1}$ deg.$^{-1}$.

Enthalpy:—Total heat content per gram of a liquid and its vapour. In steam tables the enthalpy of 1 gm. of water at 0° C. at its saturated vapour pressure is taken as zero. *Units*—mean cal. gm.$^{-1}$, joule gm.$^{-1}$, international joule gm.$^{-1}$.

ENGINEERING GRAVITATIONAL UNITS

In the following "lbwt." means the weight of a standard pound, and "kgmwt." is that of the international kilogram; both weights vary from place to place. g is the measure of the acceleration effective in a measurement, or it is a conventional value. g in latitude 45° at sea-level is such a value, and it is given below.

Quantity.	Unit.	Unit.	Quantity.	Unit.	Unit.
Fundamental			Momentum	g lb. ft. sec.$^{-1}$	g kgm. m. sec.$^{-1}$
Length	ft.	metre	Moment of Inertia	g lb. ft.^{2}	g kgm. m^2
Force	lbwt.	kgmwt.			
Mass	g lb.	g kgm.	Couple	lbwt. ft.	kgmwt. m.
Derived			Energy, Work	lbwt. ft.	kgmwt. m.
Area	ft.^{2}	m.^{2}	Power	lbwt. ft. sec.$^{-1}$	kgm. m. sec.$^{-1}$
Volume	ft.^{3}	m.^{3}	Pressure, Stress	lbwt. ft.$^{-2}$	kgm. m.$^{-2}$
Density	(lb. ft.$^{-3}$)	(kgm. m.$^{-3}$)			
Velocity	ft. sec.$^{-1}$	m. sec.$^{-1}$			
Acceleration	ft. sec.$^{-2}$	m. sec.$^{-2}$		g=32·1725	g=9·8062

NORMAL GRAVITY AND UNITS

In the above units those of force, work, power, pressure, etc., and of mass, moment of inertia, etc., are indefinite until the value of g for which they are true is known. One convention is to take as the normal acceleration of gravity its value at latitude 45° and sea-level. Helmert's formula gives this value as

980·616 cm. sec.$^{-2}$ = 9·80616 m. sec.$^{-2}$ = 32·1725 ft. sec.$^{-2}$

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Normal atmosphere:—Two slightly different units of pressure called "one atmosphere" are used. In both the pressure is that of 76 cm. of mercury at 0° C., but two values of *g* are used. The International Committee of Weights and Measures recommended in 1901 *g* be taken as 980·665 for barometric reductions. Assuming the density of mercury at 0° C. is 13·59509 gm. cm.$^{-3}$,

$$1 \text{ normal atmosphere} = A_n \text{ dyne cm.}^{-2} = 1{\cdot}013249 \,.\, 10^6 \text{ dyne . cm.}^{-2}.$$

In 1929 the same Commission (in effect eliminating the mercury column) defined the standard atmosphere as equal to 1·013250 . 10^6 dyne . cm.$^{-2}$.

Nevertheless, when $g = 980{\cdot}616$ has been used in precision measurement of physical constants, then

$$1 \text{ atmosphere} = A_{45} \text{ dyne cm.}^{-2} = 1{\cdot}013199 \,.\, 10^6 \text{ dyne . cm.}^{-2}.$$

The use of the dyne cm.$^{-2}$ as the unit of pressure would avoid the uncertainties which have been associated with the use of the atmosphere as a unit of pressure.

DIMENSIONS OF UNITS

The dimensions in terms of length, mass, and time are denoted by the indices given under L, M, and T. Thus the dimensions of power are L^2MT^{-3}.

MECHANICAL AND HEAT UNITS

Quantity.	L.	M.	T.	Quantity.	L.	M.	T.	Quantity.	L.	M.	T.	θ
Length	1	0	0	Momentum	1	1	−1	Strain	0	0	0	
Mass	0	1	0					Elasticity	−1	1	−2	
Time	0	0	1	Moment of momentum	2	1	−1	Compressibility	1	−1	2	
Angle	0	0	0					Viscosity	−1	1	−1	
Surface	2	0	0	Moment of inertia	2	1	0	Diffusion	2	0	−1	
Volume	3	0	0					Capillarity	0	1	−2	
Density	−3	1	0	Angular momentum	2	1	−1	Temperature	0	0	0	1
Velocity	1	0	−1	Force	1	1	−2	Heat	2	1	−2	0
Angular vel.	0	0	−1	Couple, Torque	2	1	−2					
Acceleration	1	0	−2	Work, Energy	2	1	−2	Thermal Conductivity	1	1	−3	−1
				Power	2	1	−3	Entropy	2	1	−2	−1
Angular acceleration	0	0	−2	Pressure, Stress	−1	1	−2					

ELECTRICAL AND MAGNETIC UNITS

References:—J. J. Thomson, "Mathematical Theory of Electricity and Magnetism"; Page and Adams, "Principles of Electricity," 1936.

Practical Absolute System of Electrical Units (see *Phys. Soc. Proc.* 48, 445, 1936). Report on Electrical and Magnetic Units to the International Conference on Physics. Appendix by H. Abraham on Magnetic Quantities, 1935.

To derive a system of electrical units four fundamental units are required.

Electromagnetic System is derived from the cm., gm., sec., and the permeability of a vacuum taken as unit permeability. It is called the e.m.c.g.s. system and e.m.u. is the abbreviation for electromagnetic unit. The inverse square law for magnetic poles is used to define unit pole, and other magnetic and electrical quantities are derived from unit pole.

Absolute System of Units is the name now given to the following multiples of the e.m. units of resistance, etc. :

1 ohm = 10^9 e.m.u., 1 amp. = 10^{-1} e.m.u., 1 volt = 10^8 e.m.u.
1 henry = 10^9 e.m.u., 1 coulomb = 10^{-1} e.m.u., 1 farad = 10^{-9} e.m.u.

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and by international agreement these will replace the international ohm, ampere, and volt, etc. In anticipation of this change the ratio of the international ohm to the absolute ohm and the same ratio for the ampere and volt have been accurately measured in national physical laboratories.

Practical System of Units:—These units were intended to be the above multiples of the e.m. units of resistance, current and e.m.f., but were actually defined in terms of a mercury ohm, and the silver coulombmeter. Derived units of this system are derived from 10^9 cm., 10^{-11} gm., 1 sec., the permeability of a vacuum as fundamental units. This system, never completely used, will now become obsolete.

Electrostatic System for which the cm., gm., sec. and the dielectric constant of a vacuum are the fundamental units is another system of electrical units.

There are many possible systems of electrical units, and any procedure followed in deriving one has arbitrary elements in it which are determined by considerations of convenience and individual preference. Writers on electrical theory following Gauss use a combination of e.s. units and e.m. units, but recently the use of two systems of units has been criticized as irrational.

Heaviside-Lorentz Units:—In writings on Maxwell's electromagnetic theory Heaviside-Lorentz units are often used, which are a modification of the combined e.m. and e.s. units obtained by simply changing the unit of force from 1 dyne to $1/4\pi$ dyne.

ELECTROSTATIC UNITS AND QUANTITIES

Quantity.	Symbol.	Defining relation in e.s.u.	Quantity.	Symbol.	Defining relation in e.s.u.
Electrostatic		Coulomb's Law :	Displacement	D	$D \equiv \epsilon_0 E + 4\pi P$
Charge . . .	Q	$F = Q_1 Q_2/\epsilon_0 r^2$	Polarization .	P	electric moment/cm.^{3}
Field . . .	E	$E = Q/\epsilon_0 r^2$	Dielectric		
Potential . .	V	$dV = -E \cos \alpha dl$	const. . .	ϵ	$\epsilon \equiv D/E$
E.M.F. . . .	$\mathcal{E}$	$\mathcal{E} = \oint E \cos \alpha dl$	Capacity . .	C	$C = Q/V$

ϵ_0 is the dielectric constant for a vacuum; in e.s.u., $\epsilon_0 = 1$.

Charge:—*Unit*—to define unit charge in the above expression for Coulomb's law the force is made 1 dyne, the distance 1 cm., the charges made equal and placed in a vacuum, *i.e.* $F = 1$, $r = 1$, $Q_1 = Q_2$, $\epsilon_0 = 1$. In words: *unit charge* is that charge which repels in a vacuum an equal and like charge with a force of 1 dyne.

Electric Field:—*Unit*—Unit field is that field which acts on unit electrostatic charge with a force of 1 dyne. The field in a vacuum at r cm. from a point charge Q is Q/r^2.

Potential:—In the above expression for potential, dV erg, is the work done by unit electrostatic charge against the electric field (E) when it is deplaced dl cm. in a direction making an angle α with the field. The work done, V erg, in bringing unit charge from infinity to a point P is the potential of P.

Unit P.D. exists between two points in an electric field when 1 erg of work is done in taking unit charge from one point to the other.

E.M.F.:—*Unit e.m.f.* exists in a circuit when 1 erg of work is done in taking unit e.s. charge round the circuit.

Electric Displacement, D, is defined as the vector sum of the electric field, $\epsilon_0 E$, and 4π times the polarization P, *i.e.* $D \equiv \epsilon_0 E + 4\pi P$. As stated above the dielectric constant (electric permeability) of a vacuum is taken as 1, that is, $\epsilon_0 \equiv 1$. If this equation is written as it often is, $D \equiv E + 4\pi P$, it is dimensionally inhomogeneous, in other words, D is the sum of two electrical quantities of different kinds, which is meaningless. (The definition of magnetic induction, which is defined in a similar manner to D, has been the subject of much recent discussion by Abraham and others.)

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Polarization, P:—When a dielectric is in an electric field, the electrons and protons are displaced relative to one another by the action of the field. Electric dipoles are formed throughout the dielectric, which is said to be polarized. The polarization is defined to be the electric moment of the dipoles per unit volume. It is the charge in e.s.u. per cm.^{2} in a plane normal to the direction of polarization.

Dielectric Constant, ϵ, is defined by $\epsilon \equiv D/E$. It can be deduced from this definition that the law of force between charges in a medium of dielectric constant ϵ (*e.g.* in air) is $F = Q_1Q_2/\epsilon r^2$, and that the dielectric constant ϵ of a medium is the ratio of the capacity of a condenser having the medium for a dielectric to the capacity of the same condenser with a vacuum as dielectric.

Capacity:—The ratio of the charge, Q e.s.u., to the potential difference, V e.s.u., for a condenser is constant, and is its capacity, C e.s.u.

Unit capacity is that of an isolated conducting sphere of 1 cm. radius in a vacuum. In an infinite medium of dielectric constant ϵ its capacity is ϵ e.s.u.

ELECTROMAGNETIC UNITS AND QUANTITIES

Quantity.	Symbol.	Defining relation in e.m.u.	Quantity.	Symbol.	Defining relation in e.m.u.
Magnetic			**Electrical**		
Pole . . .	m	$F = m_1m_2/\mu_0r^2$	Charge . .	Q	$Q = \int I\,dt$
Moment . .	M	$M \equiv m.l$	Current . .	I	$\oint H \cos a\,dl = 4\pi nI$
Field . . .	H	$H = m/\mu_0r$	Potential . .	V	$dV = -E \cos a\,dl$
Potential . .	Ω	$d\Omega = -H \cos a\,dl$	E.M.F. . .	$\mathscr{E}$	$\mathscr{E} = \oint E \cos a\,dl$
Magneto-motive force	$\mathscr{H}$	$\mathscr{H} = \oint H \cos a\,dl$	Resistance .	R	$R = \mathscr{E}/I$
Induction . .	B	$B \equiv \mu_0H + 4\pi I$	Inductance .	L	$\mathscr{E} = -L\,dI/dt$
Intensity of magnetization	I	$I \equiv M/dv$		M	$M = \mu\iint \cos a\,dl\,dl'/r$
Permeability .	μ	$\mu \equiv B/H$			
Susceptibility .	κ	$\kappa \equiv I/H$			
Flux . . .	ϕ	$\phi = \int_s B\,dS$			

Magnetic Pole:—*Unit*—as for the definition of unit e.s. charge we put $F = 1, r = 1, m_1 = m_2, \mu_0 = 1$, in Coulomb's law of force for magnetic poles, and obtain the definition:

Unit magnetic pole is that pole which repels in a vacuum an equal and like pole with a force of 1 dyne.

Magnetic Moment:—*Unit*—the moment of that dipole, which consists of unit positive and negative poles 1 cm. apart.

Magnetic Force or Field:—*Unit field* acts on unit magnetic pole with a force of 1 dyne.

Magnetic Potential:—*Unit potential* exists at any point P in the magnetic field when 1 erg of work is done against the field in bringing unit positive pole from infinity to P.

Magnetomotive Force:—*Unit* M.M.F. acts in a magnetic circuit when the work done in taking unit pole round the circuit is 1 erg.

The **ampere-turn** is a unit of m.m.f. and of magnetic potential. 1 ampere-turn = $0{\cdot}4\pi$ e.m.u. = $1{\cdot}25664$ e.m.u. of magnetic potential.

Magnetic Induction, B is defined by the vector sum, $B = \mu_0H + 4\pi I$, where $\mu_0 = 1$ in e.m.u.

Maxwell's definition of B is: the magnetic induction of a material is equal to the force which acts on unit magnetic pole placed in a narrow cavity in the material,

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the cavity having plane sides normal to the direction of the magnetization. This definition and the preceding one have been the subject of much discussion. (See " References " above, particularly Abraham's paper.)

Intensity of Magnetization, I, of a magnetic material is its magnetic moment per unit volume. It is evidently the magnetic pole per cm.^{2} over a plane surface normal to the direction of polarization.

Magnetic Permeability, μ. Although the magnetic induction B induced by a magnetizing force H is not proportional to H, for materials which show magnetic hysteresis, magnetic permeability, μ, is defined by the relation $\mu \equiv B/H$.

Magnetic Susceptibility, κ. I/H is constant for diamagnetic and some paramagnetic materials. κ is defined by the relation $\kappa \equiv I/H$. Since

$$I = (B - \mu_0 H)/4\pi, \text{ and } \mu_0 = 1 \text{ in e.m.u., therefore } \kappa = (\mu - 1)/4\pi.$$

Magnetic Flux :—The magnetic flux for an element of area dS cm. is $B.dS$. The flux ϕ for a surface S cm.^{2} is $\int_s B dS$, the quantities being vector ones.

Electrical Units :—Units of all the magnetic quantities have been derived from Coulomb's law of force and four fundamental units. To pass from magnetic to electrical units Ampère's law for the magnetic field of an electric current is used to define unit current in terms of unit magnetic pole.

Electromagnetic Unit Current flows in a conductor when the work done in taking unit magnetic pole in a closed path round the conductor is 4π erg.

Electric Charge :—*Unit* quantity of electricity crosses in 1 sec. any section of a conductor when 1 e.m.u. of current flows in the conductor.

Electromagnetic Units of the following quantities are derived from the e.m.u. of charge by means of the expressions given in the above table under electrical quantities : **Potential, E.M.F., Capacity, Resistance, Inductance.** The defining relations for **Displacement, Polarization,** and **Dielectric Constant** given in the Table of Electrostatic Units are used to derive units of these quantities from the e.m.u. of charge.

Conversion Factors :—The ratio of the electromagnetic units to the electrostatic units, and to the practical **absolute units** is given on p. 12.

Inductance is defined by Faraday's law, $\mathscr{E} = - dN/dt = - L dI/dt$, for the e.m.f. induced in a circuit when the current in it varies.

The Mutual Inductance, M, of a pair of coils is given in terms of their linear dimensions by Neumann's formula $M = \mu \iint \cos \alpha dl \,.\, dl'/r$, which is derived from Ampère's law. Both laws give the same e.m. unit of inductance sometimes called the " centimetre." L and M have the dimensions $=[\mu \,.\, \text{length}]$.

PRACTICAL ELECTRICAL UNITS

The **International Ohm** is the resistance offered to an unvarying electric current by a column of mercury at 0° C., 14·4521 grammes in mass, of a constant cross-section, and of a length of 106·300 cms.

The **International Ampere** is the unvarying electric current which, when passed through a solution of nitrate of silver in water, in accordance with authorized specification, deposits silver at the rate of ·00111800 gramme per second.

DIMENSIONS OF ELECTRICAL QUANTITIES

Dimensions of E.S. Units :—The dimensions of electric charge in terms of M, L, T and ϵ are derived from Coulomb's law thus :

$$[F] = [MLT^{-2}] = [Q_1 Q_2/\epsilon L^2],$$

giving $$[Q] = [M^{\frac{1}{2}} L^{\frac{3}{2}} T^{-1} \epsilon^{\frac{1}{2}}]$$

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The dimensions of electric field, E, potential, V, e.m.f., $\mathcal{E}$, displacement, D, polarization, P, dielectric constant, ϵ, capacity, C, are derived from those of Q using the relations in the table on electrostatic quantities.

To calculate the dimensions of magnetic quantities, Ampère's law for the magnetic field of an electric current is used. The work done on a magnetic pole, m, when taken round a path which encloses a current, I, is proportional to I and to m, but is independent of the path. Ampère's law may be expressed: $W = 4\pi Im/A$, where $4\pi/A$ is the constant of proportionality. All the systems of units in use put $A = 1$ and give to Im the dimensions of work; to do this is a convention, but so far it is a generally accepted one. (See "Giorgi units," p. 13.)

The dimensions of I are $[QT^{-1}]$, and we get for those of m

$$[m] = [M^{\frac{1}{2}}L^{\frac{1}{2}}\epsilon^{-\frac{1}{2}}]$$

The dimensions of the other magnetic quantities are derived from those of magnetic pole, using the defining relations in the table containing those quantities.

Dimensions of E.M. Units are derived in a similar manner, starting with the inverse square law for magnetic poles.

Ratio of E.M. and E.S. Units:—The ratio of the e.m.u. of charge to the e.s.u. is c, where c is the measure of the velocity of light in cm. sec.$^{-1}$ Now the dimensions of charge must be the same on all systems of units. If we equate the dimensions of the e.s. to those of the e.m. unit it is found that

$$[\mu^{-\frac{1}{2}}\epsilon^{-\frac{1}{2}}] = [L/T],$$

that is $1/\sqrt{\mu\epsilon}$ has the dimensions of a velocity. This is necessary if the dimensions which have been derived are to be consistent with Maxwell's electromagnetic theory in which $c = 1/\sqrt{\mu_0\epsilon_0}$ is the expression for the velocity of light in a vacuum. If the A mentioned above is not of zero dimensions then $A^2/\mu_0\epsilon_0 = c^2$.

The dimensions of the e.m. and e.s. units are tabulated below.

ELECTRICAL AND MAGNETIC UNITS

c, the ratio of the electromagnetic to the electrostatic unit of quantity, is usually taken as 3×10^{10}, and is a pure number (p. 84). (See Rucker, *Phil. Mag.*, 22, 1889.)

Reference: "International Conference on Physics, London, 1934": Reports on Units.

Unit.	Sym-bol.	Dimensions.								Relations.			
		E S. Unit.				E.M. Unit.				E.S.U./E.M.U.	Units.		
		L.	M.	T.	ϵ.	L.	M.	T.	μ.		Prac.	E.M.U.	E.S.U.
Electrical													
Charge	Q	$\frac{3}{2}$	$\frac{1}{2}$	-1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$1/c$	coulomb	$=10^{-1}$	$=3\times10^{9}$
Resistance	R	-1	0	1	-1	1	0	-1	1	c^2	ohm	$=10^{9}$	$=\frac{1}{9}\times10^{-11}$
Current	I	$\frac{3}{2}$	$\frac{1}{2}$	-2	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	$1/c$	ampere	$=10^{-1}$	$=3\times10^{9}$
Potential	V	$\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	-2	$\frac{1}{2}$	c	volt	$=10^{8}$	$=1/300$
E.M.F.	$\mathcal{E}$	$\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	-2	$\frac{1}{2}$	c			
Electric field	E	$-\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	-2	$\frac{1}{2}$	c	(volt/cm.)	—	—
Conductivity	κ	0	0	-1	1	-2	0	1	-1	$1/c^2$	ohm^{-1}	$=10^{-9}$	$=9\times10^{11}$
Capacity	C	1	0	0	1	-1	0	2	-1	$1/c^2$	farad	$=10^{-9}$	$=9\times10^{11}$
Inductance	L ; M	-1	0	2	-1	1	0	0	1	c^2	henry	$=10^{9}$ 1 cm.	$=\frac{1}{9}\times10^{-11}$ $=\frac{1}{9}\times10^{-20}$
Displacement	D	$-\frac{1}{2}$	$\frac{1}{2}$	-1	$\frac{1}{2}$	$-\frac{3}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$1/c$	—	1	$=3\times10^{10}$
Polarization	P	$-\frac{1}{2}$	$\frac{1}{2}$	-1	$\frac{1}{2}$	$-\frac{3}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$1/c$	—	1	$=3\times10^{10}$
Dielectric constant	ϵ	0	0	0	1	-2	0	2	-1	$1/c^2$	—	—	—

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Unit.	Sym-bol.	Dimensions.								Relations.			
		E.S. Unit.				E.M. Unit.				$\frac{\text{E.S.U.}}{\text{E.M.U.}}$	Units.		
		L.	M.	T.	ε.	L.	M.	T.	μ.		Prac.	E.M.U.	E.S.U.
Magnetic													
Pole strength .	m	$\frac{1}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	-1	$\frac{1}{2}$	c	—	1 e.m.u.	$=\frac{1}{3}\times10^{-10}$
Flux	ϕ	$\frac{1}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	-1	$\frac{1}{2}$	$1/c$	10^{-8} prac.	=1 max-well	$=3\times10^{10}$
Force . . .	H	$\frac{1}{2}$	$\frac{1}{2}$	-2	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	$1/c$	10 prac.	=1 oer-sted	$=3\times10^{10}$
Potential. . .	Ω	$\frac{3}{2}$	$\frac{1}{2}$	-2	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	$1/c$	10 prac.	=1 gil-bert	$=3\times10^{10}$
Magnetomotive force . . .	$\mathscr{H}$												
Moment . .	M	$\frac{3}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	-1	$\frac{1}{2}$	c	—	—	—
Induction . .	B	$-\frac{3}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	-1	$\frac{1}{2}$	c	10^{-8} prac.	=1 gauss	$=\frac{1}{3}\times10^{-10}$
Intensity of magnetization .	I	$-\frac{3}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	-1	$\frac{1}{2}$	c	10^{-8} prac.	=1 gauss	$=\frac{1}{3}\times10^{-10}$
Permeability .	μ	-2	0	2	-1	0	0	0	1	c^2	10^{-7} prac.	=1 "per-meabil-ity"	—

HEAVISIDE-LORENTZ UNITS

Charge:—*Unit*—Coulomb's inverse square law of force between electric charges is used to define unit charge. It is that charge which repels an equal and like charge at a distance of 1 cm. in vacuo with a force of $1/4\pi$ dyne. Unit pole is defined in the same manner. The remaining units of electricity and magnetism are derived using the defining relations given in the foregoing tables relating to e.s. and e.m. units. The relations which exist between h.l., e.m., and e.s. units are given below.

RELATIONS.—H.L.U. TO E.M.U. AND E.S.U.

Unit.	Symbol.	h.l.u.	e.m.u.	e.s.u.
Charge	Q	$2\sqrt{\pi}$ h.l.u.	$=1/c$ e.m.u.	$=1$ e.s.u.
Current.	I	$2\sqrt{\pi}$,,	$=1/c$,,	$=1$,,
Electric field	E	1 ,,	$=2c\sqrt{\pi}$,,	$=2\sqrt{\pi}$,,
Polarization	P	$2c\sqrt{\pi}$,,	$=1$,,	$=c$,,
Magnetic force . . .	H	1 ,,	$=2\sqrt{\pi}$,,	$=2c\sqrt{\pi}$,,
Magnetic potential . .	Ω	1 ,,	$=2\sqrt{\pi}$,,	$=2c\sqrt{\pi}$,,
Magnetomotive force .	$\mathscr{H}$	1 ,,	$=2\sqrt{\pi}$,,	$=2c\sqrt{\pi}$,,
Intensity of magnetization	I	$2\sqrt{\pi}$,,	$=1$,,	$=1/c$,,
Magnetic induction . .	B	1 ,,	$=2\sqrt{\pi}$,,	$=2\sqrt{\pi}/c$,,
Resistance	R	1 ,,	$=4\pi c^2$,,	$=4\pi$,,
Capacity	C	$4\pi c^2$,,	$=1$,,	$=c^2$,,
Inductance	L, M	1 ,,	$=4\pi c^2$,,	$=4\pi$,,

GIORGI UNITS

Giovanni Giorgi in 1904 proposed the metre, kgm., sec., and the ohm (practically defined) as the fundamental units of a system of electrical units. The International Electrotechnical Commission in 1933 invited its national committees to consider the Giorgi system, and whether the fourth unit should be a resistance of

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10^9 e.m.u. "or the corresponding value of the space permeability of a vacuum." The Standards, Units and Nomenclature Commission of the Union of Physics in 1935 recommended the fourth unit should be "10^{-7} henry per metre," the value of the permeability of space on that system. The following table is based on one given in the report of the latter body, but 10^8 under ohm is here altered to 10^9.

FUNDAMENTAL UNITS OF M.K.S. AND C.G.S. ELECTROMAGNETIC SYSTEMS

Systems.			μ_0	A.	μ_0/A.	Coul.	Amp.	Volt.	Ohm.
Length.	Mass.	Time.							
1 cm.	1 gm.	1 sec.	1	1	1	10^{-1}	10^{-1}	10^8	10^9
1 metre	1 kgm.	1 sec.	10^{-7}	1	10^{-7}	1	1	1	1

μ_0 = magnetic permeability of vacuum. Definition of A by Ampère's law: $F = mi \sin \phi dS/Ar^2$.

RELATION OF INTERNATIONAL PRACTICAL TO ABSOLUTE UNITS

The international ohm and ampere were defined at a conference at London in 1908.

The International Ohm is the resistance offered to an unvarying electric current by a column of mercury at 0° C. 14·4521 gm. in mass, of a constant cross section and of length of 106·300 cm.

The International Ampere is the unvarying electric current which, when passed through a solution of nitrate of silver in water deposits silver at the rate of 0·00111800 gm. per sec.

Other international practical units are derived from the ohm and the amp. The int. ohm was intended to be 10^9 e.m.u. resistance and the int. amp. 10^{-1} e.m.u. National physical laboratories have determined the actual ratios, which are expressed as:

1 int. ohm = $p \cdot 10^9$ e.m.u. of resistance,

1 int. ampere = $q \cdot 10^{-1}$ e.m.u. of current

According to the "Procès Verbaux des Séances du Comité international des Poids et Mesures" (p. 113, 1937):

p = 1·00048 q = 0·99986

these values of p and q are based on the following observations:

National Laboratory.	p.	q.	National Laboratory.	p.	q.
Great Britain	1·000504	0·999848	Germany	1·000483	—
United States	1·000454	0·999895*	Japan	1·000465	0·999938

* Nat. Bur. Standards later (1939) obtain p = 1·000479 and q = 0·999868.

The error in q (the ratio for the ampere) is possibly ± 0·00004 and is mainly due to the difficulties which arise in the use of the silver coulombmeter in precision measurements. The error in p (the ratio for the ohm) is smaller, and is possibly ± 0·000016.

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(See Birge, "General Physical Constants," *Sup. Phys. Rev.*, **1**, 14, 1929; Hartshorn, "Absolute Electrical Measurements," *Phys. Soc. Reports*, **5**, 1939.)

The ratio, international : absolute unit, for the practical units is :

Unit.	Ohm.	Amp.	Coulomb.	Volt.	Farad.	Henry.	Watt.
Value in e.m.u.	$p\ 10^9$	$q\ 10^{-1}$	$q\ 10^{-1}$	$pq\ 10^8$	$p^{-1}\ 10^{-9}$	$p\ 10^9$	$pq^2\ 10^7$
inter./absolute	1·00048	0·99986	0·99986	1·00034	0·99952	1·00048	1·00020

E.M.F. OF WESTON CADMIUM CELL

The electromotive force (E) of the Weston cell in **absolute** volts (10^8 . E.M. units) as realized from one of the accepted specifications. The present accepted international value of E is **1·01864 absolute volts** at 20° C.

This cell consists of anode Cd amalgam, electrolyte saturated cadmium sulphate, cathode Hg covered with mercurous sulphate. For precision the temperature of the cell must be uniform and *constant*.

Temperature coefficient.—Over the range 0° to 40°, Wolff (1908) obtained for the E.M.F. at $t°$—

$$E_t = E_{20} - {\cdot}0000406(t - 20) - 9{\cdot}5 \times 10^{-7}(t - 20)^2.$$

E at 20°.	Method.	Observer.	E at 20°.	Method.	Observer.
1·01868	Intl. ohm. and current weigher	Ayrton, Mather, and Smith, 1908	1·01865	Intl. ohm and Intl. ampere	P.T.R., 1935
1·01870	Intl. ohm and current weigher	Dorsey, 1911	1·01864	Intl. ohm and current weigher	N.P.L., 1935
1·01864	Intl. ohm and Intl. ampere	Intl. Ctee., 1910	1·01857	Intl. ohm and Intl. ampere	N.B.S., 1935

The E.M.F. of the **Clark cell** = 1·433 volts at 15° C. It diminishes by about 1·2 parts in 1000 for 1° C. rise of temp.

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RATIO OF E.M. TO E.S. UNITS

This ratio was first measured in 1857. To measure it for the e.m. and e.s. units of capacity a condenser is used whose capacity, C_s e.s.u., can be calculated from its linear dimensions. Its capacity, C_m e.m.u., is then found by means of Maxwell's bridge in terms of a resistance R e.m.u. and a frequency, n sec.$^{-1}$, where $C_m = 1/R\,.\,n$. For capacity, $C_m/C_s = c^2$.

Rosa and Dorsey (*Bul. Bur. St.*, 1907) obtained for the ratio $(2{\cdot}9971 \pm 0{\cdot}0003) \times 10^{10}$, but they assumed 1 int. ohm = 10^9 e.m.u. This value now accepted is 1 int. ohm. = 1·00048 . 10^9 e.m.u. ; this gives : $c = 2{\cdot}9971 \times 10^{10} \times 1{\cdot}00024 = 2{\cdot}9978 \times 10^{10}$.

The mean of the value of c found by seven observers prior to 1907 was $3{\cdot}0001 \times 10^{10}$ (see Abraham, 1900).

The accepted value of $c = 2{\cdot}99774$.

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BRITISH INTO METRIC CONVERSION FACTORS

Conversion factors based on the relations given on p. 4. *g* is taken as 980·62 cm.-sec.$^{-2}$. Reciprocals are given for converting metric into British measure.

British.	Metric.	(Reciprocal.)
Length—		
1 inch =	2·5400 cm.*	·3937†
1 foot =	30·48 cm.*	·03281
1 yard =	·9144 metre*	1·0936
1 mile =	1·6093 km.	·62137
Area—		
1 sq. inch =	6·4516 sq. cm.	·1550†
1 sq. foot =	929·03 sq. cm.	·001076
Volume—		
1 cubic inch =	16·387 c.c.	·06102
1 cubic foot =	28·317 litre	·03531
1 pint =	·5682 litre	1·7598
1 gallon =	4·5460 litre	·2200
Mass—		
1 grain =	·06480 gm.	15·432
1 oz. (avoir.) =	28·350 gm.	·03527
1 lb. ,, =	·45359 kgm.	2·2046
1 ton =	10160 kgm.§	·0$_3$9842
Density—		
1 lb./cub. ft. =	·01602 gm./cm.^{3}	62·43
Velocity—		
1 mile/hour =	44·70 cm./sec.	·02237

British.	Metric.	(Reciprocal.)
Force—		
1 poundal =	13,825 dyne	7·233×10^{-5}
1 pound wgt. =	4·448×10^5 dyne	2·248×10^{-6}
Pressure—		
1 lb./sq. inch =	68,943 dyne/cm.^{2}	1·45×10^{-5}
,, ,, =	70·306 gm./cm.^{2}	·01422
1 lb./sq. ft.	478·78 dyne/cm.^{2}	·02089
1 ton/sq. inch =	1·544×10^8 dyne/cm.^{2}	6·477×10^{-9}
,, ,, =	1·575 kgm./mm.^{2}	·6349
Work—		
1 ft. lb. =	1·356 joule‡	·7373
Power—		
1 horse-power =	·746 kwatt	1·34
Heat— ¶		
1 B. Th. unit (1 lb., 1° F.) =	252·00 calorie	·003968

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MISCELLANEOUS DATA

CONVENIENT APPROXIMATE RELATIONS

1 yard = 1 metre, less 10%
2 lb. = 1 kgm., ,,
2 galls. = 10 litre, ,,
1 ton = 1000 kgm., less 2%

SOME BRITISH WEIGHTS AND MEASURES

The avoirdupois, troy, and apothecaries **grain** are the same.

1 lb. (avoir.)	=7000 grain	=454 gm.
1 oz. ,,	=437½ ,,	=28·3 ,,
1 oz. (troy)= 1 oz. (apothecaries)	=480 ,,	=31·1 ,,
1 fl. drachm ʒ	=60 minim	= 3·55 c.c.
1 fl. oz. ℥	=8 fl. drachm	=28·41 ,,
1 pint	=20 fl. oz.	=568 ,,

1 mm. = 10^{-3} metre
1 μ = 10^{-6} ,,
1 $m\mu$ = 10^{-9} ,,
1 Å.U. = 10^{-10} ,,
1 mil = 10^{-3} inch

MATHEMATICAL

	Number.	Log. of Number.
π	3·141592654	·49715
π^2	9·869604401	·99430
$1/\pi$	·318309886	$\bar{1}$·50285
$\sqrt{\pi}$	1·772453851	·24857
1 radian	57°·29578	1·75812
1°	·017453 radian	$\bar{2}$·24188
e	2·718281828	·43429
$\log_e 10$	2·302585	·36222

To convert	*Multiply by*
Common into hyperbolic logs,	2·30258
Hyperbolic ,, common ,,	·43429

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* Correct to 1 part in a million. † Correct to 3 parts in a million.
‡ 1 joule=10^7 ergs. § 1 tonne=1000 kgm. ¶ 1 therm=100,000 B.Th. units.

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MISCELLANEOUS DATA—*continued.*

BRITISH COINAGE

Coin.	Weight.	Diameter.
sovereign	8 grams less ·15%	2·18 cm.
penny	$\frac{1}{3}$ oz. (avoir.)	1·2 inch
halfpenny	$\frac{1}{5}$,, ,,	1·0 ,,

NAUTICAL

1 nautical mile = 6082·66 feet
1 admiralty mile = 6080 feet
1 knot = 1 nautical mile/hour
1 fathom = 6 feet

	British and German.	Continental and American.
Million	10^6	10^6
Billion	10^{12}	10^9
Trillion	10^{18}	10^{12}

VOLUME OF A KILOGRAMME OF PURE WATER

At 4° C. and 760 mm. Values recalculated by Benoît. (*Trav. et Mém. Bur. Intl.*, 14, 1910.) (See p. 5.)

Observer.	c.cs.	Observer.	c.cs.
Lefèvre-Gineau and Fabbroni, 1799	1000·030	Chappuis, 1907	1000·027
Guillaume, 1904 . . .	1000·029	de Lépinay, Benoît and Buisson, 1907. . . .	1000·028

DENSITIES OF GASES

Supplementary to p. 35. Densities in grams per litre at 0° C., 760 mm., sea-level, and lat. 45°.

Gas.	gms./litre.	Observer.	Gas.	gms./litre.	Observer.
He .	·1785	Mean, 1913–1926	Ra Em.	9·727	Gray & Ramsay, *P.R.S.*, 1910
Ne .	·9002	Watson, *J.C.S.*, 1910			
Kr .	3·708	Moore ,, 1908	CH_4 .	·7168	Baume & Perrot, *C.R.*, 1909
Xe .	5·851	,, ,, ,,			

C.R., *Compt. Rend.*; *J.C.S.*, *Journ. Chem. Soc.*; *P.R.S.*, *Proc. Roy. Soc.*

UNIVERSAL CONSTANT OF GRAVITATION G

G gm.$^{-1}$. cm.^{3} . sec.$^{-2}$ in the expression for Newton's law of gravitation, $F = GM_1M_2/d^2$, has been measured by Boys, Braun, Eötvös and Heyl, using developments of the Cavendish torsion balance method, and by Poynting and Richarz and Krigar-Menzel using the common balance method. Their results are tabulated below. Value adopted for **$G = (6{\cdot}659 \pm {\cdot}005) \times 10^{-8}$**.

References:—Poynting, "The Mean Density of the Earth"; Boys, *Congrès de Physique*, 1900; Heyl, *Bur. Stand. J. Res.*, 1930.

Method.	G.	Method.	G.
Torsion Balance—		**Common Balance**—	
Boys, 1895	$6{\cdot}658 \times 10^{-8}$	Poynting, 1878	$6{\cdot}698 \times 10^{-8}$
Braun, 1896	$6{\cdot}658 \times 10^{-8}$	Richarz and Krigar-Menzel, 1898	$6{\cdot}685 \times 10^{-8}$
Eötvös, 1896	$6{\cdot}650 \times 10^{-8}$		
Heyl, 1930	$6{\cdot}670 \times 10^{-8}$		
Mean	$6{\cdot}659 \times 10^{-8}$	Mean	$6{\cdot}691 \times 10^{-8}$

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GRAVITY, LONGITUDE AND LATITUDE

ABSOLUTE VALUE OF THE ACCELERATION OF GRAVITY

The first determinations of the absolute value of the acceleration of gravity were made with "simple" pendulums. Kater introduced the reversible pendulum. When the periods of this pendulum about both knife-edges, which are unsymmetrically placed in a straight line passing through the centre of mass of the pendulum, are equal then $g=4\pi^2 l/t^2$ cm./sec.^{2}, where t sec. is the period about either knife-edge, and l cm. is the distance between the knife-edges. Bessel showed theoretically that the buoyant action of the air on the pendulum, and the inertia of the air carried by it could be eliminated by using a reversible pendulum symmetrical in external form about its middle point. The observed period of the pendulum is reduced to that for infinitely small arc, and to a standard temperature and air density. Other corrections are made for yield of support, for elastic lengthening and bending of pendulum, for the "radius" and slipping of the knife-edges.

A weighted **mean** of the results which follow (*excluding* those of 1936 and 1939) is

g = **981·274** cm./sec.^{2} at the Potsdam Geodetic Institute.‡

This value is used by Borrass in a reduction of the relative determinations of g for 2736 stations in different parts of the world. **References:** Defforges, Observations du Pendule, Imprimerie Nationale, Paris 1894; Helmert, Theorie des Reversions Pendels, Potsdam 1898; Kühnen and Furtwängler, Bestimmung der absoluten Grösze der Schwerkraft, Berlin 1906; Bullard and Jolly, *Geophys. Sup. Roy. Ast. Soc.*, 1936; P. Heyl and Cook, *J.R.N. Bur. St.*, 1936; J. S. Clark, *Phil. Trans.*, 1939.

Observer.	Station.	Method.	g for Station.	g for Potsdam
Bessel 1826 . .	Königsberg	Simple pendulum using two lengths	981·449	981·246
Pisati and Pucci .	Rome, 1894	Do. do.	980·343	·274
Lorenzoni 1888 .	Padua	Two Bessel reversible pendulums	980·643*	·263
Barraquer 1889 .	Madrid	Four Bessel reversible pendulums	979·977*	·270
Defforges 1894 .	Paris Obs.	Four Bessel pendulums : 1 m. ·5 m.	980·999	·331
	Rivesaltes	·5 m. ·25 m. length	980·952*	·282
v. Oppolzer 1904	Vienna Obs.	Two Bessel pend. of different mass	980·853*	·273
Kühnen and Furtwängler 1906	Potsdam	Five Bessel pendulums	980·270	·270
P. Heyl and G. Cook 1936.	Washington†	Three reversible silica pendulums	980·080	·254
J. S. Clark 1939 .	N.P.L. Teddington†	Reversible pendulum. Length by interferometer	$981{\cdot}181_5$‡	·261

* Corrected by K. and F. for bending of pendulum, etc.

† For latitude, etc., see pp. 20, 21.

‡ Error calculated from consistency of observations ±·0016.

RELATIVE VALUES OF GRAVITY. FIGURE OF THE EARTH

Potsdam System.—The publications of the International Geodetic Association use g=981·274 cm./sec.^{2} at Potsdam (see above) as the base for relative determinations of gravity. Gravity surveys initiated in 1818 by Kater and Sabine have been carried out in most of the European States, America, India, and Japan by observing the time of swing of invariable pendulums at the several stations in the area under survey, and at a base station where the value of g is well determined. In 1880 v. Sterneck introduced the invariable half-second pendulum. Corrections to the period of the pendulum to infinitely small arc, for temperature, for buoyancy, and for the yield of the support are made. The square of the corrected period varies inversely as g. A large part of such observations was reduced by Helmert in 1896, and by Borrass for 2736 stations in 1909. (Relativen

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RELATIVE VALUES OF GRAVITY. FIGURE OF THE EARTH (*contd.*)

Messungen der Schwerkraft . . . Inter. Geod. Ass. 1911). The base stations of this reduction are printed below in black type. The agreement of relative determinations of gravity is shown by three values for the difference between g at Potsdam and Paris Obs., viz.

·330 cm./sec.^{2} von Sterneck | ·334 cm./sec.^{2} Haid | ·333 cm./sec.^{2} Putnam

British Isles.—Bullard & Jolly (see reference above) have reviewed gravity measurements in Great Britain, values obtained by them using wireless time signals are given on p. 20.

Gravity at Sea.—Meinesz in expeditions by submarine during the period 1923–1932 has measured g over wide ocean areas. The methods used are described in Meinesz "Theory and Practice of Pendelum Observations at Sea," *Netherlands Geod. Com.* 1929.

The Figure of the Earth has been deduced from gravity observations. Each observed value of g is corrected to that value, $g.''$, which it would have at the ideal surface of the geoid, that is, it is corrected for terrain and altitude. We have

$$g_0'' = g + \delta g + \delta_1 g + \delta_2 g,$$ where

δg = topographic correction (always positive) which corrects the observed value to what it would be if the terrain surrounding the station were horizontal.

$\delta_1 g$ = Stokes' correction for altitude, $+2\,hg_0/r$, follows from Newton's Law of attraction at a point at an altitude h, and is ·0003086 cm./sec.^{2} per metre.

$\delta_2 g$ = Bouger's correction for elevated masses. This takes into account the attraction of the matter of density d forming the elevation, and is $-3d.\delta_1 g/4D$, where D is the mean density of the earth = 5·53 gm./cm.^{3}. Faye, assuming with Airy (1855) that elevated masses rest like the tops of icebergs on matter of low density, decreases Bouguer's correction.

g_0'', the corrected value of g, is compared with that calculated for assumed shapes of the geoid.

Spheroid of Equilibrium.—Clairaut, in 1743, assuming that the internal density of the earth varies so that layers of equal density are concentric coaxial spheroids of equilibrium, showed that the acceleration of gravity in latitude λ at sea-level would be

$$g_\lambda = g_e\{1 + (5\,m/2 - e)\sin^2\lambda\}$$

where g_e is gravity at the equator, m is the ratio of the centrifugal to the gravitational acceleration at the equator, that is ·0034672, and e = ellipticity = $(a-b)/a$. Stokes showed that this relation is more general than Clairaut claimed. Adding small terms to the above relation and correcting for altitude H, *Helmert* (1901) obtains for gravity,

$$\gamma_H = 978{\cdot}030\,(1 + {\cdot}005302\sin^2\lambda - {\cdot}000007\sin^2 2\lambda) - {\cdot}0003086\text{H}$$

$$= 980{\cdot}616 - 2{\cdot}5928\cos 2\lambda + {\cdot}0069\cos^2 2\lambda - {\cdot}0003086\text{H} \qquad \text{(H in metres)}$$

The value of the *ellipticity* * used in these expressions is 1/298·3. The values of gravity given by Helmert's expression agree with the observed values. In the following table the latitude λ, the longitude, altitude H in metres, the observed value of gravity g relative to Potsdam, namely, 981·274 cm./sec.^{2}, g_0'', which is g corrected as stated above, γ_0 the value at sea-level calculated by Helmert's formula, and $g_0'' - \gamma_0$, the difference between the corrected observed value and the calculated value for an ellipsoid of revolution are given. When there is no observed value for a station g is calculated and entered under observed but is marked*. The stations with values printed in heavier type are base stations. References: collected observed values of g: Helmert (1896), Borrass (1911) and others in the C. R. Association Géodésique International; U.S. Geodetic Survey; Trigonometrical Survey of India. Figure of the Earth: Clarke's "Geodesy," 1880; Helmert "Höhere Geodäsie," "Die Grösse der Erde," 1906; Bourgeois and Perrier in "Recueil de Constantes Physiques," 1913; Poynting and Thomson, "Properties of Matter."

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* The International Geophysical Union (Madrid, 1924) adopted the Hayford Spheroid with ellipticity 1/297·0

Place.	Longitude. ° ′ ″	Latitude. λ ° ′ ″	Altitude H metre.	g Observed cm./sec.²	g_0'' cm./sec.²	γ_0 Cal. cm./sec.²	$g_0''-\gamma_0$ in ·001 cm./sec.²	Observer.
Pole	—	90 0 0	0	983·216*				
Equator	—	0 0 0	0	978·030*				
Victoria Land	166 44 48	77 50 48 S	9	982·986	982·988	982·984	+ 4	Bernacchi
British Isles—								
Aberdeen (Univ.) . . .	2 6 38 W	57 8 58 N	21	981·68*				
Aberystwith	4 4 W	52 25 N	—	981·279*				
Bangor	4 8 W	53 13 N		981·350*				
Belfast	5 56 W	54 37 N		981·471*				
Birmingham	1 54 W	52 28 N		981·285*				
Bristol	2 36 2 W	51 27 5 N	75	981·187				Bullard & Jolly
Cambridge	0 5 8 E	52 12 9 N	25	981·264				Pendulum [House, B. & J.
,, (Cavendish) .	0 7 3 E	52 12 2 N	11	981·266				B. & J.
Cardiff	3 10 W	51 28 0 N		981·197*				
Dublin (Trin. Coll.) . .	6 15 W	53 20 35 N	7	981·360*				
,, (R.C.S.)	6 40 32 W	53 23 13 N	15	981·360*				
Edinburgh (Roy. Obs.) .	3 11 2 W	55 55 4 N	130	981·580				B. & J.
,, Leith Fort .	3 10 W	55 58 36 N	21	981·613	·617	·586	+ 31	Biot, Kater
Eskdalemuir (Obs.) . .	3 12 18 W	55 18 48 N	244	981·454*				
Glasgow (Univ.) . . .	4 17 12 W	55 52 31 N	46	981·563*				[Gravity St.
Greenwich (Obs.) . .	**0 00 3** E	51 28 0 N	**47**	**981·188$_3$**	·198	·198	0	B. & J., National
Kew (Obs.)	0 18 0 W	51 28 0 N	5	**981·200$_6$**	·203	.197	+ 6	B. & J., Burrard
Leeds (Univ.) . . .	1 33 15 W	53 48 30 N	18	981·376*				
Liverpool (Univ.) . .	2 57 37 W	53 24 19 N	51	981·350*				
London (N.P.L.) . .	0 20 3 W	51 25 2 N	9	981·195†				B. & J.
,, (Impl. Coll.) .	0 10 23 W	51 29 54 N	14	981·195*				
,, (Univ. Coll.) .	0 7 57 W	51 31 27 N	28	981·193*				
Manchester (Univ.) . .	2 14 2 W	53 27 53 N	39	981·359*				
Newcastle (Armst. Coll.)	1 36 53 W	54 58 50 N	55	918·483*				
Nottingham (Univ. C.) .	1 8 45 W	52 57 10 N	58	981·309*				
Oxford	1 15 1 W	51 45 6 N	58	981·207				B. & J.
Plymouth	4 c8 9 W	51 22 1 N	11	981·130				,,
Sheffield (Univ. Obs.) .	1 27 W	53 23 2 N		981·370*				
Stonyhurst (Obs.) . .	2 28 10 W	53 50 40 N	114	981·369*				
Africa—								
Bloemfontein	26 40 E	29 0 S		979·244*				
Cairo (Observatory) . .	31 17 14 E	30 4 38 N	33	979·317*				
Cape Town (Obs.) . .	18 29 E	33 56 S	11	979·659	979·661	979·640	+ 21	Loesch, Preston
Durban	30 40 E	29 40 S		979·296*				
Johannesburg (Univ.) .	28 7 E	26 11 S	1753	978·482*				
Mauritius (Roy. Alf. O.)	57 33 9 E	20 5 39 S	55	978·623*				
America—								
Baltimore (Univ.) . .	76 37 W	39 17 48 N	30	980·097	980·103	980·104	− 1	Preston
Boston	71 3 48 W	42 21 36 N	22	980·396	·401	·377	+ 24	Putnam
Chicago	87 36	41 47 24 N	182	980·283	·319	·326	− 7	Defforges, P.
Harvard, Cambridge .	71 7 48 W	42 22 48 N	14	980·398	·401	·379	+ 22	Putnam
Cincinnati	84 25 18 W	39 8 18 N	245	980·004	·056	·089	− 33	,,
Ithica, Cornell . . .	76 29 0 W	42 27 6 N	247	980·300	·352	·386	− 34	P. 1894
Madison	89 24 W	43 4 36 N	270	980·365	—	·442	—	Smith, '06
Mt. Hamilton	121 38 36 W	37 20 24 N	1282	979·660	·935	·932	+ 3	Mendenhall
Montreal (McGill Obs.).	73 34 W	45 30 24 N	40	980·652	—	·662	—	
New York (Columb. U.)	73 57 30 W	40 48 30 N	38	980·267	·275	·238	+ 37	Smith, '99
Ottawa	75 42 W	45 25 24 N	73	**980·607**		·654		Klotz, '02
Philadelphia	75 11 42 W	39 57 6 N	16	980·196	·199	·162	+ 37	Putnam
Pikes Peak	105 2 W	38 50 18 N	4293	978·954	·855	·062	− 207	,,
Princeton	74 39 30 W	40 20 54 N	64	980·178	·191	·197	− 6	,,
Quebec (Obs.)	71 13 8 W	46 48 21 N	70	980·758*				
Quito (Obs.)	78 50 W	0 0 14 S	2825	977·281	977·833	977·030	− 197	Bourgeois
Machala	80 W	0 3 16 S	2	977·989	·990	·047	− 57	,,
St. Louis	90 12 12 W	38 38 6 N	154	980·001	980·032	980·045	− 13	Putnam
San Francisco	122 25 42 W	37 47 30 N	114	979·965	979·989	979·971	+ 18	Smith, Preston,
Seattle (Univ.) . . .	122 20 6 W	47 36 36 N	74	980·726	980·741	980·852	− 111	[Mendenhall
Toronto	79 23 40 W	43 39 36 N	107	980·461*				
Washington (B. of St.) .	77 3 59 W	38 56 32 N	102	980·097*				
Washington (*C. G. S.*) .	77 0 30 W	38 53 12 N	14	**980·112‡**	·115	·067	+ 48	Putnam, 1900
Yale, New Haven (O.) .	72 55 8 W	41 19 22 N	32	980·274*				

For footnotes see p. 21.

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Place.	Longitude.	Latitude.	Altitude H metre.	g Observed cm./sec.²	g_0'' cm./sec.²	γ_0 Cal. cm./sec.²	$g_0'' - \gamma_0$ in ·001 cm./sec.²	Observer.
	° ′ ″	° ′ ″						
Asia—								
Bombay (Colaba) . .	72 48 48 E	18 53 48 N	10	978·633	978·635	978·571	+ 64	Conyngham
Dehra Dun	78 3 12 E	30 19 30 N	683	**979·065**	979·210	979·346	−136	,,
Calcutta	88 21 24 E	22 32 48 N	6	978·816	978·817	978·789	+ 28	Elblein
Hong Kong (Obs.) . .	114 10 30 E	22 18 12 N	33	978·771	·777	·773	+ 4	Hecker, '04
Jalpaiquri	88 44 12 E	26 31 18 N	82	978·924	·943	·060	−117	Conyngham
Madras	80 14 54 E	13 4 6 N	6	978·281	·282	·294	− 12	,,
Sandakphu	88 0 18 E	27 6 6 N	3586	978·192	·946	·101	−155	,,
Tokyo (*Phy. Ins.*) . . .	139 46 E	35 42 36 N	18	**979·801**	979·805	979·791	+ 14	Hecker
Australasia—								
Adelaide (Obs.) . . .	138 35 8 E	34 55 39 S	43	979·711*				
Auckland	174 46 12 E	36 50 54 S	3	979·962	·963	·888	+ 75	Elblein
Brisbane	153 1 36 E	27 28 S	40	979·148	·156	·129	+ 27	Budik
Melbourne (Obs.) . .	144 58 34 E	37 49 53 S	26	979·987	·992	·974	+ 18	Mean 5 observers
,, (Univ.) . .	144 58 E	37 48 9 S	43	979·979				
Perth	115 52 E	31 57 S	14	979·473*				
Sydney (Obs.)	151 12 24 E	33 51 42 S	43	979·683	·690	·634	+ 57	Mean 5 obs.
Wellington, N.Z. (Obs.)	174 46 4	41 17 4 S	127	980·292				Wright
Europe—								
Basle	7 34 48 E	47 33 36 N	277	980·788	980·844	980·847	− 3	Niethammer
Berlin (Reichsanstalt) .	13 19 E	52 31 N	30	981·280*				
Christiania (*Obs.*) . .	10 43 32 E	59 54 42 N	28	**981·927**	981·933	981·907	+ 26	Schumann
Copenhagen (*Obs.*) . .	12 34 42 E	55 41 12 N	14	**981·559**	·562	·562	+ 0	,,
Geneva (Obs.)	6 9 12 E	46 12 N	405	980·599	980·682	980·724	− 42	Messerschmitt
Leyden (Obs.)	4 29 3 E	52 9 20 N	6	981·280	981·281	981·257	+ 24	Haid, 1900
Moscow	37 39 48 E	55 45 36 N	147	981·562	·592	·568	+ 24	Iweronow
Paris (*Obs.*)	2 20 12 E	48 50 11 N	59	**980·943**	980·956	980·962	− 6	*See* above
,, (Int. Bur. Sèvres)	2 13 10 E	48 59 53 N	70	980·941				
Potsdam (*Geod. Inst.*) .	13 4 6 E	52 22 54 N	87	**981·274**	981·294	981·277	+ 17	*See* above
Pulkowo	30 19 42 E	59 46 18 N	71	**981·899**	·914	·896	+ 18	Borrass
Rome (Eng. Sch.) . .	12 29 30 E	41 54 N	59	980·347	980·359	980·336	+ 23	Baglione
St. Petersburg (Phy. I.)	30 18 6 E	59 56 30 N	6	981·929		981·909		Achmatow
Vienna (*Mil. Geo. Ins.*)	16 21 30 E	48 12 42 N	183	**980·860**	·897	980·906	− 9	v. Sterneck
Zurich	8 33 12 E	47 22 42 N	463	**980·673**	·770	·831	− 61	Messerschmitt

* Calculated by Helmert's formula for the latitude and altitude stated; where the altitude is not given, g is calculated for sea-level.

† Absolute determination, Clark 1939, $981{\cdot}181_5$.

‡ Absolute determination, 980·080, see p. 18.

ACCELERATION OF GRAVITY CALCULATED BY HELMERT'S FORMULA

$$\gamma = 980{\cdot}616 - 2{\cdot}5928 \cos 2\lambda + {\cdot}0069 \cos^2 2\lambda. \quad \text{Lat. } 90^\circ \ \gamma = 983{\cdot}216.$$

The length (l) of the "seconds" pendulum (*i.e.* 2 secs. period) $= g/\pi^2 = {\cdot}101321\, g$. l varies from 99·094 cms. at the equator to 99·620 cms. at the pole.

Latitude.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°
0°	978·030	·032	·036	·044	·055	·069	·086	·107	·130	·156	·186	·218	·253	·291	·332
15°	978·376	·422	·471	·523	·577	·634	·693	·754	·818	·884	·952	·022*	·094	·168	·244
30°	979·321	·400	·481	·563	·646	·730	·815	·902	·989	·077*	·166	·255	·345	·435	·525
45°	980·616	·706	·797	·887	·977	·066*	·155	·244	·331	·418	·504	·588	·672	·754	·835
60°	981·914	·992	·068*	·142	·215	·285	·354	·420	·485	·547	·606	·663	·718	·770	·820
75°	982·867	·911	·952	·990	·026*	·058	·088	·115	·138	·159	·176	·190	·201	·209	·214

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SIZE AND SHAPE OF THE EARTH

The spheroid of revolution which most nearly approximates to the earth, has the following dimensions :— [1 kilom. = ·6214 mile.]

Observer.	Equatorial radius, a.	Polar radius, b.	Ellipticity, $(a-b)/a$.
Bessel, 1841 . . .	6,377,397 metres	6,356,079 metres	1/299·2
Clarke, 1866 . . .	8,206 „	584 „	1/295·0
„ 1880 . . .	8,249 „	515 „	1/293·5
Helmert, 1906 * .	8,200 „	818 „	1/298·3
U.S. Survey, 1906 †	8,388 „ ‡	909 „ ‖	1/297·0

* "Die Grosse der Erde."

† "The Figure of the Earth," 1909, and Supplement, 1910; U.S. Coast and Geodetic Survey.

‡ 3963·339 miles. ‖ 3949·992 miles.

MEAN DENSITY OF THE EARTH

(See Poynting's "Mean Density of the Earth," 1893.)

Observer.	Density.
Common Balance Method.	
Poynting, 1878	5·493
Richarz and Krigar-Menzel, 1898	5·505
Torsion Balance Method.	
Cavendish, 1798	5·45
Boys, *Phil. Trans.*, 1895 . .	5·527
Braun, 1896	5·527
Eötvos, 1896	5·534
Mean density of surface . . .	2·65

Mean polar quadrant = 10,002,280 metres ‡

Volume of earth = $1{\cdot}083 \times 10^{21}$ metres^3 *

Mass of earth = $5{\cdot}98 \times 10^{27}$ grams †
= $5{\cdot}87 \times 10^{21}$ tons

Area of land = $1{\cdot}45 \times 10^{18}$ cm.^{2}

Area of ocean = $3{\cdot}67 \times 10^{18}$ cm.^{2}

Mean depth of ocean (Murray) = $3{\cdot}85 \times 10^{5}$ cm.

Volume of ocean = $1{\cdot}41 \times 10^{24}$ cm.^{3}

Mass of ocean = $1{\cdot}45 \times 10^{24}$ grms.

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* Mean of Helmert and U.S. Survey.

† Using Boys' and Braun's result for density.

‡ Nautical Almanac, 1940.

SUN

The mean equatorial solar parallax (Hinks, 1909) = 8″·807

Whence mean distance from earth to sun = $1{\cdot}494 \times 10^{11}$ metres = $9{\cdot}282 \times 10^{7}$ miles

Mean time taken by light to travel from sun to earth = 498·2 secs.

MOON

Mean distance from earth to moon = $60{\cdot}27 \times$ earth's radius

Mass of the moon (Hinks, 1909) = $(1/81{\cdot}53) \times$ earth's mass

Inclination of moon's orbit to ecliptic = 5° 8′ 43″

Obliquity of the Ecliptic to the equator = 23° 27′ 4″·04 in 1909, subject to a small fluctuation by nutation, and a slow continuous decline of 46″·84 per century.

Constant of aberration of a star is theoretically equal to (Earth's orbital velocity)/(velocity of light) = 20″·43 ± ″·03 (Renan and Ebert, 1905).

Constant of precession, *i.e.* annual precessional increase of the longitude of a star = $50''{\cdot}2564 + ''{\cdot}0002225t$, where t is the interval in years from 1900 (Newcomb).

ELEMENTS OF THE SOLAR SYSTEM

8″·806 is taken as the equatorial horizontal solar parallax from the observations of the asteroid Eros in 1900–1; 5·527 is adopted as the Earth's mean density (Boys, 1895; Braun, 1896). See Spencer Jones' "General Astronomy," or Russell, Dugan, and Stewart's "Astronomy." [Pluto: mass <0·7, semi-major axis 39·52, sidereal period 90737d, eccentricity of orbit 0·2486.]

Name.	Equatorial Semi-diameter.			Mass Earth = 1	Mean Density.		Gravity at Surf. Earth = 1	No. of Satellites.‡
	Angular.*	Miles.	Earth = 1		Earth = 1	Water = 1		
	′ ″							
Sun . .	16 1·18	432,890	109·2	329,390	·25	1·39	27·61	—
Mercury	3·08	1387	·350	·04	0·70	3·8	·28	0
Venus .	8·40	3783	·955	·81	·94	5·20	·91	0
Earth .	8·80	3963·3	1·000	1·000	1·00	5·527	1·00	1 (D)
Mars . .	4·68	2108	·532	·106	0·71	3·90	·38	2 (D)
Jupiter .	1 37·36	43850	11·06	314·50	·25	1·36	2·57	9(7 D; 2R)
Saturn .	1 24·75	38170	9·63	94·07	·12	·63	1·01	10(9 D; 1 R)
Uranus .	34·28	15440	3·90	14·40	·24	1·34	·95	4 (R)
Neptune	36·56	16470	4·15	16·72	·23	1·28	·97	1 (R)

Name.	Inclination of Equator to Orbit.	Time of Axial Rotation.	Semi-major Axis of Orbit.			Sidereal Period.	
			Earth = 1.		Millions of Miles.	Mean Solar Days.	Julian Years.
	° ′ ″	d h m					
Sun . .	7 15†	25 9 7	—	—	—	—	—
		h m s		Bode's Law			
Mercury .	9	88 days	·3870986	4 = (0 + 4)	36·0	87·9693	·24
Venus .	6	23 40 (?)	·7233315	7 = (3 + 4)	67·2	224·7008	·62
Earth .	23 27 8	23 56 4·09	1·0000000	10 = (6 + 4)	92·9	365·2564	1·00
Mars . .	24 52	24 37 22·74	1·523688	16 = (12 + 4)	141·6	686·9797	1·88
Asteroids	—	—	2·55 to 2·85	28 = (24 + 4)	237 to 265	—	—
Jupiter .	3 5	9 56 ±	5·202803	52 = (48 + 4)	483·3	4332·588	11·86
Saturn .	26 49	10 15 ±	9·538844	100 = (96 + 4)	886·2	10759·20	29·46
Uranus .	98	10·75 hours	19·19098	196 = (192 + 4)	1782·8	30685·9	84·01
Neptune	151	15·67 hours	30·07067	—	2793·5	60187·65	164·78

Name.	Ellipticity of Planet.§	Mean Daily Motion in Orbit.	Longitude of Perihelion.‖	Longitude of Ascending Node.¶	Inclination of Orbit to Ecliptic.	Eccentricity of Orbit.**
		° ′ ″	° ′ ″	° ′ ″	° ′ ″	
Mercury .	?	4 5 32·4	75 53 59	47 8 45	7 0 10	·205614
Venus .	?	1 36 7·7	130 9 50	75 46 47	3 23 37	·006821
Earth .	1/298·3	59 8·2	101 13 15	0 0 0	0 0 0	·016751
Mars . .	1/192	31 26·5	334 13 7	48 47 9	1 51 1	·093309
Jupiter .	1/17	4 59·1	12 36 20	99 26 42	1 18 42	·048254
Saturn .	1/9	2 0·5	90 48 32	112 47 12	2 29 39	·056061
Uranus .	1/14	42·2	169 2 56	73 29 25	0 46 22	·047044
Neptune	?	21·5	43 45 20	130 40 44	1 46 45	·008533

* This is the angle subtended by the semi-diameter at a distance equal to the Earth's mean distance from the Sun.

† The inclination of the plane of the Sun's equator to the plane of the ecliptic.

‡ D means direct; R, retrograde.

§ The ellipticity = $(a-b)/a$, where a is the major axis and b the minor axis of the spheroid of revolution. The value given for the Earth is Helmert's (p. 22).

‖ Perihelion is the point in the orbit nearest the Sun. Longitude is the angular distance from the first point of Aries (see p. 3), measured along the ecliptic.

¶ A node is one of the two points at which a planet's orbit intersects the plane of the ecliptic. At the ascending node the planet passes from south to north of the ecliptic.

** The eccentricity = $\sqrt{(a^2-b^2)}/a$, where a and b are the major and minor axes of the orbit.

EQUATION OF TIME

(+) means that the equation of time has to be added to the apparent solar time (*i.e.* sundial time) to give the mean solar or clock time (see p. 3). (M) = maximum or minimum. The values below vary by a few seconds from year to year. $C = D + E$, where C = clock time, D = dial time, and E = equation of time.

Date.	Equation of time.	Date.	Equation of time.	Date.	Equation of time.	Date.	Equation of time.
	m. s.		m. s.		m. s.		m. s.
Jan. 1	+ 3 11	April 1	+4 1	July 1	+ 3 32	Oct. 16	− 14 20
„ 16	+ 9 33	„ 16	0 0	„ 26	+ 6 18 (M)	Nov. 3	− 16 21 (M)
Feb. 1	+ 13 37	May 1	− 2 57	Aug. 16	+ 4 11	„ 16	− 15 10
„ 12	+ 14 25 (M)	„ 14	− 3 49 (M)	Sept. 1	0 0	Dec. 1	− 10 56
Mar. 1	+ 12 34	June 1	− 2 27	„ 16	− 5 6	„ 12	− 6 15
„ 16	+ 8 51	„ 15	0 0	Oct. 1	− 10 16	„ 25	0 0

PARALLAXES OF STARS

The **proper motion** of a star is its real change of place arising from the actual motion of the star itself.

The **annual parallax** is the angle between the direction in which a star appears as seen from the earth and the direction in which it would appear if it could be observed from the centre of the sun.

A **light-year** is the distance that light travels in one year (see p. 84).

Star and Magnitude.	Proper motion per year.	Annual parallax.	Distance.	
			Sun's dist. = 1	Light-years.
	"	" "		
α Centauri (·2)	3·7	·75 ± ·01	·28 × 10⁶	4·4
21185 Lalande (7·5)	7·3	·39 ± ·02	·53 „	8·4
61 Cygni (4·8)	5·2	·30	·69 „	10·9
Sirius (− 1·4)	1·3	·37 ± ·01	·56 „	8·8
Procyon (·5)	1·3	·31	·69 „	11
Altair (·9)	·7	·20 ± ·02	1·05 „	16·6
Aldebaran (1·1)	·2	·06 ± ·02	3·5 „	55
Capella (·2)	·4	·07 ± ·02	3·0 „	47
Vega (·1)	·4	·12 ± ·02	1·7 „	27
1830 Groombridge (6·4)	7·0	·10 ± ·02	2·0 „	32
Polaris (2·1)	0·0	·07 ± ·02	3·0 „	47
Arcturus (·2)	2·3	·080	26 „	410

SYSTEMATIC MOTIONS OF THE STARS

The apparent proper motions of the stars show drifts in two directions. The assigned positions of the apices of these directions are:—

Computer.	Stream I.		Stream II.	
	R.A.	Dec.	R.A.	Dec.
Kapteyn, 1904	85°	− 11°	260°	− 48°
Eddington	90°	− 19°	292°	− 58°
Dyson	94°	− 7°	240°	− 74°

STANDARD TIMES

Referred to Greenwich time.
(As in August, 1939.)

Gt. Britain, France, Portugal, Belgium, Spain	Greenwich time
Ireland	„
Holland	20 mins. fast
Austria, Denmark, Germany, Italy, Norway, Switzerland	1 hour fast
British South Africa, Egypt, Turkey	2 hours fast
Japan, Korea	9 hours fast
Australia	8, 9, 9½, or 10 hours fast
New Zealand	11½ „ „
Canada and United States	4, 5, 6, 7, or 8 hours slow
India and Ceylon	5½ hours fast

SCREWS

It is customary for British metal screws, of $\frac{1}{4}$-inch diameter and above, to have a Whitworth thread, for smaller sizes a British Association thread. In the Whitworth thread the angle between the slopes is 55°, in the B.A. thread 47·5°.

The **pitch** is the distance between adjoining crests (say) of the same thread measured parallel to the axis of the screw. It is the reciprocal of the number of turns per inch or mm. as the case may be. The **full diameter** is the maximum over-all diameter.

Micrometer screws are made with some multiple or sub-multiple of 100 threads to the inch or mm.

"**Woodscrews**" of iron or brass are numbered as follows: No. 0 has a diameter of ·05 inch, each succeeding number adding ·014 inch to the diameter of the screw: this applies to all lengths. The length of countersunk screws is measured over all; that of round-headed screws, from under the head. [1 inch = 25·4 mm.]

STANDARD WHITWORTH.				BRITISH ASSOCIATION.								
Full diameter.	**Threads to inch.**	**Full diameter.**	**Threads to inch.**	**No.**	**Full diameter.**	**Pitch.**	**No.**	**Full diameter.**	**Pitch.**	**No.**	**Full diameter.**	**Pitch.**
inch.		inch.			mm.	mm.		mm.	mm.		mm.	mm.
$1\frac{3}{4}$	5	$\frac{3}{4}$	10	0	6·0	1·0	9	1·9	·39	18	·62	·15
$1\frac{5}{8}$	5	$\frac{11}{16}$	11	1	5·3	·9	10	1·7	·35	19	·54	·14
$1\frac{1}{2}$	6	$\frac{5}{8}$	11	2	4·7	·81	11	1·5	·31	20	·48	·12
$1\frac{3}{8}$	6	$\frac{9}{16}$	12	3	4·1	·73	12	1·3	·28	21	·42	·11
$1\frac{1}{4}$	7	$\frac{1}{2}$	12	4	3·6	·66	13	1·2	·25	22	·37	·10
$1\frac{1}{8}$	7	$\frac{7}{16}$	14	5	3·2	·59	14	1·0	·23	23	·33	·09
1	8	$\frac{3}{8}$	16	6	2·8	·53	15	·9	·21	24	·29	·08
$\frac{7}{8}$	9	$\frac{5}{16}$	18	7	2·5	·48	16	·79	·19	25	·25	·07
$\frac{13}{16}$	10	$\frac{1}{4}$	20	8	2·2	·43	17	·70	·17			

MOMENTS OF INERTIA

M = mass of body. (See A. M. Worthington, " Dynamics of Rotation." London.)

Body.	Axis of rotation.	Moment of inertia.
Uniform thin rod (length l)	(1) Through centre, perpendicular to length	$M\frac{l^2}{12}$
	(2) Through end, perpendicular to length	$M\frac{l^2}{3}$
Rectangular lamina (sides a and b)	(1) Through centre of gravity, perpendicular to plane	$M\frac{a^2+b^2}{12}$
	(2) Through centre of gravity, parallel to side b	$M\frac{a^2}{12}$
Circular lamina (radius r)	(1) Through centre, perpendicular to plane	$M\frac{r^2}{2}$
	(2) Any diameter	$M\frac{r^2}{4}$
Solid cylinder (radius r; length l)	(1) Axis of cylinder	$M\frac{r^2}{2}$
	(2) Through centre of gravity, perpendicular to axis of cylinder	$M\left(\frac{l^2}{12}+\frac{r^2}{4}\right)$
Hollow cylinder (external and internal radii R and r; length l)	(1) Axis of cylinder	$M\cdot\frac{R^2+r^2}{2}$
	(2) Through centre of gravity, perpendicular to axis	$M\left(\frac{l^2}{12}+\frac{R^2+r^2}{4}\right)$
Solid sphere (radius r)	Through centre	$M\cdot\frac{2r^2}{5}$
Hollow sphere (external and internal radii R and r)	Through centre	$M\left(\frac{2}{5}\cdot\frac{R^5-r^5}{R^3-r^3}\right)$
Anchor ring (mean radius of ring R; radius of cross-section r)	(1) Through centre, perpendicular to plane of ring	$M\left(R^2+\frac{3r^2}{4}\right)$
	(2) Any diameter	$M\left(\frac{R^2}{2}+\frac{5r^2}{8}\right)$

VOLUME CALIBRATION OF VESSELS BY WATER OR MERCURY

Volume content of vessel at $t°$ C. = $V_t = W_t v_t \equiv w_t(f)$, where—

w_t = observed weight in grams (against brass weights in air) of contained water (or mercury) at $t°$ C.

W_t = weight of such liquid *in vacuo* (*i.e.* corrected for buoyancy in air).

v_t = volume of 1 gram of liquid at $t°$ C.

(f) is a factor which introduces the buoyancy and specific volume corrections.

The following table of values of the factor (f) is based on tables on pp. 28 and 31.

Temp. (t) of weighing	**10° C.**	**11°**	**12°**	**13°**	**14°**	**15°**	**16°**	**17°**
Value of factor (f) H_2O .	1·00133	1·00143	1·00154	1·00166	1·00179	1·00193	1·00209	1·00226
Value of factor (f) **Hg** .	·073683	·073697	·073710	·073724	·073737	·073750	·073764	·073777

Temp. (t) of weighing	**18°**	**19°**	**20°**	**21°**	**22°**	**23°**	**24°**	**25°**
Value of factor (f) H_2O .	1·00244	1·00263	1·00283	1·00305	1·00327	1·00350	1·00375	1·00400
Value of factor (f) **Hg** .	·073790	·073804	·073817	·073831	·073844	·073857	·073871	·073884

The above gives the volume content V_t of the vessel at the temperature of weighing, $t°$ C. At any other temperature, t', the volume $V_{t'} = V_t\{1 + \gamma(t' - t)\} \equiv V_t(F)$, where γ is the coefficient of cubical expansion of the material of the vessel. Values of the factor (F) for **glass vessels** (γ = ·000025) are tabulated below.

$(t' - t)$	**2° C.**	**4°**	**6°**	**8°**	**−2° C.**	**−4°**	**−6°**	**−8°**
Value of factor (F)	1·00005	1·00010	1·00015	1·00020	·99995	·99990	·99985	·99980

Example.—Weight of water contained in a vessel at 10° C. = 10 grams: thence volume of vessel at 10° C. = 10 × 1·00133 c.cs. The same vessel, if of glass, would contain at 16° C., 10 × 1·00133 × 1·00015 = 10·0148 c.cs.

CAPILLARITY CORRECTIONS OF MERCURY COLUMNS

The height of the meniscus and the value of the capillary depression depend on the bore of the tubing, on the cleanliness of the mercury, and on the state of the walls of the tube. The correction is negligible for tubes with diameters greater than about 25 mms. The table below gives the amount of the correction (which has to be added to the height) for various diameters of glass tubing and meniscus heights. (Mendeléeff and Gutkowsky, 1877. See also Scheel and Heuse, *Ann. d. Phys.*, 33, 1910.)

Bore of tube.	**Height of meniscus in mms.**								**Bore of tube.**	**Height of meniscus in mms.**					
	·4	**·6**	**·8**	**1·0**	**1·2**	**1·4**	**1·6**	**1·8**		**·8**	**1·0**	**1·2**	**1·4**	**1·6**	**1·8**
mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm
4	·83	1·22	1·54	1·98	2·37	—	—	—	**9**	·21	·28	·33	·40	·46	·52
5	·47	·65	·86	1·19	1·45	1·80	—	—	**10**	·15	·20	·25	·29	·33	·37
6	·27	·41	·56	·78	·98	1·21	1·43	—	**11**	·10	·14	·18	·21	·24	·27
7	·18	·28	·40	·53	·67	·82	·97	1·13	**12**	·07	·10	·13	·15	·18	·19
8	—	·20	·29	·38	·46	·56	·65	·77	**13**	·04	·07	·10	·12	·13	·14

REDUCTION OF BAROMETER READINGS TO 0° C.

Corrected height $H_0 = H\left\{1 - \frac{(\beta - \alpha)t}{(1 + \beta t)}\right\}$, where H and t are the observed height and temperature of the barometer, β = ·0001818 (Regnault), the coefficient of cubical expansion of mercury; α = ·0000085, the coefficient of linear expansion of glass, or ·0000184 for brass. Hydrogen temperature scale. (After Broch, Inter. Bur. Weights and Measures.)

(In accurate barometry, the height of the mercury column is corrected to 0° C. (32° F.). Inch scales are corrected to 62° F., and mm. scales, as in the table below, to 0° C.

Temp. (t).	Correction in mms. to be subtracted.									
	GLASS SCALE.					BRASS SCALE.				
	Uncorrected height in mms.					Uncorrected height in mms.				
	700	720	740	760	780	700	720	740	760	780
2° C.	mm. ·24	·25	·26	·26	·27	mm. ·23	·24	·24	·25	·25
4	·48	·49	·51	·53	·54	·46	·47	·48	·50	·51
6	·73	·75	·77	·79	·81	·69	·71	·72	·74	·76
8	·97	·99	1·02	1·05	1·08	·91	·94	·97	·99	1·02
10	1·21	1·25	1·28	1·31	1·35	1·14	1·17	1·21	1·24	1·27
12	1·45	1·49	1·53	1·58	1·62	1·37	1·41	1·45	1·49	1·53
14	1·69	1·74	1·79	1·84	1·89	1·60	1·64	1·69	1·73	1·78
16	1·94	1·99	2·05	2·10	2·16	1·82	1·88	1·93	1·98	2·03
18	2·18	2·24	2·30	2·36	2·43	2·05	2·11	2·17	2·23	2·29
20	2·42	2·49	2·56	2·62	2·69	2·28	2·34	2·41	2·47	2·54
22	2·66	2·73	2·81	2·89	2·96	2·51	2·58	2·65	2·72	2·79
24	2·90	2·98	3·06	3·15	3·23	2·73	2·81	2·89	2·97	3·05
26	3·14	3·23	3·32	3·41	3·50	2·96	3·04	3·13	3·21	3·30
28	3·38	3·47	3·57	3·67	3·77	3·19	3·28	3·37	3·46	3·55
30	3·62	3·72	3·83	3·93	4·03	3·41	3·51	3·61	3·71	3·80
32	3·86	3·97	4·08	4·19	4·30	3·64	3·74	3·85	3·95	4·05
34	4·10	4·21	4·33	4·45	4·57	3·87	3·98	4·09	4·20	4·31

REDUCTION OF BAROMETER READINGS TO LAT. 45° AND SEA-LEVEL

It is a convention to take "g" at lat. 45° and sea-level as the standard value for "gravity." The corrections below result from the variation of "g" with latitude and height above sea-level (see p. 18). The barometer correction for **latitude** = $\frac{H_0}{760}(C)$, has to be subtracted from the temperature—corrected barometer reading H_0 for latitudes between 0° and 45°; and added for latitudes from 45° to 90°.

Latitude	0° 90°	5° 85°	10° 80°	15° 75°	20° 70°	25° 65°	30° 60°	35° 55°	40° 50°	45° 45°
C	mm. 1·97	1·94	1·85	1·70	1·51	1·27	·98	·67	·34[*]	·00

The correction of the barometer due to diminution of gravity with increasing **height** above sea-level amounts to about ·24 mm. of mercury per 1000 metres above sea-level. The correction has to be subtracted from the observed reading.

[*] London, ·45.

REDUCTION OF WEIGHINGS TO VACUO

The buoyancy correction $= M\sigma(1/\Delta - 1/\rho) = Mk$, where M is the apparent mass in grams of the body in air, σ is the density of air (= ·0012) in grams per c.c., Δ is the density of the body, ρ is the density of the weights. The correction is true to 4% for the following limits: 740 mm. press., 1° to 22°; 760 mm., 8° to 29°; 780 mm., 15° to 35°. If the correction is required more accurately, multiply the value of k given below by $\sigma'/{\cdot}0012$, where σ' is the true density of the air for the temp. and press. at the time of the weighing (for σ', see p. 34). The corrections for quartz weights are the same as for Al. + means cor^n. to be added to observed weight.

Density of Body weighed Δ.	Correction Factor (k) in Milligms.			Density of Body weighed Δ.	Correction Factor (k) in Milligms.		
	Brass wgts. $\rho = 8{\cdot}4$.	Pt wgts. $\rho = 21{\cdot}5$.	Al wgts. $\rho = 2{\cdot}65$.		Brass wgts. $\rho = 8{\cdot}4$.	Pt wgts. $\rho = 21{\cdot}5$.	Al wgts. $\rho = 2{\cdot}65$.
·5	+ 2·26	+ 2·34	+ 1·95	1·6	+ ·61	+ ·69	+ ·30
·55	+ 2·04	+ 2·13	+ 1·73	1·7	+ ·56	+ ·65	+ ·25
·6	+ 1·86	+ 1·94	+ 1·55	1·8	+ ·52	+ ·62	+ ·21
·65	+ 1·70	+ 1·79	+ 1·39	1·9	+ ·49	+ ·58	+ ·18
·7	+ 1·57	+ 1·66	+ 1·26	2	+ ·46	+ ·54	+ ·15
·75	+ 1·46	+ 1·55	+ 1·15	2·5	+ ·34	+ ·43	+ ·03
·8	+ 1·36	+ 1·44	+ 1·05	3	+ ·26	+ ·34	− ·05
·85	+ 1·27	+ 1·36	+ ·96	3·5	+ ·20	+ ·29	− ·11
·9	+ 1·19	+ 1·28	+ ·88	4	+ ·16	+ ·24	− ·15
·95	+ 1·12	+ 1·21	+ ·81	5	+ ·10	+ ·19	− ·21
1	+ 1·06	+ 1·14	+ ·75	6	+ ·06	+ ·14	− ·25
1·1	+ ·95	+ 1·04	+ ·64	8	+ ·01	+ ·09	− ·30
1·2	+ ·86	+ ·94	+ ·55	10	− ·02	+ ·06	− ·33
1·3	+ ·78	+ ·87	+ ·47	15	− ·06	+ ·03	− ·37
1·4	+ ·71	+ ·80	+ ·40	20	− ·08	+ ·004	− ·39
1·5	+ ·66	+ ·75	+ ·35	22	− ·09	− ·001	− ·40

REDUCTION OF GASEOUS VOLUMES TO 0° AND 760 MMS. PRESSURE

Corrected volume $v_0 = \{v/(1 + {\cdot}00367t)\}\,.\,p/760$, where v, t, and p are the observed volume, temp., and pressure (in mms. of mercury) of the gas respectively. $g = 980{\cdot}62$ cms. per sec^2. The coefficient ·00367 observed by Regnault.

Values of $(1 + {\cdot}00367t)$.

Temp. (t).	0	1	2	3	4	5	6	7	8	9
0° C.	1·0000	1·0037	1·0073	1·0110	1·0147	1·0183	1·0220	1·0257	1·0294	1·0330
10	0367	0404	0440	0477	0514	0550	0587	0624	0661	0697
20	0734	0771	0807	0844	0881	0917	0954	0991	1028	1064
30	1101	1138	1174	1211	1248	1284	1321	1358	1395	1431
40	1468	1505	1541	1578	1615	1651	1688	1725	1762	1798
50	1835	1872	1908	1945	1982	2018	2055	2092	2129	2165
60	2202	2239	2275	2312	2349	2385	2422	2459	2496	2532
70	2569	2606	2642	2679	2716	2752	2789	2826	2863	2899
80	2936	2973	3009	3046	3083	3119	3156	3193	3230	3266
90	3303	3340	3376	3413	3450	3486	3523	3560	3597	3633
100	3670	3707	3743	3780	3817	3853	3890	3927	3964	4000
110	4037	4074	4110	4147	4184	4220	4257	4294	4331	4367

Values of $p/760$

Press. (p).	0	1	2	3	4	5	6	7	8	9
700 mm.	·9211	·9224	·9227	·9250	·9263	·9276	·9289	·9303	·9316	·9329
710	·9342	·9355	·9368	·9382	·9395	·9408	·9421	·9434	·9447	·9461
720	·9474	·9487	·9500	·9513	·9526	·9539	·9553	·9566	·9579	·9592
730	·9605	·9618	·9632	·9645	·9658	·9671	·9684	·9097	·9711	·9724
740	·9737	·9750	·9763	·9776	·9789	·9803	·9816	·9829	·9842	·9855
750	·9868	·9882	·9895	·9908	·9921	·9934	·9947	·9961	·9974	·9987
760	1·0000	1·0013	1·0026	1·0039	1·0053	1·0066	1·0079	1·0092	1·0105	1·0118
770	1·0132	1·0145	1·0158	1·0171	1·0184	1·0197	1·0211	1·0224	1·0237	1·0250

DENSITIES OF THE ELEMENTS

Average densities of liquid and solid elements in grams per c.c. at ordinary temperatures unless otherwise stated. For gaseous densities see pp. 17, 35. The density of a specimen may depend considerably on its state and previous treatment, *e.g.* the density of a cast metal is increased by drawing, rolling, or hammering.

Element.	Density.	Element.	Density.	Element.	Density.
Aluminium . . .	2·70	Indium	7·3	Samarium . . .	7·8
Antimony . . .	6·68	Iodine	4·95	Scandium . . .	(?)
Argon (liq.). . .	1·4/−185°	Iridium	22·41	Selenium, amorph.	4·8
Arsenic	5·73	Iron (pure) . . .	7·87	„ cryst. .	4·5
Barium	3·75	Krypton (liq.) . .	2·16	„ liq. . .	4·27
Beryllium . . .	1·83	Lanthanum . . .	6·12	Silicon	*c.* 2·3
Bismuth	9·80	Lead	11·37	Silver	10·5
Boron	2·5 (?)	Lithium	·534	Sodium	·971
Bromine	3·102/25°	Magnesium . . .	1·74	Strontium . . .	2·54
Cadmium . . .	8·64	Manganese . . .	7·39	Sulphur, rhombic	2·07
Cæsium	1·87	Mercury (see p. 24)	13·56/15°	„ monoclinic	1·96
Calcium	1·55/29°	Molybdenum . .	10·0	„ amorphous	1·92
Carbon—		Neodymium . .	6·96	„ liquid 113°	1·81
Diamond . . .	3·52	Neon (liq.) . . .	(?)	Tantalum . . .	16·6
Graphite . . .	2·3	Nickel	8·9	Tellurium . . .	6·25
Cerium	6·92	Niobium	8·5	Terbium	(?)
Chlorine (liq.) . .	2·49/0°	Nitrogen (liq.) .	·79/−196°	Thallium . . .	11·9
Chromium . . .	7·1	Osmium	22·5	Thorium	11·3
Cobalt	8·6	Oxygen (liq.) . .	1·27/−235°	Tin	7·29
Copper	8·93	Palladium . . .	11·4	Titanium . . .	4·5
Erbium	4·77 (?)	Phosphorus, red .	2·20	Tungsten . . .	19·3
Fluorine (liq.) . .	1·11/−187°	„ yellow	1·83	Uranium . . .	18·7
Gadolinium . . .	5·91	Platinum . . .	21·50	Vanadium . . .	6·0
Gallium	5·95	Potassium . . .	·862	Xenon (liq.) . .	3·5
Germanium . . .	5·47	Praseodymium .	6·48	Ytterbium . . .	5·5
Gold	19·32	Radium	(?)	Yttrium	3·8 (?)
Helium (liq.) . .	·12/B.P.	Rhodium . . .	12·44	Zinc	7·1
Hydrogen (liq.) .	·07/B.P.	Rubidium . . .	1·532	Zirconium . . .	6·5
„ „	·086/M.P.	Ruthenium . . .	12·3		

The densities of the alkali metals Li, Na, K, Rb, Cs are due to Richards and Brink, 1907; of He at −268°·6, Onnes, 1908; of Ta, Nb, and Th, von Bolton, 1905, 1907, 1908; of Ca, Goodwin, 1904; of Rh and Ir, Holborn, Henning, and Austin, 1904; of Br, Andrews and Carlton, 1907.

DENSITIES OF COMMON SUBSTANCES

Average densities in grams per c.c. at ordinary temperatures. For densities of acids, alkalies, and other solutions, see pp. 32 *et seq.*; of "chemical compounds," p. 130; of gases, p. 35; of other minerals, p. 147.

Substance.	Density.	Substance.	Density.	Substance.	Density.
Metals & Alloys.		Coins (English)		**Woods** (seasoned).	
Iron, cast . . .	7·1–7·7	„ silver § . .	10·31	Ash ; mahogany .	·6–·8
„ wrought . .	7·8–7·9	Constantan ‖ . .	8·88	Bamboo	*c.* ·4
„ wire . . .	7·7	Duralumin . .	2·79	Beach ; oak ; teak	·7–·9
Steel	7·7–7·9	German silver ¶ .	8·5–8·9	Box	·9–1·1
Brass (ordy.) * . .	8·4–8·7	Gunmetal . . .	8·0–8·4	Cedar	·5–·6
Brass weights . .	*c.* 8·4	Magnalium ** . .	*c.* 2	Ebony	1·1–1·3
Bronze (Cu, Sn) .	8·7–8·9	Manganin †† . .	8·5	Lignum vitæ . .	1·2–1·3
Coins (English)		Phosphor bronze ‡‡	8·7–8·9	Pitchpine ; walnut	·6–·7
„ bronze † . .	8·96	Platinoid §§ . . .	*c.* 9	Red pine (deal) .	·5–·7
„ gold ‡ . .	17·72	Pt (90), Ir (10). .	21·62	White pine . . .	·4–·5

* *c.* 66 Cu, 34 Zn. † 95 Cu, 4 Sn. 1 Zn. ‡ 91⅔ Au, 8⅓ Cu. § Prior to 1921, 92½ Ag, 7½ Cu.; since 1927, 50 Ag, 40 Cu, 5 Ni, 5 Zn (density 9·58). ‖ 60 Cu, 40 Ni. ¶ 60 Cu, 15 Ni, 25 Zn. ** *c.* 70 Al, 30 Mg. †† 84 Cu, 12 Mn, 4 Ni. ‡‡ 92½ Cu, 7 Sn, ½ P. §§ Described as German silver with a little tungsten.

DENSITIES OF COMMON SUBSTANCES (*contd.*)

Substance.	Density.	Substance.	Density.	Substance.	Density.
Minerals, etc.		**Liquids.**		Gelatine	1·27
Agate; slate	2·5–2·7	Glycerine	1·26	Glass, flint	2·9–4·5
Asbestos	3·0	Methylated spirit	·83	,, crown; window	2·4–2·6
,, board	1·2	Milk	*c.* 1·03	,, optical	(see p. 85.)
Carbon (see above)		Naphtha	·85	,, pyrex	2·25
Charcoal	·3–·6	Oil, castor	·97	Ice (Roth, 1908), 0°	·9168
Coal	1·2–1·5	,, linseed	·91–·93	,, (Vincent, '02), 0°	·9160
,, anthracite	1·4–1·8	,, lubricating	·90–·92	Indiarubber (pure)	·91–·93
Coke (pieces)	1·0–1·7	,, olive; palm	·91–·93	Ivory	1·8–1·9
,, (in bulk)	·6–·8	,, paraffin	*c.* ·8	Leather	·85–1
Gas carbon	1·9	Petrol	·68–·72	Paper	·7–1·1
Emery	4·0	Sea-water	1·01–1·05	Pitch	*c.* 1·1
Granite	2·5–3	Turpentine	·87	Porcelain	2·2–2·4
Marble	2·5–2·8	Vinegar	1·02	Resin	*c.* 1·1
Masonry	*c.* 2			Red fibre	1·45
Pumice (natural)	·4–·9	**Miscellaneous.**		Snow (loose)	*c.* ·12
Quartz	2·66	Amber	1·1	Tar	1·02
Silica, fused		Bone	1·8–2·0	Wax, soft paraffin	·87–·88
,, transparent	2·21	Butter, lard	·92–·94	,, hard ,,	·88–·93
,, translucent	2·07	Celluloid	1·4	,, white; bees-	·95–·96
Sand (silver)	2·63	Cork	·22–·26	,, sealing	*c.* 1·8
Sandstone; kaolin	2·2–2·3	Ebonite	1·8	,, soft red	*c.* 1·0

DENSITY DETERMINATION CORRECTIONS

In the determination of the density of a body by weighing in water, the true density (corrected for air buoyancy and water density) is given by $\Delta(D - \sigma) + \sigma$, where Δ is the uncorrected density of the body, D is the density of the water, and σ is the density of the air. The table below gives the correction to be applied to Δ. D is taken as ·9992 (correct to 1 part in 2000 between 10° and 18° C., see p. 31) and σ as ·0012 (see p. 35). – means that the correction has to be subtracted from Δ. (See Stewart and Gee, "Practical Physics," vol. i.)

Δ	Corr.	Δ	Corr.	Δ	Corr.	Δ	Corr.	Δ	Corr.	Δ	Corr.
0·5	+·0002	4·0	–·0068	7·5	–·0138	8·4	–·0156	9·5	–·0178	16·0	–·0308
1·0	–·0008	4·5	–·0078	7·8	–·0144	8·5	–·0158	10·0	–·0188	17·0	–·0328
1·5	–·0018	5·0	–·0088	7·9	–·0146	8·6	–·0160	11·0	–·0208	18·0	–·0348
2·0	–·0028	5·5	–·0098	8·0	–·0148	8·7	–·0162	12·0	–·0228	19·0	–·0368
2·5	–·0038	6·0	–·0108	8·1	–·0150	8·8	–·0164	13·0	–·0248	20·0	–·0388
3·0	–·0048	6·5	–·0118	8·2	–·0152	8·9	–·0166	14·0	–·0268	21·0	–·0408
3·5	–·0058	7·0	–·0128	8·3	–·0154	9·0	–·0168	15·0	–·0288	22·0	–·0428

DENSITY OF DAMP AIR

The density of damp air may be derived from the expression $\sigma = \sigma_d(H - 0{\cdot}378p)/H$, where σ_d is the density of dry air at a pressure H mms. (see p. 34), H is the barometric height, and p is the pressure of water-vapour in the air (p. 49).

HYDROMETERS

Common: Density = degrees/1000.

Baumé: Density at 15° = 144·3/(144·3 – Baumé degrees).

Twaddell: Density = 1 + (Twaddell degrees/200).

Sikes: One degree = a density interval of ·002 on the average.

DENSITY OF WATER

In grams per millilitre.* Pure air-free water under 1 atmos. Temps. on const.-vol. H.scale. Water has a **maximum density** at 3°·98 (Chappuis, 1897; Thiesen, Scheel and Diesselhorst; De Coppet, 1903). The temp. (t_m) of maximum density at different pressures (p), measured in atmos., is given by $t_m = 3\cdot98 - \cdot0225(p - 1)$.

The **specific volume** is the reciprocal of the density. [* 1 litre = 1000·028 c.cs.] (See Chappuis, *Trav. et Mém. Bur. Intl.*, **13**, 1907.)

Heavy water has a max. density of 1·1059 at 11·6° C.

Density of water at −**10°** = ·99815; at −**5°** = ·99930.

Temp.	0	2	4	6	8	10	12	14	16	18
0° C.	·99987	·99997	1·00000	·99997	·99988	·99973	·99953	·99927	·99897	·99862
20	·99823	·99780	·99732	·99681	·99626	·99567	·99505	·99440	·99371	·9930
40	·9922	·9915	·9907	·9898	·9890	·9881	·9872	·9862	·9853	·9843
60	·9832	·9822	·9811	·9801	·9789	·9778	·9767	·9755	·9743	·9731
80	·9718	·9706	·9693	·9680	·9667	·9653	·9640	·9626	·9612	·9598
100	·9584	—	—	—	—	·951	—	—	—	—

Density at **150°** = ·917; at **200°** = ·863; at **250°** = ·79; at **300°** = ·70.

DENSITY OF MERCURY

In grams per m.l. Hydrogen scale of temp. For reciprocals, see p. 158. (See Chappuis, *Trav. et Mém. Bur. Intl.*, 16, 1917.)

Temp.	0	2	4	6	8	10	12	14	16	18
	13	13	13	13	13	13	13	13	13	13
−20° C.	·6450	·6400	·6351	·6301	·6251	·6202	·6152	·6103	·6053	·6004
0	·5955	·5905	·5856	·5806	·5757	·5708	·5659	·5609	·5560	·5511
20	·5462	·5413	·5364	·5315	·5266	·5217	·5168	·5119	·5070	·5022
40	·4973	·4924	·4875	·4826	·4778	·4729	·4680	·4632	·4583	·4534
60	·4486	·4437	·4389	·4340	·4292	·4243	·4195	·4146	·4098	·4050
80	·4001	·3953	·3904	·3856	·3808	·3759	·3711	·3663	·3615	·3566
	0	20	40	60	80	100	120	140	160	180
100	13·3518	13·304	13·256	13·208	13·160	13·113	13·065	13·018	12·970	12·922
300	12·875	12·827	12·779	12·737	—	—	—	—	—	—

(B.P. = 357·1° C.)

DENSITY OF ETHYL ALCOHOL, C_2H_5OH . Aq

In grams per c.c. % indicates grams of C_2H_5OH in 100 grams of aqueous solution. Hydrogen scale of temp. (Calculated by E. W. Morley from Mendeléeff's Observations, *Jour. Am. Chem. Soc.*, Oct. 1904.)

At 17° C.

%	0	1	2	3	4	5	6	7	8	9
0	·9988	·9969	·9951	·9933	·9916	·9899	·9884	·9869	·9854	·9840
10	·9826	·9813	·9800	·9787	·9775	·9762	·9750	·9737	·9725	·9713
20	·9700	·9687	·9674	·9661	·9647	·9633	·9619	·9604	·9589	·9573
30	·9557	·9540	·9524	·9506	·9489	·9470	·9452	·9433	·9414	·9394
40	·9375	·9354	·9334	·9313	·9292	·9271	·9250	·9228	·9207	·9185
50	·9163	·9140	·9118	·9096	·9073	·9051	·9028	·9005	·8982	·8959
60	·8936	·8913	·8890	·8867	·8843	·8820	·8797	·8773	·8749	·8726
70	·8702	·8678	·8655	·8631	·8607	·8582	·8558	·8534	·8510	·8485
80	·8461	·8436	·8411	·8386	·8361	·8336	·8310	·8285	·8259	·8232
90	·8206	·8179	·8152	·8124	·8096	·8068	·8039	·8010	·7980	·7950
100	·7919	—	—	—	—	—	—	—	—	—

For other temperatures, interpolate from the above and the following :—

At 22° C.

0%, ·9978; 10%, ·9813; 20%, ·9678; 30%, ·9526; 40%, ·9338; 50%, ·9122; 60%, ·8895; 70%, ·8660; 80%, ·8417; 90%, ·8162; 100%, ·7876.

DENSITY OF HYDROCHLORIC ACID, HCl . Aq

Grams per c.c. at 15° C. (Lunge and Marchlewski, 1891.)

Dens.	Grams HCl in		Dens. Change for ± 1°.	Dens.	Grams HCl in		Dens. Change for ± 1°.	Dens.	Grams HCl in		Dens. Change for ± 1°.
	100 gm.	1 litre			100 gm.	1 litre			100 gm.	1 litre	
	of Solution.				of Solution.				of Solution.		
1·01	2·14	22	·00016	1·08	16·15	174	·00035	1·15	29·6	340	·00052
1·02	4·13	42	·00019	1·09	18·1	197	·00038	1·16	31·5	366	·00054
1·03	6·15	64	·00021	1·10	20·0	220	·00040	1·17	33·5	392	·00056
1·04	8·16	85	·00024	1·11	21·9	243	·00043	1·18	35·4	418	·00058
1·05	10·17	107	·00027	1·12	23·8	267	·00045	1·19	37·2	443	·00059
1·06	12·19	129	·00030	1·13	25·7	291	·00048	1·20	39·1	469	·00060
1·07	14·17	152	·00032	1·14	27·7	315	·00050				

DENSITY OF NITRIC ACID, HNO_3 . Aq

Grams per c.c. at 15° C. % N_2O_5 = ·857 × % HNO_3—by weight. (Lunge and Rey, 1891.)

Dens.	Grams HNO_3 in		Dens. Change for ± 1°.	Dens.	Grams HNO_3 in		Dens. Change for ± 1°.	Dens.	Grams HNO_3 in		Dens. Change for ± 1°.
	100 gm.	1 litre			100 gm.	1 litre			100 gm.	1 litre	
	of Solution.				of Solution.				of Solution.		
1·02	3·70	38	·00022	1·22	35·3	430	·00080	1·42	69·8	991	·00137
1·04	7·26	75	·00028	1·24	38·3	475	·00086	1·44	74·7	1075	·00143
1·06	10·7	113	·00034	1·26	41·3	521	·00091	1·46	80·0	1168	·00149
1·08	13·9	151	·00040	1·28	44·4	568	·00097	1·48	86·0	1274	·00154
1·10	17·1	188	·00045	1·30	47·5	617	·00103	1·50	94·1	1411	·00160
1·12	20·2	227	·00051	1·32	50·7	669	·00109	1·504	96·0	1444	·00161
1·14	23·3	266	·00057	1·34	54·1	725	·00114	1·508	97·5	1470	·00162
1·16	26·4	306	·00062	1·36	57·6	783	·00120	1·512	98·5	1490	·00163
1·18	29·4	347	·00068	1·38	61·3	846	·00126	1·516	99·2	1504	·00164
1·20	32·4	388	·00074	1·40	65·3	914	·00132	1·520	99·7	1515	·00166

DENSITY OF SULPHURIC ACID, H_2SO_4 . Aq

Grams per c.c. at 15° C. % SO_3 = ·816 × % H_2SO_4—by weight. (Lunge and Isler, 1895.)

Density.	Grams H_2SO_4 in		Density.	Grams H_2SO_4 in		Density.	Grams H_2SO_4 in	
	100 gm.	1 litre		100 gm.	1 litre		100 gm.	1 litre
	of Solution.			of Solution.			of Solution.	
1·02	3·03	31	1·44	54·1	779	1·822	90·4	1647
1·04	5·96	62	1·46	56·0	817	1·824	90·8	1656
1·06	8·77	93	1·48	57·8	856	1·826	91·2	1666
1·08	11·60	125	1·50	59·7	896	1·828	91·7	1676
1·10	14·35	158	1·52	61·6	936	1·830	92·1	1685
1·12	17·01	191	1·54	63·4	977	1·832	92·5	1695
1·14	19·61	223	1·56	65·1	1015	1·834	93·0	1706
1·16	22·19	257	1·58	66·7	1054	1·836	93·8	1722
1·18	24·76	292	1·60	68·5	1096	1·838	94·6	1739
1·20	27·3	328	1·62	70·3	1139	1·840	95·6	1759
1·22	29·8	364	1·64	72·0	1181			
1·24	32·3	400	1·66	73·6	1222	1·8405	95·9	1765
1·26	34·6	435	1·68	75·4	1267	1·8410	97·0	1786
1·28	36·9	472	1·70	77·2	1312	1·8415	97·7	1799
1·30	39·2	510	1·72	78·9	1357	1·8410	98·2	1808
1·32	41·5	548	1·74	80·7	1404	1·8405	98·7	1816
1·34	43·7	586	1·76	82·4	1451	1·8400	99·2	1825
1·36	45·9	624	1·78	84·5	1504	1·8395	99·4	1830
1·38	48·0	662	1·80	86·9	1564	1·8390	99·7	1834
1·40	50·1	702	1·81	88·3	1598	1·8385	99·9	1838
1·42	52·1	740	1·82	90·0	1639			

DENSITY OF AMMONIA, NH_4HO . Aq

Grams per c.c. at 15° C.

Dens.	Grams NH_3 in 100 gm. of Solution.	Grams NH_3 in 1 litre of Solution.	Dens. Change for ± 1°.	Dens.	Grams NH_3 in 100 gm. of Solution.	Grams NH_3 in 1 litre of Solution.	Dens. Change for ± 1°.	Dens.	Grams NH_3 in 100 gm. of Solution.	Grams NH_3 in 1 litre of Solution.	Dens. Change for ± 1°.
·996	·91	9·1	·00019	·956	11·03	105·4	·00031	·916	23·03	210·9	·00049
·992	1·84	18·2	·00020	·952	12·17	115·9	·00033	·912	24·33	221·9	·00051
·988	2·80	27·7	·00021	·948	13·31	126·2	·00035	·908	25·65	232·9	·00053
·984	3·80	37·4	·00022	·944	14·46	136·5	·00037	·904	26·98	243·9	·00055
·980	4·80	47·0	·00023	·940	15·63	146·9	·00039	·900	28·33	255·0	·00057
·976	5·80	56·6	·00024	·936	16·82	157·9	·00041	·896	29·69	266·0	·00059
·972	6·80	66·1	·00025	·932	18·03	168·1	·00042	·892	31·05	277·0	·00060
·968	7·82	75·7	·00026	·928	19·25	178·6	·00043	·888	32·50	288·6	·00062
·964	8·84	85·2	·00027	·924	20·49	189·3	·00045	·884	34·10	301·4	·00064
·960	9·91	95·1	·00029	·920	21·75	200·1	·00047	·880	35·70	314·2	·00066

DENSITY OF SODIUM HYDROXIDE, NaHO . Aq

Grams per c.c. at 18° C. The percentages indicate grams of NaOH in 100 grams of solution. (Bousfield and Lowry, 1905.)

%	Density.	%	Density.	%	Density.	%	Density.	%	Density.
0	·9986	10	1·1098	20	1·2202	30	1·3290	40	1·4314
1	1·0100	11	1·1208	21	1·2312	31	1·3396	41	1·4411
2	1·0213	12	1·1319	22	1·2422	32	1·3502	42	1·4508
3	1·0324	13	1·1429	23	1·2532	33	1·3605	43	1·4604
4	1·0435	14	1·1540	24	1·2641	34	1·3708	44	1·4699
5	1·0545	15	1·1650	25	1·2751	35	1·3811	45	1·4794
6	1·0656	16	1·1761	26	1·2860	36	1·3913	46	1·4890
7	1·0766	17	1·1871	27	1·2968	37	1·4014	47	1·4985
8	1·0877	18	1·1982	28	1·3076	38	1·4115	48	1·5080
9	1·0987	19	1·2092	29	1·3184	39	1·4215	49	1·5174

DENSITY OF SODIUM CARBONATE, Na_2CO_3 . Aq

Grams per c.c. at 15° C. (Lunge.)

Density.	Grams Na_2CO_3 in 100 gm. of Solution.	Grams Na_2CO_3 in 1 litre of Solution.	Density.	Grams Na_2CO_3 in 100 gm. of Solution.	Grams Na_2CO_3 in 1 litre of Solution.	Density.	Grams Na_2CO_3 in 100 gm. of Solution.	Grams Na_2CO_3 in 1 litre of Solution.
1·007	·67	6·8	1·060	5·71	60·5	1·116	10·95	122·2
1·014	1·33	13·5	1·067	6·37	68·0	1·125	11·81	132·9
1·022	2·09	21·4	1·075	7·12	76·5	1·134	12·61	143·0
1·029	2·76	28·4	1·083	7·88	85·3	1·142	13·16	150·3
1·036	3·43	35·5	1·091	8·62	94·0	1·152	14·24	164·1
1·045	4·29	44·8	1·100	9·43	103·7			
1·052	4·94	52·0	1·108	10·19	112·9			

Change of density per 1° C. (0° to 30°), 0 to 7 % = ·0002 ; 11 to 20 % = ·0004.

DENSITY OF CALCIUM CHLORIDE, $CaCl_2$. Aq

Grams per c.c. at 17·9° C. The percentages indicate grams of anhydrous $CaCl_2$ in 100 grams of solution. (Pickering, 1894.)

%	Density.	%	Density.	%	Density.	%	Density.	%	Density.
1	1·007	11	1·094	21	1·189	31	1·294	41	1·406
3	1·024	13	1·112	23	1·209	33	1·316	43	1·429
5	1·041	15	1·131	25	1·229	35	1·338		
7	1·058	17	1·150	27	1·250	37	1·361		
9	1·076	19	1·169	29	1·272	39	1·384		

DENSITIES OF SOME AQUEOUS SOLUTIONS

Grams per c.c. at 18° C. The indicated % is the number of grams of anhydrous substance in 100 grams of solution. (Kohlrausch, "Prakt. Phys.")

Substance.	5%	10%	15%	20%	25%	Substance.	5%	10%	15%	20%
$NaCl$.	1·034	1·071	1·109	1·148	1·190	$MgSO_4$.	1·050	1·104	1·160	1·220
$Na\underline{N}O_3$	1·033	1·068	1·105	1·144	1·185	$BaCl_2$.	1·044	1·093	1·147	1·204
$Na\bar{A}$.	1·025	1·051	1·078	1·105	1·132	NH_4Cl .	1·014	1·029	1·043	1·057
H_3PO_4 .	1·027	1·054	1·083	1·114	1·145	$CuSO_4$.	1·051	1·107	1·167	1·230
$ZnSO_4$.	1·051	1·107	1·167	1·232	1·305	KCl . .	1·031	1·064	1·098	1·133
$FeCl_3$.	1·130	1·175	1·226	1·278	1·331	KNO_3 .	1·030	1·063	1·097	1·133
$SrCl_2$.	1·044	1·093	1·146	1·202	1·256	K_2SO_4 .	1·039	1·081	—	—
$MgCl_2$.	1·042	1·086	1·130	1·176	1·225	$K_2Cr_2O_7$	1·035	1·072	1·109	—

Substance.	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
KBr . .	1·035	1·073	1·114	1·157	1·204	1·254	1·307	1·365	1·429	—
KI . .	1·036	1·076	1·120	1·168	1·218	1·273	1·332	1·397	1·468	1·545
K_2CO_3 .	1·044	1·091	1·140	1·191	1·244	1·299	1·356	1·415	1·477	1·541
$LiCl$ . .	1·027	1·056	1·085	1·115	1·147	1·181	1·217	1·255	—	—
$CdSO_4$.	1·049	1·103	1·161	1·224	1·295	1·372	1·457	—	—	—
$Ag\underline{N}O_3$.	1·042	1·089	1·140	1·196	1·255	1·321	1·394	1·477	1·570	1·674
$Pb\bar{A}_2$.	1·036	1·075	1·118	1·163	1·212	1·265	1·322	1·386	—	—
Sugar*.	1·018	1·039	1·060	1·081	1·104	1·128	1·152	1·177	1·203	1·230

* 60%, 1·287 ; [75%, 1·380 (supersaturated)].

DENSITY OF DRY AIR AT DIFFERENT TEMPERATURES AND PRESSURES

Grams per c.c. ; pressures in mm. of mercury at 0° C. lat. 45° ; $g = 980{\cdot}62$ cms. per sec.². These densities are calculated by the expression $\frac{\cdot001293}{(1 + \cdot00367t)} \cdot \frac{H}{760}$, where ·001293 is due to Leduc, 1898, and Rayleigh, 1893 (p. 35) ; and ·00367 to Regnault. For density of damp air, see p. 30.

Temp. (t).	Pressure in Millimetres (H).							
	710	720	730	740	750	760	770	780
0° C.	·001208	·001225	·001242	·001259	·001276	·001293	·001310	·001327
2	·001199	·001216	·001233	·001250	·001267	·001284	·001300	·001317
4	·001190	·001207	·001224	·001241	·001258	·001274	·001291	·001308
6	·001182	·001199	·001215	·001232	·001248	·001265	·001282	·001298
8	·001173	·001190	·001207	·001223	·001240	·001256	·001273	·001289
10	·001165	·001182	·001198	·001214	·001231	·001247	·001264	·001280
12	·001157	·001173	·001190	·001206	·001222	·001238	·001255	·001271
14	·001149	·001165	·001181	·001197	·001214	·001230	·001246	·001262
16	·001141	·001157	·001173	·001189	·001205	·001221	·001237	·001253
18	·001133	·001149	·001165	·001181	·001197	·001213	·001229	·001245
20	·001125	·001141	·001157	·001173	·001189	·001205	·001220	·001236
22	·001118	·001133	·001149	·001165	·001181	·001196	·001212	·001228
24	·001110	·001126	·001141	·001157	·001173	·001188	·001204	·001220
26	·001103	·001118	·001134	·001149	·001165	·001180	·001196	·001211
28	·001095	·001111	·001126	·001142	·001157	·001173	·001188	·001203
30	·001088	·001103	·001119	·001134	·001149	·001165	·001180	·001195

DENSITIES OF GASES

Only those gases for which accurate density determinations have been made are included in this table (see also p. 17). Other gases will be found in the table below. For density of air under different temperatures and pressures, see p. 34.

Densities are in grams per litre (1000·028 c.cs.; see p. 17) at 0° C. under 760 mm. of mercury at 0° C. and lat. 45° ($g = 980·62$), *i.e.* under a pressure of $1·01323 \times 10^6$ dynes per sq. cm. (After P. A. Guye, *Chem. News*, 1908.)

Gas.	Density and Observer.	Accepted density.	Density rel. to O
		Grams/litre.	
Air	1·2927 L.; 1·2928 R.	1·2928	0·90469
Oxygen, O_2	1·4288 L.; 1·42905 R.; 1·42900 M.; 1·42896 Gr.; 1·4292 J.P.	1·42900	**1·00000**
Hydrogen, H_2	0·08982 L.; 0·08998 R.; 0·089873 M.	0·08987	0·06289
Nitrogen, N_2	1·2503 L.; 1·2507 R.; 1·2507 Gr.	1·2507	0·87523
Argon, A	1·7809 R.; 1·7808 Ra.	1·7809	1·2463
Nitrous oxide, N_2O	1·9780 L.; 1·9777 R.; 1·9774 G.P.	1·9777	1·3840
Nitric oxide, NO	1·3429 L.; 1·3402 Gr.; 1·3402 G.D.	1·3402	0·93786
Ammonia, NH_3	0·7719 L.; 0·77085 P.D.; 0·7708 G.P.	0·7708	0·5394
Carbon monoxide, CO	1·2501 L.; 1·2504 R.	1·2504	0·87502
Carbon dioxide, CO_2	1·9763 L.; 1·9769 R.; 1·9768 G.P.	1·9768	1·3833
Hydrochloric acid, HCl	1·6407 L.; 1·6397 Gr.; 1·6398 G.G.	1·6398	1·1475
Sulphur dioxide, SO_2	2·9266 L.; 2·9266 J.P.; 2·9266 B.	2·9266	2·0480

B., Berthelot; G.D., Guye & Davila; G.G., Guye & Gazarian; G.P., Guye & Pintza; Gr., Gray; J.P., Jacquerod & Pintza; L., Leduc; M., Morley; P.D., Perman & Davies; R., Rayleigh; Ra., Ramsay.

The densities below are all **experimental values**, and are relative to that of oxygen ($O_2 = 16$) at 0° and 760 mms. at lat. 45° (see above).

Gas.	Rel. dens.	Gas.	Rel. dens.	Gas.	Rel. dens.
Acetylene, C_2H_2	13·32	Helium, He	1·98	Nitrogen oxychloride,	
Arsine, AsH_3	39·02	Hydrobromic acid,		NOCl	33·45
Boron fluoride, BF_3	33·48	HBr	39·24	Nitrogen peroxide—	
Bromine, Br_2 *c.* **228**°C.	79·99	Hydrofluoric acid, HF	10·32	(N_2O_4) **26°·7** C.	38·37
Butane, C_4H_{10}	29·10	Hydriodic acid, HI	63·36	„ „ **39°·8**	35·62
Carbon oxychloride,		Hydrogen selenide,		„ „ **60°·2**	30·12
$COCl_2$	50·75	H_2Se	40·47	„ „ **80°·6**	26·06
„ oxysulphide, COS	30·47	„ sulphide, H_2S	17·22	„ „ **100°·1**	24·33
Chlorine, Cl_2	36·07	„ telluride, H_2Te	65·00	„ „ **121°·5**	23·46
„ monoxide, Cl_2O	43·54	Krypton, Kr	41·5	„ (NO_2) **154°·0**	22·88
„ dioxide, ClO_2	33·74	Methane, CH_4 (1909)	8·03	„ „ **183°·2**	22·73
Cyanogen, C_2N_2	26·16	Methylamine,		Phosphine, PH_3	17·58
Ethane, C_2H_6	15·57	CH_3NH_2	15·64	Phosphorus chloro-	
Ethylamine,		Methyl chloride,		fluoride, PCl_2F_3	78·19
$C_2H_5NH_2$	22·77	CH_3Cl	25·06	„ oxyfluoride, POF_3	53·29
Ethyl chloride,		Methyl ether, C_2H_6O	23·41	„ pentafluoride, PF_5	65·01
C_2H_5Cl	32·13	„ fluoride, CH_3F	17·67	„ trifluoride, PF_3	43·76
Ethyl fluoride, C_2H_5F	24·62	Methylene fluoride,		Propylene, C_3H_6	21·69
Ethylene, C_2H_4	14·27	CH_2F_2	26·21	Silicon fluoride, SiF_4	52·13
Fluorine, F_2	18·97	Neon, Ne (1910)	10·82	Xenon, Xe	65·35

DENSITY OF SATURATED WATER VAPOUR

Densities in grams per litre under different pressures. (Zeuner, 1890.)

Atmos.	0	0·5	1	1·5	2	2·5	3	3·5	4	4·5
0	—	0·315	0·606	0·887	1·16	1·43	1·70	1·97	2·23	2·49
5	2·75	3·01	3·26	3·52	3·77	4·02	4·27	4·52	4·77	5·02
10	5·27	5·52	5·76	6·01	6·25	6·50	6·74	6·99	7·23	—

ELASTICITIES

Young's Modulus, or Longitudinal Elasticity, E in dynes per sq. cm.
Rigidity, Torsion Modulus, or Shear Modulus, n in dynes per sq. cm.
Volume Elasticity, Cubic Elasticity, or Bulk Modulus, k in dynes per sq. cm.
Compressibility (cubic), $C = 1/k$.

Poisson's Ratio, σ = lateral contraction per unit breadth/longitudinal extension per unit length. For a homogeneous isotropic substance—

$$n = \frac{E}{2(1+\sigma)} \quad \ldots (a); \qquad \sigma = \frac{E}{2n} - 1 \quad \ldots (b); \qquad k = \frac{E}{3(1-2\sigma)} \quad \ldots (c)$$

For an isotropic solid Poisson's Ratio must lie between $+\frac{1}{2}$ and -1, but for some materials it may, when deduced from E and n, exceed $+1$. (See Searle's "Elasticity.")

1 bar = 10^6 dynes per sq. cm. = ·987 atmos. = 1/1·013 atmos. = the pressure measured by 750·15 mms. of mercury at 0° C. sea-level, and latitude 45° = 749·66 mms. at 0° in London.

The elasticities of a substance depend considerably upon its history. The extent of the agreement between the calculated and observed values of n and of σ below gives an indication of the degree of isotropy of the metals used. (Grüneisen, Reichsanstalt, *Ann. d. Phy.*, 1908.)

ELASTICITIES OF METALS

Metal at 18° C. (see also below and pp. 37, 38).	Young's Modulus, E.	Rigidity, n.		Poisson's Ratio, σ.		Vol. Elast. k.	Compress^y C. per bar (calculated).
	By static method or longl. vibns.	By oscilln. method.	Calcd. by formula (a).	Observed.	Calcd. by formula (b).	Calcd. by formula (c).	
Aluminium (W) * .	7·05 × 10^{11}	2·67 × 10^{11}	2·63 × 10^{11}	·339	·310	7·46 × 10^{11}	1·33 × 10^{-6}
Bismuth (C), pure .	3·19	—	1·20	·33	—	3·14	3·2
Cadmium (C), pure	4·99	—	1·92	·30	—	4·12	2·4
Copper (W), pure .	12·3	4·55	4·55	·337	·356	13·1	·74
Gold (W), pure .	8·0	2·77	2·80	·422	·495	16·6	·60
Iron (W), ·1%C. .	21·3	—	8·31	·280	—	16·1	·63
Steel (W), 1%C. .	20·9	8·12	8·12	·287	·287	16·4	·62
Lead (C), pure . .	1·62	—	·562	·446	—	5·00	2·0
Nickel (W) † . .	20·2	—	7·70	·309	—	17·6	·57
Palladium (C), pure	11·3	5·11	4·04	·393	·101	17·6	·57
Platinum (C), pure	16·8	6·10	6·04	·387	·368	24·7	·41
Silver (W), pure .	7·90	2·87	2·86	·379	·369	10·9	·92
Tin (C), pure . .	5·43	—	2·04	·33	—	5·29	1·9
Bronze (C) ‡ . . .	8·08	3·43	2·97	·358	·177	9·52	1·05
Constantan (W) § .	16·3	6·11	6·11	·325	·329	15·5	·65
Manganin (W) ‖ .	12·4	4·65	4·65	·329	·329	12·1	·83

(C) means cast; (W) worked. * ·5% Fe, ·4% Cu. † 97% Ni, 1·4% Co, 1% Mn.
‡ 85·7% Cu, 7·2% Zn, 6·4% Sn. § 60% Cu, 40% Ni. ‖ 84% Cu, 12% Mn, 4% Ni.

The (experimental) results below are mostly for **ordinary laboratory materials**, chiefly wires.

Substance.	Young's Modulus, E.	Rigidity, n.	Volume Elast. k.	Poisson's Ratio, σ.
Copper	12·4–12·9 × 10^{11} S.	3·9–4 × 10^{11} S.	14·3 × 10^{11} M.	·26 S.
Iron (wrought) . . .	19–20	7·7–8·3	14·6	*c.* ·27
„ (cast)	10–13 G.	3·5–5·3	9·6	·23–·31
Steel	19·5–20·6	7·9–8·9	18·1 M.	·25–·33
Zinc (1% Pb)	8·7 § G.	3·8	—	·21
Brass (*c.* 66 Cu, 34 Zn) .	9·7–10·2	*c.* 3·5	10·65 M.	·34–·40
German silver * . . .	11·6 S.	4·3–4·7	—	·37
Platinoid †	13·6 S.	3·60 S.	—	·37
Phosphor bronze ‡ . .	12·0 S.	4·36 S.	—	·38 S.
Quartz fibre	5·18	3·0 H.	1·4	—
Rubber, soft vulcanized	·10–·70	·00016	—	·46–·49 Sc.
Jena Glasses, Crowns .	6·5–7·8	2·6–3·2	4·0–5·9	·20–·27
„ „ Flints	5·0–6·0	2·0–2·5	3·6–3·8	·22–·26

(G.) Grüneisen, 1907. (H.) Horton, 1905. (M.) Mallock, 1905. (S.) Searle, 1900.
(Sc.) Schiller, 1906. * 60 Cu, 15 Ni, 25 Zn. † German silver with a little tungsten.
‡ 92·5 Cu, 7 Sn, ·5 P. § Pure Zn, 12·5 × 10^{11} dynes/cm².

ELASTICITIES (*contd.*)

Substance.	Young's Modulus, E. dynes/cm.²	Temperature coefficient α in $\text{Elast}_t = \text{Elast}_{15}\{1 - \alpha(t - 15)\}$			Compressibility C. per bar (i.e. 10^6 dynes/cm.²) (Buchanan, *Proc. R. Soc.*, 1904).	
		At 15° C.	α for E.*	α for n †	7–11° C.; 200–300 bars (see also pp. 36, 38).	
Iridium ‖	$5·2 \times 10^{11}$ (G.)	Aluminium	$21·3 \times 10^{-4}$	$13·5 \times 10^{-4}$	Aluminium	$1·7 \times 10^{-6}$
Rhodium ‖	3·2 (G.)	Copper	3·64	4·0	Copper	·88
Tantalum	18·6 (Bo.)	Gold	4·8	3·3	Gold	·80
Invar	14·1	Iron	2·3	7·3	Lead	2·8 (A.)
90 Pt, 10 Ir	21·0	Steel	2·4	2·6	Magnesium	3·2
Duralumin	7·4	Platinum	·98	1·0	Platinum	·56
Silk fibre	·65 ‡	Silver	7·5	4·5	Flint glass	3·0
Spider thread	·3 (B.)§	Tin	—	5·9	Germ. glass tubing	2·57
Catgut	·32	Brass	3·7	4·6	Steel	·51 (Br.)
Ice (−2°)	·28	German silver		6·5		
Quartz	6·8	Phosphor-bronze		c. 3		
Marble	2·6	Quartzfibre	−1·3	−1·2		
Oak	1·3					
Deal	·9					
Mahogany	·88					
Teak	1·66					

(A.) Amagat. (B.) Benton, 1907 and 1908. (Bo.) v. Bolton, 1905. (Br.) Bridgman, 1909. (G.) Grüneisen, 1907. * Wassmuth, 1906, and Schaefer, 1902. † Horton, 1904 and 1905. ‡ Diminishes rapidly with increasing load. § Shows marked elastic fatigue. ‖ Pure.

TENSILE STRENGTHS OF MATERIALS

Tenacities or breaking stresses in dynes per sq. cm. The elastic limit is always exceeded before the breaking stress is reached. The process of drawing into wire seems to strengthen the material, and the finer the wire the greater is the breaking stress. (See Poynting and Thomson's "Properties of Matter.")

For crushing and shearing strengths, see Ewing's "Strength of Materials" or one of the Engineering "Pocket-books." For bursting strengths of tubing, see p. 48.

To reduce to kilogrammes per sq. mm., it is sufficient to divide by 10^8; to lbs. per sq. inch, divide by 7×10^4; to tons per sq. inch, divide by $1·5 \times 10^8$.

* Along the grain.

Substance.	Tenacity.	Substance.	Tenacity.
	dynes/cm.²		dynes/cm.²
Aluminium, cast	$·6–·9 \times 10^9$	White or yellow pine *	$·2–·5 \times 10^9$
" rolled	·9–1·5	Leather belt	c. ·3
Copper, cast	1·2–1·9	Hemp rope	·6–1·0
" rolled	2·0–2·5	Catgut	4·2
Iron, (*a*) cast	·8–2·3	Spider thread	1·8
(*b*) wrought	2·9–4·5	Silk fibre	2·6
(*c*) steel castings	2·3–7·0	Quartz fibre	c. 10
Mild steel (·2 % C)	4·3–4·9	WIRES.	
High carbon (for springs) annld.	7·0–7·7	Aluminium	1·7–2·0
High carbon (for springs) temprd.	9·3–10·8	Copper, hard drawn	4·0–4·6
Tungsten or chrome	11–12	" annealed	2·8–3·1
Ni steel, 5 %; 12 %	6·2; 14	Gold	2·6
Lead	c. ·16	Iron (charcoal), hard drawn	5·4–6·2
Tin	·16–·38	" " annealed	c. 4·6
Zinc, rolled	1·1–1·5	Steel; (1) ordinary; (2) tempd.	c. 11; 15·5
Brass (ordinary), 66 Cu 34 Zn cast	1·5–1·9	" pianoforte	18·6–23·3
" " rolled	2·3–3·7	Nickel	5·3
Phosphor-bronze	2·5–2·8	Platinum	3·3
Gun-metal (90 Cu, 10 Sn)	1·9–2·6	Silver	2·9
Soft solder	c. ·5	Tantalum	4·2
Glass	·3–·9	Brass	3·1–3·9
Ash, beech, oak, teak, mahogany*	·6–1·1	Phosphor-bronze, hard drawn	6·9–10·8
Fir, pitch-pine *	·4–·8	German silver	4·6
Red or white deal *	·3–·7	Duralumin	4–5 5

COMPRESSIBILITIES OF ELEMENTS

Coefficient of compressibility $C = \frac{1}{V} \cdot \frac{\delta V}{\delta p}$, where δV is the change in volume of a volume V under a change of pressure δp (temp. constant). See also pp. 36, 37.

The values of C below are per bar (*i.e.* 10^6 dynes per sq. cm.). To express as compressibility per atmosphere, increase C by $\frac{1}{80}$ of its value. Room temp. Pressure range, 100–500 bars. Based on compressibility of mercury = $0{\cdot}_5371$ per bar. The results show a periodic relation with atomic weight. See Richards, *Journ. Chem. Soc.*, 1911; and Bridgman, *Proc. Nat. Acad. Sci.*, 1915 *et seq.*

Element.	C	Element.	C	Element.	C	Element.	C
Al. . .	$1{\cdot}3 \times 10^{-6}$	Cl (liq.).	95×10^{-6}	Hg . .	$3{\cdot}71 \times 10^{-6}$	Si. . .	$\cdot16 \times 10^{-6}$
Sb. . .	2·2 „	Cr. . .	·7 „	Mo . .	·26 „	Ag . .	·84 „
As. . .	4·3 „	Cu . .	·54 „	Ni . .	·27 „	Na . .	15·4 „
Bi. . .	2·8 „	Au . .	·47 „	Pd . .	·38 „	S. . .	12·5 „
Br. . .	51·8 „	I . . .	13 „	P, red .	9·0 „	Tl . .	2·6 „
Cd . .	1·9 „	Fe . .	·40 „	white.	20·3 „	Sn . .	1·7 „
Cs. . .	61 „	Pb . .	2·2 „	Pt . .	·21 „	Zn . .	1·5 „
Ca. . .	5·5 „	Li . .	8·8 „	K. . .	31·5 „		
C, diamond	·5 „	Mg . .	2·7 „	Rb . .	40 „		
graphite	3 „	Mn . .	·67 „	Se . .	11·8 „		

COMPRESSIBILITIES OF LIQUIDS

C = compressibility per bar (*i.e.* 10^6 dynes per cm.^{2}). To express as compressibility per atmosphere, increase C by $\frac{1}{80}$ of its value.

As the pressure increases C becomes less. In general a rise in temperature increases the compressibility of a liquid; but water, however, shows a minimum value of C at about 50° C. (Amagat). The compressibility of a solution diminishes as the concentration increases (see Poynting and Thomson's "Properties of Matter," and Bridgman's "The Physics of High Pressure").

Where the limits of pressure are not given, they are—for Amagat, 8–37 atmos.; for Röntgen, 8 atmos.; for Richards, 100–200 atmos.

Liquid.	Temp.	Comp. C per bar.	Liquid.	Temp.	Comp. C per bar.
Water, 1–25 atmos. (A.)	15° C.	$48{\cdot}9 \times 10^{-6}$	Carbon tetrachloride (Ri.)	20° C.	$89{\cdot}6 \times 10^{-6}$
900–1000 „ (A.)	15	36·3 „	Carbon bisulphide (A.)	15·6	85·9 „
900–1000 „ (A.)	198	55·4 „	Ether, 1–50 atmos. (A.)	0	145·2 „
2500–3000 „ (A.)	14·2	25·8 „	900–1000 „ (A.)	0	64·2 „
Sea-water (Grassi, 1851)	—	43·1 „	„ „ (A.)	198	142·2 „
Mercury . . . (A.)	20	3·82 „	Methyl acetate . (A.)	14·3	95·8 „
„ . . . (Ri.)	15	3·71 „	Ethyl acetate . . (A.)	13·3	102·7 „
Methyl alcohol, CH_3OH (A.)	14·7	102·7 „	„ bromide . (A.)	99·3	291·3 „
Ethyl alcohol—			„ chloride . (A.)	15·2	151·1 „
1–500 atm. (A.)	0	76 „	Acetic acid, 1–16 atm. (C. & S.)	0	40·2 „
150–200 atm. (Ba.)	310	4147 „	Glycerine, $C_3H_5(OH)_3$ (Q.)	20·5	24·8 „
Propyl alcohol, C_3H_7OH . . (R.)	17·7	95·8 „	Olive oil . . . (Q.)	20·5	62·5 „
Propyl alcohol iso- (R.)	17·8	101·7 „	Paraffin oil (de Metz, 1890)	14·8	61·9 „
Butyl alcohol, C_4H_9OH (R.)	17·4	88·9 „	Petroleum (Martini) .	16·5	68·7 „
Butyl alcohol iso- (R.)	17·9	96·8 „	Pentane, C_5H_{12} . (G.)	20	314 „
Amyl alcohol, $C_5H_{11}OH$ . . (R.)	17·7	89·4 „	Benzene, C_6H_6 . (R.)	17·9	90·8 „
Chloroform . . (Ri.)	20	9·4 „	Turpentine, $C_{10}H_{16}$ (Q.)	19·7	78·14 „

(A.) Amagat, *Comptes Rendus*, 1884–93; (B.) Bartoli, 1896; (Ba.) Barus, 1891; (C. & S.), Colladon and Sturm, 1827; (G.) Grimaldi, 1886; (Q.) Quincke, *Wied. Ann.*, 19, 1883; (R.) Röntgen, *Wied. Ann.*, 44, 1891; (Ri.) Richards, 1907.

VISCOSITIES OF LIQUIDS

If two parallel planes are at unit distance apart in a fluid, and one of them is moving in its own plane with unit velocity relatively to the other plane, then the tangential force exerted per unit area on each of the planes is equal to the viscosity. The dimensions of a viscosity are $ML^{-1}T^{-1}$.

For the capillary-tube method of determining viscosities, Poiseuille's formula is, Viscosity $\eta = \frac{\pi p r^4 t}{8 l V}$, where p is the pressure difference between the two ends of the tube, r the radius of the tube, l its length, V the volume of liquid delivered in a time t.

VISCOSITY OF WATER

Determined by an efflux method and corrected for kinetic energy of outflow. (Hosking, *Phil. Mag.*, 1909.) Heavy water is about 30% more viscous at 20° C. than ordinary water.

Temp.	Viscosity.	Temp.	Viscosity.	Temp.	Viscosity.	Temp.	Viscosity.
	c.g.s.						
0° C.	·01793	20° C.	·01006	50° C.	·00550	90° C.	·00316
5	·01522	25	·00893	60	·00469	100	·00284
10	·01311	30	·00800	70	·00406	124*	·00223
15	·01142	40	·00657	80	·00356	153*	·00181

* de Haas, 1894.

VISCOSITY OF MERCURY

(Koch, 1881.)

Temp.	−20° C.	0°	20°	50°	100°	200°	300°
Viscosity (c.g.s.)	·0186	·0169	·0156	·0141	·0122	·0101	·0093

VISCOSITIES OF VARIOUS LIQUIDS

Substance.	0° C.	10°	20°	30°	40°	50°	60°	70°
	c.g.s.							
Methyl alcohol, CH_4O	·00813	·00686	·00591	·00515	·00450	·00396	·00349	—
Ethyl " C_2H_6O	·0177	·0145	·0119	·00989	·00827	·00697	·00591	·00504
Propyl " C_3H_8O	·0388	·0292	·0225	·0178	·0140	·0113	·00919	·00757
Isopropyl " . . .	·0456	·0324	·0237	·0175	·0133	·0103	·00804	·00642
Ether $(C_2H_5)_2O$ . .	·00286	·00258	·00234	·00212	·00197	—	·00166	—
Chloroform, $CHCl_3$.	·00700	·00626	·00564	·00511	·00465	·00426	·00390	—
Carbon tetrachloride .	·0135	·0113	·00969	·00841	·00738	·00653	·00583	·00524
" bisulphide . .	·00429	·00306	·00367	·00342	·00319	—	—	—
" dioxide (liq.) .	—	·00085	·00071	·00053	—	—	—	—
Benzene, C_6H_6 . . .	·00902	·00759	·00649	·00562	·00492	·00437	·00390	·00351
Aniline, $C_6H_5NH_2$ . .	—	·0655	·0440	·0319	·0241	·0189	·0156	—
Glycerine, $C_3H_5(OH)_3$	46·0	21·0	8·5	3·5	—	—	—	—
Bromine	·0126	·0111	·00993	·00898	·00817	·00746	—	—
Turpentine, dens. = ·87	·0225	·0178	·0149	·0127	·0107	·00926	·00821	·00728
Pentane (n), C_5H_{12} .	·00283	·00255	·00232	·00212	—	—	—	—
Hexane (n), C_6H_{14} .	·00396	·00355	·00320	·00290	·00264	·00241	·00221	
Formic acid, HCO_2H	—	·0224	·0178	·0146	·0122	·0103	·0089	·0077
Acetic acid, CH_3CO_2H	—	—	·0122	·0104	·0090	·0079	·0070	·0062
Propionic acid, $C_3H_6O_2$	·0152	·0129	·0110	·0096	·0084	·0075	·0067	·0060
Butyric " $C_4H_8O_2$	·0228	·0185	·0154	·0130	·0112	·0097	·0085	·0076
Isobutyric " "	·0188	·0157	·0131	·0113	·0098	·0086	·0076	·0068
Methyl formate . . .	·00429	·00384	·00347	·00317	—	—	—	—
Ethyl " . . .	·00505	·00448	·00402	·00362	·00328	·00299	—	—
Methyl acetate . . .	·00478	·00425	·00381	·00344	·00312	·00284	—	—

Machine oil, *c.* 1/19° ; olive oil, ·99/15° ; paraffin oil, *c.* ·02/19° ; rape oil, 1·6/20°.

RELATIVE VISCOSITIES OF SOME AQUEOUS SOLUTIONS

Strength of solutions 1 normal. Viscosities relative to that of water at same temp. For a complete list, see "International Critical Tables".

Substance.	Temp.	Relative Viscosity.	Substance.	Temp.	Relative Viscosity.
Ammonia	25° C.	1·02	Potassium chloride .	17°·6 C.	·98
Ammonium chloride .	17·6	·98	Potassium iodide . .	17·6	·91
Calcium chloride . .	20	1·31	Sodium hydrate . .	25	1·24
Hydrochloric acid .	25	1·07	Sulphuric acid . .	25	1·09

VISCOSITIES OF SOLIDS

Venice turpentine * at **17°·3**, 1300, c.g.s.
Pitch † at **0°**, 51×10^{10}; at **15°**, $1{\cdot}3 \times 10^{10}$.
Glacier ice, ‡, 12×10^{13}.
Shoemaker's wax † at **8°**, $4{\cdot}7 \times 10^{6}$. c.g.s.
Soda glass † at **575°**, 11×10^{12}.
Golden Syrup (Lyle), 1400/12°.

* R. Ladenburg, 1906. † Trouton and Andrews, 1904. ‡ Deeley, 1908.

VISCOSITY OF AIR

Precision determinations of the viscosity of air, η, have been carried out using either the rotating cylinder or the capillary tube method. The results of careful determinations by these methods are tabulated below. Weighted mean (using the weights shown), $\eta_{23} = (1830{\cdot}0 \pm 2{\cdot}5) \times 10^{-7}$ c.g.s. units.

Temperature Variation.—The linear relation—

$$\eta_{23} = \eta_t + 4{\cdot}93 \times 10^{-7}(23 - t)$$

has generally been used to reduce observations of η to 23° C., but this is not correct. Sutherland's expression $\eta_\theta = \eta_{273}(273 + c)/(\theta + c) \, . \, (\theta/273)^{3/2}$ is accurate over a wide range of temperature, and using the mean of recent experimental determinations of c, namely, $c = 117$, the value of the temperature coefficient of the viscosity of air at 23° C. is $4{\cdot}83 \times 10^{-7}$ c.g.s. units and not $4{\cdot}93 \times 10^{-7}$ c.g.s. units as is generally assumed.

VISCOSITY OF AIR AT 23° C.

Rotating Cylinder Method.				Capillary Tube Method.			
Observer.	Date.	$\eta_{23} \times 10^7$ c.g.s.	Wt.	Observer.	Date.	$\eta_{23} \times 10^7$ c.g.s.	Wt.
Bearden	1939	1838·8 ± ·06	4	Rigden	1938	1830·0 ± ·69	2
Houston	1937	1829·2 ± 2·5	3	Bond	1937	1834·6 ± ·8	1
Kellstrom . . .	1937	1832·6 ± 3·0	2	Rapp	1913	1822·7 ± 1·8	1
Harrington . . .	1916	1822·6 ± 0·7	1	Maxwell . . .	1916	1827·3	1
Gilchrist . . .	1913	1825·7 ± 1·3	1				
Mean	1830·6			Mean . . .	1829·7		

Final Weighted Mean $\eta_{23} = (\mathbf{1830{\cdot}0 \pm 2{\cdot}5}) \times \mathbf{10^{-7}}$ c.g.s. units.

VISCOSITIES OF GASES AND VAPOURS

Clerk Maxwell showed in 1860 that, on the basis of the kinetic theory, the coefficient of viscosity of a gas would be independent of the pressure, and would vary as the square root of the absolute temperature. The first relation is true except at very low pressures; the second deduction is not supported by experiment.

Of the formulæ connecting gaseous viscosity (η) and temperature (t), there are the convenient but only approximate relation of O. E. Meyer, $\eta_t = \eta_0 (1 + \alpha t)$, where α is a const.; and the less manageable but accurate formula of Sutherland (*Phil. Mag.* **31**, 1893), who, by taking account of the effects of molecular forces in bringing about collisions which otherwise would have been avoided, derived the expression $\eta_t = \eta_0 \dfrac{273 + C}{\theta + C} \, . \left(\dfrac{\theta}{273}\right)^{\frac{3}{2}}$, where θ is the absolute temperature, and C is Sutherland's constant. The formula only holds for temps. above the critical, and for pressures such that Boyle's law is approximately obeyed. Sutherland's relation is thus of the form (which lends itself to graphical treatment), $\theta = \dfrac{K\theta^{3/2}}{\eta} - C$, where K is a constant. (See Fisher, *Phys. Rev.*, 1907, 1909 *et seq.*; O. E. Meyer's "Kinetic Theory of Gases," and Loeb's "Kinetic Theory of Gases.") The values below are for dry gases.

VISCOSITIES OF GASES AND VAPOURS (*contd.*)

Gas or Vapour.	Temp.° C.	η.	Observer.
		$\times 10^{-6}$	
Hydrogen .	−21	82	Breitenbach
	0	86	,, (1901)
	15	89	,, ,,
	99	106	,, ,,
	302	139	,, ,,
Oxygen . .	0	192	Mean
	15	198	,,
	100	248	M., 1904
Nitrogen . .	−78	127	T. & B., '29
	0	167	Mean
	15	174	,,
	100	213	,,
Helium . .	−258	27	
	0	189	Schultze, '01
	15	197	,,
	185	270	,,
Neon . . .	15	312	Rankine, '10
Argon . .	0	210	Schultze, '01
	15	221	,,
	184	322	,,
Krypton . .	15	246	Rankine, '10
Xenon . .	15	222	,,
Chlorine . .	13	129	,, '12
	99	168	,,
Water (vap.) .	0	87	Sheyerer, '25
	100	120	B. & L., '30
	100	127	Smith, '24
Mercury (vap.)	0	162	Koch, '83
	300	532	,,
	380	656	,,
Nitrous oxide	−21	125	v. Obermayer ['76
	0	137	Smith, '22
	100	184	,,
Sulphur dioxide	0	117	,,
	18	125	,,
Hydrogen sulphide	0	118	Rankine & Smith, '21
	100	161	
Carbon monoxide	−78	126	T. & B., '29
	0	166	Smith, '21
	100	208	T. & B., '29
	100	212	Smith, '21
Carbon dioxide	−78	103	Vogel, '14
	0	137	Mean
	15	144	Smith, '22
	100	184	,, ['01
	302	268	Breitenbach
Methane .	20	108	Mean
Ethylene .	−21	89	Breitenbach
	0	97	,, (1901)
	15	102	,, ,,
	99·3	128	,, ,,
Alcohol (vap.)	100	109	Rappenecker
	212·5	142	,, (1910)
Ether (vap.)	100	97	,, ,,
	212·5	123	,, ,,
Chloroform (vap.)	0	99	Breitenbach
	17·4	103	,, (1901)
	61	189	,, ,,
Benzene (vap.)	0	70	Mean
	16	74	,,
	100	94	Nasini, '29

B. and L., Braune and Linke; M., Markowski; T. and B., Trautz and Baumann.

TEMPERATURE COEFFICIENTS OF VISCOSITY

Based largely on W. J. Fisher's computations (ref. above).

Gas or Vapour.	Sutherland's Consts. C	Sutherland's Consts. K	Meyer's Const. a
Air	124	150×10^{-7}	·00273
Hydrogen . . .	72	66 ,,	—
Oxygen	127	175 ,,	·00283
Nitrogen . . .	110	143 ,,	·00269
Helium	80	148 ,,	—
Neon	56	220 ,,	—
Argon	170	207 ,,	—
Krypton	188	240 ,,	—
Xenon	252	246×10^{-7}	—
Water (vap.) . .	650	—	—
Carbon monoxide	102	135 ,,	·00269
,, dioxide .	240	158 ,,	·00350
Nitrous oxide . .	313	172 ,,	·00345
Ethylene . . .	226	106 ,,	·00350
Chloroform (vap.)	454	159 ,,	—

SIZE, VELOCITY, AND FREE PATH OF MOLECULES

ρ = density of gas in gms./c.c. at 0° C. and 76 cms.
p = 1 atmos. = $1·0132 \times 10^6$ dynes/cm.^{2}
θ = absolute temperature.
R = gas constant.
b = b of Van der Waals' equation (p. 43).
k = thermal conductivity of gas (p. 61).
c_v = specific heat at const. volume (p. 68).
η = viscosity of gas (p. 40).
N = number of molecules of gas per c.c. at 0° C. and 76 cms.
σ = molecular diameter in cms.
m = mass of a single molecule (in grams).
G = square root of mean square molecular vel. (cm./sec. at 0° C.).
Ω = mean molecular velocity (cm./sec.).
L = length of mean free path in cms.

Assuming a Maxwell-Boltzmann distribution of velocities—

$$G = \sqrt{3p/(\mathrm{N}m)} = \sqrt{3p/\rho} = \sqrt{3\mathrm{R}\theta}$$
$$\Omega = 4G/\sqrt{6\pi} = ·921G$$
$$L = \eta/(·31\rho\Omega) = 2·02\eta/\sqrt{p\rho}$$

Collision frequency = $\Omega/L = 5 \times 10^9$ per sec. for O_2

SIZE, VELOCITY, AND FREE PATH OF MOLECULES (*contd.*)

MOLECULAR SIZE

The molecular diameter σ has been calculated by the following formulæ :—

1. The **viscosity** η of a gas is a function of the size of its molecules.

$$\eta = {\cdot}44\rho\Omega/(\sqrt{2}N\pi\sigma^2) \quad . \quad . \quad . \quad \text{Jeans} \qquad \therefore \sigma = \{{\cdot}0912\rho G/(N\eta)\}^{\frac{1}{2}}$$

2. The **thermal conductivity**, $k = 1{\cdot}6\eta c_v = {\cdot}158\rho\Omega c_v/N\sigma^2$

$$\therefore \sigma = \{{\cdot}146\rho G c_v/(Nk)\}^{\frac{1}{2}}$$

3. **Van der Waals'**, $b = 2\pi N\sigma^3/3 \qquad \therefore \sigma = \{3b/(2\pi N)\}^{\frac{1}{3}}$

4. **Limiting density**, *i.e.* density D of densest known form. $\sigma = \{6\rho/(\pi DN)\}^{\frac{1}{3}}$

The values of ρ and η used in calculating G and L below are given on pp. 35, 41. The values of σ tabulated are mostly taken from Jeans' "Dynamical Theory of Gases," or Rudorf (*Phil. Mag.*, 1909, p. 795). Jeans takes $N = 4 \times 10^{19}$, while in the table following, the more recent value $2{\cdot}75 \times 10^{19}$ has been used. Molecular diameters also follow from the properties of monomolecular films on liquids (see Langmuir).

Gas.	**G at 0° C.**	**Mean free path, L.**	**Molecular diameter σ deduced from**			
			η	k	b	Lt. ρ [= D]
	cm./sec.	cm.	cm.	cm.	cm.	cm.
Hydrogen, H_2 .	$18{\cdot}39 \times 10^4$	$18{\cdot}3 \times 10^{-6}$	$2{\cdot}47 \times 10^{-8}$	$2{\cdot}40 \times 10^{-8}$	$2{\cdot}32 \times 10^{-8}$	$2{\cdot}92 \times 10^{-8}$
Helium, He .	13·11 "	28·5 "	2·18 "	—	2·30 "	4·34 "
Nitrogen, N_2 .	4·93 "	9·44 "	3·50 "	3·31 "	3·53 "	2·97 "
Oxygen, O_2 .	4·61 "	9·95 "	3·39 "	3·11 "	—	2·79 "
Neon, Ne . .	5·61 "	19·3 "	—	—	—	—
Argon, A . .	4·13 "	10·0 "	3·36 "	—	2·86 "	4·43 "
Krypton, Kr .	2·86 "	9·49 "	—	—	3·14 "	4·93 "
Xenon, Xe . .	2·28 "	5·61 "	—	—	3·42 "	4·88 "
Chlorine, Cl .	3·07 "	4·57 "	4·96 "	—	—	—
Methane, CH_4	6·48 "	7·79 "	—	—	—	—
Ethylene, C_2H_4	4·88 "	5·47 "	4·55 "	4·68 "	—	5·26 "
Carbon monoxide, CO .	4·93 "	9·27 "	3·50 "	3·31 "	—	—
Carbon dioxide, CO_2 .	3·92 "	6·29 "	4·18 "	4·32 "	3·40 "	4·42 "
Ammonia, NH_3	6·28 "	6·95 "	—	—	—	—
Nitrous oxide, N_2O . . .	3·92 "	6·10 "	4·27 "	4·20 "	—	4·58 "
Nitric oxide, NO . . .	4·76 "	9·06 "	3·40 "	3·40 "	—	—
Sulph. hydrogen, H_2S . .	4·44 "	5·90 "	—	—	—	—
Sulph. dioxide, SO_2 . . .	3·22 "	4·57 "	—	—	—	—
Hydrochloric acid, HCl .	4·30 "	6·86 "	—	—	—	—
Water, H_2O .	7·08 "	7·22 "	4·09 "	—	—	3·45 "

The formulæ above assume the molecules to be spherical. Sutherland (*Phil. Mag.*, 1910), adopting his formula (see p. 40) for the variation of η with temp., obtains the following values of σ. Unit, 10^{-8} cm.

H	**He**	**A**	**O_2**	**N_2**	**N_2O**	**NO**	**CO**	**CO_2**	**C_2H_4**	**Cl_2**
2·17	1·92	2·66	2·71	2·95	3·33	2·59	2·74	2·90	3·31	3·76

CRITICAL DATA AND VAN DER WAALS' CONSTANTS

Critical temperature, θ_c, is the highest temperature at which a gas can be liquefied by subjecting it to pressure.

Critical pressure, p_c, is the pressure (of gas and liquid) at the critical temperature.

Critical volume, v_c, is here defined as the ratio of the volume that a gas has at the critical temp. and press. to that which it would have at 0° C. and 760 mms., *i.e.* it is the volume of gas at θ_c and p_c which at N.T.P. would have unit volume. Some writers take the critical volume to be the specific volume (c.cs. per gram) at θ_c and p_c.

Most of the characteristic equations of state which have been proposed for gases take the form $(p + a/v^2)(v - b) = R\theta$, where p is the pressure, v the volume, θ the absolute temperature of the gas, and R is the "gas constant." a expresses the mutual attraction of the molecules. The "covolume" b is proportional to the space occupied by the molecules: O. E. Meyer takes $b = 4\sqrt{2}$ (volume of molecule). Van der Waals assumes a is constant: if this were true the constant volume and thermodynamic scales of temperatures would agree—they do not, however (see p. 54). Joule and Thomson, Clausius, Amagat, and Berthelot, among others, regard a as a function of θ (*e.g.* $a \propto 1/\theta$), and b as constant.

Assuming with Van der Waals that a and b are constants, the equation can be regarded as a cubic in v, which has its three roots equal at the critical point, whence $a = 27R^2\theta_c^2/(64p_c)$, and $b = R\theta_c/(8p_c)$.

Taking pressures in atmos., and the volume of the gas at 0° C. and 1 atmos. as 1, $R = pv/\theta = 1/273$. In these units, b is in terms of the volume of the gas at 0° C. and 1 atmos.

Example.—For CO_2 $p_c = 73$ atmos. and $\theta_c = 273 + 31{\cdot}1 = 304{\cdot}1$, whence $b = 304{\cdot}1/(8 \times 273 \times 73) = {\cdot}00191$ of the volume of the gas at 0° C. and 1 atmos.

See Preston's "Heat," Nernst's "Theoretical Chemistry," Young's "Stoichiometry," Berthelot (*Trav. et Mém. Bur. Intl.*, 1907). * Indicates calculated values.

Substance.	Critical			Van der Waals'		Observer.
	Temp. θ_c	Press. p_c atmos.	Vol. v_c	a.	b.	
Hydrogen	−239°·9C.	12·8	·00264*	·00042	·00088	Mean value
Oxygen	−118	50	·00426*	·00273	·00142	v. Wroblewski, '85
Nitrogen	−146	33	·00517*	·00259	·00165	" "
Air	−140	39	·00468*	·00257	·00156	Olszewski, '84
Helium	−268	2·26	·00299*	·0000615	·000995	Mean value
Neon	−228·7	26·9	—	—	—	Mean value
Argon	−122	48·0	·00404*	·00259	·00135	
Krypton	−62·5	54·3	·00532*	·00462	·00178	Ramsay and Travers, 1900
Xenon	14·7	57·2	·0069*	·00818	·00230	
Chlorine	146	76	·00615*	·01063	·00205	Mean value
Bromine	302	131*	·00605	·01434	·00202	Nadejdine, '85
Water	374	218·5	·00248	·0110	·00136	Keyes & Smith,
Hydrochloric acid	52·3	86	·0052*	·00697	·00173	Dewar, 1884 ['31
Carbon monoxide	−141·1	35·9	·00505*	·00275	·00168	v. Wroblewski, '83
Carbon dioxide	31·1	73	·0066	·00717	·00191	Andrews, 1869
Carbon bisulphide	273	72·9	·0090	·02316	·00343	Battelli, 1890
Ammonia, NH_3	130	115·0	·00481*	·00798	·00161	Dewar, 1884
Nitrous oxide, N_2O	38·8	77·5	·00436	·00710	·00184	Villard, 1894
Nitric oxide, NO	−93·5	71·2	·00347*	·00257	·00116	Olszewski, '85
Nitrogen tetroxide, NO_2	171·2	147*	·00413	·00756	·00138	Nadejdine, '85
Sulphuretted hydrogen	100	88·7	·00578*	·00888	·00193	Olszewski, '90
Sulphur dioxide	155·4	78·9	·00745*	·01316	·00249	Sajotschewsky, '78
Methane, CH_4	−82	46	·00488*	·00357	·00162	Mean value
Acetylene, C_2H_2	36·5	61·6	·0069*	·00880	·00230	Mackintosh, '07
Ethylene, C_2H_4	10	51·7	·00752*	·00877	·00251	Olszewski, '95
Ethane, C_2H_6	34	50·2	·00839*	·01060	·0028	" " ['86
Ethyl alcohol, C_2H_5OH	243	62·7	·0071	·02407	·00377	Ramsay & Young,
Ether $(C_2H_5)_2O$	197	35·8	·0158	·03496	·00602	Battelli, '92
Chloroform, $CHCl_3$	260	54·9	·0133	·0293	·00445	Sajotschewsky, '78
Aniline, $C_6H_5NH_2$	425·6	52·3	·0183*	·05282	·00611	Guye & Mallet, '02
Benzene, C_6H_6	288·5	47·9	·0161*	·03726	·00537	Young, 1900

DIFFUSION OF GASES

The Coefficient of diffusion, D, is the mass of the " diffusing " gas which crosses unit area in unit time under unit concentration gradient; the dimensions of the coefficient are cm.^{2} sec.$^{-1}$. D is inversely proportional to the total pressure of the two gases, and roughly proportional to the square of their absolute temperature. Total pressure 1 atmosphere. H_2—O_2 implies that H_2 is diffusing into O_2.

(See Jeans' " Kinetic Theory of Gases " and Kennard's " Kinetic Theory," 1938.)

Gases.	t° C.	D	Gases.	t° C.	D	Gas (Winkelmann).	t° C.	D into		
								Air.	CO_2	H_2
H_2—O_2 .	**0°**	·677, O.	CO—H_2 .	**0°**	·642, L.	Formic acid .	**0°**	·131	·088	·513
H_2—O_2 .	**0**	·681, O.	CO—C_2H_4	**0**	·101, O.	Acetic . . .	**0**	·106	·071	·404
H_2—CH_4	**0**	·625, O.				Propionic acid	**0**	·082	·058	·326
H_2—CO .	**0**	·649, O.	CO_2—CO	**0**	·131, O.	Butyric acid .	**0**	·053	·037	·201
H_2—CO_2.	**0**	·538, O.	CO_2—CO	**0**	·141, L.	Isobutyric acid	**0**	·07	·047	·271
H_2—C_2H_4	**0**	·483, O.	CO_2—Air	**0**	·142, L.	Me. alcohol .	**0**	·132	·088	·500
H_2—N_2O	**0**	·535, O.	CO_2—CH_4	**0**	·146, O. ; ·16, L.	Et. ,, .	**0**	·102	·068	·378
			CO_2—O_2 .	**0**	·18, L.	Propyl alcohol	**0**	·080	·058	·315
O_2—N_2 .	**0**	·171, O.	CO_2—N_2O	**0**	·1, L. ; ·15, O.	Butyl ,, .	**0**	·068	·048	·272
O_2—H_2 .	**0**	·722, L.	CO_2—H_2	**0**	·55, L.	,, ,, .	**99**	·126	·088	·504
H_2O—CO_2	**18**	·155, G.	Air—O_2 .	**0**	·178, O.	Benzene . .	**0**	·075	·053	·294
H_2O—Air	**8**	·239, G.	Air—H_2 .	**17**	·66, Sc.	Me. acetate .	**0**	·084	·056	·328
H_2O—Air	**15**	·246, G.				Et. formate .	**0**	·085	·057	·336
H_2O—Air	**18**	·248, G.	CS_2—Air	**0**	·1, S.	Et. acetate .	**0**	·071	·049	·273
H_2O—Air	**0**	·203, H.				Et. butyrate .	**0**	·057	·041	·224
						Et.iso-butyrate	**0**	·055	·040	·224

G., Guglielmo, 1884; H., Houdaille, 1896; L., Loschmidt, 1870; O., v. Obermayer, 1887; S., Stefan, 1879; Sc., Schulze, 1897.

DETERMINATION OF ALTITUDES BY THE BAROMETER

Babinet's formula (*Compt. Rend.*, 1850) is, Altitude $= \frac{C(H_1 - H_2)}{H_1 + H_2}$, where H_1 = barometer reading at lower station, H_2 at upper station. If altitudes are in metres, and barometric heights in mms.,

$$C = 32(500 + t_1 + t_2)$$

where t_1 and t_2 are the corresponding station temperatures (° C.).

In the table below the mean temperature, $(t_1 + t_2)/2$, is taken as 10° C., and the barometric height at sea-level as 760 mm., so that altitudes are in metres above sea-level. The values are of course only approximate. Babinet's formula is not applicable to very great altitudes.

Altitude	0	100	200	300	400	500	600	700	800	900
metres.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
0	760	751	742	733	724	716	707	699	690	682
1000	674	666	658	650	642	635	627	620	612	605

THICKNESS OF THIN METAL FOIL

Approximate thickness of the thinnest beaten metal leaf at present commercially obtainable. Unit 10^{-6} cm.

Metal. .	Al	Cu	Au	Pt	Ag	Dutch metal.	(Cigarette paper.)
Thickness	20	34	8	25	21	70	2500

SURFACE TENSIONS

In dynes per cm. (A) indicates liquid in contact with air, (V) indicates liquid in contact with its vapour. The surface tension of a liquid varies somewhat with the age (and contamination) of the surface.

Temperature variation. It follows from Eötvos' rule, that the surface tension T at temp. t is approximately proportional to $(t_c - t)$, where t_c is the critical temp., the constant of proportionality being much the same for chemically similar substances. The surface tension at t_c is generally believed to be zero.

See Poynting and Thomson's "Properties of Matter."

WATER ($t_c = 374°$ C.)

Surf. Tens. T at 15° C.	Method.	Observer.	Temp. (t).	T_t/T_{15}	Temp. (t).	T_t/T_{15}
dynes per cm.						
72·8 (A)	Vibrating jet	Bohr., *Phil. Trans.*, '09	**0°** C.	1·030	**60°** C.	·901
74·3 (A)	Vibrating jet	Pedersen, *P. Trans.*, '07	**10**	1·010	**70**	·876
74·2 (A)	Capillary waves	Kalähne, *Ann. d. Phy.*,	**15**	**1·000**	**80**	·851
73·8 (A)	Hanging drop	Sentis, 1897 ['02	**20**	·990	**90**	·827
73·3 (A)	Tension of film	Hall, 1893 ['93	**30**	·970	**100**	·80
74·3 (A)	Capillary waves	Rayleigh, *Phil. Mag.*,	**40**	·947	**120**	·75
73·3 (A)	Capillary tube	Volkmann, 1895	**50**	·925	**140**	·70
71·4 (V)	Capillary tube	Ramsay & Shields, '93	Ramsay & Shields, '93; Volkmann & Brunner			
77·6 (A)	Pull on ring	Weinberg, 1892				

Heavy Water: $T_0 = 75·23$; $T_{20} = 72·80$; $T_{40} = 69·65$; $T_{60} = 66·16$ (Cockett and Ferguson, 1939).

Substance.		Temp. (t).	Surf. Tens.	Method.	Observer.
INORGANIC.			dynes/cm.		
Cadmium	N_2	**320°** C.	630	Weight of drop	Sauerwald, '31
Gold	A	**1130**	1103	" "	"
Lead	CO_2	**350**	453	Curvature of drop	Bircumshaw, '33
Mercury ($T_t = T_0 - 0·02t$)	N_2	**20**	465	" "	"
Potassium	CO_2	**58**	364	Weight of drop	Quincke
Sodium	CO_2	**90**	290	" "	Poindexter, '26
Sulphur (M.P. 115°) . .	A	**160**	59	Press. reqd. to bubble air from cap. tube thro' liquid	Zickendraht, '06; and Quincke, '08
"	A	**250**	118		
" . . . (B.P.)	A	**445**	44		
Liquid oxygen	A	**−183**	13·1	Capillary waves	Grunmach, 1906
" nitrogen . . .	A	**−196**	8·5	" "	" 1906
" nitrous oxide . .	A	**−89·4**	26·3	" "	" 1904
Nickel carbonyl, $Ni(CO)_4$	V	**19·8**	14·2	Capillary tube	Ramsay and Shields, 1893
Ammonia soln. (d = ·96)	A	**15**	64·7	Vibrating jet	Pedersen, 1907
Sulph^c acid sol. (d = 1·14)	A	**15**	74·4	" "	" 1907
CARBON COMPOUNDS.					
Acetone, $(CH_3)_2CO$ . .	V	**16·8**	23·3	Capillary tube	Ramsay and Shields, 1893
	V	**78·3**	15·9	" "	
Acetic acid, CH_3CO_2H .	V	**20**	23·5	" "	" "
	V	**300**	1·16	" "	" "
Alcohol—methyl, CH_4O	V	**20**	23	" "	" "
	V	**200**	5·2	" "	" "
—ethyl, C_2H_5OH	V	**20**	22·0	" "	" "
($T_t = T_0 - ·092t$) . .	V	**150**	9·5	" "	" "
—propyl (n),	V	**16·4**	23·8	" "	" "
C_3H_7OH	V	**78·3**	18·7	" "	" "
Aniline, $C_6H_5.NH_2$ . .	A	**15**	43·0	Vibrating jet	Pedersen, 1907
Benzene, C_6H_6. ($T_t = T_0 - ·146t$)	A	**17·5**	29·2	Capillary tube	Volkmann

Substance.		Temp. (*t*).	Surf. Tens.	Method.	Observer.
CARBON COMPOUNDS.—(*contd.*)			dynes/cm.		
Butyric acid, $C_3H_7CO_2H$	V	**15° C.**	26·7	Capillary tube	Ramsay and Shields, 1893
	V	**132**	16·4	" "	
Carbon bisulphide . .	V	**19·4**	33·6	" "	" "
	V	**46·1**	29·4	" "	" "
Carbon tetrachloride. .	V	**20**	25·7	" "	" "
	V	**250**	1·93	" "	" "
Chloroform, $CHCl_3$ . .	A	**15**	27·2	" "	Kaye, 1905
Ether (ethyl), $(C_2H_5)_2O$.	V	**20**	16·5	" "	Jaeger, 1892
$(T_t = T_0 - {\cdot}115t)$ . .	V	**150**	2·9	" "	"
Ethyl acetate, $CH_3CO_2C_2H_5$	V	**20**	23·6	" "	"
	V	**100**	14	" "	"
Formic acid, HCOOH .	V	**17**	37·5	" "	Ramsay and Shields, 1893
	V	**80**	30·8	" "	
Olive oil (d/20° = ·91) .	A	**20**	32	Curvature of drop	Magie, 1888
Paraffin oil (d = ·847) .	A	**25**	26·4	Capillary tube	Frankenheim, '47
Propionic acid, $C_3H_6O_2$	V	**16·6**	26·6	" "	Ramsay and Shields, 1893
	V	**132**	15·5	" "	
Pyridine, C_5H_5N . . .	V	**17·5**	36·7	" "	Dutoit and Friderich, 1900
	V	**91**	26·5	" "	
Toluene, $C_6H_5 . CH_3$.	A	**15**	28·8	Vibrating jet	Pedersen, 1907
Turpentine, $C_{10}H_{16}$ . .	A	**15**	27·3	Capillary tube	Kaye, 1905

SURF. TENSIONS OF SOLUTIONS

The surface tension of aqueous salt solutions is generally greater than that of pure water. Dorsey (*Phil. Mag.*, 1897) has shown

$$T_n = T + A . n$$

T_n is the surf. tens. of a sol. of n gram – equivalents per litre, T that of water at same temp.

Salt.	A.
NaCl	1·53
KCl	1·71
$\frac{1}{2}(Na_2CO_3)$	2·00
$\frac{1}{2}(K_2CO_3)$	1·77
$\frac{1}{2}(ZnSO_4)$	1·86

SURFACE TENSIONS AT INTER-LIQUID BOUNDARIES

Liquids at 20° C.	Surface Tension T.	Observer.
	dynes/cm.	
Water-benzene . . .	33·6	Pockels, 1899
" chloroform † .	29·5	Quincke
" ether	12·2	"
" olive oil ‡ . .	20·6	"
" paraffin oil . .	48·3	Pockels, 1899
Mercury-water . . .	427 *	Gouy, 1908
" alcohol § . .	399	Quincke
" chloroform † .	399	"

* Diminishes with time.
‡ Density = ·91.
† Density = 1·49.
§ Density = ·79.

ANGLES OF CONTACT BETWEEN GLASS AND LIQUIDS

Angles of contact vary largely with the freshness of the surfaces in contact.

Liquid.	Angle.	Observer.	Liquid.	Angle.	Observer.
Mercury . . .	52° 40′ *	Quincke	Acetic acid . .	20°	Magie, '88
Water	8°–9°	"	Benzene . . .	0°	"
Water	0° †	Wilberforce	Paraffin oil . .	26°	"
Methyl alcohol .	0°	Magie, '88	Turpentine . .	17°	"
Ethyl alcohol . .	0°	"			
Ether . . .	16°	"			
Chloroform . .	0°	"			

* For freshly formed drop, 41° 5′.
† Glass **quite** clean.

The angle of contact of water against different **metals** varies between 3° and 11°.

SIZE OF DROPS AND THICKNESS OF LIQUID FILMS

Reference may be made to the writings of J. J. Thomson ("Conduction of Electricity through Gases"), C. T. R. Wilson, Laby (*Phil. Trans. A*, 1908), Reinold & Rücker (*Phil. Trans.*, 1886), Lord Rayleigh, and Johonnot (*Phil. Mag.*, 1906).

RELATIVE HUMIDITY AND DEW-POINT

The relative humidity is the ratio (expressed as a percentage) of the water vapour actually present in unit volume, to that which the air would contain if saturated at the air temperature t. For all practical purposes, this is equal to the ratio of the pressure (p) of the vapour actually present (*i.e.* the saturation pressure at the dew-point) to the saturation pressure at air temperature. For a table of saturation pressures, see p. 49.

CHEMICAL HYGROMETER

The values below are grams of water contained in a cubic metre (10^6 c.c.) of saturated air at 760 mm. total pressure. Calculated from Regnault's observations.

Temp.	0	1	2	3	4	5	6	7	8	9
0° C.	4·84	5·18	5·54	5·92	6·33	6·76	7·22	7·70	8·21	8·76
10	9·33	9·93	10·57	11·25	11·96	12·71	13·50	14·34	15·22	16·14
20	17·12	18·14	19·22	20·35	21·54	22·80	24·11	25·49	26·93	28·45
30	30·04	31·70	33·45	35·27	37·18	39·18	41·3	43·5	45·8	48·2

WET- AND DRY-BULB HYGROMETER

Apjohn (1835), August (1825), and others, by making various assumptions (some of doubtful legitimacy) have derived formulæ of the type:

$$p_w - p = AH(t - t_w)[1 + B(kt - t_w)]$$

Where t_w is the wet-bulb temperature, p the actual pressure, and p_w the saturation pressure at temperature t_w, H is the barometric pressure and A, B and k are constants. Thus the relative humidity is $100\,p/p_s$ where p_s is the saturation pressure at the dry-bulb temperature. (See Love and Sineat, *Proc. Roy. Soc.*, Victoria, **10**, 1, 1911; Whipple, *Proc. Phys. Soc.*, 1933; Arnold, *Phys. Rev.*, 1932.) The values of A in this formula depend on the speed of the air passing the wet bulb, appropriate values being shown below for the case where H is measured in mm. and t, t_w in Centigrade degrees.

A = 0·00068 for moving air, as in Assmann ventilated psychrometer. A = 0·00075 in a Stevenson screen as used by Meteorological Office. A = 0·0008 in open air with slight wind. A = 0·00084 in open air with no wind. A = 0·001 in a small closed room.

The values below are based on tables issued by the Prussian Meteorological Office and by the National Physical Laboratory, both of which are for use with ventilated instruments.

WET- AND DRY-BULB HUMIDITY VALUES

Dry-bulb Temperature.	Wet-bulb depression.										
	0°·5C.	**1°·0**	**1°·5**	**2°·0**	**2°·5**	**3°·0**	**3°·5**	**4°·0**	**5°·0**	**6°·0**	**7°·0**
−9° C. †	85%	71%									
−8 †	87	73	59%	46%							
−6 †	88	76	64	52	40%	29%					
−4 †	89	78	67	57	46	36					
−2 †	90	80	70	61	52	42	33%	25%			
0	91	82	73	65	56	48	39	31			
2	92	84	76	68	60	52	45	37	22%		
4	92	85	78	70	63	56	49	42	29		
6	93	86	79	73	66	60	53	47	35	23%	
8	94	87	81	75	69	63	57	51	40	29	18%
10	94	88	82	76	71	65	60	54	44	34	24

† Super-cooled water (not ice) on wet-bulb.

WET- AND DRY-BULB HUMIDITY VALUES *(contd.)*

Dry-bulb Temperature.	Wet-bulb depression.										
	1°	**2°**	**3°**	**4°**	**5°**	**6°**	**8°**	**10°**	**12°**	**14°**	
15° C.	90%	80%	71%	61%	52%	44%	27%	12%			
20	91	83	74	66	59	51	37	24	12%		
25	92	84	77	70	63	57	44	33	22	12%	
	2°	**4°**	**6°**	**8°**	**10°**	**12°**	**14°**	**16°**	**18°**	**20°**	
30	86	73	61	50	39	30	21	13	5		
35	87	75	64	53	44	35	27	20	13	7	
40	87	76	66	56	47	39	32				
45	88	77	67	59	51	43	36				
50	89	79	70	61	53	46	40				
55	90	80	72	64	56	49	42				
	2°	**4°**	**6°**	**8°**	**10°**	**15°**	**20°**	**25°**	**30°**	**35°**	**40°**
60	90	81	73	65	58	42	30	19			
70	91	83	76	69	62	47	35	25	17		
80	92	85	78	71	65	51	40	30	21	15	10
90	92	86	79	73	67	54	43	33	25	19	14
100	93	86	80	74	69	56	46	37	29	22	17

WET-BULB ICE COVERED *

Dry-bulb Temperature.	Wet-bulb depression.									
	−0°·1C.	**0°·0**	**0°·5**	**1°·0**	**1°·5**	**2°·0**	**2°·5**	**3°·0**	**3°·5**	**4°·0**
−18° C.	64%	62%	47%	33%						
−16	67	66	51	37	(24)%					
−14	71	69	56	42	30	17%				
−12	77	75	62	49	36	24				
−10	83	82	68	55	42	30	(17)%			
−8	90	89	75	62	48	36	25	16%		
−6	95	94	81	68	56	45	34	25	16%	
−4	98	97	85	74	63	53	42	32	24	17%
−2	100	98	88	78	68	58	48	39	31	24
0	—	100	90	80	71	62	53	44	37	31

* The relative humidity is here defined as the ratio of the actual moisture content per unit volume to that which the air would hold when in equilibrium with water (not ice) at the dry-bulb temperature.

BURSTING STRENGTHS OF GLASS TUBING

Bursting pressures in atmospheres for German soda glass tubing. Most glass-tubing is in a state of considerable strain, and a factor of safety of not less than two should usually be employed. (Roebuck, *Phys. Rev.*, 1909; and Onnes and Braak, *Kon. Ak. Wet.*, Amsterdam, 1908.) Ordinary boiler water-gauge glasses stand between 12 and 24 atmospheres.

Thickness of Wall.	Bore.						
	1 mm.	**2**	**3**	**4**	**5**	**6**	**7**
1 mm.	atmos. —	310	280	230	220	150	190
2	570	—	340	—	330	240	220
3	560	420	460	400	—	—	230
4	—	450	—	400	310	320	280

VAPOUR PRESSURES

Inter- and Extrapolation of Vapour Pressures.—The Kirchhoff-Rankine-Dupré formula, $\log p = A + B/\theta + C \log \theta$, where p is the vapour pressure, θ the absolute temperature, and A, B, C are constants, is accurate and convenient (*e.g.* see p. 50). For values of A, B, C, see Juliusburger, *Ann. d. Phys.*, p. 618, 1900.

Ramsay and Young's Method.—If two liquids, one at absolute temperature θ and the other at θ', have the same vapour pressure, the ratio θ/θ', when plotted against θ, gives a straight line. This method may be used to find roughly the vap. press. of a substance at any temperature when only its boiling-point is known.

Interpolation by Logarithms.—The curve of vapour pressure (p) against temp. (t) is approximately hyperbolic, and thus $\log p$ plotted against t gives a graph of slight curvature, which over 10° intervals of t may, for approximate work, be regarded as a straight line: thus the following method of interpolation :—

Example.—Required vap. press. of water at 15°, given

t	p	$\log p$
10°	9·2	·964
20°	17·5	1·243

$$\frac{\cdot 964 + 1\cdot 243}{2} = 1\cdot 104 = \log 12\cdot 7\text{; i.e. } p \text{ at } 15° = 12\cdot 7,$$

actually it is 12·8.

VAPOUR PRESSURE OF ICE

In mms. of mercury at 0° C.; $g = 980\cdot 62$ cms. per sec.^{2}; hydrogen (const. vol.) scale of temps. (Scheel, and Heuse, Reichsanstalt *Ann. d. Phys.*, 1909.)

Temp. . .	−50° C.	−40°	−30°	−20°	−10°	−5°	−2°	0°
Vap. press.	·030 mm.	·096	·288	·784	1·963	3·022	3·885	4·579

(SATURATED) VAPOUR PRESSURE OF WATER

In mms. of mercury at 0° C.; $g = 980\cdot 67$ cms. per sec.^{2} Thermodynamic scale of temp. (see p. 53). From −20° to 0° the observations are due to Scheel and Heuse (*v.* ice); from 0° to 50°, to Thiesen and Scheel; from 50° to 200°, to Holborn and Henning, Reichsanstalt (*Ann. d. Phys.*, **26**, 833, 1908). For vapour pressures at temps. near 100° see also the table of boiling-points on next page.

Vap. press. at −20° C., ·960 mm.; −10°, 2·160; −5°, 3·171; −2°, 3·958; −1°, 4·258.

Temp.	0	1	2	3	4	5	6	7	8	9
0° C.	4·579	4·924	5·290	5·681	6·097	6·541	7·011	7·511	8·042	8·606
10	9·205	9·840	10·513	11·226	11·980	12·779	13·624	14·517	15·460	16·456
20	17·51	18·62	19·79	21·02	22·32	23·69	25·13	26·65	28·25	29·94
30	31·71	33·57	35·53	37·59	39·75	42·02	44·40	46·90	49·51	52·26
	0	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**
40	55·13	61·30	68·05	75·43	83·50	92·30	101·9	112·3	123·6	135·9
60	149·2	163·6	179·1	195·9	214·0	233·5	254·5	277·1	301·3	327·2
80	355·1	384·9	416·7	450·8	487·1	525·8	567·1	611·0	657·7	707·3
100	760·0	815·9	875·1	937·9	1004	1074·5	1149	1227	1310	1397
120	1489	1586	1687	1795	1907	2026	2150	2280	2416	2560
140	2709	2866	3030	3202	3381	3569	3764	3968	4181	4402
160	4633	4874	5124	5384	5655	5937	6229	6533	6848	7175
180	7514	7866	8230	8608	8999	9404	9823	10256	10705	11168
200	11647	12142	12653	—	—	—	—	—	—	—

(Battelli, 1892.)

Temp. . .	220° C.	240°	260°	280°	300°	320°	340°	360°
Vap. Press.	17,380 mm.	25,170	35,760	50,600	67,620	88,340	113,830	141,870

Interpolate logs of vapour pressures as explained above.

BOILING-POINT OF WATER UNDER VARIOUS BAROMETRIC PRESSURES

International scale of temp. Pressures in mm. Hg at 0° C.; $g = 980{\cdot}665$ cm. per sec.^{2} (Moser, 1932.) Heavy water boils at 101·42° C.; v.p. at 100° C. = 721·6 mm.

Barometric Height.	0	1	2	3	4	5	6	7	8	9
	° C.									
680 mm.	96·910	950	990	031*	071*	111*	151*	191*	231*	271*
690	97·311	351	391	431	471	510	550	590	630	669
700	97·709	748	788	827	866	906	945	984	023*	062*
710	98·102	141	180	219	258	296	335	074	413	451
720	98·490	529	567	606	644	683	721	759	798	836
730	98·874	912	950	989	027*	065*	102*	140*	178*	216*
740	99·254	292	329	367	405	442	480	517	554	592
750	99·629	666	704	741	778	815	852	889	926	963
760	100·000	037	074	110	147	184	220	257	294	330
770	100·367	403	439	476	512	548	584	620	657	693
780	100·729	765	801	836	872	908	944	980	015*	051*

* For entries marked with an asterisk, the integral number advances by 1 degree C.

VAPOUR PRESSURE OF MERCURY

In mms. of mercury at 0° C. Reduced from the observations of Hertz, Ramsay and Young, Callendar and Griffiths, Pfaundler, Morley, Gebhardt, Cailletet, Colardeau, Rivière. For interpolation from 15° to 270°.

$$\log p = 15{\cdot}24431 - 3623{\cdot}932/\theta - 2{\cdot}367233 \log \theta \quad . \; . \; . \; . \; . \; . \; . \quad \text{(A)}$$

From 270° to 450°

$$\log p = 10{\cdot}04087 - 3271{\cdot}245/\theta - {\cdot}7020537 \log \theta$$

$\frac{\delta p}{\delta t}$ at the boiling-point = 13·6 mm. per degree (Laby, *Phil. Mag.*, Nov., 1908).

Temp.	Vap. Press.	Temp.	Vap. Press.	Temp.	Vap. Press.	Temp.	Vap. Press.	Temp.	Vap. Press.
	mm.		mm.		mm.		mm.		atmos.
0° C.	·00016*	25°	·00168	60°	·0246	250°	75·83	500°	8
5	·00026*	30	·00257	80	·0885	300	248·6	600	22·3
10	·00043*	35	·00387	100	·276	356·7	760	700	50
15	·00069	40	·00574	150	2·88	400	1566	800	102
20	·00109	50	·0122	200	17·81	450	3229	880	162

* Extrapolated by formula A.

VAPOUR PRESSURE OF ETHYL ALCOHOL

Vap. press. in mms. of mercury at 0° C. Calculated by Bunsen from Regnault's results (1862), which are in good agreement with the mean of those of Ramsay and Young (1886), and Schmidt (1891).

Regnault, Vapour press. at −20°, 3·34 mm.; at −10°, 6·47 mm.

Temp.	0	1	2	3	4	5	6	7	8	9
0° C.	12·73	13·65	14·6	15·59	16·62	17·7	18·84	20·04	21·31	22·66
10	24·08	25·59	27·19	28·9	30·7	32·6	34·6	36·8	39·0	41·4
20	44·0	46·7	49·5	52·5	55·7	59·0	62·5	66·2	70·1	74·1
30	78·4	—	—	—	—	—	—	—	—	—

(Ramsay and Young, 1886.)

Temp.	30° C.	40°	50°	60°	70°	80°	100°	120°	140°	160°
Press.	78·1 mm.	133·4	219·8	350·2	541	812	1692	3220	5670	9370

Interpolate logs of vapour pressures as explained on p. 49.

VAPOUR PRESSURES OF ELEMENTS

p = vapour pressure in mms. of mercury at 0° C. lat. 45° and sea-level (g = 980·62) (*i.e.* 1 mm. Hg = 1333·2 dynes per sq. cm.). If followed by *at.*, p is in atmospheres; θ = absolute temp. (A.); t = temp. in ° C.; (*s*) solid; (*l*) liquid. The thermometry is in many cases somewhat dubious.

Interpolate logs of vapour pressures as explained on p. 49.

Argon	t	-121° C.	-128·6	-129·6	-134·4	-135·1	-136·2	-138·3	-139·1	—
(Olszewski, 1895)	p	50·6 at.	38·0	35·8	29·8	29·0	27·3	25·3	23·7	—
Argon	θ	78°·9 A.	86·9	97·9	107·3	155·6	= crit. temp.		—	—
Krypton	θ	110°·5 A.	121·3	135·2	147·3	—	210·5	= crit. temp.		—
Xenon	θ	148°·9 A.	163·9	182·9	199·6	—	—	287·8	= crit. temp.	
(Ramsay & Travers)	p	300 mm.	760	2000	4000	40,200	41,240	43,500	—	—
Bromine	t	-16°·6 C.	-12·0	-5·0	8·2	16·9	23·4	40·5	51·9	58·7
(Ramsay & Young, 1886)	p	20 mm.	30	50	100	150	200	400	600	760
Chlorine	t	-80° C.	-60°	-40	-34·6	-20	0	10	20	30
(Knietsch, 1890)	p	62·5 mm.	210	560	760	1·84 at.	3·66	4·95	6·62	8·75
Iodine (Baxter, Hickey,	t	0° C.	15	30	55	85	117	137	160·9	185·3
& Holmes, 1907)	p	·03 mm.	·131	·469	3·08	20	100	200	400	760
	t	-258°C.	-257	-256	-255	-254	-253	-252·75	252·87	—
Hydrogen—Para	p	103·5 mm.	166·7	250·5	365·0	515·5	708·2	—	760	—
(Keesom, '29)—Normal	p	108·7 mm.	174·0	261·7	381·7	534·5	732·9	760	—	—
Helium	θ	0°·90 A.	1·54	2·64	4·22	**Neon** (Travers	θ	15°·65 A.(*s*)	20·4(*s*)	He
(Keesom, 1929)	p	0·05 mm.	5·0	100	760	& Jaquerod, '02)	p	2·4 mm.	12·8	Scale
Mercury		See p. 50.				**Ra. Emanation**		See p. 117.		
Nitrogen (Baly, 1900	θ	62°·5 A.	67·8	72·4	77·3	80	83	86	89	91
Fischer & Alt., 1902)	p	86 mm.	200	400	760	1013	1386	1880	2465	2916
Oxygen (Jaquerod, Travers,	θ	79°·1 A.	82·1	84·4	86·3	87·9	89·3	90·1	90·6	H. Scale
& Senter, 1902)	p	200 mm.	300	400	500	600	700	760	800	—
Phosphorus	t	165° C.	170	180	200	209	219	226	230	287·3
(Schrötter, 1848)	p	120 mm.	173	204	266	339	359	393	514	760
Sulphur (Ruff & Graff, '08;	t	50° C.	100	147	211	400	444·6	δt/δp = 0°·09/mm. near		
B., 1899; C., 1899)	p	·0003 mm.	·0089	·192	3·14	*c.* 372	760	B.P. (see p. 53).		

VAPOUR PRESSURES OF COMPOUNDS

Hydrochloric acid	t	-73°·3 C.	-45·5	-23·3	-3·9	4·0	9·2	13·8	22·0	33·4
(F., 1845; Ansdell, 1880).	p	1·8 at.	6·3	12·8	23·1	29·8	33·9	37·7	45·7	58·8
Sulphuretted hydrogen	t	-25° C.	-15	-5	0	10	30	50	60	70
(R., 1862)	p	4·93 at.	6·84	9·3	10·8	14·3	23·7	36·6	44·4	53·1
Sulphur dioxide	t	-30° C.	-20	-10	0	10	20	30	40	50
(Regnault, 1862)	p	·39 at.	·63	1·00	1·53	2·26	3·24	4·52	6·15	8·19
Ammonia, NH_3	t	-80° C.	-77·6	-70·4	-64·4	-60·8	-54·4	-46·2	-39·8	-33·0
(Brill, 1906)	p	35·2 mm.	44·1	74·9	116·0	157·6	239·5	403·5	568·2	761
Nitrous oxide, N_2O	t	-80° C.	-60	-40	-20	-10	0	10	20	40
(Cailletet, '78; R., '62)	p	1·9 at.	5·05	11·0	23·1	28·9	36·1	44·8	55·3	83·4
Nitric oxide, NO	t	-176·5°C.	-167	-138	-129	-119	-110	-105	-100·9	-97·5
(Olszewski, 1885)	p	·024 at.	·182	5·4	10·6	20·0	31·6	41·0	49·9	57·8
Nickel carbonyl, $NiCO_4$	t	-9° C.	-7	-2	0	10	16	20	30	—
(D. & Jones, 1903)	p	94·3 mm.	104·3	129·1	144·5	215·0	283·5	329·5	462	—

Interpolate logs of vapour pressures as explained on p. 49.

VAPOUR PRESSURES OF COMPOUNDS (*contd.*)

Interpolate logs of vapour pressures as explained on p. 49.

Carbon dioxide	t	-130°C.(*s*)	-100 (*s*)	-80 (*s*)	-65 (*s*)	-56·4 ‡	-65 (*l*)	-40 (*l*)	-20 (*l*)	-10 (*l*)
(Zeleny & Smith, 1906) .	p	2·5 mm.	119	657	2100	3910	2508	7510	14,830	19,630
Carbon bisulphide . . .	t	-20° C.	-10	0	10	20	40	60	80	100
(Regnault, 1862) . . .	p	47·3 mm.	79·4	128	198	298	618	1164	2033	3325
Chloroform, $CHCl_3$ . . .	t	20° C.	30	40	50	60	70	80	90	100
(Regnault, 1862). . . .	p	160·5 mm.	248	369	535	755	1042	1408	1865	2429
Carbon tetrachloride, CCl_4	t	-20° C.	-10	0	10	20	40	60	80	100
(R., 1862)	p	9·8 mm.	18·47	32·9	56	91	215	447	843	1467
Acetylene, C_2H_2	t	-90° C. (*s*)	-85 (*s*)	-81	-70	-50	-23·8	0	20·2	36·5
(Villard, 1895)	p	·69 at.	1·00	1·25	2·22	5·3	13·2	26·05	42·8	61·6 (M.)
Benzene, C_6H_6	t	-10° C.	0	10	20	40	60	80	100	120
(Young, 1889)	p	14·8 mm.	26·5	45·4	74·6	181·1	389	754	1344	2238
Aniline, $C_6H_5NH_2$ . . .	t	101°·9 C.	119·4	138·7	151·5	161·1	168·7	175·0	180·8	183·9
(Kahlbaum, 1898) . . .	p	50 mm.	100	200	300	400	500	600	700	760
Bromnaphthalene . . .	t	215° C.	220	230	240	250	260	270	275	280·4
$C_{10}H_7Br$ (Ra. & Y., 1885)	p	158·9 mm.	181·8	236·0	303·4	386·4	487·4	608·8	677·9	760
Me. alcohol, CH_3OH . .	t	-10° C.	0	17	20	30	50	80	120	150
(R., '62 ; Ra. & Y. ; Ri., '86)	p	14·8 mm.	28·5	78·3	88·7	150	381·7	1238	4342	9361
n. propyl alcohol, †, C_3H_7OH	t	0° C.	10	17	30	40	60	80	100	120
(Ra. & Y. ; S. ; Ri., '86) .	p	3·9 mm.	7·8	12·4	28·2	51·4	157	389	843	1668
Iso-butyl alcohol † . . .	t	10° C.	17	20	40	60	80	100	108	120
C_4H_9OH (Ri., '86 ; S., '91)	p	4·1 mm.	6·8	8·1	30·3	94·2	245	569	760	1195
Iso-amyl alcohol † . . .	t	17° C.	30	40	50	60	80	100	120	130
$C_5H_{11}OH$ (Ri., '86 ; S., '91)	p	1·78 mm.	4·68	9·33	17·4	32·0	151	234	522	741
Formic acid, † CH_2O_2 . .	t	0° C.	10	17	20	30	40	70	80	101
(S., 1891 ; K., 1898) . .	p	10·2 mm.	18·4	26·3	31·6	51·3	79·4	266	373	760
Acetic acid, † $C_2H_4O_2$ . .	t	17° C.	30	50	70	90	110	130	150	200
(Ra. & Y. ; Ri., '86 ; S., '91)	p	9·8 mm.	20·6	56·2	133	288	582	1068	1847	5905
Propionic acid, † $C_3H_6O_2$.	t	15° C.	17	20	30	40	60	70	80	140
(Ri., '86 ; S., '91 ; K., '98)	p	1·7 mm.	2·0	2·45	4·9	9·1	28·2	46·1	74·5	760
Butyric acid, † $C_4H_8O_2$.	t	17° C.	20	30	50	70	90	110	130	150
(Ra. & Y., '86 ; S. '91 ; K. '94)	p	·52 mm.*	·66*	1·4	5·2	16·2	44·9	111	245	497
Iso-butyric acid, † $C_4H_8O_2$	t	17° C.	30	50	70	90	110	130	150	153·5
(Ri., '86 ; S., '91 ; K., '94)	p	·88 mm.*	1·9	8·2	25·1	67·6	162	347	684	760
Methyl formate † . . .	t	-20° C.	-10	0	10	20	40	60	80	100
CHO_2CH_3 (Y. & T., '93) .	p	67·7 mm.	117·6	195	309	476	1029	1990	3497	5782
Methyl butyrate † . . .	t	-10° C.	0	10	20	40	60	80	100	—
$C_4H_7O_2 \cdot CH_3$ (Y. & T., '93)	p	3·55 mm.	7·3	13·8	24·5	69·2	167·5	361	701	—
Methyl isobutyrate † . .	t	-10° C.	0	10	20	40	60	80	100	120
$C_4H_7O_2.CH_3$ (Y. & T., '93)	p	6·22 mm.	12·15	22·4	38·9	104·7	244	505	956	1660
Ethyl acetate †	t	-20° C.	-10	0	10	20	40	60	80	100
$C_2H_3O_2.C_2H_5$ (Y. & T., '93)	p	6·5 mm.	12·9	24·3	42·7	72·8	186	415	833	1515
Ethyl propionate † . . .	t	-10° C.	0	10	20	40	60	80	100	120
$C_2H_5O_2.C_2H_5$ (Y. & T., '93)	p	4·05 mm.	8·3	15·5	27·7	77·9	188·0	403·6	785	1388
Propyl acetate †	t	-10° C.	0	10	20	40	60	80	100	120
$C_2H_3O_2 \cdot C_3H_7$ (Y. & T., '93)	p	3·6 mm.	7·4	13·9	25·1	70·8	172	373	724	1288
Ethyl ether, $(C_2H_5)_2O$.	t	-10° C.	0	10	20	40	60	80	100	193·8 ‖
(Young, 1910)	p	112·3 mm.	184·9	290·8	439·8	921	1734	2974	4855	27,060

Interpolate logs of vapour pressure as explained on p. 49.

* Extrapolated.

† The vapour pressures here given have been graphically interpolated from the observers' values. B., Bodenstein ; C., Callendar ; D., Dewar ; F., Faraday ; K., Kahlbaum ; M., Mackintosh ; R., Regnault ; Ra. and Y., Ramsay and Young ; Ri., Richardson ; S., Schmidt ; Y. and T., Young and Thomas.

‡ Triple point. ‖ Critical temp.

THE INTERNATIONAL SCALE OF TEMPERATURE

The ideal scale of temperature is one that can be defined without reference to the physical properties of any particular material, and in this connection Lord Kelvin showed long ago the theoretical advantages of the thermodynamic (absolute) scale. Accordingly the thermodynamic Centigrade scale is recognised as the fundamental scale to which all temperature measurements should ultimately be referable.

The thermodynamic scale is, however, only susceptible of direct practical realisation through the medium of the gas thermometer, and the experimental difficulties are such that, on the joint proposals of the Reichsanstalt, the Bureau of Standards and the National Physical Laboratory, the International Committee of Weights and Measures adopted in 1927 a practical scale of temperature designated as the **International Temperature Scale.** This scale conforms with the thermodynamic scale as closely as is possible with present knowledge, and is designed to be definite, conveniently and accurately reproducible, and to provide means for uniquely determining any temperature within the range of the scale, thus promoting uniformity in numerical statements of temperature.

The necessity of repeating gas thermometer experiments for obtaining standard temperatures is obviated by basing the International Temperature Scale on a number of basic fixed and reproducible equilibrium temperatures (to which definite numerical values are assigned on the thermodynamic scale through the medium of gas thermometer observations), and upon the use of selected interpolating instruments calibrated according to a specified procedure.

The basic fixed points, and the numerical values assigned to them for the pressure of one standard atmosphere, are given in the following table, together with formulæ which represent the temperature (t_p) as a function of vapour pressure (p) over the range 680 mm. to 780 mm. of mercury. Interpolation between these fixed points is carried out (*a*) by platinum resistance thermometry from −190° to 0° and from 0° to 660° C.; (*b*) by platinum platinum-rhodium thermocouples from 660° to 1063° C.; and (*c*) above 1063° C. by optical pyrometry.

Basic Fixed Points of the International Temperature Scale.

(*a*) Temperature of equilibrium between liquid and gaseous oxygen at the pressure of one standard atmosphere. (Oxygen point) . . . . . . −182·97° C.

$$t_p = t_{760} + 0{\cdot}0126(p-760) - 0{\cdot}0000065(p-760)^2$$

(*b*) Temperature of equilibrium between ice and air-saturated water at normal atmospheric pressure. (Ice point) . . . . 0·000° C.

(*c*) Temperature of equilibrium between liquid water and its vapour at the pressure of one standard atmosphere. (Steam point) . . . . 100·000° C.

$$t_p = t_{760} + 0{\cdot}0367(p-760) - 0{\cdot}000023(p-760)^2$$

(*d*) Temperature of equilibrium between liquid sulphur and its vapour at the pressure of one standard atmosphere. (Sulphur point) . . . . 444·60° C.

$$t_p = t_{760} + 0{\cdot}0909(p-760) - 0{\cdot}000048(p-760)^2$$

(*e*) Temperature of equilibrium between solid silver and liquid silver at normal atmospheric pressure. (Silver point) . . . . 960·5° C.

(*f*) Temperature of equilibrium between solid gold and liquid gold at normal atmospheric pressure. (Gold point) . . . . 1063° C.

Standard atmospheric pressure is defined as the pressure due to a column of mercury 760 mm. high having a mass of 13·5951 grammes per cm.^{3}, subject to a gravitational acceleration of 980·665 cm./sec.^{2}, and is equal to 1,013,250 dynes/cm.^{2}.

A number of secondary fixed points are also specified ranging from the equilibrium point of solid carbon dioxide to the melting point of tungsten. Cf. pp. 58 and 59. (*See* N.P.L. Annual Report for 1928, p. 31.)

GAS THERMOMETRY

The thermodynamic scale of temperature is realized by the aid of the gas-thermometer, together with a knowledge of the equation of state of the gas used. In particular, the position of the zero of the Centigrade scale on the absolute scale is determined in this way.

THERMODYNAMIC TEMPERATURE OF THE ICE-POINT

Method.	H_2	N_2	Air.	CO_2	He	Computer.
	°	°	°	°	°	
Joule-Thomson effect . . .	273·14	273·09	—	273·05	—	Callendar, 1903
Extrapolation to zero pressure .	273·07	273·09	—	—	—	Berthelot and Chappuis, 1907
Joule-Thomson effect . . .	273·05	—	273·19	273·10	—	Berthelot, 1907
Extrapolation to zero pressure .	—	—	—	—	273·16	Heuse & Otto, 1930
„ „	—	—	—	—	273·16	Roebuck, 1936
„ „	—	—	—	—	273·14	Keesom and Tuyn, 1936
„ „	—	—	—	—	273·17	Kinoshita and Oishi, 1937
„ „	—	—	—	—	273·16 to 273·17	Beattie, 1937

Probable **Mean 273·16°.**

PLATINUM THERMOMETRY

TO REDUCE PT-SCALE TEMPS. (t_{pt}) TO INTERNATIONAL SCALE TEMPS. (t)

The interpolation formula for use with the platinum resistance thermometer for temperatures above 0° C. is $R_t = R_0(1 + At + Bt^2)$. For ease in computation, Callendar adopted the following method. The temperature is first calculated on the "platinum scale" (t_{pt}) by assuming the linear relation $R_{pt} = R_0(1 + at_{pt})$ between temperature and resistance. The difference-coefficient, δ, is then introduced to correct to the parabolic relation by means of the formula $t - t_{pt} = \delta . t(t - 100)10^{-4}$. For temperatures between 0° C. and $-$ 190° C. the interpolation formula is $R_t = R_0[1 + At + Bt^2 + C(t - 100)t^3]$ for which the corresponding "difference" formula becomes $t - t_{pt} + \delta . t(t - 100)10^{-4} + \beta . t^3(t - 100)10^{-8}$. The three constants of the quadratic law are determined by calibration at the ice, steam and sulphur points. These values are also used in the low-temperature law, the additional constant being obtained by calibration at the boiling point of liquid oxygen. Pure platinum has a mean value of a over the range 0° to 100° C. of about 0·00392, while δ lies between 1·49 and 1·495. Impure platinum has usually a high value of δ. Platinum thermometers are suitable for use at temperatures up to 1100° C. See Ezer Griffiths' "Methods of Measuring Temperature" (Griffin).

The use of the different formulæ involves the use of a series of successive approximations. The use of the following table for a first approximation will shorten the work when high accuracy is required, and, above $-$40° C., will give sufficiently accurate results for most purposes without calculation.

VALUES OF t FOR $\delta = 1·50$

Pt Temps. t_{pt}.	0	20	40	60	80	100	120	140	160	180
	t	t	t	t	t	t	t	t	t	t
−200°	—	−171°·5	−153°·2	−134°·7	−115°·9	−97°·0	−77°·84	−58°·59	−39°·18	−19°·65
0	0°	19·76	39·64	59·64	79·76	**100**	120·4	140·9	161·5	182·3
+200	203·1	224·2	245·4	266·7	288·1	309·8	331·5	353·4	375·5	397·8
400	420·2	442·8	465·5	488·5	511·6	534·9	558·4	582·1	606·0	630·1
600	654·4	679·0	703·7	728·7	754·0	779·4	805·2	831·2	857·4	884·0
800	910·8	937·9	965·3	993·0	1021	1050	1078	1107	(1137)	(1167)
1000	(1197)	(1228)	(1259)	(1290)	(1323)	(1355)	—	—	—	—

CHANGE Δt IN THE INTERNATIONAL SCALE TEMP. (t) FOR A CHANGE OF −0·01 IN δ

t	Δt	t	Δt	t	Δt	t	Δt	t	Δt
−40° C.	−0°·006	**50°** C.	+0°·002	**300°** C.	−0°·06	**600°** C.	−0°·30	**900°** C.	−0°·7
−20	−0·002	**100**	**0**	**400**	−0·12	**700**	−0·42	**1000**	−0·9
0	**0**	**200**	−0·02	**500**	−0·20	**800**	−0·56	**1100**	−1·1

HIGH TEMPERATURES

See Burgess and Le Chatelier's "High Temperature Measurements, 1912," and "Pyrometric Practice" (Technological Paper 170 of the Bureau of Standards, 1921).

For the measurement of high temperatures (say above 1550° C., which is about the present upper experimental limit of the gas scale) the instruments in general use are thermo-junctions and optical or radiation pyrometers. Pt thermo-couples may be used with precautions up to 1700° C. At higher temperatures optical pyrometers afford the most reliable means.

THERMO-ELECTRIC THERMOMETRY

The International Temperature Scale between 660° and 1063° is defined by means of a platinum, platinum 10% rhodium thermo-couple, the relation between e.m.f. and temperature being given by a quadratic law determined by observations at the melting points of antimony, silver, and gold. Thermo-couples of platinum, platinum 13% rhodium are also in common use. Among base metal thermo-couples standard values have been given for the chromel, alumel couple up to temperatures as high as 1400° C., but the life of all thermo-couples is shortened and constancy impaired by exposure to the highest temperatures for considerable periods. The figures given in the table below for the platinum couples and the chromel, alumel couples are taken from the standard values given by the National Bureau of Standards (U.S.A.), while those for copper-constantan * and iron-constantan * are the averages of values which have been determined from time to time at the National Physical Laboratory. Individual couples of the latter may show variations up to 10%. All values are given for a cold junction temperature of 0° C. For accurate work, an actual calibration of the batch of wire in use should be made.

E.M.F.'S OF COMMON THERMO-COUPLES IN MILLIVOLTS (10^{-3} VOLT)

Temp.	Pt. Pt −10% Rh.	Pt, Pt −13% Rh.	Chromel-Alumel.	Iron-Constantan.*	Copper-Constantan.*
100° C.	0·64	0·65	4·1	5	4
200	1·44	1·46	8·1	11	9
300	2·32	2·39	12·2	16	15
400	3·25	3·40	16·4	22	(21)
500	4·22	4·45	20·6	27	—
600	5·22	5·56	24·9	33	—
700	6·26	6·72	29·1	39	—
800	7·33	7·93	33·3	45	—
900	8·43	9·18	37·4	—	—
1000	9·57	10·47	41·3	—	—
1100	10·74	11·81	45·1	—	—
1200	11·92	13·18	48·8	—	—
1300	13·12	14·56	52·4	—	—
1400	14·31	15·94	55·8	—	—
1500	15·50	17·32	—	—	—
1600	16·67	18·68	—	—	—
1700	17·83	20·02	—	—	—

* Constantan (or Eureka): 60% Cu, 40% Ni.

THERMO-E.M.F.'S AGAINST PLATINUM IN MICRO VOLTS (10^{-6} VOLT)

One junction at 0° C. The current flows across the other junction from the metal with the (algebraically) smaller value to the other metal.

Metal.	−190°	+100°	Metal.	−190°	+100°	Metal.	−190°	+100°
Aluminium	+ 390	+ 380	Lead .	+ 210	+ 410	Tantalum .	—	+ 330
Antimony	—	+4700				Tin . .	+200	+ 410
Bismuth .	+12300	−6500	Magnesium .	+ 330	+ 410	Zinc . .	−120	+ 750
Cadmium .	− 60	+ 900	Mercury	—	0	Brass . .	—	c.+ 400
Cobalt .	—	−1520	Nickel .	+2220	−1640	Constantan*	—	−3440
Copper .	− 200	+ 740						
Gold . .	− 120	+ 730	Palladium .	+ 790	− 560	German silver † . .	—	c.−1000
Iron . .	− 2900	c.+1600	Silver .	− 140	+ 710	Manganin ‡	—	+ 570

* Eureka, 60 Cu, 40 Ni. † 60 Cu, 15 Ni, 25 Zn. ‡ 84 Cu, 4 Ni, 12 Mn.

RADIATION AND OPTICAL PYROMETRY

Most total radiation thermometers depend upon the Stefan-Boltzmann law, $E=\sigma(\theta^4-\theta_0^4)$, where E is the total energy (all wave-lengths) radiated per sec. by a black body at absolute temp. θ to surroundings at absolute temp. θ_0, and σ is a const. ($\sigma = 5{\cdot}7 \times 10^{-12}$ watts per cm.^{2} per 1°—see p. 128). Optical pyrometers using monochromatic light depend on Wien's equation connecting the temperature with the intensity of some particular wave-length of light emitted (p. 128). The Wien equation is, Intensity $I = c_1\lambda^{-5}e^{-c_2/\lambda\theta}$, where λ is the wave-length, θ is the "black body" temp. on the absolute scale, c_1 and c_2 are constants, and e is the base of the Napierian logarithms. Both equations give results which agree very accurately with the gas scale over the calibrated range up to 1550° C.

The "black body" temperature of a radiating substance is the temperature at which an ideal black body would emit radiation of the same intensity as that from the substance, the radiation considered being of some particular wave-length. A perfectly black body absorbs all the radiation which falls upon it; it is destitute of reflecting power. An enclosure of uniform temperature, viewed through a small aperture, acts as a black body. When black body conditions are not realized, the observed temperature will be lower than the true temperature and a correction dependent on the emissivity (ϵ) of the object on which the pyrometer is sighted must be added to the observed temperature. The relation between observed (θ_{obs}) and true temperature is given by the equation $\theta_{obs}^4 = \epsilon.\theta^4$ for a total radiation pyrometer, and by the equation $1/\theta - 1/\theta_{obs} = \lambda \log \epsilon_\lambda/6219$ for an optical pyrometer using light of effective wave-length λ.

EMISSIVITY CORRECTIONS FOR OPTICAL AND RADIATION PYROMETERS

Obs. Temp. (° C.).	**Corrections (° C.).**														
	Optical Pyrometer (λ = 0·65μ, c_2 = 1·432 cm. deg.). ϵ =							**Total Radiation Pyrometer. ϵ =**							
	0·3	**0·4**	**0·5**	**0·6**	**0·7**	**0·8**	**0·9**	**0·3**	**0·4**	**0·5**	**0·6**	**0·7**	**0·8**	**0·9**
600	44	34	26	18	13	8	4	306	224	165	119	81	49	23
800	67	50	37	27	19	12	6	377	276	203	146	100	60	29
1000	95	71	53	39	27	17	8	447	328	241	173	119	72	34
1200	129	96	71	52	36	22	10	517	379	279	200	137	82	39
1400	169	125	93	67	46	28	13	587	431	316	228	157	94	45
1600	214	159	117	85	58	35	17	657	482	354	256	174	105	50
1800	265	196	145	105	72	44	20	728	354	392	282	194	117	55
2000	322	238	176	127	87	53	25	798	586	430	309	212	128	63
2500	495	362	266	190	131	78	38	974	714	525	378	259	156	74
3000	713	516	377	269	183	110	53	1149	842	618	445	305	183	86

AVERAGE EMISSIVITIES AT WAVE-LENGTH 0·65μ

The emissivity at a given wave-length varies slightly with temperature. The values in the following table may be taken as accurate to within ±0·05.

Material.	**Emissivity (0·65μ).**		**Material.**	**Emissivity (0·65μ).**	
	Solid.	**Liquid.**		**Solid.**	**Liquid.**
Carbon	0·85	—	Nickel	0·35	—
Copper	0·1	0·15	,, (oxidized) .	0·9	—
,, (oxidized) .	0·7	—	Palladium . . .	0·35	0·35
Gold	0·15	0·2	Platinum	0·35	0·35
Iridium	0·3	—	Rhodium . . .	0·3	0·3
Iron	0·35	0·35	Silver	0·1	—
,, (oxidized) . .	0·95	—	Slag (average) . .	—	0·65
Nichrome . . .	0·9	—	Thoria	0·6	0·7
			Tungsten . . .	0·45	—

TEMPERATURE AND COLOUR OF HOT OBJECTS

Appearance .	**Red—just visible.**	**Dull Red.**	**Cherry Red.**	**Orange.**	**White.**
Temperature .	*c.* 550° C.	*c.* 700°	*c.* 900°	*c.* 1100°	*c.* 1400° upwards

Temp. of positive crater of electric arc 3400° C.; under pressure 3600° C.

MERCURY THERMOMETRY

Details of the technique of mercury in glass thermometry for work of high precision will be found in Guillaume's "Thermométrie de Précision" (Paris, 1889), Higgins's "Thermometry" (Roy. Soc. Arts, 1926), and "The Dictionary of Applied Physics" (Macmillan).

CORRECTIONS TO REDUCE MERCURY-IN-GLASS SCALE TEMPS. TO GAS SCALE TEMPS.

The values for verre dur are given by the Bureau International des Poids et Mesures, and those for the Jena glasses by Grützmacher. The French glass, verre dur, was used by Tonnelot of Paris for the manufacture of the original standard mercury thermometers of the International Bureau. Later thermometers of this type were made by Baudin. Jena 16‴ may be identified by the presence of a thin red line embedded in the glass. Jena 59‴ is a boro-silicate glass (p. 85), and has now been superseded by Jena 2954‴, which is identified by a thin black line.

Temp.	Verre Dur.	Jena 16‴.	Jena 59‴.	Temp.	Verre Dur.	Jena 16‴.	Jena 59‴.
	$t_H - t_{V.D.}$	$t_H - t_{16'''}$	$t_H - t_{59'''}$		$t_N - t_{V.D.}$	$t_N - t_{16'''}$	$t_N - t_{59'''}$
−20°	+°·17	+°·19	+°·10	110°	+°·04	+°·03	−°·00
0	0	0	0	120	+ ·06	+ ·05	− ·02
10	− ·05	− ·06	− ·02	130	+ ·07	+ ·07	− ·04
20	− ·08	− ·09	− ·04	140	+ ·07	+ ·09	− ·08
30	− ·10	− ·11	− ·04	150	+ ·06	+ ·10	− ·13
40	− ·11	− ·12	− ·04	160	+ ·03	+ ·10	− ·10
50	− ·10	− ·11	− ·03	170	0	+ ·08	− ·28
60	− ·09	− ·10	− ·02	180	− ·04	+ ·06	− ·39
70	− ·07	− ·08	− ·01	190	− ·09	+ ·02	− ·52
80	− ·05	− ·06	− ·00	200	− ·13	− ·04	− ·67
90	− ·03	− ·03	− ·00	250	—	− ·63	− 1·7
100	0	0	0	300	—	− 1·91	− 4·1

DEPRESSION OF ZERO OF MERCURY THERMOMETERS

After a mercury thermometer has been heated the zero suffers a temporary depression. When the thermometer has been calibrated as an absolute instrument, it is therefore necessary to make an observation of the zero immediately after reading the temperature. If, however, the thermometer has been calibrated by comparison with standard thermometers, as is done at the National Physical Laboratory and other standardising institutions, this procedure is not necessary. After heating to 100° C. the zero depression of a verre dur thermometer is about 0·11° C., while the more modern glasses (Powell's blue stripe, Tomey's double blue stripe, Jena 16‴, 59‴, and 2954‴, and Fischer's Gege-Eff) show a depression of about 0·04° C. after 100° C. Early samples of Jena 16‴, however, show a depression after 100° C. of about 0·07° C. These mean values should not be utilised for accurate work. For other temperature rises, the consequential zero depressions may be taken as proportional to the depression after 100° C.

STEM EXPOSURE OR EMERGENT COLUMN CORRECTION

Whenever possible a mercury thermometer should be used so that the whole of the mercury column is exposed to the temperature to be measured. If this cannot be done, the thermometer will read low by an amount depending on the length and temperature of the exposed column. The correction to be added (if the thermometer has been calibrated for total immersion) is equal to

$$n\alpha(t - t_s)$$

where n is the length of exposed column in degrees, α is the coefficient of apparent expansion of mercury in glass, t the temperature of the bulb, and t_s the mean temperature of the exposed column. On the Centigrade scale, α may be taken as 0·00016, and on the Fahrenheit scale as 0·00009. In general, this correction cannot be determined to a greater accuracy than about 10% owing to the difficulty of measuring the temperature of the exposed column. For this purpose a "thread thermometer" may be used. This thermometer has a long bulb of capillary tubing, and is selected so that the length of the bulb is approximately equal to that of the exposed column alongside which it is placed. Alternatively a series of auxiliary thermometers of ordinary type may be used. The lowest of these should be placed quite close to the point at which the thermometer stem leaves the region of which the temperature is being measured, and the others at intervals not exceeding 10 cm. along the stem. The mean of the readings of all the auxiliary thermometers should be taken. Thermometers which are graduated for use at a specified fixed immersion only need correction when the stem temperature departs from the normal value.

MELTING AND BOILING POINTS OF THE ELEMENTS

For melting and boiling points of chemical compounds, see p. 130; of fats and waxes, see p. 60. The melting points of a number of elements are adopted as basic and secondary fixed points in the International Temperature Scale (p. 53, where an account of temperature measurements will be found).

Element.	Melting Point.	Observer.	Boiling Point.	Observer.
Aluminium .	660° C.	Edwards, 1925	> 2200 °C.	Wartenberg, 1908
			1800	Greenwood, 1911
Antimony .	630·5	Roeser, Schofield and Moser, 1933	1645	Kohlmeyer, 1932
Argon. . .	−189·3	Simon, Ruhemann and Edwards, 1930	−185·8	Henning, 1915
Arsenic . .	volatilizes	—	{sublimes 450}	—
Barium . .	704	Hoffman and Schulze, 1935	1140 (?)	—
Beryllium .	1281	Sloman, 1932	1500 (?)	—
Bismuth . .	269	Awbery and Griffiths, 1926	1560	Leitgebel, 1931
Boron. . .	2000 to 2500	Weintraub, 1909	{sublimes 3500 (?)}	—
Bromine . .	−7·3	Baker, 1923	58·80	Bouzat and Leluan, 1924
Cadmium. .	320·9	Day and Sosman, 1912	767	Leitgebel, 1931
Cæsium . .	28·45	Rengade, 1914	670	Ruff and Johanssen, 1905
Calcium . .	851	Hoffmann and Schulze, 1935	1175	Ruff and Hartmann, 1924
Carbon . .	3500	Fajans, 1924	3927	Kohn and Guckel, 1924
Cerium . .	815	Billy and Trombe, 1931	1400 (?)	—
Chlorine . .	−103	Graff, 1933	−33·95	Harteck, 1928
Chromium .	1830	Adcock, 1931	2260	Baur and Brunner, 1934
Cobalt . .	1490	Day and Sosman, 1910	3467	Warmuth, 1928
Copper . .	1084·3	Holborn and Day, 1900	2360	Ruff and Konschak, 1926
,, . .	1082·8	Day and Sosman, 1910		
,, . .	1083	Waidner and Burgess, 1910		
Fluorine . .	−223	Moissan and Dewar, 1903	−188	Claussen, 1934
Gallium . .	29·78	Roeser and Hoffmann, 1934	2300	Harteck, 1928
Germanium .	958·5	Dennis, Tressler and Hance, 1933	—	—
Gold . . .	1062·9	Holborn and Day, 1899	2360	Ruff and Konschak, 1926
,, . . .	1062·8	Day and Sosman, 1911		
,, . . .	1062·8	Wensel and Roeser, 1936		
Hafnium . .	2227	de Boer and Fast, 1930	—	—
Helium . .	272·0	Keesom, 1926	−268·98	K. Onnes and Weber, 1915
Hydrogen .	−259	Keesom and Lisman, 1932	−252·75	Keesom, van der Bijl and Horst, 1931
			−252·78	Heuse and Otto, 1931
Heavy hydrogen * . .	−254·58 (121 mm.)	Brickwedde, Scott, Urey and Wahl, 1934	−249·7	Brickwedde, Scott, Urey and Wahl, 1934
Indium . .	156·4	Roth, Meyer & Zeumer, 1933	> 1400	Thiel, 1904
Iodine . .	113·7	Kracek, 1931	184·4	Drugmann and Ramsay, 1900
Iridium . .	2454	Henning and Wensel, 1933	2550 (?)	—
Iron . . .	1527	Jenkins and Gayler, 1930	3235	Millar, 1925
Krypton .	−156·6	Allen and Moore, 1931	−152·9	Allen and Moore, 1931
Lanthanum .	812	Rolla, 1933	—	—
Lead . . .	327·4	Natl. Phys. Lab., 1931	1755	Fischer, 1934
Lithium . .	186	Kahlbaum, 1900	> 1400	Ruff and Johanssen, 1905
Magnesium .	659	Haughton and Payne, 1934	1107	Hartmann and Schneider, 1929
Manganese .	1242	Gayler, 1927	1900	Millar, 1925
Mercury . .	−38·86	Natl. Phys. Lab., 1931	356·7	Callendar, 1899
Molybdenum.	2622	Worthing, 1925	c. 3560	van Liempt, 1920
Neodymium .	840	Muthmann and Weiss, 1904	—	—
Neon . .	−248·7	Simon, Ruhemann and Edwards, 1930	−246·3	K. Onnes and Crommelin, 1916
Nickel . .	1455	Wensel and Roeser, 1930	3075	Millar, 1925
Niobium .	1950	Bolton, 1907	—	—
Niton . .	−71	Gray and Ramsay, 1910	−62	Gray and Ramsay, 1910

* Deuterium.

MELTING AND BOILING POINTS OF THE ELEMENTS (*contd.*)

Element.	Melting Point.	Observer.	Boiling Point.	Observer.
Nitrogen	−210·02° C.	Giauque and Clayton, 1933	−195·84° C.	Giauque and Clayton, 1933
Osmium	2700 (?)	—	—	—
Oxygen	−219·1	Clusius, 1929	−182·96	Heuse and Otto, 1931
,,	−218·8	Giauque and Johnston, 1929	−182·98	Keesom, v.d. Horst and Jansen, 1929
Ozone	−251·4	Riesenfeld, 1923	−111·5	Briner and Biedermann, 1933
Palladium	1549	Day and Sosman, 1910	—	—
,,	1553·6	Natl. Bur. Standards, 1929		
,,	1554·5	Jaeger and Veenstra, 1934		
,,	1554·4	Natl. Phys. Lab., 1936		
Phosphorus	44·1	Hulett, 1899	279	Jolibois, 1910
Platinum	1773·5	Natl. Bur. Standards, 1931	4300 (?)	—
,,	1773·2	Natl. Phys. Lab., 1934	—	—
,,	1773·8	Phys.-Tech. Reichsanstalt, 1934	—	—
Potassium	63·6	Edwardson and Egerton, 1927	758	Ruff and Johanssen, 1905
Præsodymium	940	Muthmann and Weiss, 1904	—	—
Radium	960 (?)	—	—	—
Rhenium	3167	Agte, Heyne & Moers, 1930	—	—
Rhodium	1966	Roeser and Wensel, 1934	2500 (?)	—
,,	1966	Schofield, 1939	—	—
Rubidium	39·0	Rengade, 1913	696	Ruff and Johanssen, 1905
Ruthenium	1900 (?)	—	2520 (?)	—
Samarium	> 1350	—	—	—
Selenium	220	Berger, 1914	684·8	de Selincourt, 1940
Silicon	1415	Gayler, 1938	2392	Ruff and Konschak, 1927
Silver	960·5	Holborn and Day, 1899	2152	Fischer, 1934
,,	960·6	Day and Sosman, 1911	—	—
,,	960·5	Roeser and Dahl, 1933	—	—
,,	960·5	Roeser, Schofield and Moser, 1933	—	—
Sodium	97·6	Ezer Griffiths, 1914	878	Ruff and Johanssen, 1905
Strontium	771	Hoffman and Schulze, 1935	1366	Hartmann and Schneider, 1929
Sulphur	114·6 (rhombic)	Farr and McLeod, 1928	444·58* (c.v.N.)	Day and Sosman, 1912
	119–120 (monoclinic)		444·63* (c.p.N.)	Chappuis, 1914
Tantalum	2996	Malter and D. Langmuir, 1939	—	—
Tellurium	452·0	Šimek and Stehlick, 1930	1390	Deville and Troost, 1880
Thallium	302·5	Roth, Meyer and Zeumer, 1933	1457	Leitgebel, 1931
Thorium	1680 to 1730	Thompson, 1933	—	—
Tin	231·86	Natl. Phys. Lab., 1931	2270	Greenwood, 1909
Titanium	1800	Burgess and Waltenberg, 1913	—	—
Tungsten	3387	Pirani, 1923	4830	van Liempt, 1920
Uranium	1689	Driggs and Liliendahl, 1930	—	—
Vanadium	1720	Burgess and Waltenberg, 1913	—	—
Xenon	−111·8	Clusius and Riccoboni, 1937	−108·0	Clusius and Riccoboni, 1937
Zinc	419·5	Roeser, Schofield and Moser, 1933	913	Fischer, 1934
Zirconium	1857	de Boer, 1930	—	—

* Corrected by Berthelot to the thermodynamic scale.

Alloys.—Brass, M.P. 800–1000° C.; Cast Iron, M.P. *c.* 1100° C.; Duralumin, M.P. 650° C.; German Silver, M.P. 1000–1100° C.; Nichrome, M.P. *c.* 1500° C.; Phosphor Bronze, M.P. *c.* 1000° C

EFFECT OF PRESSURE ON BOILING POINTS

$\delta p/\delta t$ is given as mm. Hg per degree C. for pressures not very far removed from 760 mm.

The boiling point in absolute degrees C. of a substance under 760 mm. $= t + c(760 - p)(t + 273)$, where c is a constant for the substance, and t is the B.P. in degrees C. at the pressure p mm. The constant c is the same for chemically similar substances.

(See Young, "Fractional Distillation.")

Substance.	$\delta p/\delta t$	c	Substance.	$\delta p/\delta t$	c	Substance.	$\delta p/\delta t$	c
		$\times 10^{-6}$			$\times 10^{-6}$			$\times 10^{-6}$
Hydrogen . .	230	—	CCl_4	23	123	Benzene . .	23·5	121
Oxygen . . .	77	146	Pentane, n. .	25·8	125	Toluene. . .	21·7	120
Carbon dioxide	55	—	Alcohol, methyl	29·6	100	Aniline . . .	19·6	112
Water† . . .	27·2	99	„ ethyl .	30·3	94	Naphthalene .	17·1	119
Mercury . .	13·6	118	„ amyl .	25	98	Benzophenone	15·8	109
Nitrogen . .	92	—	Ether, ethyl .	26·9	121	Acetone. . .	26·4	115
Sulphur * . .	11·0	114						

* $tp = t_{760} + \cdot0910(p-760) - \cdot0_449(p-760)^2$, Mueller & Burgess, 1919. See also p. 53.

† See also pp. 50, 53.

MELTING, FREEZING, AND BOILING POINTS OF FATS AND WAXES

At 760 mm. pressure. (See Lewkowitsch's treatise.)

Substance.	M.P.	F.P.	Substance.	M.P.	F.P.	Substance.	M.P.	B.P.
	°C.	°C.		°C.	°C.		°C.	°C.
Butter. . .	28–33	20–23	Beeswax . .	61–64	60–63	Paraffin wax,		
Lard . . .	36–40	27–30	Spermaceti .	42–49	42–47	Soft. . .	38–52	350–390
Tallow, beef.	40–45	27–35	Stearin . .	71·6	70	Hard . .	52–56	390–430
„ mutton	44–45	36–41	Naphthalene	80·0	—	Olive oil . .	—	c. 300

THERMAL CONDUCTIVITIES

The thermal conductivity, k, is given below as the number of (gram) calories conducted per sq. cm. per sec. across a slab of the substance 1 cm. thick, having a temp.-gradient of 1° C. per cm., *i.e.* calorie $cm.^{-1}$ $sec.^{-1}$ $temp.^{-1}$. To reduce to pound-calories per sq. inch per sec. across a slab 1 inch thick with a temp.-gradient of 1° C. per inch, the values below must be multiplied by 0·0056. (See Callendar, "Conduction of Heat," *Encyc. Brit.*; Schofield, "Glazebrook's Dictionary of Applied Physics," Vol. I.; and Geiger and Scheel's "Handbuch der Physik.")

METALS AND ALLOYS

k for most pure metals decreases with rise of temperature; the reverse appears to be true for alloys. If κ be the electrical conductivity and θ the absolute temp., then $k/(\kappa\theta)$ is very approximately a constant for pure metals. (See Hume-Rothery, "The Metallic State.") The electrical conductivity of the same specimen of many of the substances below will be found on p. 92.

T. H. L.

METALS AND ALLOYS (*contd.*)

Substance.	Temp.	Cond. k.	Observer.	Substance.	Temp.	Cond. k.	Observer.
	C.				C.		
Metals—				Nickel	**−160**	·129	Lees, '08
Aluminium * .	**−160**	·514	Lees,	,, {97% Ni}	**18**	·142	J. & D.,
,, .	**18**	·504	*P.T.*, '08	,,	**100**	·138	1900
,, .	**18**	·480	J. & D.,	Palladium . .	**18**	·168	J. & D.,
,, .	**100**	·492	1900	,, . .	**100**	·182	1900
Antimony . . .	**0**	·044	Lorenz,	Platinum . . .	**18**	·166	J. & D.,
,, . . .	**100**	·040	1881	,, . . .	**100**	·173	1900
Bismuth . . .	**−186**	·025	M., 1907	Silver, pure . .	**−160**	·998	Lees,
,, . . .	**18**	·0194	J. & D.,	,, .	**18**	·974	1908
,, . . .	**100**	·0161	1900	,, .	**18**	1·006	J. & D.,
Cadmium, pure	**−160**	·239	Lees, '08	,, .	**100**	·992	1900
,, .	**18**	·222	J. & D.,	Tin, pure . . .	**−160**	·192	Lees, '08
,, .	**100**	·216	1900	,, . .	**18**	·155	J. & D.,
Copper, pure .	**−160**	1·079	Lees, '08	,, . .	**100**	·145	1900
,, .	**18**	·918	J. & D.,	Tungsten . . .	**18**	·35	Coolidge
,, .	**100**	·908	1000	Zinc, pure . .	**−160**	·278	Lees, '08
Gold	**18**	·700	J. & D.,	,, . . .	**18**	·265	J. & D.,
,, ...	**100**	·703	1900	,, . . .	**100**	·262	1900
Iron, pure . .	**100**	·176	Powell, 1934	**Alloys—** Al alloys.			
,, wrought .	**−160**	·152	Lees, '08	Al 88, Cu 12 .	**70**	·36	Griffiths,
,, ,, †	**18**	·144	J. & D.,		**170**	·38	1920
,, ,, †	**100**	·143	1900	Al 79·7, Cu 6·6	**70**	·39	Griffiths,
,, cast ‡	**54**	·114	Callendar	Zn 0·9, Sn 0·8	**170**	·41	1920
,, ,, ‡	**102**	·111		Al 83·8, Zn 13·5	**70**	·34	Griffiths,
,, ,, §	**30**	·149	Hall	Cu 2·7 . . .	**170**	·35	1920
,, steel {1% C.}	**−160**	·113	Lees,	Duralumin . .	**18**	·31	—
,, ,,	**18**	·115	1908	Brass ‖	**−160**	·181	Lees,
,, ,, ,,	**18**	·108	J. & D.,	,,	**17**	·260	1908
,, ,, ,,	**100**	·107	1900	Bronze,	**15**	·099	Griffiths,
Lead, pure . .	**−160**	·092	Lees, '08	Cu 89·4, Sn 9·6	**205**	·131	1920
,, ,, . .	**18**	·083	J. & D.,	Constantan	**18**	·054	J. & D.,
,, ,, . .	**100**	·082	1900	(Eureka) ¶	**100**	·064	1900
Magnesium . .	**0** to	·376	Lorenz,	German Silver .	**0**	·070	Lorenz,
,, . .	**100**		1881	,, ,,	**100**	·089	1881
Mercury . . .	**0**	·0148	H. F.	Manganin ** .	**−160**	·035	Lees, '08
,, . . .	**50**	·0189	Weber, '79	,, .	**18**	·053	J. & D.,
,, . . .	**15·5**	·0201	N., 1913	,, .	**100**	·063	1900
,, . . .	**17**	·0197	R. W., '02	Platinoid . . .	**18**	·060	Lees, '08

* 99% Al. † ·1% C., ·2% Si, ·1% Mn. ‡ 2% C., 3% Si, 1% Mn.
§ 3·5% C., 1·4% Si, ·5% Mn. ‖ 70 Cu, 30 Zn. ¶ 60 Cu, 40 Ni. ** 84 Cu, 4 Ni, 12 Mn.

A., Ångström ; J. & D., Jaeger & Diesselhorst ; M., Macchia ; N., Nettleton ; R. W., R. Weber ; *P.T.*, *Phil. Trans.*

GASES

In the case of a gas the thermal conductivity $k = 1{\cdot}603\eta c_v$, where η is the viscosity, and c_v the specific heat at constant volume. Stefan, and Kundt and Warburg have found, in agreement with this formula, that k for air, hydrogen, etc., is constant between the pressures 76 cm. and ·1 cm. k increases with the temperature. (See Laby, *P.R.S.*, 1934.)

Gas.	Temp.	Cond. *k*.	Gas.	Temp.	Cond. *k*.	Gas.	Temp.	Cond. *k*	Gas.	Temp.	Cond. *k*.
	C.	$\times 10^{-5}$		C.	$\times 10^{-5}$		C.	$\times 10^{-5}$		C.	$\times 10^{-5}$
H_2	**−150°**	11·7, E.	Air	**0**	5·77*	CO	**0°**	5·58, D.	N_2O	**0°**	3·61, K.M.
,,	**0**	31·8, E.	,,	**100°**	7·55*	CO_2	**0**	3·43, K.M.	,,	**100**	5·06, W.
,,	**0**	41·3, K.M.	O_2	**0**	5·83, K.M.	,,	**0**	3·51, D.	NO	**8**	4·60, W.
He	**0**	34·3, K.M.	A	**0**	3·89, S.	,,	**100**	5·06, Sc.	Hg	**203**	1·85, Sc.
N_2	**0**	5·81, D.	CH_4	**8**	6·47, W.	NH_3	**0**	5·22, D.	Ne	**0**	11·1, K.M.
			C_2H_4	**0**	3·95, W.						

*Mean. D., Dickins, 1934; E., Eckerlein, 1900; K.M., Kannuluik and Martin, 1934; S., Schwarze, 1903; Sc., Schleiermacher, 1889; W., Winkelmann, 1875.

MISCELLANEOUS SUBSTANCES

The values below are at ordinary temperatures except where stated. They must be regarded as rough average values in the case of indifferent conductors. Nearly all liquids have very approximately the same conductivity. Temperatures are in °C.

Substance.	k	Substance.	k	Substance.	k	Substance.	k
	$\times 10^{-3}$		$\times 10^{-3}$		$\times 10^{-3}$		$\times 10^{-3}$
Glass—		Charcoal	·13	Quartz, ‖ axis	22·2, K.	Slag wool, 0°	·10, G.
Crown; window	2·5, L.	Cement	·7, L.	70° ⊥ ,,	12·9, K.	Slate	4·7, L.
Flint	2, L.	Cotton	·55, L.	Silica, 60°	3·30, K.	Sulphur,	
Jena	1–2, L.	Cotton wool	·06	vitreous 240°	3·64, K.	Rhombic, 20°	·65, K.
Soda	1·3–1·8	Cork, slab, 0°	·11, G.	Rubber, Para	·45, L.	,, Plastic	·2?, K.
Woods (dry)—		,, gran'ld. 0°	·10, G.	Sand	·13	,, Monoclinic, 100°	·4, K.
Mahogany	·5, L.	Diatomaceous earth, 0°	·19, G.	Silk	·22, L.		
Oak, teak	·6	Earth's crust†	4				
Pine, walnut	·4, L.	Ebonite	·42, L.	**Liquids**—	$\times 10^{-4}$	**Oils**—	$\times 10^{-4}$
Miscellaneous		Felt	·09	Alcohol, 25°	4·3, L.	Castor, 20°	4·32, K.
Asbestos	·3	Flannel	·23, L.	Aniline, 20°	4·12, K.	,, 160°	4·02 ,,
Asbestos paper	·6	Gas carbon	10	CCl_4, 15°	2·7	Cylinder, 20°	3·66 ,,
Bricks—		Graphite‡	300	Glycerine, 20°	6·80, K.	,, 200°	3·39 ,,
		Ice	5	Turpentine, 13°	3	Olive, 0°	4·05 ,,
Diatomaceous, 100°	·3, G.	Marble, white	7·1, L.	Vaseline, 25°	4·4, L.	,, 200°	3·76 ,,
,, 500°	·45, G.	Mica*	1·8, L.	Water, 10°	14·7, K.	Paraffin, 0°	3·00 ,,
Fireclay, 600°	3·0 D.H. & C.	Paper	·3, L.	,, 50°	15·4, K.	,, 120°	2·9 ,,
,, 1000°	4·0	Paraffin wax	·6, L.	,, 80°	16·0, K.	Transformer, 0°	3·24 ,,
Cardboard	·5	Porcelain	2·5, L.			,, 100°	3·04 ,,

* Perp. to cleavage plane. † Average for igneous and sedimentary rocks; see Brit. Ass. Reports. D. H. & C., Dougill, Hodsman and Cobb, 1915; G., Ezer Griffiths, 1916; L., Lees, 1892 & 1898; K., Kaye and Higgins, 1928 and 1929. ‡ Acheson graphite.

COEFFICIENTS OF LINEAR EXPANSION OF SOLIDS

To represent accurately over any considerable range the variation of length (l) with temperature (t) requires for almost all solid substances a parabolic or cubic equation in t. But if the temperature interval is not large, a linear equation $l_t = l_0(1 + \alpha t)$ may be employed; and this gives a definition of the mean coefficient of linear expansion (α) over that temperature range. The coefficient of **cubical expansion** = 3α.

There is little point in tabulating coefficients of higher-powered terms of t, since for a given specimen it is as a rule impossible without measurement to assume with any accuracy anything more definite than the average value of even the first power coefficient (α). Except in a few cases the linear coefficient as defined above increases with the temperature. The values of α subjoined are per degree C., and except when some temperature is specified, for a range round and about 20° C. Some substances expand irregularly, and extrapolation of α may therefore be dangerous. Interpolation of α from the constituent metals must be employed with caution in the case of alloys. (See Geiger and Scheel's "Handbuch der Physik.")

Element.	α.	Obs.	Element.	α.	Obs.	Element.	α.	Obs.
	$\times 10^{-6}$			$\times 10^{-6}$			$\times 10^{-6}$	
Aluminium	25·5	V. '93	Gold	13·9	V. '93	Potassium	83	H. '82
Antimony	12	F. '69	Iridium	6·5	B. '88	Selenium, 40°	36·8	F. '69
Bismuth	13·3	Mean	Iron (cast)	10·2	D. '02	Silver	18·8	V. '93
C. (diamond)	1·2	F. '69	,, (wrought)	11·9	H.D.'00	Sodium	75	G. '15
,, (gas carbon)	5·4	F. '69	Steel, 10·5 to	11·6	N.P.L.	Sulphur	c. 70	—
			Lead	29·1	Mean	Thallium, 40°	30·2	F. '69
,, (graphite)	7·9	F. '69	Magnesium	25·4	V. '93	Tin	21·4	M. '66
Cadmium	28·8	M.'66	Nickel	12·8	T. '99	Tungsten, 27°	4·44	W. '17
Cobalt	12·3	T. '99	Palladium	11·7	S. '03	,, 2027°	7·26	W. '17
Copper	16·7	V. '93	Platinum	8·9	B. '88	Zinc, 25·8 to	26·3	N.P.L.

COEFFICIENTS OF LINEAR EXPANSION OF SOLIDS (*contd.*)

Substance.	*a.*	Obs.
	$\times 10^{-6}$	
Alloys—		
Aluminium bronze . . .	17·0	N.P.L.
Brass (ordy.) *c.* 66 Cu, 34 Zn	18·9	N.P.L.
Bronze, 32 Cu, 2 Zn, 5 Sn §	17·7	B. '88
Constantan (Eureka), 60 Cu, 40 Ni	17·0	N.P.L.
Duralumin	22·6	—
German silver, 60 Cu, 15 Ni, 25 Zn, 50°	18·4	Pf. '72
Gunmetal (Admiralty) . .	18·1	N.P.L.
Magnalium, 86 Al, 13 Mg	24	St. '01
Nickel steel, * 10 % Ni . .	13·0	N.P.L.
,, ,, 20 % ,, . .	19·5	N.P.L.
,, ,, 30 % ,, . .	12·0	N.P.L.
,, ,, 36 % ,, . . (Invar †)	0·9	N.P.L.
,, ,, 40 % ,, . .	6·0	N.P.L.
,, ,, 50 % ,, . .	9·7	N.P.L.
,, ,, 80 % ,, . .	12·5	N.P.L.
Phosphor bronze, 97·6 Cu, 2 Sn, ·2 P.	16·8	B. '88
Platinum-iridium, 90 Pt, 10 Ir ‡	8·7	B. '88
Platinum-silver, 33 Pt, 67 Ag	15	—
Solder, 2 Pb, 1 Sn, 50° . .	25	Sm.
Speculum metal, 68 Cu, 32 Sn	19·3	Sm.
Stainless steel . . . 10 to	11	—
Type metal, *c.* 135° . . .	19	Dl.
Miscellaneous—		
Brick (Egyptian)	9·5	N.P.L.
Cement and concrete, 10 to	14	—
Ebonite . . . . . 64 to	77	—
Fluor spar, CaF_2	19	F. '68
Glass, soft, 68 SiO_2, 14 Na_2O, 7 CaO	8·5	Sc.
,, hard, 64 SiO_2, 20 K_2O, 11 CaO	9·7	Sc.
Miscellaneous (*contd.*)	$\times 10^{-6}$	
Glass, flint, 45 SiO_2, 8 K_2O, 46 PbO	7·8	Sc.
,, Jena, 16‴ (see p. 78)	7·8	T.S.S. '96
,, ,, 59‴ (see p. 78)	5·7	
,, Verre dur (see p. 78)	7·2	C. '07
,, typical soda . . .	8·5	—
,, ,, lead . . .	9·5	—
,, pyrex	3	—
Granite	8·3	—
Gutta-Percha	198	Ru. '82
Ice, − 10° to 0°	50·7	Vn. '02
Iceland spar, ∥ axis . .	25·1	B. '88
,, ,, ⊥ axis. . .	− 5·6	B. '88
Marble, white Carrara, 15°, 1·4 to	3·5	N.P.L.
,, black.	4·4	—
Masonry. . . . . 4 to	7	—
Paraffin wax, 0°–40° . .	*c.* 110	—
Porcelain, Berlin . . .	2·8	S. '03
,, ,, 0°–100°	3·1	H.G. '01
,, Bayeux . . .	3·4	Bd. '00
,, ,, 0° . .	3·5	T. '02
Portland stone	*c.* 3	—
Quartz (crystal, ∥ axis . .	7·5	B, '88
,, ,, ⊥ axis. .	13·7	B. '88
Silica (fused), − 80° to 0° .	·22	S. '07
,, ,, 0° to 30° .	·42	C. '03
,, ,, 0° to 100°	·50	S. '07
,, ,, 0° to 1000°	·54	R. '10
Sandstone . . . . 7 to	12	—
Slate . . . . 6 to	10	—
Woods (1) along grain—		
Beech ; mahogany ; box .	*c.* 3	Vl. '68
Oak ; pine	*c.* 5	Vl. '68
(2) across grain—		
Beech ; box	*c.* 60	Vl. '68
Mahogany	*c.* 40	Vl. '68
Pine	*c.* 34	Vl. '68

* See Guillaume's "Les Applications des Aciers au Nickel," 1904. † Invar is obtainable in three qualities, with a range of coefficients of (—·3 to + 2·5) $\times 10^{-6}$ at ordinary temperatures. ‡ Used for international prototype metre (see p. 3). § Used for Imperial Standard Yard (see p. 4). B. Benoît; Bd. Bedford; C. Chappuis; D. Dittenberger; Dl. Daniell; F. Fizeau; G. Ezer Griffiths; H. Hagen; H.D. Holborn and Day; H.G. Holborn and Grüneisen; M. Matthiessen; N.P.L. National Physical Laboratory; Pf. Pfaff; R. Randall; Ru. Russner; S. Scheel; Sc. Schott; Sm. Smeaton; St. Stadthagen; T. Tutton; T.S.S. Thiesen, Scheel, and Sell; V. Voigt; Vl. Villari; Vn. Vincent; W. Worthing.

COEFFICIENTS OF CUBICAL EXPANSION OF GASES

The volume coefficient, α, at constant pressure is defined by $v_t = v_0(1 + \alpha t)$; the pressure coefficient, β, at constant volume is defined by $p_t = p_0(1 + \beta t)$, where v_t and p_t are the volume and pressure respectively corresponding to $t°$, the initial volume and pressure (v_0, p_0) being measured at 0° C. The values of both α and β depend on the initial pressure of the gas. If a gas obeys Boyle's law exactly, $\alpha = \beta$.

Comparison of rarefied gas, H_2 and absolute temperature scales.—By graphically or otherwise extrapolating α and β to zero pressure, they become equal (as we should expect, for rarefied gases should behave as ideal gases and obey Boyle's law), and we may write $\alpha = \beta = \gamma$. For example, Berthelot finds from Chappuis' data—

$$\text{For } H_2\text{, mean } \gamma = ·00366207 = 1/273·07 \text{ (see p. 54)}$$
$$N_2\text{, ,, } \gamma = ·00366182 = 1/273·09 \text{ (see p. 54)}$$

Kelvin's absolute temperature scale agrees with the ideal gas scale, and therefore with the rarefied gas scale. Now, as will be seen below, β for $H_2 = \gamma$ very nearly, and thus the constant-volume hydrogen scale of temperature may justifiably be taken as closely approximating to the thermodynamic scale.

Gas.	Temp.	p_0.	α.	Obs.
AT CONSTANT PRESSURE.				
	C.	cm. Hg.		
Air .	0°–100°	100·1	·0036728	C., 1914
,,	0–100	76	3671	R., 1847
H_2 .	0–100	100	36600	C., 1903
,, .	0–100	99·4	36589	H. O., '29
,, .	0–100	76	36609	R. M.
N_2 .	0–100	110·5	36742	H. H., '21
,, .	—	200 atm.	434	A., 1890
,, .	—	1000 ,,	218	A., 1890
O_2 .	—	100 ,,	486	A., 1890
He .	0–100	99·4	36579	H. O., '29
CO .	—	76 ,,	3669	R., 1847
CO_2	0–20	51·8	37128	C., 1903
,, .	0–100	,,	37073	,,
,, .	0–20	99·8	37602	,,
,, .	0–100	,,	37410	,,
,, .	0–20	137·7	37972	,,
,, .	0–100	,,	37703	,,
N_2O	—	76	3719	R., 1847
NH_3	0–50	76/15°	3854	P.D., '06
SO_2	—	76	3903	R., 1847

A., Amagat; C., Chappuis; H. H., Holborn & Henning; H. O., Heuse & Otto; J. P., Jacquerod & Perrot; K., Keesom; K. R., Kuenen & Randall; K. T. J., Keyes, Townshend, & Joung; M., Melander; M. N., Makower & Noble; P. D., Perman & Davies; R., Regnault; R. M., Richards & Marks.

Gas.	Temp.	p_0.	β.	Obs.
AT CONSTANT VOLUME.				
	C.	cm. Hg.		
Air .	—	·58	·0037666	M., 1892
,,	—	1·32	37172	,,
,,	—	10·0	36630	,,
,,	—	17–24	36513	R., 1847
,,	—	76	36650	,,
,,	0°–100°	100·1	36744	C., 1914
,,	—	200	3690	R., 1847
,,	—	2000	3887	,,
,,	0–1067	23	36643	J. P.
H_2 .	0–100	99·4	36621	H. O., 1929
,,	0–100	100	36630	C., 1907
,,	0–100	109	36627	O., 1908
N_2 .	0–100	65·4	36696	K. T. J., '22
,,	0–100	99·4	36740	H. O., 1929
O_2 .	0–100	66	36738	M. N., '03
,, .	0–1067	18–23	36652	J. P.
He	0–100	98·0	36612	K., 1928
,, .	0–100	99·4	36604	H. O., 1929
A .	—	51·7	3668	K. R., 1896
CO	0–100	76	3667	R., 1847
,,	0–1067	23	36648	J. P.
CO_2	0–100	51·8	36981	C., 1903
,, .	0–20	99·8	37335	,,
,, .	0–100	99·8	37262	,,
,, .	0–1067	24	36756	J. P.
N_2O	—	76	3676	R., 1847
SO_2	—	76	3845	R., 1847

COEFFICIENTS OF CUBICAL EXPANSION OF LIQUIDS

As with solids (see p. 62), if the temperature interval is not large, a linear equation $v_t = v_0(1 + at)$ may be employed to show the relation between the volume (v) of a liquid and its temperature (t). The mean coefficient (a) thus defined increases in general with the temperature. The values of a subjoined are per ° C., and for a range round 18° C. unless otherwise specified.

Liquid.	a.	Liquid.	a.	Liquid.	a.	Liquid.	a.
	$\times 10^{-5}$		$\times 10^{-5}$		$\times 10^{-5}$		$\times 10^{-5}$
Acetic acid .	107	Ether, ethyl .	163	Pentane .	159	Water,60–80	58·7
Alcohol, me. .	122	Ethyl bromide	137	Toluene .	109		
,, ethyl	110	Glycerine .	53	Turpentine .	94	**Solutions**–	
,, amyl	93	Mercury (see	p. 31)	Xylol (m) .	101	$CaCl_2$,5·8 %	25·0
Aniline . .	85	Methyl iodide	121	Water,5°–10°	5·3	,, 40·9%	45·8
Benzene . .	124	Oil, olive . .	70	,, 10–20	15·0	NaCl, 26% .	43·6
CS_2 . . .	121	,, paraffin .	90	,, 20–40	30·2	H_2SO_4,100%	57
Chloroform .	126	,, ,, 20°–199°	110	,, 40–60	45·8		

MECHANICAL EQUIVALENT OF HEAT

If W erg of work is completely converted into H calorie of heat, W = J . H, where J erg per calorie is the **mechanical equivalent of heat.**

If electrical energy is completely converted into thermal energy, then one of the relations

$$I^2Rt = J \,.\, H, \qquad EIt = J \,.\, H, \qquad E^2t/R = J \,.\, H,$$

applies, where J erg per calorie is the **electrical equivalent of heat,** and I e.m.u. is the current, R e.m.u. is the resistance, E e.m.u. the e.m.f. If the electrical units are the international ampere, ohm and volt J is in international joule per calorie (1 international joule = 1·00020 joule).

For the variation of the specific heat of water with temperature see p. 66. Birge (1929) proposed a new expression for J as a function of temperature; it gives for the ratio of the 20° C. to the 15° C. calorie $J_{20}/J_{15} = 0{\cdot}99906$.

Direct determinations of J have been made by Joule, Rowland, Laby and Hercus from 15° to 20° C. and by Reynolds and Moorby for the mean calorie, 1·3° to 100° C.

Indirect electrical determinations.—The value of the electrical units used in the older of these determinations is uncertain. The electrical equivalent of heat has been determined by Callendar and Barnes, by Jaeger and Steinwehr at the Reichsanstalt, and by Osborne, Stimson, and Ginnings at the National Bureau of Standards (*Journ. of Res.* 1939) at the instance of the Third International Conference on Steam Tables. The last and Birge (General Physical Constants, 1929) have given critical discussions of the value of J.

Values of J_{15} are given in the following table. **Mean value** here adopted of determinations (2), (4) and (5) is

$$J_{15} = \mathbf{4{\cdot}1852} : \mathbf{10^7} \text{ erg per } 15^\circ \text{ calorie.}$$

Observer.	J_{15}.	Observer.	J_{15}.
Direct measurements—		**Electrical measurements**—	
(1) Rowland	4·188	(3) Callendar and Barnes . .	4·1834
(2) Laby and Hercus . .	$4{\cdot}1852_6$	(4) Jaeger and Steinwehr . .	4·1841
		(5) Osborne, Stimson and Ginnings	4·1858

Direct measurement, Reynolds and Moorby,

1 mean calorie 1·3°–100° = 4·1832 . 10⁷ erg.

International Steam Table calorie

1 I.T. calorie = 4·1860 int. joule = 4·1868 . 10⁷ erg.

T. H. L.

SPECIFIC HEAT OF WATER

Callendar and Barnes (*Phil. Trans.*, 1902) used an electrical method of determining the temperature variation of the specific heat of water. The specific heats below are reduced by Callendar ("Encyc. Brit.," Art. "Calorimetry") from their results; they are relative to the specific heat at 20° C. on the C.P. nitrogen scale. The specific heat has a minimum at 37·5° C.

Temp.	Specific heat.	Temp.	Specific heat.	Temp.	Specific heat.	Temp.	Specific heat.	Temp.	Specific heat.
−5° C.	1·0158	25° C.	·9992	55° C.	·9992	85° C.	1·0043	160° C.	1·0238
0	1·0094	30	·9987	60	1·0000	90	1·0053	180	1·0308
5	1·0054	35	·9983	65	1·0008	95	1·0063	200	1·0384
10	1·0027	40	·9982	70	1·0016	100	1·0074	220	1·0467
15	1·0011	45	·9983	75	1·0024	120	1·0121		
20	1·0000	50	·9987	80	1·0033	140	1·0176		

Osborne, Stimson and Ginnings (*J. Res. Nat. Bur. St.*, 1939) by an electrical method obtain for C_p for water the following values in abs. joule gm.$^{-1}$.

Temp.	C_p.	Temp.	C_p.	Temp.	C_p.	Temp.	C_p.	Temp.	C_p.
0° C.	4·2177	20° C.	4·1819	40° C.	4·1786	60° C.	4·1848	80° C.	4·1964
5	4·2022	25	4·1796	45	4·1795	65	4·1868	85	4·2005
10	4·1922	30	4·1784	50	4·1807	70	4·1896	90	4·2051
15	4·1858	35	4·1782	55	4·1823	75	4·1928	95	4·2103
								100	4·2160

Heavy water in terms of ordinary water = 1·000 at 20° C. (Cockett and Ferguson, 1940).

Temperature . . .	10° C.	20° C.	30°	40° *	50°
Specific heat . . .	1·009$_7$	1·006$_2$	1·004$_4$	1·003$_7$	1·004$_1$

J. L.

* Minimum at 41° C.

SPECIFIC HEAT OF MERCURY

In terms of the gram calorie at 15°·5 on the const. vol. H. scale. (Barnes and Cooke, *Phys. Rev.*, 15, 1902.) Mercury has a minimum specific heat at 140° C. (Barnes, *Brit. Ass. Rep.*, 1909.)

Temp.	0° C.	20°	40°	60°	80°	100°	200°
Specific heat . .	·0335	·0333	·0331	·0329	·0328	(·0327)	(·032)

SPECIFIC HEATS OF THE ELEMENTS

For gases, see p. 68.

Substance.	Temperature.	Sp. heat.	Observer.	Substance.	Temperature.	Sp. heat.	Observer.
Aluminium .	−240	·0092	Nernst, 1912	Bromine, liqd.	13° to 45°	·107	Andrews, '48
„ .	0	·2096	Griffiths, '14	Cadmium .	−165	·0491	Griffiths, '14
	600	·282	Richards, '93	„ . .	0	·0547	„
Antimony .	−186 to −79	·0462	Behn, 1900	Cæsium . .	0 to 26	·048	E. & G., 1900
	17 to 92	·0508	Gaede, 1902	Calcium . .	−185 to 20	·157	N. & B., 1906
Arsenic, cryst.	21 to 68	·083	B. & W., 1868		0 to 100	·149	Be., 1906
„ amorph.	21 to 65	·076	„	Carbon—			
Barium . .	−185 to 20	·068	N. & B., 1906	Gas carbon	24 to 68	·204	B. & W., 1868
Beryllium .	0 to 100	·425	N. & P., 1880	Charcoal .	0 to 24	·165	H. F. Weber, '75
Bismuth . .	−186	·0284	Giebe, 1903	„ .	0 to 224	·238	„
	22 to 100	·0304	W., 1896	Graphite .	−188	·025	Magnus, 1923
Boron, amor.	0 to 100	·307	M. & G., 1893	„ .	11	·160	„
Bromine, solid	−78 to −20	·184	Regnault, '49	„ .	277	·133	„

SPECIFIC HEATS OF THE ELEMENTS (*contd.*)

Substance.	Temperature.	Sp. heat.	Observer.
Carbon (*contd.*)			
Graphite	827° C.	·440	Magnus, 1923
Diamond	−186	·0025	,,
,,	22	·122	,,
,,	53	·136	,,
,,	827	·429	,,
Cerium	0 to 100	·045	H., 1876
Chlorine, liqd.	0 to 24	·226	Knietsch
Chromium.	−200	·067	Adler, 1903
(1·4% Fe & Si)	0	·104	,,
	100	·112	,,
	400	·133	,,
Cobalt	−182 to 15	·082	Tilden, 1903
	15 to 100	·103	,,
	15 to 630	·123	,,
Copper	−250	·0035	Nernst, 1912
,,	0	·0909	Griffiths, '14
,,	97·5	·0952	,,
Didymium	0 to 100	·046	H., 1876
Gallium, solid	12 to 23	·079	B., 1878
,, liquid	12 to 119	·080	,,
Germanium	0 to 100	·074	N. & P., 1887
Gold	−185 to 20	·035	N. & B., 1906
	18 to 99	·0303	Voigt, 1893
Indium	0 to 100	·057	Bunsen, 1870
Iodine	9 to 98	·054	Regnault, 1840
Iridium	−186 to 18	·0282	Behn, 1898
	18 to 100	·0323	,,
Iron	−133	·0770	Griffiths, '14
	0	·1045	,,
	97·6	·1137	,,
	0 to 1100	·153	Harker, 1905
Lanthanum	0 to 100	·045	H., 1876
Lead	−250	·0143	Griffiths, '14
	0	·0302	,,
	300	·0338	Naccari, 1888
Lithium	0 to 19	·837	Be., 1906
	0 to 100	1·093	,,
Magnesium	−186 to −79	·189	Behn, 1900
	18 to 99	·246	Voigt, 1893
	225	·281	Stücker, 1905
Manganese	14 to 97	·122	Regnault, 1862
Mercury	See preceding page.		
Molybdenum	−185 to 20	·063	N. & B., 1906
	15 to 91	·072	D. & G., 1901
Nickel	0	·106	Moser, 1936
	500	·125	,,
Osmium	19 to 98	·031	Regnault, 1862
Palladium	−186° to 18°	·053	Behn, 1898
	18 to 100	·059	,,
Phosphorus yellow	−78 to 10	·17	Regnault, 1849
	13 to 36	·202	Kopp, 1864
,, liquid	49 to 98	·205	Person, 1847
,, red	15 to 98	·17	Regnault, 1853
Platinum	−186 to 18	·0293	Behn, 1898
	18 to 100	·0324	,,
	1230	·0461	Tilden, 1903
Potassium	−23	·173	C. & S., 1939
	27	·191	,,
Rhodium	10 to 97	·058	Regnault, 1862
Ruthenium	0 to 100	·061	Bunsen, 1870
Selenium, cryst.	22 to 62	·084	B. & W., 1868
,, amorph.	18 to 38	·095	,,
Silicon, cryst.	−185 to 20	·123	N. & B., 1906
	77	·182	Magnus, 1923
	727	·224	,,
Silver	−238	·0146	Nernst, 1912
	0	·0556	Griffiths, '14
	427	·059	Tilden, 1903
Sodium	−150	·2466	Griffiths, '14
	0	·2829	,,
	138	·3189	,,
Sulphur—			
,, rhombic	17 to 45	·163	Kopp, 1865
,, liquid	119 to 147	·235	Person, 1847
Tantalum	−185 to 20	·033	N. & B., 1906
	58	·036	v. Bolton, 1905
Tellurium, crys.	15 to 100	·048	Fabre, 1887
Thallium	−192 to 20	·0300	Schmitz, 1903
	20 to 100	·0326	,,
Thorium	0 to 100	·028	Nilson, 1883
Tin	−186 to −79	·0486	Behn, 1900
	0	·0536	Griffiths, '14
,, molten	240	·064	Spring, 1886
Titanium	−185 to 20	·082	N. & B., 1906
	0 to 100	·113	N. & P., 1887
	0 to 440	·162	,,
Tungsten	−185 to 20	·036	N. & B., 1906
	20 to 100	·034	Gin, 1908
Uranium	11 to 98	·062	Regnault, 1840
	0 to 98	·028	Blümcke, 1885
Vanadium	0 to 100	·115	Mache, 1897
Zinc	−233	·0271	Nernst, 1912
	0	·0918	Griffiths, '14
	300	·104	Naccari, 1888
Zirconium	0 to 100	·066	M. & D., 1873

B., Berthelot; Be., Bernini; B. & S., Bartoli & Stracciati; B. & W., Bettendorff & Wüllner; C. & S., Carpenter & Steward; D. & G., Defacqz & Guichard; E. & G., Eckardt & Graefe; H., Hillebrand; M. & D., Mixter & Dana; M. & G., Moissan & Gautier; N. & B., Nordmeyer & Bernouilli; N. & P., Nilson & Pettersson; W., Waterman.

SPECIFIC HEATS OF GASES AND VAPOURS

In calories per gram per degree C. The values at const. pressure are normally at atmospheric pressure. See Partington & Shilling, "The Specific Heats of Gases."

Gas.	Temp.	Sp. ht.	Observer.
AT CONSTANT PRESSURE (c_p)			
Air (dry) . . .	20° C.	·2417	Swann, 1909
,, ,, . . .	100	·2430	,, ,,
,, ,, . . .	20–440	·2366	H. & A., 1905
,, ,, . . .	20–98	·2372	Witkowski,
,, ,, . . .	−102–17	·2372	,, 1896
,, ,, 70 atmos.	—50	·312	,, ,,
Argon	15	·127	S. & H., '19
Hydrogen . . .	16	3·42	,, ,,
Nitrogen . . .	0	·2350	* H. & H., '07
,, (liq.) .	—200	·43	Alt, 1904
Oxygen . . .	20–440	·2419	H. & A., 1905
,, . . .	20–800	·2497	,, ,,
,, (liq.) .	—190	·347	Alt, 1904
Chlorine . . .	16	·114	Partington, '14
Carbon monoxide	18	·250	S. & H., '19
,, dioxide .	0	·2010	* H & H., '07
,, ,, .	100	·221	Swann, 1909
Steam	100	·4652	* H & H., '07
,, ...	100	·4878	Brinkworth, '15
Ammonia, NH_3 .	23°–100°	·520	Wiedemann,
Nitrous oxide, N_2O	26–103	·213	1876
Nitric oxide, NO .	13–172	·232	Regnault, '62
N. peroxide, NO_2	27–67	1·625	B. & O., 1883
H_2S	20–206	·245	Regnault, '62
CS_2	86–190	·160	,, ,,
Methane, CH_4 .	—	·530	S. & H., '19
Ethylene, C_2H_4 .	—	·364	,, ,,
Benzene, C_6H_6 .	34–115	·299	Wiedemann,
Chloroform, $CHCl_3$	27–118	·144	1877
Me. alcohol, CH_4O	101–223	·458	Regnault, '62
Et. alcohol C_2H_6O	108–220	·453	,, ,,
,, ether, $(C_2H_5)_2O$	25–111	·428	W., 1876
Turpentine, $C_{10}H_{16}$	179–249	·506	Regnault, '62
AT CONSTANT VOLUME (c_v)			
Air,† 1 atmos.. .	0°	·1715	Joly, 1891
Hydrogen ‡ . .	c. 50	2·402	,, ,,
Carbon dioxide § .	c. 55	·1650	,, 1894
Argon	0–2000	·0746	Pier, 1909
Nitrogen ‖ . .	0	·175	,,
Water vapour . .	100	·340	,,
Carbon monoxide	1000	·1715	Sherratt &
,, ,,	1800	·1765	Griffiths, '34

B. & O., Berthelot & Ogier; H. & A., Holborn & Austin (Reichsanstalt); S. & H., Scheel & Heuse; W., Wiedemann.

* H. & H., Holborn and Henning (Reichsanstalt).
Nitrogen (0–1400°), $c_p = \cdot2350 + \cdot000019t$
CO_2 (0–1400°), $c_p = \cdot2010 + \cdot0000742t - \cdot0_718t^2$
Steam (100–1400°), $c_p = \cdot4669 - \cdot0000168t + \cdot0_744t^2$
Mean specific heats between 0° and t° C.

† Air, $c_v = \cdot1715 + \cdot02788\rho$ where ρ is the density (gm./c.c.).

‡ H, c_v diminishes with increasing density and falling temp.

§ CO_2, $c_v = \cdot165 + \cdot2125\rho + \cdot34\rho^2$, ρ being density.

‖ N, $c_v = \cdot175 + \cdot00016t$, t being the temp.

RATIO OF THE SPECIFIC HEATS FOR GASES AND VAPOURS

γ = the ratio of the specific heat at constant pressure to that at constant volume. γ is usually determined directly by some method involving an adiabatic expansion, such as the determination of the velocity of sound in the gas. From a knowledge of either (1) the pressure or (2) the temperature immediately following an adiabatic expansion (Clément and Desormes, Lummer and Pringsheim's methods respectively), γ can be deduced from pv^γ = const., or $\theta v^{\gamma-1}$ = const. (See Capstick, "Science Progress," 1895; and Moody, *Phys. Rev.*, Ap., 1912.)

Gas.	Temp.	γ	Observer.	Gas.	Temp.	γ	Observer.
Monatomic gases				Air (dry)	0°	1·402	Koch, 1907
Helium	0° C.	1·63	B. & G., 1907	,, ,, ...	0	1·402	F., 1908
Argon	0	1·667	Niemeyer, '02	,, ,, ...	500	1·399	,, ,,
Neon	19	1·642	Ramsay, 1912	,, ,, ...	900	1·39	Kalähne, '03
Krypton	19	1·689	,,	,, ,, ...	−79·3	1·405	Koch, 1907
Xenon	19	1·666	,,	,, ,, 200	0	1·828	,, ,,
Mercury vapour .	310	1·666	K. & W., 1876	,, ,, atmos.	−79·3	2·333	,, ,,
				Hydrogen . . .	17	1·407	Brinkw'th, '25
Diatomic gases—				,, . . .	4–16	1·408	L. & P., 1898
Air (dry)	5–14	1·402	L. & P., 1898	Nitrogen	—	1·41	Cazin, 1862
,, ,, ...	0	1·401	Stevens, 1905	Oxygen	5–14	1·400	L. & P., 1892
,, ,, ...	15	1·401	Makower, '03	Carbon monoxide .	1800	1·297	S. & G., 1934
,, ,, ...	17	1·402	Brinkw'th, '25	Nitric oxide, NO .	—	1·394	Masson

B. & G., Behn & Geiger; F., Fürstenau; K. & W., Kundt & Warburg; L. & P., Lummer & Pringsheim; S. & G., Sherratt & Griffiths.

RATIO OF THE SPECIFIC HEATS FOR GASES AND VAPOURS (*contd.*)

Gas.	Temp.	γ	Observer.	Gas.	Temp.	γ	Observer.
Triatomic gases				Acetylene, C_2H_2 .	—	1·26	M. & F., 1897
Ozone	—	1·29*	Jacobs, 1905	Ethylene, C_2H_4 . .	—	1·264	Capstick, '95
Water vapour . .	100° (?)	1·305	Makower, '03	Benzene, C_6H_6 . .	20°	1·40	Pagliani, '96
Carbon dioxide . .	4–11	1·300	L. & P., 1898	"	99·7	1·105	Stevens, '02
" " . .	300	1·260	D. & G., 1924	Chloroform,	24–42	1·110	Müller, 1883
" " . .	500	1·26	F., 1908	$CHCl_3$ . . .	99·8	1·150	Stephens, '02
Ammonia, NH_3 .	—	1·336	Leduc, 1898	CCl_4	—	1·130	Capstick, '95
Nitrous oxide, N_2O	—	1·324	" "	Me. alcohol . . .	99·7	1·256	Stevens, '02
Nitrogen peroxide N_2O_4 . .	20°	1·172	Natanson, '85	" bromide . .	—	1·274	Capstick, '93
Nitrogen peroxide NO_2 . .	150	1·31	" "	" chloride . .	19–30	1·279	" "
H_2S	—	1·340	Capstick, '95	" iodide . . .	—	1·286	" "
CS_2	—	1·239	" "	Et. alcohol . . .	53	1·133	Jaeger, 1889
Sulphur dioxide.	16–34	1·26	Müller, 1883	" " . . .	99·8	1·134	Stevens, '02
	500	1·2	F., 1908	" bromide . . .	—	1·188	Capstick, '93
				" chloride . . .	22·7	1·187	" "
Polyatomic gases				" ether	12–20	1·024	Low, 1894
Methane, CH_4 . .	—	1·313	Capstick, '93	" "	99·7	1·112	Stevens, '02
Ethane, C_2H_6 . .	—	1·22	Daniel & Pierron, '99	Acetic acid . . .	136·5	1·147	" "
Propane, C_3H_8 . .	—	1·130					

* Extrapolated; D. & G., Dixon & Greenwood; F., Fürstenau; L. & P., Lummer & Pringsheim; M. & F., Maneuvrier and Fournier.

SPECIFIC HEATS OF VARIOUS BODIES

In most cases, the specific heats given must only be regarded as average values.

Substance.	Temp.	Sp. ht.	Substance.	Temp.	Sp. ht.	Substance.	Temp.	Sp. ht.
Alloys—	°C		Oil, linseed . .	20	·44 ‡	Ice (N & E) .	−250	·0242
Brass, red . .	0	·090	" olive . .	7	·47	" " .	−160	·273
" yellow .	0	·088	" paraffin .	20–60	·51 to ·54	" . . .	−21 to −1	·502
Eureka . . .	18	·098						
(Constantan)			" rape . .	20	·488 ‡	Indiarubber .	15–100	·27 to ·48
German silver .	0–100	·095	" sperm . .	20	·493 ‡			
Solder * . . .	0	·042	Sea-water . .	17	·94	Marble, white .	18	·21 to ·22
			Toluene . . .	18	·40			
Liquids—			Turpentine . .	18	·42	NaCl (N & E)	−248	·0099
Alcohol, amyl .	18	·55				" "	−38	·197
" ethyl .	0	·547	**Miscel-**			" . . .	10	·21
" "	40	·648	**laneous**—			KCl (N & E)	−250	·0156
" methyl	12	·601	Asbestos . .	20–100	·20	" "	−187	·117
Aniline † . . .	15	·514	Basalt . . .	20–100	·20 to ·24	" "	277	·177
Benzene . . .	10	·340				Paraffin wax .	0–20	·69
" . . .	40	·423	Ebonite . . .	20–100	·33	Porcelain ‖ . .	15-1000	·255
Brine, density = 1·2 (Harker)	−20	·69	Fluorspar, CaF_2	30	·21	" . .	15–200	·18
	0	·71	Glass, crown .	10–50	·16	Quartz, SiO_2 .	0	·174
	15	·72	" flint . .	10–50	·12	" " .	350	·279
Ether, ethyl .	18°	·56	" Jena 16‴§	18°	·19	Sand	20–100	·19
Glycerine . .	18–50	·58	" Jena 59‴§	18	·19	Silica (fused) ¶	15–200	·200
Oil, castor . .	20	·508 ‡	Granite . . .	20–100	·19 to ·20	" "	15–800	·248

* $S = ·0422 + ·000038t$. Sn 54%, Pb 46%. Ezer Griffiths, 1914. † Griffiths, *Phil. Mag.*, 1893.
‡ Ezer Griffiths & Williams, 1918. N. & E. Nernst & Eucken, 1912.
§ See p. 85. ‖ Harker, 1905. ¶ Greenwood, 1911.

LATENT HEAT OF FUSION

The quantity of energy required to convert 1 gram of substance from solid into liquid without change of temperature.

ICE

Temp.	Lt. ht.	Observer, etc.
	cals.	
−6·5° C.	76·03	Pettersson, 1881.
0	79·59	Regnault, 1843, corrected.
0	80·02	Bunsen, 1870, with ice calorimeter.
0	79·77	Smith, *Phys. Rev.*, 1903 (in terms of 15° calorie = 4·184 joules, taking Clark cell = 1·433 volts at 15° C.).
0	79·67	(333·5 joules) Osborne *N.B.S.* 1939 (I.T. calorie = 4·186 joules).

VARIOUS SUBSTANCES

Substance.	Temp.	Lt.ht.	Substance.	Temp.	Lt.ht.	Substance.	Temp.	Lt. ht.
Elements—	°C.	cals.	Palladium .	1550	36	**Compounds**—	°C.	cals.
Aluminium †.	658	92·4	Phosphorus .	44	5	NH_3 . . .	−75	108
Antimony* .	625	24·3	Platinum . .	1750	27	$NaNO_3$ . .	333	45·3
Bismuth*. .	269	13·0	Potassium .	62	16	KNO_3 . . .	308	25·5
Cadmium . .	321	14	Silver . . .	960	22	H_2SO_4 . . .	10·3	24
Copper. . .	—	43	Sodium (G.)	97·6	27·5	Acetic acid .	4	44
Lead . . .	327	5	Sulphur . .	115	9	Benzene . .	5·4	30
Magnesium*	644	46·5	Tin* . . .	232	14·6	Glycerine . .	13	42
Mercury . .	—	3	Zinc* . . .	418	26·6	Naphthalene.	80	35

* Griffiths and Awbery, 1926. † Awbery, 1939. G., Ezer Griffiths, 1914.

LATENT HEAT OF VAPORISATION

Latent heats are given as the number of gram calories required to convert 1 gram of substance from liquid into vapour without change of temperature. The latent heat of vaporisation vanishes at the critical temperature.

Trouton's Rule.—The latent heat of vaporisation of 1 gramme molecule of a liquid divided by the corresponding boiling point (on the absolute scale) is a constant (C). C = 21 for substances of which both liquid and vapour are unassociated. If the liquid is associated, $C > 21$ (*e.g.* water, C = 26); if the vapour is associated, $C < 21$ (*e.g.* acetic acid, C = 15). [See Nernst's "Theoretical Chemistry."]

STEAM

Regnault's equation connecting latent heat and temperature takes no account of the temperature variation of the specific heat of water (see p. 66). The equation gives values which are too large at low temperatures. The equations of Griffiths, Henning, and Smith have been reduced and are here expressed in terms of the **I. T. calorie** = 4·186 joules (p. 65). Griffiths' and Smith's results rest further on an attributed value of 1·433 volts for the e.m.f. of the Clark cell at 15° C.

See also next page. [The critical temp. of water is about 374° C.]

Observer.	Temp. range of expts.	Latent heat L_t at t° C.
Regnault, 1847 .	63°–194° C.	$L_t = 606{\cdot}5 - {\cdot}695t$
Griffiths, 1895 .	30° and 40°	$L_t = 598{\cdot}0 - {\cdot}605t$
Henning, *Ann. d. Phys.*, 1906, 1909 . . .	30°–100°	$L_t = 599{\cdot}1 - {\cdot}60t$, to ·3% or $L_t = 94{\cdot}2\,(365 - t)^{3125}$, to ·1%
	100°–180°	$L_t = 538{\cdot}71 - {\cdot}6425(t - 100) - {\cdot}0_3834(t - 100)^2$
Smith, *Phys. Rev.*, 1907 .	14°–40°	$L_t = 596{\cdot}9 - {\cdot}580t$

LATENT HEAT OF STEAM (*contd.*)

In terms of I. T. calorie. (4·186 j.)	Regnault, 1847.	Griffiths, 1895.	Joly, 1895.	Callendar, *	Osborne, Stimson & Ginnings, 1939.	Jakob & Fritz, 1935.	Carlton Sutton, 1917.	Mathews, 1917.
L_0 . .	606 †	598 †	—	595 †	596·7	596·3	—	—
L_{100} . .	537	537·5 †	540 ‡	540	538·5	538·7	538·88	539·2

* From sp. ht. of steam experiments and total heat formula. † Extrapolated.

‡ By comparing L_{100} (by steam calorimeter) with the mean specific heat of water between 12° and 100°. Callendar and Barnes' specific heat has been used (p. 66).

LATENT HEATS OF VAPORISATION OF VARIOUS SUBSTANCES

The values below are for pure substances, and are due to Young, *Proc. Roy. Dublin Soc.*, 1910. The precise calorie employed is not stated.

Temp.	$SnCl_4$.	CCl_4.	Pentane (*n*).	Methyl	Ethyl	Propyl	Ethyl ether.	Methyl	Ethyl	Propyl	Acetic acid.	Benzene.
				Alcohol.				Acetate.				
C.	cals.	cals.	cals.	cals.	cals.	cals.	cals.	cals.	cals.	cals.	cals.	cals.
0°	—	—	—	289·2	220·9	—	92·52	—	—	—	—	—
20	—	—	—	284·5	220·6	—	87·54	—	—	—	84·05	—
40	—	—	84·31	277·8	218·7	—	82·83	—	—	—	87·02	—
60	—	—	80·07	269·4	213·4	—	78·44	98·59	—	—	89·69	—
80	—	46·00	75·33	259·0	206·4	173·0	73·50	94·07	85·78	79·80	91·59	95·45
100	31·76	44·15	69·94	246·0	197·1	164·0	68·42	88·39	82·15	76·33	92·32	91·41
120	30·54	42·08	64·48	232·0	184·2	153·0	62·24	82·87	77·53	71·84	94·38	86·58
140	29·12	39·92	56·58	216·1	171·1	142·4	55·93	76·83	72·24	67·66	91·83	82·82
160	27·69	37·95	47·42	198·3	156·9	129·0	46·07	69·96	65·91	62·80	89·63	78·94
180	26·29	35·40	35·01	177·2	139·2	116·3	31·87	61·00	59·87	57·23	87·71	74·62
200	24·57	32·61	24·68*	151·8	116·6	102·2	19·38‡	50·56	52·71	50·78	85·55	68·81
220	22·82	29·45	—	112·5	88·2	85·3	—	34·87	42·63	42·40	82·02	62·24
240	20·86	25·56	—	84·5†	40·3	63·4	—	20·99§	27·17	30·70	78·18	54·11
260	18·50	20·07	—	—	—	33·5	—	—	12·03‖	11·73¶	72·26	43·82
280	15·60	10·43	—	—	—	—	—	—	—	—	63·48	27·43
Crit. temp.	318°·7	283°·1	197°·2	240°	243°·1	263°·7	193°·8	233°·7	250°·1	276°·2	321°·6	288°·5

* At 190°. † At 230°. ‡ At 190°. § At 230°. ‖ At 249°. ¶ At 275° C.

Substance.	Temp.	Lt. ht.	Substance.	Temp.	Lt. ht.	Substance.	Temp.	Lt. ht.
	C.	cals.		C.	cals.		C.	cals.
Mercury . .	358°	68	Liquid N_2O .	− 20°	67	Chloroform .	61°	58
Sulphur . .	316	362	„ NH_3 .	—	341	Et. bromide .	38	60
Phosphorus .	287	130	„ CO_2 .	0	57	„ propionate	100	79
Liquid H_2 . .	—	123	„ „ .	22	32	„ iodide . .	71	47
„ O_2 . .	− 188	58	„ SO_2 .	− 10	96	„ formate	50	98
„ N_2 . .	—	50	„ CS_2 .	46	85	Am. alcohol .	131	120
„ air . .	—	*c.* 50	Me. formate .	32·5	110·5	Aniline . . .	—	104
„ Cl . .	− 22	67	„ iodide . .	42	46	Toluene . .	111	84
Bromine . .	58	46	Chloroform .	0	67	Turpentine . .	159	70
Iodine . . .	174	24						

THERMOCHEMISTRY

In thermochemistry the conservation of energy is assumed in accordance with experiment, and consequently (1) if a cycle of chemical change takes place so that the final state of the reacting substances is identical with the initial, then as much heat is absorbed as is given out, *i.e.* the total heat of the reaction is zero; (2) the heat of reaction only depends on the initial and final states of the reacting substances, and not on the intermediate stages. The results below are affected by, but have not been corrected for, any changes in the accepted values of the atomic weights since the experiments were carried out.

MOLECULAR HEAT OF FORMATION

The **molecular heat of formation** (H.F.) is the heat liberated when the molecular weight in grams of a compound is formed from its elements. When the state of aggregation of an element or compound is not given, it is the state in which it occurs at room temperature and pressure. A minus sign before an H.F. means that heat is absorbed in the building up of the compound.

Unit—the gram calorie (at 15° to 20° C.) per gm. molecule of compound. Aq = solution in a large amount of water. The reactions are at constant pressure.

Example.—H.F. of $CuSO_4$ = 183,000; of $CuSO_4 . Aq$ = 198,800. ∴ the heat of solution of $CuSO_4$ = 198,800 − 183,000 = 15,800 cals. per gram mol.

(T., Thomsen, "Thermochemistry," trans. by Miss K. A. Burke; B., Berthelot, *Ann. d. Chim. et d. Phys.*, 1878; T.B., mean of both these observers' values; N.P.L., Natl. Phys. Lab.; Rh., Roth; Ri., Rossini.) For organic compounds, see p. 74.

INORGANIC COMPOUNDS

Compound.	Mol. H.F. in calories.	Compound.	Mol. H.F. in calories.	Compound.	Mol. H.F. in calories.
Non-Metals	$\times 10^3$		$\times 10^3$		$\times 10^3$
HCl gas	22·063 Ri.	CO_2, from graphite	94·20, Rh.	$NH_4Cl . Aq$	72·4
HCl . Aq.	39·3, T.	CO_2 from diamond	$94{\cdot}4_2$, Rh.	$(NH_4)_2SO_4$	283, T.B.
HBr gas	8·4, T.	B_2O_3; amp. B.	273, B.	$(NH_4)_2SO_4.Aq$	280·6
HBr . Aq.	28·6, T.B.	SiO_2Aq; crys.	180, B.	$NH_4OH . Aq$	90, B.
HI gas	−6·1, T.B.	As_2O_3 [Si	155, T.	BaO	126, T.
HI . Aq	+13·2, T.B.	As_2O_5	219, T.	$Ba(OH)_2$	217, T.
HF ,,	+38·5	CCl_4 from diamond	76, B.	$BaCl_2$	197, T.
H_2O liq.	68·313 Ri.	$SbCl_3$ solid	91·4, T.	$BaCl_2Aq$	199·1, T.
$H_2O_2 . Aq$	47·0	$SbCl_5$ liq.	105, T.	Bi_2O_3	20
H_2S from rhombic S.	2·7, T.	CS_2 from diamond & rhombic S.	−19, B.	$BiCl_3$	91, T.
NH_3	$11{\cdot}0_7$, Rh.	C_2N_2 gas from diam.	−74, B.	$Cd(OH)_2$ $Cd+O+H_2O$	66, T.
AsH_3	−36·7	H_2SO_4 liq.	193, T.	$CdCl_2$	93, T.
SbH_3	−87, B.	$H_2SO_4 . Aq$ from rhombic S.	210, T.	$CdSO_4$	222, T.
SiH_4	25	HNO_3 liq.	41·6, B.	$CdSO_4.8/3H_2O$ on sol. in Aq	+2·66, T.
SO_2 from rhombic S.	70	$HNO_3 . Aq$	49	$CdSO_4 . Aq$	232·7, T.
SO_3 liq. from rhombic S.	103	HCN gas from diam.	−30·5	Cs_2O	100
N_2O	−19	HCN liq.	−24·8	CaO	131, T.
NO	−21·6, T.	H_3PO_4 liq.	302	,, Moissan	145
N_2O_3	−21·4, B.	**Metals—**		$Ca(OH)_2$,,	229
NO_2/22°	−1·7, B.	Al_2O_3	380, B.	CaC_2	−7·25
,, /150°	−7·6, B.	$AlCl_3$	161	$CaCl_2$	170, T.
N_2O_5 liq.	3·6, T.	$Al_2(SO_4)_3 . Aq$	880	$CaCl_2 . Aq.$	187·4, T.
P_2O_5 solid	369	NH_4Cl	76·3, T.B.	$CaSO_4$	318, T.
$P_2O_5 . Aq.$	405			$CaCO_3$	270, T.
CO from amorph. C.	29, T.			$Ca(NO_3)_2$	202, B.
CO from diamond	26·1, B.			CoO	64
				$CoCl_2$	76·5. T.
				$CoSO_4 . 7H_2O$	234, T.
				$Co(NO_3)_2.6H_2O$	119, T.
				CuO	37·2, T.
				$CuCl_2$	51·6

INORGANIC COMPOUNDS (*contd.*)

Compound.	Mol. H.F. in calories.	Compound.	Mol. H.F. in calories.	Compound.	Mol. H.F. in calories.
Metals (*contd.*)	$\times 10^3$		$\times 10^3$		$\times 10^3$
$CuSO_4$	183, T.	$MgCl_2$	151, T.	$AgCl$	29·2, T.B.
$CuSO_4 . Aq$	198·8, T.	$MgSO_4$	302, T.	Na_2O	91 to 100
$CuSO_4 . 5H_2O$ on sol. in Aq.	−2·75	$MgSO_4 . Aq$	322	$NaHO$	102·3, T.B.
		MnO	91	$NaHO . Aq$	112·2, T.B.
$AuBr_3$	8·8, T.	$MnCl_2$	112	$NaCl$	97·8, T.B.
$AuCl_3$	23, T.	Hg_2O	24·9, T.	$NaNO_3$	111, T.B.
FeO	64·6	HgO	21·1	Na_2SO_4	328·3, T.B.
$Fe_2O_3/400°$	196	Hg_2SO_4	175	Na_2CO_3	272, T.B.
Le Chatelier		$HgCl$	31·3	SrO	130, T.B.
$FeSO_4 . 7H_2O$	240	$HgCl_2$	53·2	$Sr(OH)_2$	217, B.
$FeSO_4 . Aq$	236	NiO	59·7	$SrCl_2$	185, T.B.
$FeCl_3$	96, T.	$NiCl_2$	74·5, T.	$SrCl_2 . Aq$	196, T.
PbO	50·3, T.	$NiSO_4 . Aq$	229, T.	Tl_2O	42·2, T.
PbO_2	62·4	$PtCl_4$	59·4	$TlCl$	48·6, T.
$PbCl_2$	83, T.	K_2O	97	Tl_2SO_4	221, T.
$PbSO_4$	216, T.	KHO	104, B.T.	SnO	70
$Pb(NO_3)_2$	105·5	$KHO . Aq$	117, B.T.	$SnCl_2$	81, T.
$Pb(NO_3)_2 . Aq$	97·9	KCl	106, B.T.	$SnCl_4$	128
Li_2O	140	$KCl . Aq$	101·6, T.	ZnO	85·4, T.
$LiOH$	111	KNO_3	119, B.T.	$ZnCl_2$	97·3, T.B.
$LiCl$	94, T.	K_2SO_4	344, T.B.	$Zn(NO_3)_2 . Aq$	132
$LiCl . Aq$	102·4	Ag_2O	5·9, T.	$ZnSO_4$	230·3, T.B.
Li_2SO_4	334, T.	"	7, B.	$ZnSO_4 . Aq$	248·7
$LiNO_3$	112, T.	$AgNO_3$	28·7, T.B.	$ZnSO_4 . 7H_2O$ on sol. in Aq	−4·26
MgO	143, B.	$AgNO_3 . Aq$	23·3, T.		

MOLECULAR HEAT OF NEUTRALISATION

Unit—the gram calorie (at 15° to 20°) per gram molecule of base. Thus $KOH . Aq + HCl . Aq = KCl . Aq + H_2O + 13{,}750$ calories. Thomsen (= T.) observed at 18° to 20° C., and the final dilution was 3600 gms. (7200 for Na salts) per gm. mol. of base. Berthelot (= B.) used at least 2000 gms. of H_2O per 17 gms. of hydroxyl ion, — HO.

Base.	HCl	HF	HNO_3	HCN	$\frac{1}{2}H_2SO_4$	$\frac{1}{2}H_2CO_3$	$1H_3PO_4$	1 Oxalic.
	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$
1NaOH	13·74, T.; 13·7, B.	16·3, T.	13·7, T.; 13·5, B.	2·8	15·64, T.	10·1, T.; 10·2, B.	14·8, T.	13·8, T.
2NaOH	—	—	—	—	31·38‡, T.	20·2 §, T.	27·1*, T.	28·3, T.
1LiOH	13·85, T.	16·4 †	—	2·93	15·64, T.	—	—	—
1KOH	13·7, T.; 13·6, B.	16·1	13·8, T.	2·8, T.	15·7, T.B.	10·1, B.	—	13·8, B.
$1NH_4OH$	12·3, T.; 12·4, B.	15·2	12·3, T.	1·3, B.	14·3, T.B.	8·4, T.; 5·3, B.	13·5, B.	12·7
$\frac{1}{2}Ca(OH)_2$	14·0, B.	18·4 †	13·9, B.	3·2	15·6, T.	9·3,† T.; 9·8,† B.	—	—
$\frac{1}{2}Sr(OH)_2$	13·8, T.	17·8 †	13·9, B.	3·15	15·4, T.	10·4,† T.B.	—	—
$\frac{1}{2}Ba(OH)_2$	13·9, B.	16·1	14·1, T.; 13·9, B.	3·15	18·4, B.T.	11·0,† T.B.	—	—
$\frac{1}{2}Mg(OH)_2$	13·8, B.	15·2	13·8, T.	1·5	15·3, B.T.	8·95,† B.	—	—
$\frac{1}{2}Cu(OH)_2$	7·5, T.	10·1	7·6	—	9·2	—	—	—

* 3NaOH gives $34·0 \times 10^3$, T. † Base in solid state. ‡ $1H_2SO_4$. § $1H_2CO_3$.

HEATS OF COMBUSTION AND FORMATION OF CARBON COMPOUNDS, COAL, ETC.

Molecular heats of formation (H.F.) of organic compounds are deduced from their heats of combustion (H.C.), by subtracting the latter from the heat generated on burning the carbon and hydrogen contained in the compound. Experimental errors in the H.C. thus become magnified in the H.F. Heats of combustion determined by Thomsen are for the vapour of the compound at 18° C.; for the liquid the H.C. and H.F. would be greater by the latent heat of evaporation. Thomsen assumes H.F. of CO_2 from amorphous C as = 96,960 cal.; of water as 68,360 cal. per gm. molecule. For H.F. of inorganic compounds, see p. 72.

The International Union of Pure and Applied Chemistry has adopted as standard, the value $771 \cdot 2 \times 10^3$ for the H.C. of benzoic acid, with succinic acid (256·0) as secondary standard.

Unit—the gram calorie (at 15° to 20°) per gram molecule.

Example.—16 gms. of methane, CH_4, give out 212,000 gram calories of heat when burnt at **constant pressure,** to water and CO_2 at 18° C.

(T., Thomsen, "Thermochemistry"; B., Berthelot; R., Richards, 1915; Ri., Rossini, 1934.)

Compound.	H.C.	H.F.
	$\times 10^3$	$\times 10^3$
Methane, CH_4 . . .	212·79, Ri.	21·7
Ethane, C_2H_6 . . .	372·81, Ri.	28·6
Propane, C_3H_8 . . .	530·57, Ri.	35·1
Acetylene, C_2H_2 . .	310 T., 314	−47·8
Ethylene, C_2H_4 . . .	333, T.	− 2·7
Benzene, C_6H_6 . . .	780, R.	−12·5
Naphthalene, $C_{10}H_8$.	1231	—
Toluene, C_7H_8 . . .	956, T.	−3·5
Me. alcohol, CH_4O . .	173·61, Ri.	51·4
Me. chloride, CH_3Cl .	177, T.	22·6
Chloroform, $CHCl_3$.	107, T.	24·1
Et. alcohol, C_2H_6O . .	326·61, Ri.	58·5
Et. ether, $C_4H_{10}O$.	660, T.	70
Et. chloride, C_2H_5Cl .	334, T.	30·7
Acetic aldehyde, C_2H_4O	282, T.	48·7
Formic acid, CH_2O_2 .	69·4, T.	95·9
Acetic acid, $C_2H_4O_2$.	225, T.	105·3
Propionic acid, $C_3H_6O_2$	387, T.	109·4
Me. formate, $C_2H_4O_2$.	241, T.	89·4

Compound.	H.C.	H.F.
	$\times 10^3$	$\times 10^3$
Me. acetate, $C_3H_6O_2$.	399, T.	96·7
Carb. bisulphide, CS_2 .	265, T.	−26
Methylamine, CH_5N .	258, T.	9·5
Dimethylamine, C_2H_7N	420, T.	12·7
Aniline, C_6H_7N . . .	838, T.	−17·4
Pyridine, C_5H_5N. . .	675, T.	−19·4
Sugar, $C_{12}H_{22}O_{11}$. . .	1350	—
Coal gas per cub. metre	4500 to 6000	—
Coal (anthracite) . .	7·6 to 8·4	per gm.
Coal (brown)	4·7	,, ,,
Coke	6·9	,, ,,
Paraffin oil	9·8	,, ,,
Wood.	3·9 to 4·4	,, ,,
Albumens—		
Casein	5·86	,, ,,
Flesh	5·66	,, ,,
White of egg	5·67	,, ,,
Yolk of egg	8·12	,, ,,
Hæmoglobin	5·9	,, ,,

MOLECULAR HEAT OF DILUTION

The heat set free or absorbed on diluting a gram molecule of liquid with water is the molecular heat of dilution: thus on diluting HCl to (HCl, **300** H_2O), 17,300 calories per 36·5 grams of HCl are set free; diluting 2NaCl, $nH_2O(n = 20)$ to (2NaCl, **100**H_2O) absorbs 1060 cal. per 2 × 58·65 gm. of NaCl. **Unit**—the gram calorie (at 15° to 20°) per gram molecule. (See Thomsen, "Thermochemistry.")

HCl n = 0		HNO_3 n = 0		H_2SO_4 n = 0		NaHO n = 3		NH_3*		2NaCl n = 20		$2NaNO_3$ n = 12		Na_2SO_4 n = 50		$ZnCl_2$ n = 5		$Zn(NO_3)_2$ n = 10	
H_2O	$\times 10^3$	H_2O	$\times 10^3$	H_2O	$\times 10^3$	H_2O	$\times 10^3$	$\overset{n}{H_2O}$	$\times 10^3$	H_2O	$\times 10^3$	H_2O	$\times 10^3$	H_2O	$\times 10^3$	H_2O	$\times 10^3$	H_2O	$\times 10^3$
1	5·37	1	3·28	1	6·38	5	2·13	1	1·26	100	−1·06	50	−2·26	100	−·665	10	1·85	15	·91
2	11·36	5	6·6	5	13·1	7	2·9	3	·385	200	−1·31	100	−3·29	200	−1·13	20	3·15	20	1·15
5	14·96	10	7·32	49	16·7	9	3·1	5·8	·21	400	−1·41	200	−3·86	400	−1·38	50	5·32	50	1·20
50	17·1	20	7·46	199	17·1	25	3·26	9·5	·02	—	—	400	−4·19	800	−1·48	100	6·81	100	1·11
300	17·3	320	7·49	1600	17·9	200	2·94	110	·00	—	—	—	—	—	—	400	8·02	200	1·07

* Heat developed on diluting $NH_3.nH_2O$ to $NH_3.200H_2O$ (Berthelot).

ENERGY AND WAVE-LENGTH OF FULL RADIATION

The radiation from a full or black body radiator depends both in quality and quantity upon the temperature. The total energy radiated (of all wave-lengths), from unit area in unit time, is given by *Stefan's law*, $E = \sigma\theta^4$, where σ is Stefan's constant and θ is the absolute temperature (see Optical Pyrometry, p. 56, and below).

The dependence of the quality on the temperature is expressed by *Wien's displacement law*, $\lambda_m\theta = \text{const.}$, where λ_m is the length of the particular waves which have maximum emissive power. Thus the emissive power E_m of the waves of length λ_m, varies as the 5th power of the temperature (absolute) : $E_m\theta^{-5} = \text{const.}$

The emissive power of some particular wave-length λ is expressed accurately by

$$E_\lambda = c_1\lambda^{-5}/(e^{c_2/\lambda\theta} - 1) \quad . \; . \; . \; . \; . \quad \textit{Planck's formula}$$

where $c_1 = 3{\cdot}71 \times 10^{-5}$ erg.-cm.^{2} sec.$^{-1}$, $c_2 = 1{\cdot}433$ cm.-deg., and e is the base of Napierian logs.

At low temperatures or for short wave-lengths ($\lambda\theta < 3$ cm.-deg.) Planck's formula becomes (to ·8 % at least)—

$$E_\lambda = c_1\lambda^{-5}e^{-c_2/\lambda\theta} \quad . \; . \quad \textit{Wien's formula} \text{ (see p. 57)}$$

For long waves and high temperatures ($\lambda\theta > 730$ cm. deg.), we have (to 1 % at least)—

$$E_\lambda = c_1\lambda^{-4}\theta e^{-c_2/\lambda\theta} \quad . \; . \; . \; . \; . \quad \textit{Rayleigh's formula}$$

References: Roberts' "Heat and Thermodynamics," Wensel, *J. Res. Nat. Bur. St.*, 1939.

WIEN'S DISPLACEMENT LAW

$\lambda_m\theta = \text{const.} = A$. (See above.) λ is measured in cms.

A	Observer.
·2898	Mendenhall, 1914, 1917
·2876	Michel, 1922
·2892	mean of all observations

STEFAN'S LAW

Total radiation from a full radiator $= \sigma\theta^4$ (see above). σ is in erg cm.$^{-2}$ sec.$^{-1}$ deg^{-4}.

σ	Observer.
$5{\cdot}79 \times 10^{-5}$	Mendenhall, 1929
$5{\cdot}7 \times 10^{-5}$	Foote, 1918
$5{\cdot}77 \times 10^{-5}$	Müller, 1929
$5{\cdot}73 \times 10^{-5}$	Hoare, 1932
$5{\cdot}79 \times 10^{-5}$	Kussmann, 1924
$5{\cdot}76 \times 10^{-5}$	Hoffmann, 1923
$5{\cdot}75 \times 10^{-5}$	mean of all observations

See Wensel, *J. Res. Nat. Bur. St.*, 22, p. 1189, 1939. Wensel gives 19 observations of σ.

c_1 AND c_2

The determination of the constant c_2 in Planck's equation has received considerable attention on account of its importance in optical pyrometry. A knowledge of c_1 is not, however, necessary for such work.

c_2 is given below in micron-degrees, *i.e.* 10^{-4} cm. degrees.

c_2	Observer.
14,320 micron-degrees	Coblentz, 1920
14,300 ,, ...	Rubens and Michel, 1921
14,360 ,, ...	Wensel, 1939

THE UNIVERSAL CONSTANT *h*

Planck's radiation law (above) may also be written—

$$E_\lambda = 2\pi c^2 h\lambda^{-5}/(e^{ch/k\lambda\theta} - 1)$$

where c is the velocity of light, k is Boltzmann's constant, and h is Planck's universal constant. Planck's constant on the quantum theory is the constant of proportionality connecting the energy of a quantum with the frequency of vibration (ν), *i.e.* the energy of a quantum $= h\nu$.

h is intimately related with the several radiation constants, and may be determined by use of either of the following relations—

$$h = c_2 k/c\,; \qquad h = 15 c_2{}^4\sigma/2\pi^5 c^2 = c_2{}^4\sigma/(40{\cdot}8026 c^2)$$

where σ is the Stefan-Boltzmann constant (above).

See Planck's constant, p. 128.

T. H. L., V. D. H.

SOLAR CONSTANT AND TEMPERATURE OF SUN

The solar constant S is the energy received from the sun by the earth (at its mean distance) per sq. cm. in unit time, corrected for the loss by absorption in the earth's atmosphere.

The determination of the absorption loss is difficult; it is best derived from simultaneous observations at high and low stations.

Langley and Abbot ("Smithsonian Reports," 1903 *et seq.*) give the following relation between atmospheric absorption and wave-length :—

Wave-length (Å.U. = 10^{-8} cm.)	4000	6000	8000	10,000	12,000
Fraction transmitted	·49	·74	·85	·89	·91

If R is the energy radiated in unit time from a sq. cm. of the sun's surface, then

$$R = \left\{\frac{\text{earth's solar distance}}{\text{sun's radius}}\right\}^2 \times S = \left\{\frac{9{\cdot}28 \times 10^7}{4{\cdot}33 \times 10^5}\right\}^2 \times S = 46{,}000S$$

Assuming the sun to be a full or black body radiator, its "effective" absolute temperature θ may be deduced either from (1) Stefan's law, $R = \sigma(\theta^4 - T^4)$, where σ is Stefan's constant (see above) and T is the earth's absolute temperature, or (2) Wien's displacement law, $\theta\lambda_m = \text{const.}$ (see above).

Langley and Abbot (ref. above) find the distribution of the energy of solar radiation among the different wave-lengths (λ) to be as follows :—

Wave-length (Å.U.)	4000	4500	5000	5500	6000	7000	8000	10,000	12,000	14,500	21,000
Relative energy, E	15·2	18·4	19	16	14	11	8·8	5·4	3·2	2	·6

λ for $E_{\text{max.}} = 4900 \times 10^{-8}$ cm. Taking Wien's displacement law to be $\theta\lambda_{\text{max}} = {\cdot}29$, and assuming the sun to be a full radiator, its temperature $\theta = 5920°$ absolute.

SOLAR CONSTANT AND TEMPERATURE OF THE SUN (*contd.*)

The values of S below are expressed in both (1) calories per min. per cm.^{2}, and (2) watts per cm.^{2} (1 calorie per sec. = 4·18 watts). The sun's mean temp. θ is in degrees C. absolute. Abbot and Fowle find the solar constant varies by about 8 %. (See Poynting and Thomson's "Heat;" Chree, *Nature*, **82**, 2090; Report (1910) of the International Union for Solar Research; and "Smithsonian Reports.")

Solar Const.		Sun's Temp.	Account.	Observer.
cals. min.$^{-1}$ cm.$^{-2}$	watts cm.$^{-2}$			
—	—	Abs. 5770°	Comparison with const. temp. Atmos. absorp. taken as 29 %	Wilson, 1902
—	—	5920	Using Wien's displacement law (above)	Langley & Abbot, '03
2·25	·154	7060	Gorner Grat, Switzerland	Scheiner, 1908
—	—	5610	Natl. Phys. Lab., England. Atmos. absorp. taken as 29 %	Harker & Blackie, '08
2·38	·166	5630	Mt. Blanc. Comparison with const. temp. Atmos. absorp., 9 % with zenith sun	Féry & Millochau
—	—	5360		Féry, 1909
—	—	5630	Mt. Blanc. Atmos. absorp., 3·4 %	Millochau, 1909
2·1	·146	5860†	Washington (sea-level) and Mt. Wilson (6000 ft.)	Abbot & Fowle, '09
2·1	·146	5860†	Review of previous work	Bellia, 1910
1·925*	·134	5740†	Mt. Wilson (6000 ft.) and Mt. Whitney (14,500 ft.)	Abbot, 1910

* Mean value for period 1904–9 (*Nature*, 1911).

† Calculated from S, taking Stefan's const. as $5·7 \times 10^{-12}$ watts cm.$^{-2}$ sec.$^{-1}$ deg.$^{-4}$.

THE CRYOSCOPIC CONSTANT

The cryoscopic constant, K, would be the depression of the freezing-point of a solvent when the molecular weight in grams of any substance (which does not dissociate or associate) is dissolved in 100 grams of the solvent, supposing the laws for dilute solutions held for such a concentration (Raoult, 1882). Van't Hoff (1887) showed that $K = R\theta^2/(100L)$, where R = the gas constant (see p. 7), θ the absolute freezing-point of the solvent, L its latent heat of fusion in ergs. **Example.**—For 1 gram-molecule of solute in 100 gms. of water—

$$K = 8·315 \times 10^7 \times (273·1)^2/(79·67 \times 4·184 \times 10^9) = 18·60$$

(See Whetham's "Theory of Solution.")

Solvent.	M. pt.	Lat. ht. (cals.)	K		Solvent.	M. pt.	Lat. ht. (cals.)	K	
			Calcd.	Obsd.				Calcd.	Obsd.
Water . .	0° C.	79·6	18·6	18·58, G. 18·52*	Benzene .	5·5	30·1, F.	51·6	51·2, P.
					Formic acid	8	57·4, Pe.	27·5	28, R.
$H_2SO_4.H_2O$	8·4	31·7, B.	50	48, L.	Phenol . .	40	24·9, P.W.	78·6	72·7, E.
$SbCl_3$ . .	73·2	13·4, T.	174	184, T.	p. Xylol .	16	39·3, C.	42·5	43, P.M.
Acetic acid	17	43·7, Pe.	38·5	39, R.					
Aniline . .	− 6	—	—	58·7, A.R.					

* Mean of six observers; A.R., Ampola and Rimatori, 1897; B., Berthelot; C., Colson; E., Eykman, 1889; F., Fischer; G., Griffiths (who used 0·0005 to 0·02 normal sugar solutions); L., Lespieau, 1894; P., Paternò, 1889; Pe., Pettersson; P.M., Paternò and Montemartini, 1894; P.W., Pettersson and Widman; R., Raoult; T., Tolloczko, 1899.

VELOCITY OF SOUND

The velocity of sound (longitudinal waves) in a body, $V = \sqrt{E/\rho}$, E being the elasticity, and ρ the density. In gases and liquids E is the adiabatic volume elasticity; in isotropic solid rods or pipes E is Young's Modulus. For gases $V = \sqrt{\gamma P/\rho}$, P being the pressure, and γ the ratio of the specific heat of the gas at constant pressure to that at constant volume. For values of γ, see p. 68.

For moderate temperature variations, the velocity of sound in gases is given by $V_t = V_0(1 + \frac{1}{2}\alpha t) = V_0 + 61t$ in cms. per sec. for dry air (α = ·00367).

The velocity of sound decreases with decreasing intensity down to the normal value and increases in the supersonic region. In gases in tubes the velocity increases with the diameter up to a limiting value for free space (K. & S.). The values below are for free space. Barton's "Sound" and Poynting and Thomson's "Sound" may be consulted. [1 foot = 30·48 cms.]

Substance.	Temp.	Velocity.	Observer.
Gases—		cms./sec.	
Air (dry)	0° C.	(3·3133) × 10^4	Calcd. (γ = 1·401)
,, ...	0	3·308 ,,	A. & L., 1921
,, ...	0	3·309 ,,	Esclangon, 1919
,, ...	0	3·3129 ,,	Hebb, 1905
,, ...	− 45·6	3·056 ,,	Greely, 1890
,, ...	− 182·4	1·815 ,,	Cook, 1906
,, ...	18	3·424 ,,	K. & S., 1933
,, ...	100	3·873 ,,	,, ,,
,, (Krakatoa wave)	—	3·21 ,,	1883
,, Sound-waves from	sparks 0	3·50–4·45 ,, *	Töpler, 1908
Hydrogen	18	13·01 ,,	K. & S., 1933
Oxygen	0	3·17 ,,	Stewart, 1931
,, ...	− 184·7	1·737 ,,	Cook, 1906
Nitrous oxide, N_2O .	0	2·60 ,,	Wullner, 1878
Ammonia, NH_3 . .	18	4·282 ,,	K. & S., 1933
Carbon monoxide . .	0	3·37 ,,	Stewart, 1931
,, ,, . .	1000	7·10 ,,	S. & G., 1934
Carbon dioxide . . .	18	2·658 ,,	K. & S., 1933
Coal-gas	0	4·9–5·15 ,,	—
Sulphur dioxide. . .	18	2·162 ,,	K. & S., 1933
Water-vapour (satd.) .	110	4·13 ,,	Treitz, 1903
Liquids—			
Water	20	14·10 × 10^4	Brillié, 1919
,, (sea) . . .	20	15·40 ,,	Wood, 1922
,, (sea) Explosion	waves 18	17·3–20·1 ,, *	Threlfall & Adair, 1889
Alcohol (abs.), C_2H_6O	8·4	12·6 ,,	Martini, 1888
Ether, $(C_2H_5)_2O$ . .	0	11·4 ,,	,,
Turpentine, $C_{10}H_{16}$.	3·5	13·7 ,,	,,

* The range of speeds is given by varying intensities. A. & L., Angerer and Ladenberg; K. & S., Kaye and Sherratt; S. & G., Sherratt and Griffiths.

The values for metals are due to Wertheim, 1849; Masson, 1857; and Gerossa, 1888.

Solid.	Velocity cms./sec.	Solid.	Velocity cms./sec.	Solid.	Velocity cms./sec.
Aluminium. .	51·0 × 10^4	Lead	12·3 × 10^4	Brass . . .	c. 36·5 × 10^4
Cadmium . .	23·1 ,,	Nickel . . .	49·7 ,,	Deal (along grain)	49–50 ,,
Cobalt . . .	47·2 ,,	Platinum . .	26·8 ,,		
Copper . . .	39·7 ,,	Silver . . .	26·4 ,,	Fir ,,	42–53 ,,
Gold	20·8 ,,	Tin	24·9 ,,	Mahogany ,,	41–46 ,,
Iron (wrought)	49–51 ,,	Zinc	36·8 ,,	Oak ,,	40–44 ,,
,, (cast). .	c. 43 ,,	Glass (soda) .	50–53 ,,	Pine ,,	c. 33 ,,
Steel	47–52 ,,	,, (flint) .	c. 40 ,,	Indiarubber .	·5–·7 ,,

SOUND AND HEARING

The **bel** (10 decibels) is a tenfold unit of intensity change, so that if two sounds have intensities I_1 and I_2, they differ by $\log_{10}(I_1/I_2)$ bels.

The subjective quality known as the *loudness* of a sound is measured by reference to the intensity in free air of a pure tone of frequency 1000 cycles per sec., which is judged by a normal observer facing the source, to be as loud as the sound. In the International scale, this intensity, expressed in decibels above a reference "zero" of 0·0002 dyne per sq. cm., expresses numerically the equivalent loudness of the sound in *phons*.

WAVE-LENGTH OF ORGAN PIPES

(Length L)

Closed pipe 4L, 4L/3, 4L/5, etc.
Open pipe 2L, 2L/2, 2L/3, etc.

	cycles/sec.
Lower limit of audition .	about 20
Upper limit of audition .	20,000 to 30,000
Highest pitch in piano .	3520
Highest pitch in orchestra (piccolo d^{v})	4752
Lowest pitch in organs (64-foot pipe) . . .	8

The *auditory sensation area*, the assemblage of frequencies and intensities which give rise to the sensation of hearing, is bounded on the low intensity side by the *threshold of audibility*, and on the other by the *threshold of feeling*, above which the sensation of sound gives place to pain. The table below, which gives the R.M.S. pressure in dynes per sq. cm. at the ear drum for both thresholds, is based on curves given by Fletcher (1929), and by Sivian and White (1933).

Frequency (cycles per sec.)		**20**	**32**	**64**	**128**	**256**	**512**
Pressure at threshold of	audibility	12	2	0·15	0·018	0·0040	0·0010
	feeling	12	60	200	700	1260	2300

Frequency (cycles per sec.)		**1024**	**2048**	**4096**	**8192**	**12,000**	**20,700**
Pressure at threshold of	audibility	0·00050	0·00040	0·00057	0·0020$_5$	0·020	10·0
	feeling	2200	1000	400	90	30·6	10·0

TRANSVERSE VIBRATIONS OF RODS

L, length ; K, radius of gyration of cross-section ; E, Young's Modulus ; ρ, density

	No. of Nodes.	Distance of Nodes from one end.	Frequency $\propto \frac{K}{L^2}\sqrt{\frac{E}{\rho}}$		No. of Nodes.	Distance of Nodes from one end.	Frequency $\propto \frac{K}{L^2}\sqrt{\frac{E}{\rho}}$
Both ends free	2	·224 L ; ·776L	1	One end fixed	0	—	1
	3	·132L ; ·5L ; ·868L	2·76		1	·226L	6·27
	4	·094L ; ·356L ·644L ; ·906L	5·40		2	·132L ; ·5L	17·5
					3	·094L; ·356L; ·644L	34·4

FREQUENCY RATIOS OF MUSICAL SCALE

	C **Doh**	**D** **Ray**	**E** **Me**	**F** **Fah**	**G** **Soh**	**A** **Lah**	**B** **Te**	**c** **Doh**
Natural scale		$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$
	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
	24	27	30	32	36	40	45	48
	1·000	1·125	1·250	1·333	1·500	1·667	1·875	2·000
Equally tempered scale	1·000	1·122	1·260	1·335	1·498	1·682	1·888	2·000
Standard forks (König) (marked c' = 512 and so on)	c′ 256	d′ 288	e′ 320	f′ 341·3	g′ 384	a′ 426·7	b′ 480	c″ 512

ACOUSTICAL ABSORPTION AND TRANSMISSION

For data on acoustical absorption and transmission by materials, see "Acoustics of Buildings," by Davis & Kaye. (Bell.)

INTERNATIONAL CONCERT PITCH

The long overdue question of the standardization of concert pitch has assumed a new prominence in view of the requirements of international broadcasting. At an International Conference held in London in May 1939, it was agreed that the international standard of concert pitch should be based on a frequency of 440 cycles per second for the note A in the treble clef. Of late years there had been a general upward departure from the Vienna Standard of some 50 years ago, *i.e.* the French Diapason Normal (A = 435 c/s at a working temperature of 15° C.).

In connection with the international standard, the British Standards Institution makes the following recommendations :—

TEMPERATURE AND PITCH OF MUSICAL INSTRUMENTS

In view of the dependence of the pitch of nearly all musical instruments on temperature, such instruments should be constructed to be in accord with the international standard of concert pitch at a temperature of 20° C. (68° F.). For many countries this may be taken to be a fair average figure for the temperature of the air of a concert hall during a performance. The increasing employment of "air conditioning" for concert halls is an important factor in this connection.

In those cases where it is possible, instruments should be provided with adequate pitch-adjustments to allow the player to correct for the effects of such temperature variations as may occur during a concert. The following changes of pitch occur when musical instruments, as at present constructed, are subjected to moderate temperature changes :—

Flue Pipes of Wind Organs.—The flue pipes of wind organs have the largest temperature co-efficient of any musical instrument, the pitch rising by about 1 part in 500 for 1° C. rise in the temperature of the air (*i.e.* 1 part in 900 for 1° F. rise). For example, the international standard pitch of A = 440 at 20° C., corresponds to approximately 435 at 15° C. (59° F.)—which is the *Diapason Normal.*

Reed Pipes of Wind Organs and Orchestral Wind Instruments are, on the average, subject to about half the rise of pitch experienced by the flue pipes of the organ for the same temperature-rise of the surrounding air.

Pianos.—The pitch of pianos falls by about 1 part in 10,000 for 1° C. rise in temperature (*i.e.*, 1 part in 18,000 for 1° F. rise).

Electro-Acoustic Organs and similar instruments have a negligible temperature coefficient.

SUB-STANDARDS OF PITCH

When the proposed broadcast standard is not available, the use of suitable tuning forks as sub-standards of pitch is recommended on the score of reliability and convenience. Tuning forks, if of steel, drop in pitch by only about 1 part in 9,000 for 1° C. rise in temperature (*i.e.* about 1 part in 16,000 for 1° F. rise). Elinvar forks are to be preferred, in that they have a negligible temperature coefficient and are not liable to rust. Tuning forks are demonstrably superior in respect of temperature to the oboe, which is often used as an orchestral standard of pitch.

VELOCITY OF LIGHT

(*See page* 84)

PHOTOMETRIC STANDARDS

The unit of luminous intensity now generally adopted, except in some central European countries, is the **International Candle** (c), maintained by agreement between the national standardizing laboratories of Great Britain, France and the U.S.A. The **candle-power** (I) of a source in a specified direction is its luminous intensity expressed in candles. The **mean spherical candle-power** (I_0) (m.s.c.p.) is the mean of the candle-powers measured in all directions about the source as origin. The **mean horizontal candle-power** (I_H) is the mean of the candle-power measured in all directions in a horizontal plane, the source being in its normal burning position.

Light is radiant energy perceptible to the eye. A given amount of energy is differently evaluated by the eye according to its wave-length. The value assigned by the average human eye to a given amount of energy at wave-length λ is termed the **relative visibility factor,** K_λ, when the value of K_λ at the wave-length of maximum visibility is taken as unity. The values of K_λ adopted internationally are as follows:—

THE RELATIVE VISIBILITY FACTOR

λ mμ	0	10	20	30	40	50	60	70	80	90
400	0·0004	0·0012	0·0040	0·0116	0·023	0·038	0·060	0·091	0·139	0·208
500	0·323	0·503	0·710	0·862	0·954	0·995	0·995	0·952	0·870	0·757
600	0·631	0·503	0·381	0·265	0·175	0·107	0·061	0·032	0·017	0·0082
700	0·0041	0·0021	0·00105	0·00052	0·00025	0·00012	0·00006	—	—	—

The time rate of passage, or emission, of radiant energy (*i.e.* radiant power), evaluated in accordance with the visibility factor as described above, is termed **luminous flux** (F). Thus the total luminous flux emitted by a source is a measure of its light-giving power without reference to distribution. The unit of luminous flux is the **lumen** and is the flux emitted within the unit solid angle by a uniform source of one candle-power. Since the total solid angle at a point is 4π, the total flux emission from a source of m.s.c.p. equal to I_0 is $4\pi I_0$ lumens. Further it follows that the candle-power of a source in any direction is equal to the angular flux density in that direction expressed in lumens per unit solid angle, *i.e.* $I = dF/d\omega$.

The **mechanical equivalent of light** is the ratio of the radiant flux (in watts) to the luminous flux (in lumens) at the wave-length for which K_λ is a maximum. It is equal to 0·0016 watt per lumen, approximately (see H. E. Ives, "Opt. Soc. Am., J.," Vol. 9, 1924, p. 638).

The **illumination** (E) of a surface is equal to the luminous flux it receives per unit area. The British unit is the **foot-candle** (f.c.), equal to 1 lumen per square foot. The metric unit is the **lux** or **metre-candle** (m.c.), which equals 1 lumen per square metre. Hence 1 f.c. = 10·76 lux or m.c.

The **brightness** (B) of a surface in a given direction is the luminous intensity per unit projected area in that direction. It is measured in candles per square inch, per sq. cm., etc. Alternatively brightness may be expressed in terms of the brightness of a perfectly diffusing surface (*i.e.* a surface having the same brightness whatever the direction in which it is viewed) emitting 1 lumen per square centimetre. This unit is termed the **lambert,** and its one-thousandth part, the **millilambert,** is frequently used in America as a unit of brightness.

1 candle per sq. cm. = π lamberts.   1 candle per sq. inch = 487 millilamberts.

BRIGHTNESS AND TEMPERATURE OF COMMON LIGHT SOURCES

	Brightness (c/mm²)	Brightness Temperature [° K]. ‖	Colour Temperature [° K].
Candle	0·005	—	1930
Paraffin flame (flat wick) . . .	0·0125	1500	2055
„ „ (round wick). . .	0·015	1530	1920
Acetylene (Kodak burner) . . .	0·108	1730	2360
Welsbach mantle (low pressure) .	0·048–0·058	—	—
„ „ (high pressure) .	0·25	—	—
Tungsten fil. lamp (vac. 7·9 l/w)* .	1·25	2150	2400
„ „ „ (gas-f. 12·9 l/w)	5·97	—	2740
„ „ „ („ 15·2 l/w)	7·72	—	2810
„ „ „ („ 18·1 l/w)	10·00	—	2920
„ „ „ („ 21·2 l/w)	13·25	—	3000
Mercury vapour (glass)	0·023	—	—
Arc crater (solid plane carbon) .	172	3700 †	3780
Clear blue sky	0·004	—	12.000 to 24,000
Zenith sun (at earth's surface) . .	1650	—	5400

The brightness temperature is often termed the "black-body" temperature (see p. 57).

The colour temperature is the temperature of the black-body giving light of the same colour as that emitted by the source under consideration. See Walsh, "Photometry," p. 270 (Constable).

It is to be noted that the Hefner candle = 0·90 int. candle. The system of photometric units used in Germany and some other countries is based on this unit (symbol HK). The units affected are (a) the candle, (b) the lumen, and (c) the meter-candle (1 Meter-kerze = 0·9 m.c.).

* l/w = lumens per watt; ‖ λ = 0·665μ; † λ = 0·65μ.

GASEOUS REFRACTIVE INDICES AND DISPERSIONS

Dispersion.—Cauchy's equation is $n - 1 = A(1 + B/\lambda^2)$, where n is the refractive index for the wave-length λ; A and B are constants. B is the coefficient of dispersion. The **refractivity** $(n-1) = A$, when $\lambda = \infty$. The values of A and B are for wave-lengths measured in cms. The refractive indices are mostly for the sodium D line ($\lambda = 5893 \times 10^{-8}$ cm.). The values of n are reduced to a standard density at 0° and 760 mms. by assuming that $(n - 1)/\rho$ is a constant for each gas, ρ being the density. Cauchy's formula is in general inadequate over large dispersions. (See Cuthbertson, *Science Progress*, 1908; and *Proc. & Trans. Roy. Soc.* for 1905 *et seq.*)

Gas or Vapour.	Refractive Index n for Na D line.	Cauchy's Constants.		Observer.
		A.	B.	
Air . . .	1·0002918	$28{\cdot}71 \times 10^{-6}$	$5{\cdot}67 \times 10^{-11}$	Scheel (Reichsanstalt), 1907
Hydrogen .	1·0001384	13·58 „	7·52 „	„
Helium . .	1·0000350	3·48 „	2·3 „	Burton; Cuthbertson & Metcalfe, 1907
Neon . .	1·0000671	6·66 „	2·4 „	C. & M. Cuthbertson, 1909
Argon . .	1·0002837	27·92 „	5·6 „	Burton, 1907
Krypton .	1·0004273	41·89 „	6·97 „	C. & M. Cuthbertson, 1908
Xenon . .	1·000702	68·23 „	10·14 „	„ „
Fluorine .	1·000195	—	—	Cuthbertson & Prideaux, 1906
Chlorine .	1·000768	—	—	Mascart, 1878
Bromine .	1·001125	—	—	„ „
Iodine . .	1·00192 †	—	—	Hurion, 1877
Oxygen . .	1·000272	26·63 „	5·07 „	Rentschler, 1908
Sulphur . .	1·001111	104·6 „	21·2 „	Cuthbertson & Metcalfe, 1908
Selenium .	1·001565	—	—	„ „
Tellurium	1·002495	—	—	„ „
Nitrogen .	1·000297	29·06 „	7·7 „	Scheel (Reichsanstalt), 1907
Phosphorus	1·001212	116·2 „	15·3 „	Cuthbertson & Metcalfe, 1908
Arsenic . .	1·001552	—	—	„ „
Zinc . . .	1·002050	—	—	„ „
Cadmium .	1·002675	—	—	„ „
Mercury .	1·000933	87·8 „	22·65 „	„ „

Gas or Vapour.	Refractive Index n for Na D line.	Observer.
Water-vapour . .	1·000257	Mascart, '78
„ „ . .	1·000250	Lorenz, '74
Ammonia . . .	1·000377	Mascart, '78
„ . . .	1·000373	Lorenz, '74
Nitrous oxide . .	1·000515	Mascart, '78
Nitric oxide . .	1·000297	„ „
Hydrochloric acid	1·000444	„ „
Hydrobromic acid	1·000570	„ „
Hydriodic acid .	1·000906	Hurion, '77
Carbon monoxide	1·000334	Mascart, '78
„ dioxide .	1·0004498	Perreau, '96
„ bisulphide	1·001476	Mascart, '78
Sulph. hydrogen	1·000641 *	D., 1826
„ „	1·000619	Mascart, '78
Sulphur dioxide .	1·000660	Walker, '03
„ trioxide .	1·000737	C. & M., '08
„ hexafluoride	1·000783	„
Selenium „	1·000895	„
Tellurium „	1·000991	„

Gas or Vapour.	Refractive Index n for Na D line.	Observer.
Tellurium tetrachloride . . .	1·002600	P. & M.
Phosph. hydrogen	1·000786 *	D., 1826
Phosphorus trichloride . . .	1·001730	Mascart, '78
Methane, CH_4 .	1·000441	„ „
Pentane, C_5H_{12} .	1·001701	„ „
Acetylene, C_2H_2 .	1·000606	„ „
Ethylene, C_2H_4 .	1·000719	„ „
„ . . .	1·000674	Prytz, '80
Benzene, C_6H_6 .	1·001812	Mascart, '78
„	1·001765	Prytz, '91
Methyl fluoride .	1·000449	Cuthbertson
„ chloride .	1·000865	Mascart, '78
„ alcohol .	1·000552	Prytz, '80
„ „ .	1·000619	Mascart, '78
Chloroform, $CHCl_3$	1·001455	„ „
Carbon tetrachloride . . .	1·001768	„ „

* White light. † Violet light. $n = 1{\cdot}00205$ for red light. Iodine shows anomalous dispersion. C. & M., Cuthbertson & Metcalfe; D., Dulong; P. & M., Prideaux & Metcalfe.

REFRACTIVE INDICES

Refractive indices, *n*, (against air) at 15° C. for various wave-lengths.

The **temperature coefficient** given below is the change of refractive index per 1° C. rise of temperature for the case of the sodium D line.

The refractive indices are due chiefly to Gifford (*Proc. Roy. Soc.*, 1902, 1904, 1910); Rubens and Paschen (for the infra-red) and Martens (1902). The two Jena glasses are selected as typical. Other glasses are dealt with on p. 85.

Wave-length in Å.U. (10^{-8} cm.).	Calcspar, 18°.		Jena glass.		Fluorite, CaF_2, 18°.	Quartz, 18°.		Fused silica.	Rock salt, 18°.	Sylvin, KCl 18°.	Water at 20°.
	ord. ray.	ext. ray.	Crown*	flint.†		ord. ray.	ext. ray.				
Infra-red.	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
223,000	—	—	—	—	—	—	—	—	3403	3712‡	—
94,290	—	—	—	—	3161	—	—	—	4983	4587	—
42,000	—	—	—	—	4078	4569	—	—	5213	4720	—
21,720	6210	4746	4946	6153	4230	5180	5261	—	5262	4750	—
12,560	6388	4782	5042	6268	4275	5316	5402	—	5297	4778	3210
Visible.											
Li, (*r*) **6708**	6537	4843	5140	6434	4323	5415	5505	4561	5400	4866	3308
H, (C) **6563**	6544	4846	5145	6444	4325	5419	5509	4564	5407	4872	3311
Cd, (*r*) **6438**	6550	4847	5149	6453	4327	5423	5514	4568	5412	4877	3314
Na, (D) **5893**	6584	4864	5170	6499	4339	5443	5534	4585	5443	4904	3330
Hg, (*g*) **5461**	6616	4879	5191	6546	4350	5462	5553	4602	5475	4931	3345
Cd, (*g*) **5086**	6653	4895	5213	6598	4362	5482	5575	4619	5509	4961	3360
H, (F) **4861**	6678	4907	5230	6637	4371	5497	5590	4632	5534	4983	3371
Cd, (*b*) **4800**	6686	4911	5235	6648	4369	5501	5594	4636	5541	4990	3374
Hg, (*v*) **4047**	6813	4969	5318	6852	4415	5572	5667	4697	5665	5097	3428
Ultra-violet.											
Sn **3034**	7196	5136	5552	—	4534	5770	5872	4869	6085	5440	3581
Cd **2144**	8459	5600	—	—	4846	6305	6427	5339	7322	6618	4032
Al **1852**	—	—	—	—	5099	6759	6901	5743	8933	8270	—
Temp. coefficient (D)	$+{\cdot}0_5 5$	$+{\cdot}0_4 14$	$-{\cdot}0_5 1$	$+{\cdot}0_5 3$	$-{\cdot}0_4 1$	$-{\cdot}0_5 5$	$-{\cdot}0_5 6$	$-{\cdot}0_5 3$	$-{\cdot}0_4 4$	$-{\cdot}0_4 4$	$-{\cdot}0_4 8$

* Light barium crown. † Dense silicate flint. ‡ *n* = 1·3692 for λ = 225,000.

REFRACTIVE INDICES

Refractive indices n_D (against air) at 15° C. for sodium D line (λ = 5893 × 10^{-8} cm.).

Substance.	n_D	Substance.	n_D	Substance.	n_D
Solids.		Alcohol, ethyl	1·362	Monobrom benzene	1·563
Alum (potash)	1·456	„ amyl	1·41	„ „ naphthalene	1·660
Cyanin	1·71	Aniline	1·590	Nitrobenzene	1·553
Diamond	2·417	Benzene	1·504	Oil, cedar	1·516
Glass (see above and p. 85)		Bromoform	1·591	„ cloves	1·532
Ice	1·31	Canada balsam	1·53	„ cinnamon	1·601
Mica 1·56 to	1·60	Carb. bisulphide	1·632	„ olive	1·46
Ruby	1·76	„ tetrachloride	1·464	„ paraffin	1·44
Sugar	1·56	Chloroform	1·449	Sulphuric acid	1·43
Topaz	1·63	Ether, ethyl	1·354	Turpentine	1·47
Liquids.		Ethylene dibromide	1·540	Water (see above)	1·333
Alcohol, methyl	1·33	Glycerine	1·47		
		Methylene iodide	1·744		

DISPERSIVE POWERS

The dispersion ν given below $= (n_D - 1)/(n_C - n_F)$ where n_C, n_D, n_F are the refractive indices corresponding to the red (C) H line (6563), the yellow Na (D) line (5893), and the green-blue (F) hydrogen line (4862).

Substance.	ν	Substance.	ν	Substance.	ν
Solids.		Quartz, ord.	70	**Liquids.**	
Calcite, ord.	49	,, ext.	68	Carb. bisulphide	18·3
,, ext.	80	Fused silica	69	Alcohol	58
Fluorite	95	Rock salt	43	Turpentine	49
Glass (see p. 85)		Sylvin	44	Water	56

G. W. C. K.

VELOCITY OF LIGHT

VELOCITY OF LIGHT IN VACUO

Methods.—T. W. toothed wheel; R. M. rotating mirror.

For ratio of e.s. to e.m. units, see p. 15.

Weighted mean of last three observations $c =$ **299,774 ± 11 km.sec.$^{-1}$**

Date.	Author.	Method.	Vel. km.sec.$^{-1}$.	Date.	Author.	Method.	Vel. km.sec.$^{-1}$.
1849	Fizeau	T.W.	315,300	1902	Perrotin	R.M.	299,901 ± 84
1863	Foucault	R.M.	298,100 ± 500	1924	Michelson	R.M.	299,802 ± 30
1875	C—H	T.W.	299,990 ± 200	1926	Michelson	R.M.	299,796 ± 4
1879	Michelson	R.M.	299,970 ± 50	1928	K and M	R.M.	299,778 ± 20
1883	Newcomb	R.M.	299,860 ± 30	1932	M, P and P	R.M.	299,774 ± 11
1882	Michelson	R.M.	299,853 ± 60	1937	Anderson	R.M.	299,764 ± 15

C—H, Cornu—Helmert, K and M, Karolus and Mittelstædt; M, P and P, Michelson, Pease and Pearson.

VELOCITY OF HERTZIAN WAVES

Mercier (1923) using stationary waves on Lecher wires found $c = 299{,}782 \pm 30$ km. sec.$^{-1}$.

V. D. H.

VELOCITY OF LIGHT IN LIQUIDS

Liquid.	$\frac{\text{Vel. in vacuo}}{\text{Vel. in liquid}}$	Refractive index for Na D line.	Method.	Observer.
Water	1·330	1·333/20°	Rotating mirror	Michelson, 1883
CS_2	1·758	1·627/20°	,, ,,	,, ,,

GLASS

The **raw materials** for the manufacture of glass are (1) silica—usually as sand or felspar; (2) salts of the alkali metals—Na_2SO_4, Na_2CO_3, or K_2CO_3; (3) salts of bases other than alkalies—red lead, limestone or chalk, $BaCO_3$ or $BaSO_4$, $MgCO_3$, ZnO, MnO_2, Al_2O_3, As_2O_3, etc. In general, glasses rich in silica and lime are hard, while glasses in which alkali, lead, or barium preponderate are soft. Hardness is, of course, also largely dependent on annealing. Ordinary " soft " (*i.e.* easily fusible) German glass is a soda-lime glass rather rich in alkali ; " hard " (refractory) glass is a potash-lime glass rather rich in lime. Jena combustion tubing is a borosilicate containing some magnesia.

Thermometry Glasses.—Glasses which contain **both** soda and potash to any extent give a large temporary zero depression (see p. 57). Data concerning *Verre dur* (71% SiO_2, 12% Na_2O, ½% K_2O, 14% CaO, 2% Al_2O_3 and MgO), *Jena* 16‴ (67% SiO_2, 14% Na_2O, 7% CaO, 12% ZnO, Al_2O_3 and B_2O_3), *Jena* 59‴ (72% SiO_2, 12% B_2O_3, 11% Na_2O, 5% Al_2O_3), will be found on p. 57.

Optical Glasses.—In building up achromatic lens systems a knowledge of the dispersion (ν) of each glass employed is essential. This is defined as the ratio of the deviation at a selected wave-length to the difference of deviations at two neighbouring wave-lengths. It thus depends on the colours selected ; for visual work they are usually the red (C) line of hydrogen (wave-length $\lambda_C = 6563 \times 10^{-8}$ cm.), the yellow sodium (D) line ($\lambda_D = 5893$), and the green-blue (F) hydrogen line ($\lambda_F = 4862$). If n_C, n_D, n_F are the corresponding refractive indices, $\nu = (n_D - 1)/(n_C - n\ )$ for the brightest part of the visible spectrum.

Flint glass—a term which survives from times when ground flints were extensively employed in making the best glass—now always implies a dense glass which contains lead and has a high refractive index and dispersive power.

Crown glass, originally designating only lime-silicate glasses, is now applied generally to glasses having a low dispersive power.

Optical Glasses.—For ordinary flints and crowns ν and n are roughly proportional, and this was true for all commercially available glasses prior to the advances initiated in 1881 by Abbe and Schott at Jena. They succeeded (*e.g.* by the addition of barium) in producing glasses which do not obey any such proportionality ; *e.g.* the very valuable barium crown glasses (below) combine the high refractive index of a flint glass with the low dispersive power of a crown. In more recent years other manufacturers in this country and abroad have extended the variety of combinations possible. Such glasses have brought about the excellent achromatism and flatness of field which now obtain in photographic lenses and large telescopic objectives. The relative dispersions at the two ends of the spectrum can also be varied independently by the addition of suitable constituents : such control over the dispersion has made the modern microscope possible.

Some typical examples of British and Jena glasses are subjoined. For a complete list, see the catalogue of Chance Bros. The U.V. glasses are markedly transparent to ultra-violet light as far as about $\lambda = 2880$.

See p. 83, and Zschimmer's " History of the Jena Glass Works," Hovestadt's " Jena Glass," and Rosenhain's " Glass Manufacture " (with bibliography).

(After Zschimmer, *Zeit. Inst.*, 1908.)

Glass.	n_D	$\nu_{(C,D,F)}$	Dens. grms./c.c.	Glass.	n_D	$\nu_{(C,D,F)}$	Dens. grms./c.c.
Crowns—				**Flints**—*contd.*			
(Silicate) crown	†1·4782	66	2·23	U.V. flint	†1·5329	76	—
	*1·5189	60	2·60	Borosilicate flint	†1·5753	46	2·90
	†1·5215	59	2·48	Barium flint	*1·5670	55	3·14
U.V. crown	†1·5035	65	—		*1·6226	40	3·63
Fluor crown	†1·4645	66	2·28		*1·6683	36	3·98
Borosilicate crown	*1·5096	65	2·46	Telescope flint	*1·5149	57	2·59
Barium crown	*1·5406	60	2·87		†1·5286	52	2·50
Dense barium crown	*1·5886	61	3·31		*1·5302	51	2·56
	*1·6123	58	3·55	Dense flint	*1·6224	36	3·65
	†1·6385	55	3·69		*1·6509	34	3·89
Flints— (Silicate) flint	*1·5290	52	2·56		*1·7482	28	4·75
	*1·5782	41	3·26		†1·9229	21	6·03
	†1·6489	34	3·87				

* British Optical Glass. † Jena Glass.

SPECTROSCOPY

It is now agreed that the use of the diffraction-grating in fundamental work must be limited to interpolation between standard wave-lengths obtained by other means. The accepted standard lines are three in the spectrum of cadmium. Their wave-lengths (λ) obtained by interference methods, and measured (by direct comparison with the standard metre at Paris) in dry air at 15° C. (H-scale) and 760 mms. mercury pressure, are given below in tenth-metres (= 10^{-8} cm. = 1 Ångström unit). (See Michelson's "Light Waves and their Uses.") [$\mu = 10^{-4}$ cm.; $m\mu = 10^{-7}$ cm.]

Observer.	λ Cd red.	λ Cd green.	λ Cd blue.
Michelson and Benoit, 1894	6438·4700	5085·8218	4799·9085
Benoit, Fabry, and Perot, 1907 . . .	6438·4702	—	—
Watanabe and Imaizumi, 1928 . . .	6438·4682	—	—
Sears and Barrell, 1933	6438·4708	—	—
Kösters, 1934	6438·4672	—	—

STANDARD LINES—IRON ARC SPECTRUM

Obtained by an interference method, and based on Benoît, Fabry, and Perot's value for the wave-length of the red line of cadmium. The wave-lengths below are given in tenth-metres (10^{-8} cm.), measured in dry air at 15° (H-scale) and 760 mms. mercury. (Buisson and Fabry, *Compt. Rend.*, 1907 and 1909.)

2373·737	2987·293	3724·379	4352·741	4878·226	5405·780	5952·739
2413·310	3030·152	3753·615	4375·935	4903·324	5434·530	6003·039
2435·159 *	3075·725	3805·346	4427·314	4919·006	5455·616	6027·059
2506·904 *	3125·661	3843·261	4466·554	4966·104	5497·521	6065·493
2528·516 *	3175·447	3865·526	4494·572	5001·880	5506·783	6137·700
2562·541	3225·790	3906·481	4531·155	5012·072	5535·418	6191·569
2588·016	3271·003	3935·818	4547·854	5049·827	5569·632	6230·732
2628·296	3323·739	3977·745	4592·658	5083·343	5586·770	6265·147
2679·065	3370·789	4021·872	4602·944	5110·415	5615·658	6318·029
2714·419	3399·337	4076·641	4647·437	5127·364	5658·835	6335·343
2739·550	3445·155	4118·552	4678·855	5167·492	5709·396	6393·612
2778·225	3485·344	4134·685	4707·287	5192·362	5760·843 ‡	6430·859
2813·290	3513·820	4147·677	4736·785	5232·958	5763·013	6494·994
2851·800	3556·879	4191·441	4754·046 †	5266·568	5805·211 ‡	
2874·176	3606·681	4233·615	4789·657	5302·316	5857·760 ‡	* Si.
2912·157	3640·391	4282·407	4823·521 †	5324·196	5892·882 ‡	† Mn.
2941·347	3677·628	4315·089	4859·756	5371·498	5934·683	‡ Ni.

CHIEF ABSORPTION (FRAUNHOFER) LINES IN SOLAR SPECTRUM

Rowland's wave-lengths corrected approximately by the use of Fabry and Perot's results, measured in tenth-metres (10^{-8} cm.) in air at 20° and 760 mms. Owing to atmospheric absorption, the sun's spectrum extends only to about wave-length 3000.

Line.	Subst.	Rel. Intens.	Line.	Subst.	Rel. Intens.	Line.	Subst.	Rel. Intens.
3047·5	Fe	20	L 3820·4	Fe–C	25	(H_γ)4340·4	H	20
3057·3	Ti–Fe	20	3825·8	Fe	20	F 4861·37	H (β)	30
3059·0	Fe	20	3838·2	Mg–C	25	b_2 5172·7	Mg	20
O{3440·6	Fe	20	3859·8	Fe–C	20	b_1 5178·22	Mg	30
3441·0	Fe	15	K 3933·6	Ca	1000	E 5269·56	Fe	8
3524·5	Ni	20	3961·5	Al	20	($D_3$5875·62)†	He	—
N 3581·2	Fe	30	H 3968·4	Ca	700	D_2 5889·97	Na	30
3608·8	Fe	20	4045·8	Fe	30	D_1 5895·93	Na	20
3618·7	Fe	20	4063·6	Fe	20	C 6562·8	H (α)	40
M 3719·9	Fe	40	(H_δ) 4101·8	H	40	B 6867·3	‡	6
3734·8	Fe	40	4226·7	Ca	20	A 7661 *	‡	—
3737·1	Fe	30	G 4307·9	Fe	6	Z 8228 *	—	—

* Langley, 1900.
† Emission line in chromosphere alone.
‡ Oxygen in earth's atmos.

EMISSION SPECTRA OF SOLIDS

For a fuller treatment of wave-lengths see Watts' "Index of Spectra" and appendices, Kayser's "Handbuch der Spectroscopie," Hagenbach and Konen's "Atlas of Emission Spectra," 1905. For recent work consult the *Astrophysical Journal*. The wave-lengths below are measured in tenth-metres (10^{-8} cm.) in air at 15° C. and 760 mms. The visible spectrum colours are indicated—*r*, *o*, *y*, *g*, *b*, *v*.

The brightest lines are emphasized and the approximate boundary of the ultra-violet region is indicated thus . . . . . .

ALUMINIUM
(arc).
3083
3093
. . . . . .
3944 *v*
3962 *v*
4663 *b*
5057 *g*
5696 *y*
5723 *y*

BARIUM
($BaCl_2$ in flame).
Full of bands, some diffuse, and some resolvable.
3501
. . . . . .
3910 *v*
3994 *v*
4131 *v*
4554 *b*
4934 *g*
5536 *gy*
5778 *y*
5854 *y*
6142 *o*
6497 *r*

BORON
(Boric acid in flame).
Diffuse maxima at
4500 *b*
4700 *b*
4900 *b*
5200 *g*
5450 *g*
5800 *y*
6000 *o*

CADMIUM
(arc).
3261
3404
3466
3611
. . . . . .
3982 *v*

CADMIUM
(*contd.*)
4413 *b*
4678 *b*
4799·908 *b*
5085·822 *g*
5338 *g*
5379 *g*
6438·470 *r*

CÆSIUM
(CsCl in flame).
3611·8
3617
3877
3889
. . . . . .
4555 *b*
4593 *b*
5664 *y*
5845 *y*
6011 *o*
6213 *o*
6724 *r*
6974 *r*

CALCIUM
($CaCl_2$ in flame).
Bands predominate; line at
4227

(Flame arc).
3362
3644
. . . . . .
(K) 3934 *v*
(H) 3968 *v*
4227 *v*
4303 *b*
4426 *b*
4435 *b*
4455 *b*
4586 *b*
4878 *b*
5270 *g*
5350 *g*
5589 *y*
5595 *y*
5858 *y*

CALCIUM
(*contd.*)
6122 *o*
6162 *o*
6440 *o*
6463 *o*
6500 *r*

COPPER
(arc in vacuo).
Fabry and Perot, 1902.
3248
3274
. . . . . .
4023 *v*
4063 *v*
5105·543 *g*
5153·251 *g*
5218·202 *g*
5700 *y*
5782·090 *y*
5782·159 *y*

INDIUM
($In(OH)_2$ in flame).
4102 *v*
4511 *v*

IRON
(see p. 79).

LITHIUM
(LiCl in flame).
4132 *v*
4602 *b*
6104 *o*
6707·846 *r*[1]

[1] Fabry and Perot, 1902.

MAGNESIUM
(arc).
3091
3093
3097
3330
3332
3337
3830

MAGNESIUM
(*contd.*)
3832
3838
5168 *g*
(b_2) **5173** *g*
5184 *g*
5529 *y*

MERCURY
(Mercury lamp).
Stiles, *Astro. Journ.*, 1909.
3126
3131
3650
. . . . . .
4046·8 *v*
4078·1 *v*
4358·343 *v*[2]
4916·4 *bg*
4959·7 *g*
5460·742 *g*[2]
5769·598 *y*[2]
5790·659 *y*[2]
6152 *o*
6232·0 *o*

[2] Fabry and Perot, 1902, and Rayleigh, 1906.

POTASSIUM
(KCl in flame).
3446
3447
. . . . . .
4044 *v*
4047 *v*
5802 *y*
7668 *r*
7702 *r*

RADIUM
($RaBr_2$ in flame).
Runge and Precht, 1903.
3650
3815
. . . . . .
4341 *v*

RADIUM
(*contd.*)
4683 *v*
4826 *b*
5210 *g*
5360 *g*
5655 *y*
5685 *y*
6210 *o*[3]
6216 *o*[3]
6228 *o*[3]
6247 *o*[3]
6250 *o*[3]
6260 *o*[3]
6269 *o*[3]
6285 *o*[3]
6329 *o*[3]
6349 *o*
6530 *r*[3]
to
6700 *r*[3]
6653 *r*

[3] Bands.

RUBIDIUM
(RbCl in flame).
3349
3351
3587
3592
. . . . . .
4202 *v*
4216 *v*
5648 *y*
5724 *y*
6207 *o*
6298·7

SILVER
(arc in vacuo).
3281
3383
. . . . . .
4055 *v*
4212 *v*
4669 *b*
5209·081 *g*[4]
5465·489 *g*[4]
5472 *g*
5623 *g*

[4] Fabry and Perot, 1902.

SODIUM
(NaCl in flame).
Fabry and Perot, 1902; Rayleigh, '06.
(D_2)5889·965 *o*
(D_1)5895·932 *o*

STRONTIUM
($SrCl_2$ in flame).
Band spectr'm with lines at
4607·5 *b*
6387 *o*

THALLIUM
(Tl or $TlCl_2$ in flame).
5350·7 *g*

TIN
(spark).
3009
3034
3175
3262
3283
3331
3596
3746
. . . . . .
4525 *v*
5563 *y*
5589 *y*
5799 *y*
6453 *o*

ZINC
(arc in vacuo).
3036
3072
3345
. . . . . .
4680·138 *b*[5]
4722·164 *b*[5]
4810·535 *b*[5]
4912 *b*
4925 *gb*
6108 *o*
6362·345 *o*[5]

[5] Fabry and Perot, 1902.

EMISSION SPECTRA OF GASES

The gases are all in vacuum tubes (2–4 mms. press.); only the brightest lines are given. The visible spectrum colours are indicated—*r*, *o*, *y*, *g*, *b*, *v*.

ARGON,
Red spectrum
(small current density).

4159 *v*
4192 *v*
4198 *v*
4201 *v*
4259 *b*
4300 *b*
4334 *b*
4511 *b*
4703 *b*
5452 *g*
5607 *y*
5912 *o*
6031 *o*
6059 *o*

Blue spectrum
(large current density).

3583
. . . . . .
4072 *v*
4104 *v*
4228 *v*
4331 *b*
4348 *b*
4426 *b*
4430 *b*
4431 *b*
4610 *b*
4806 *b*

CARBON MONOXIDE or DIOXIDE
(of common occurrence in many vacuum-tube spectra). Numerous bands shaded towards violet edges at

3590 (CN)
3884 (CN)
. . . . . .
4123 *v*
4216 (CN) *v*
4393 *b*
4511 *b*
4735 (C) *b*
4835 *b*
5165 (C) *g*
5198 *g*
5610 *y*
6079 *o*

HELIUM
Rayleigh, 1908.

3188
. . . . . .
3889 *v*
4026 *v*
4471·482 *b*
4713·144 *b*
4921·930 *gb*
5015·680 *g*
(D$_3$) 5875·625 *y*
6678·150 *r*
7065·200 *r*

HYDROGEN
Elementary spectrum.

3750
3771
3798
3836
3889
. . . . . .
3970 *v*
4102 (δ) *v*
4340 (γ) *b*
(F) 4861 (β) *gb*
(C) 6563 (α) *r*

For very short wave-lengths (1030–1675) see Lyman, *Astro. Journ.*, 1906.

Secondary spectrum (see Watson, *Proc. Roy. Soc.*, 1909).

KRYPTON AND XENON
Brit. Ass. Rep., 1905.

NEON
Baly, *Phil. Trans.*, 1903. Very rich in red rays.

3448
3473
3521
3594
. . . . .
5765 *y*

NEON (*contd.*)

5853 *y*
5882 *o*
5945 *o*
5976 *o*
6030 *o*
6075 *o*
6096 *o*
6129 *o*
6143 *o*
6164 *o*
6182 *o*
6217 *o*
6267 *o*
6305 *o*
6383 *o*
6402 *o*
6507 *r*

NITROGEN
Band spectrum from positive column.
Many bands all made up of fine lines. From 3000 to 4574 the edges occur at intervals of about 60 Å.U. Other bands have edges at

4648 *b*
4666 *b*
4723 *b*
4813 *b*
5340 *g*
5614 *y*
5755 *y*

NITROGEN (*contd.*)

5804 *y*
5854 *y*
5906 *o*
5959 *o*
6013 *o*
6069 *o*

With large current densities, N gives a line spectrum.

OXYGEN
Elementary line spectrum.

3919
3973
. . . . . .
4070 *v*
4072 *v*
4076 *v*
4415 *b*
5208 *g*

Diffuse maxima at

5335 *g*
5440 *g*
6110 *o*
6170 *o*

There are three other oxygen spectra: continuous, band, and series spectra.

RADIUM EMANATION
Royds, *Phil. Mag.*, 1909.

The following values (all in tenth-metres) are of course only approximate:—

Hertzian Waves.	Infra-red.	Red.	Orange.	Yellow.	Green.	Blue.	Violet.	Ultra-violet.
$10^{14} - 4 \times 10^7$	$3\cdot1 \times 10^6$ 7700	6470	5880	5500	4920	4550	3600	600

ABSORPTION SPECTRA

Among the enormous literature on absorption spectra, reference may be made to Kayser's "Handbuch der Spectroscopie," Baly's "Spectroscopy," Vogel's "Praktische Spectralanalyse," the writings of Prof. Hartley, Jones and Anderson's "Absorption Spectra of Solutions," 1909, Smiles' "Chemical Constitution and Physical Properties," and the British Association Reports of 1901 *et seq.*

Convenient substances which show good absorption spectra are—neodymium and praseodymium salts and didymium glass (which yield some extremely narrow absorption lines), iodine vapour, nitrogen peroxide, chlorine, chlorophyll, blood, and potassium permanganate solution.

OPTICAL ROTATIONS OF PURE LIQUIDS AND SOLUTIONS

A_t = the rotation in degrees (for light of some given wave-length) of the plane of polarization by a liquid when at the temperature t° C.

l_t = the length of the column of liquid in **decimetres** (*i.e.* 10 cms.).

p = the number of grams of active substance in 100 **grams** of **solution.**

$q = (100 - p)$ = the percentage (by weight) of inactive solvent in the solution.

ρ_t = the density in grams per c.c. of the liquid or solution at t°.

$c_t = p\rho_t$ = the concentration expressed as grams of active substance per 100 **c.cs.** of **solution** at t°.

$[\alpha]_t$ = the **specific rotation** (at t°) $= \dfrac{\text{rotation per decimetre of sol.}}{\text{grams of active substance per c.c. of sol.}}$

For a pure liquid $[\alpha]_t = \dfrac{A_t}{l_t\rho_t}$.

For an active substance in solution $[\alpha]_t = \dfrac{A_t}{l_t} \Big/ \left(\dfrac{p}{p+q}\rho_t\right) = \dfrac{100A_t}{l_t p\rho_t} = \dfrac{100A_t}{l_t c_t}$, since $(p + q) = 100$.

The rotation depends on the wave-length of the light used; it increases as the wave-length (λ) diminishes ($\alpha \propto \frac{1}{\lambda^2}$ approx.). α also varies with the nature of the inactive solvent and with the concentration of the solution.

The rotation is called positive or right-handed (dextro, *d*) if the plane of polarization appears to be rotated in an anti-clockwise direction when looking through the liquid **away** from the source of light. The contrary rotation is called lævo (*l*). The **molecular rotation** is the specific rotation multiplied by the molecular weight.

$[\alpha]^D_{20}$ indicates that the specific rotation is measured at 20° C. using sodium (D) light.

(See Landolt's "Optical Rotations of Organic Substances and their Practical Application.")

Optically Active Substance.	**Solvent.**	**Conditions.**	**Specific Rotation $[\alpha]_t$**
Cane Sugar or Candy (*d*), $C_{12}H_{22}O_{11}$ (Landolt, 1888; Pellat, 1901)	water	$c = 4$ to 28	$[\alpha]^D_{20} = +66{\cdot}67 - {\cdot}0095c$
		$t = 14^\circ$ to 30° C.	$[\alpha]^D_t = [\alpha]^D_{20}\{1 - {\cdot}00037(t - 20)\}$
Invert Sugar(*l*),* $C_6H_{12}O_6$ = 1 mol. of dextrose + 1 mol. of levulose (Gubbe, 1885)	water	$c = 9$ to 35	$[\alpha]^D_{20} = -19^\circ{\cdot}7 - {\cdot}036c$
		$t = 3^\circ$ to 30° C.	$[\alpha]^D_t = [\alpha]^D_{20} + {\cdot}304(t - 20) + {\cdot}00165(t - 20)^2$
Dextrose (*d* – glucose), $C_6H_{12}O_6$ (Parcus and Tollens, 1890; Tollens, 1884)	water	$c = 9{\cdot}1$	$[\alpha]^D_{20} = +105^\circ{\cdot}2$ after 5·5 mins. (α modification) $= +52^\circ{\cdot}5$ after 6 hrs. (β modification)
	water	$p = 1$ to 18	$[\alpha]^D_{20} = +52^\circ{\cdot}5 + {\cdot}025p$
l – **Glucose**, $C_6H_{12}O_6$ (Fischer, 1890)	water	$p = 4$	$[\alpha]^D_{20} = -94^\circ{\cdot}4$ after 7 mins. $= -51^\circ{\cdot}4$ after 7 hrs.
Levulose (*l*) (fruit sugar), $C_6H_{12}O_6$ (Parcus and Tollens, 1890; Ost, 1891)	water	$c = 10$	$[\alpha]^D_{20} = -104^\circ$ after 6 mins. $= -92^\circ$ after 33 mins.
	water	$p = 2$ to 31	$[\alpha]^D_{20} = -91^\circ{\cdot}9 - {\cdot}11p$

* The molecular weight of cane-sugar is 342; which, after conversion to invert sugar, becomes 360. Hence the new concentration of the invert sugar solution is $\frac{360}{342}c$, where c is the number of grams of cane-sugar in 100 c.cs. of the original solution.

OPTICAL ROTATIONS

Optically Active Substance.	Solvent.	Conditions.	Specific Rotation $[\alpha]_t$
Galactose (*d*), $C_6H_{12}O_6$ (Meissl, 1880)	water	$p = 4$ to 36 $t = 10^\circ$ to 30° C.	$[\alpha]_t^D = +83^\circ{\cdot}9 + {\cdot}078p - {\cdot}21t$
Ordy. **Tartaric acid** (*d*), $H_2C_4H_4O_6$	water	—	$[\alpha]_{20}^D = +15{\cdot}06 - {\cdot}131c$
Potassium tartrate (*d*), $K_2C_4H_4O_6$ (Thomsen, 1886)	water	$c = 8$ to 50	$[\alpha]_{20}^D = +27{\cdot}14 + {\cdot}0992c - {\cdot}00094c^2$
Rochelle salt (*d*), $KNaC_4H_4O_6$	water	—	$[\alpha]_{20}^D = +29{\cdot}73 - {\cdot}0078c$
l – **Turpentine**, $C_{10}H_{16}$ (Gernez, 1864; Landolt, 1877)	pure liquid	—	$[\alpha]_{20}^D = -37^\circ$
	vapour	at 761·7 mms.	$[\alpha]_{168}^D = -35^\circ{\cdot}5$ for mean yellow
	alcohol ($\rho_{20} = {\cdot}796$)	$q = 0$ to 90	$[\alpha]_{20}^D = -37^\circ - {\cdot}00482q - {\cdot}00013q^2$
	benzene	$q = 0$ to 91	$[\alpha]_{20}^D = -37^\circ - {\cdot}0265q$
	paraffin oil	Within wide limits $[\alpha]$ **increases** with the percentage of paraffin.	
Quinine sulphate (*l*), $C_{20}H_{24}N_2O_2.H_2SO_4$ (Oudemans, 1876)	water	c about 1·6 % of alkaloid (calculated)	Salt $[\alpha]_{17}^D = -214^\circ$ Alkaloid $[\alpha]_{17}^D = -278^\circ$
Nicotine (*l*), $C_{10}H_{14}N_2$ (Landolt, 1877; Hein, 1898)	pure	$t = 10^\circ$ to 30°C.	$[\alpha]_{20}^D = -162^\circ$
	benzene	$p = 8$ to 100	$[\alpha]_{20}^D = -164^\circ$
	water	$p = 1$ to 16	$[\alpha]_{20}^D = -77^\circ$
Ethyl malate (*l*), $(C_2H_5)_2C_4H_4O_5$ (Purdie & Williamson, '96)	pure liquid	—	$[\alpha]_{11}^D = -10^\circ{\cdot}3$ to $-12^\circ{\cdot}4$
Camphor (*d*), $C_{10}H_{16}O$ (Landolt, 1877; Rimbach, 1892)	alcohol	$q = 45$ to 91	$[\alpha]_{20}^D = +54^\circ{\cdot}4 - {\cdot}135q$
	benzene	$q = 47$ to 90	$[\alpha]_{20}^D = +56^\circ - {\cdot}166q$

OPTICAL ROTATION AND WAVE-LENGTH

Wave-length (λ) in 10^{-8} cm.	Specific Rotation at 20° C. $[\alpha]_{20}^{\lambda}$			
	Cane-sugar or Candy in H_2O.	Turpentine (pure liq.).	Tartaric acid in H_2O (p = 41%).	Nicotine (pure liq.).
H (C) 6563 (*r*)	52°·9	−29°·5	7°·75	−126°
Na (D) 5893 (*o*)	66·5	−37	8·86	−162
Tl 5351 (*g*)	81·8	−45	9·65	−207·5
H (F) 4861 (*g*)	100·3	−54·5	9·37	−253·5

QUARTZ AT 20° C.	
Wave-length (λ) in 10^{-8} cm.	Rotation for 1 mm. thickness.
Li 6708 (*r*)	16°·4
H (C) 6563 (*r*)	17·3
Na (D) 5893 (*o*)	21·72*
Tl 5351 (*g*)	26·53
H (F) 4861 (*g*)	32·7
H (δ) 4102 (*b*)	47·48

* For quartz at temperature t°, rotation $= 21^\circ{\cdot}72\,\{1 + 0{\cdot}000147(t - 20)\}$ for D line.

MAGNETIC ROTATION OF POLARIZED LIGHT

This effect was discovered by Faraday in 1845. The rotation per cm. per unit magnetic field—**Verdet's constant,** $r = a/(Hl)$, where a is the rotation in minutes for the substance in a magnetic field of H gauss, and l is the length of light-path parallel to the lines of force. r varies with the temperature and is roughly inversely proportional to the square of the wave-length of the light used. Films of Fe, Ni, and Co are exceptions to this rule.

If the light is travelling with the lines of force (*i.e.* from N. to S.), then the direction of rotation is positive, if the plane of polarization is rotated clockwise, to an observer looking in the direction in which the light is moving. If the light is reflected back on its path, the rotation is increased.

The **Molecular rotation** $r_m = rM/d$, where M is the molecular weight of the substance, and d is its density. r_m is an additive property in organic compounds (Perkin, *Journ. Chem. Soc.*, 1884).

The rotations below are for the sodium D line ($\lambda = 5893 \times 10^{-8}$ cm.).

(For Voigt's theory of magneto-rotation, see Schusters, "Optics," 1909. See also Becquerel's papers in *Compt. Rend.*, etc.)

Substance.	Temp.	Rotation r in mins. of arc.	Substance.	Temp.	Rotation relative to Water.
Water	**0**°C.	+·01311, R.W.	Ethyl alcohol . . .	**16·8**	·8637, P.
"	**20**	+·01312, R.W.	n. propyl alcohol . .	**15·6**	·9139, P.
Carbon bisulphide . .	**0**	+·04347, R.W.	Amyl(iso) alcohol . .	**19·9**	·9888, P.
" " . .	**18**	+·04200, Ra.	Ethyl bromide . . .	**19·7**	1·395, P.
Quartz, ⊥ axis . . .	**20**	+·01368,* Bo.	" chloride . . .	**5·0**	1·035, P.
" " . . .	**20**	+·01664, Bo.	" iodide	**18·1**	2·251, P.
" " . . .	**20**	+·1587,† Bo.	Formic acid	**20·8**	·7990, P.
Jena glass {phosphate crown	**18**	+·0161, D.B.	Acetic "	**21·0**	·7976, P.
Jena glass {heaviest flint . .	**18**	+·0888, D.B.	Propionic acid . . .	**20·3**	·8369, P.
$FeCl_3$ dens. = 1·693 .	**15**	−·2026, B.	Benzene	**15**	2·062, B.
" " 1·023 .	**15**	+·0122, B.			

* $\lambda = 6439$. † $\lambda = 2194$. B., Becquerel; Bo., Borel, 1903; D.B., Du Bois, 1894; P., Perkin; Ra., Rayleigh, 1884; R.W., Rodger and Watson, 1896.

METALLIC REFLECTION OF LIGHT

(The percentage of normally incident light reflected from different surfaces.)

The column of figures (below) in the case of **speculum metal** (7 Cu, 3 Sn) reads 30% (for $\lambda = 2510$); 51%, 56%, 64%, 67%, 71%, 89%, 94% (for $\lambda = 140{,}000$).

Wave-length λ in A.U. (10^{-8} cm.).		Cu.	Au.	Ni.	Pt.	Ag.	Steel.	Magnalium.*	Glass mirror.	
									Ag back.	Hg back.
Ultra-violet	2,510	26%	39%	38%	34%	34%	33%	67%	—	—
	3,570	27	28	49	43	74	45	81	—	—
Visible	4,200	33	29	57	52	87	52	83	86%†	73%†
	5,500	48	74	63	61	93	55	83	88	71
	7,000	83	92	69	69	95	58	83	90	73
Infra-red	10,000	90	95	72	73	97	63	84		
	40,000	97	97	91	91	98	88	89		
	140,000	98	98	97	96	99	96	92		

* 69 Al, 31 Mg.
† $\lambda = 4500$.

DIOPTER

In applied optics the "power" of a lens or mirror is expressed in diopters. The number of diopters equals the reciprocal of the focal length expressed in metres.

ELECTRICAL RESISTIVITIES

Electrical specific resistances or resistivities in ohm-cms. **Conductivities** (in reciprocal ohms) are the reciprocals of resistivities. For a table of reciprocals, see p. 157.

METALS AND ALLOYS

The resistivity depends to some extent on the state of the metal. In general, cold drawing increases, while annealing diminishes the resistance. The winding of a wire into a coil increases its resistance.

For pure metals, the resistance is roughly proportional to the absolute temperature, and would apparently vanish not far from the absolute zero. This rule does not hold even approximately for alloys.

For wire resistances, see p. 94; for temperature coefficients, next page. The thermal conductivities of the same samples of many of the substances below will be found on p. 61.

Substance.	Temp.	Sp. Re.	Observer.	Substance.	Temp.	Sp. Re.	Observer.
Metals—	° C.	$\times 10^{-6}$		**Metals** (*contd.*)	° C.	$\times 10^{-6}$	
Aluminium* .	**−160**	0·81	Lees, '08	Platinum . . .	**−203**	2·4	D.&F., '96
" . .	**18**	3·21	J. & D.,	" . . .	**18**	11·0	J. & D.,
" . .	**100**	4·13	1900	" . . .	**100**	14·0	1900
Antimony . .	**15**	40·5	Berget, '90	Potassium . .	**0**	6·64	B., '04
Bismuth . . .	**18**	119·0	J. & D.,	Rhodium . . .	**18**	6·0	—
" . . .	**100**	160·3	1900	Silver, 99·9 % .	**−160**	0·56	Lees,
Cadmium, drawn	**−160**	2·72	Lees. '08	" . . .	**18**	1·66	*P.T.* 1908
"	**18**	7·54	J. & D.,	" . . .	**18**	1·63	J. & D.,
"	**100**	9·82	1900	" . . .	**100**	2·13	1900
Calcium . . .	**20**	10·5	M.&C., '05	Sodium . . .	**0**	4·74	B., 1904
Chromium . .	**20**	13·1	Adcock, '31	Strontium . .	**20**	25	M., 1857
Cobalt . . .	**20**	9·71	R., 1901	Tantalum . .	**18**	14·6	—
Copper, drawn .	**−160**	0·49	Lees, '08	Tellurium . .	**20**	21	M., 1858
"	**18**	1·78	J. & D.,	Thallium, pure .	**0**	17·6	D.&F., '96
"	**100**	2·36	1900	Thorium . . .	**15**	40·1	Bo., '09
" annealed	**18**	1·59	Mean	Tin, drawn . .	**−160**	3·5	Lees, '08
Gold	**−183**	0·68	D.&F., '96	"	**18**	11·3	J. & D.,
"	**18**	2·42	J. & D.,	"	**100**	15·3	1900
"	**100**	3·11	1900	Tungsten . . .	**25**	5·5	Mean
Iridium . . .	**18**	5·3	—	Zinc, pure . .	**−160**	2·2	Lees, '08
Iron, pure . .	**50**	11·5	N.P.L.	"	**18**	6·1	J. & D.,
" {·1% . .	**18**	12·0	J. & D.,	"	**100**	7·9	1900
" C.} . .	**100**	16·8	1900	**Alloys**—			
" wrought .	**−160**	5·4	Lees, '08	Brass	**−160**	4·1	Lees,
" " † .	**18**	13·9	J. & D.,	" ‡ . . .	**17**	6·6	1908
" " † .	**100**	18·8	1900	" ‡ . . .	**18**	6–9	Mean
" steel {·1% .	**18**	19·9	J. & D.,	Constantan	**18**	49·0	J. & D.
" " C.} .	**100**	25·6	1900	(Eureka) §	**100**	49·1	1900
Lead, drawn .	**−160**	7·43	Lees, '08	German silver ‖	**18**	16–40	Mean
" . .	**18**	20·8	J. & D.,	" " .	**0**	26·6	Lorenz,
" . .	**100**	27·7	1900	" " .	**100**	27·6	1881
Lithium . . .	**0**	8·4	B., '04	Manganin ¶ .	**−160**	43·13	Lees,
Magnesium . .	**0**	4·35	D. & F.	" . .	**18**	44·50	1908
Mercury . . .	**0**	94·07	See	" . .	**18**	42·05	J. & D.,
" . . .	**20**	95·76	p. 11.	" . .	**100**	42·11	1900
Molybdenum .	**25**	4·8	Mean	Phosphor-bronze	**18**	5–10	Mean
Nickel . . .	**−160**	5·9	Lees, '08	Platinoid ‖ . .	**−160**	32·5	Lees,
" {97% .	**18**	11·8	J. & D.,	" . .	**18**	34·4	1908
" Ni.} .	**100**	15·7	1900	90 Pt, 10 Rh .	**0**	21·1	D. & F., '96
Osmium . . .	**20**	9·5	Blair, '05	67 Pt, 33 Ag .	**0**	24·2	—
Palladium . .	**18**	10·7	J. & D.,	Nichrome . .	**20**	110	N.P.L.
" . .	**100**	13·8	1900	Invar** . . .	**0**	75	—

* 99 % Al. † ·1 % C, ·2 % Si, ·1 % Mn. ‡ 70 Cu, 30 Zn. ** Steel 64, Ni 36.
§ 60 Cu, 40 Ni. ‖ 62 Cu, 15 Ni, 22 Zn. ¶ 84 Cu, 4 Ni, 12 Mn.

B., Bernini; Bo., Bolton; D. & F., Dewar & Fleming; J. & D., Jaeger and Diesselhorst; M., Matthiessen; M. & C., Moissan & Chavanne; R., Reichardt; *P. T.*, *Phil. Trans.*

ELECTRICAL RESISTIVITIES (*contd.*)

NON-METALS AND INSULATORS

The resistivities are in ohm-cms. at room temperatures unless otherwise stated. The values for insulators naturally vary widely, and the figures below are merely typical and are probably, in many cases, nothing more than the resistances of the surfaces. For a discussion of some electrical insulators, see Kaye, *Proc. Phy. Soc. Lond.*, 1911.

Substance.	Sp. Re.	Substance.	Sp. Re.	Substance.	Sp. Re.
Gas carbon . .	·004 to ·007	Sulphur, 70° . .	$4 \cdot 10^{15}$	Guttapercha . .	$2 \cdot 10^{9}$
Graphite . . .	·003	Ebonite	$2 \cdot 10^{15}$	Mica	$9 \cdot 10^{16}$
Diamond . . .	10^{12} to 10^{13}	Glass, soda-lime *	$5 \cdot 10^{11}$	Paraffin wax . .	$3 \cdot 10^{18}$
C. lamp filament .	·004	,, Jena, combustion *	$>2 \cdot 10^{14}$	Porcelain, 50° . .	$2 \cdot 10^{15}$
Selenium ‡ (1907)	$2 \cdot 10^{16}$	,, conducting†	$5 \cdot 10^{8}$	Quartz	$1{\cdot}2 \cdot 10^{14}$
Silicon § . . .	·06	,, Pyrex . .	10^{14}	Fused silica * . .	$>2 \cdot 10^{14}$

* National Physical Laboratory. † Phillips. ‡ In dark. § Wick, 1908.

TEMPERATURE COEFFICIENTS OF RESISTANCE

To represent accurately over any considerable range the variation of electrical resistance (R) with temperature (t) requires for almost all substances a parabolic or cubic equation in t. But if the temperature interval is not large, a linear equation $R_t = R_0(1 + \alpha t)$ may be employed; and this gives a definition of the mean temperature coefficient (α) over that temperature range. The table of resistivities above will readily yield the associated values of α. The coefficients given below are average ones.

Substance.	Temp.	α	Substance.	Temp.	α
Metals—		$\times 10^{-4}$	**Metals** (*contd.*)—		$\times 10^{-4}$
Aluminium	**18-100**	38	Silver	**0-100**	40
Bismuth	**18**	42	Tantalum	**0-100**	33
Cadmium	**18-100**	40	Tin	**0-100**	45
Copper *	**18**	42·8	Tungsten (1910) . .	**0-170**	51
Cobalt	**0-160**	33	Zinc	**18-100**	37
Gold	**0-100**	40			
Iron, pure	**18**	62	**Alloys**—		
Steel	**18**	16-42	Brass	**18**	10 ‡
Lead	**18**	43	Constantan (Eureka) .	**18**	−·4 to +·1 ‡
Mercury †	**0-24**	9·0			
Nickel, electrolytic .	**0-100**	62	German silver . . .	**18**	2·3-6
,, commercial .	**0-1000**	27	Manganin §	**20**	·02-·5 ‡
Palladium	**18-100**	37	Platinoid	**18**	2·5
Platinum	**−100-0**	35	90 Pt, 10 Ir	**16**	15
,, ...	**0-100**	38	90 Pt, 10 Rh	**15**	17
Molybdenum (1910) .	**0-170**	50	Platinum-silver (coils)	**16**	2·4-3·3
			Nichrome	**20**	1·7

* High conductivity annealed commercial. † $R_t = R_0(1 + \cdot 0_2 88t + \cdot 0_5 1t^2)$—Smith (N. P. L.), 1904. ‡ N. P. L. § Most samples of manganin have a zero temp. coeff. at from 30° C. to 40° C.

STANDARD WIRE GAUGE

The sizes of wires are ordinarily expressed by an arbitrary series of numbers. There are, unfortunately, four or five independent systems of numbering, so that the wire gauge used must be specified. The following are English Legal Standard wire gauge values. (See Foster's "Electrical Engineers' Pocket Book.")

Size.	Diameter.		Size.	Diameter.		Size.	Diameter.	
S.W.G.	Mm.	Inch.	S.W.G.	Mm.	Inch.	S.W.G.	Mm.	Inch.
6	4·88	·192	**20**	·914	·036	**34**	·234	·0092
8	4·06	·160	**22**	·711	·028	**36**	·193	·0076
10	3·25	·128	**24**	·559	·022	**38**	·152	·0060
12	2·64	·104	**26**	·457	·018	**40**	·122	·0048
14	2·03	·080	**28**	·376	·0148	**42**	·102	·0040
16	1·63	·064	**30**	·315	·0124	**44**	·081	·0032
18	1·22	·048	**32**	·274	·0108	**46**	·061	·0024

WIRE RESISTANCES

Average values in ohms per metre at 15° C. The **safe currents** for copper (high conductivity annealed commercial) are calculated at the rate of about 270 amps./cm.^{2} for No. 12 wire, 430 amps./cm.^{2} for No. 22 wire, and 500 amps./cm.^{2} for smaller diameters. Larger current densities than these are allowed in the revised "Wiring Rules" of the Institution of Electrical Engineers. Eureka is practically identical with constantan.

The average **temperature coefficient** of resistance of copper is ·00428; of nickel, ·0027; of manganin, ·00001; of German silver, ·00044; of Eureka, – ·00002; of platinoid, ·00025 per degree Centigrade. The values for the alloys may vary considerably. The **composition** of manganin is 84Cu, 4Ni, 12Mn; of German silver, 60Cu, 15Ni, 25Zn; of Eureka, *c.* 60Cu, 40Ni. Platinoid is said to be German silver with a little tungsten. For specific resistances, see p. 92.

S.W.G.	COPPER.		MANGANIN.	GERMAN SILVER.	S.W.G.	COPPER.		MANGANIN.	GERMAN SILVER.
	Ohms per metre.	Safe current.	Ohms per metre.	Ohms per metre.		Ohms per metre.	Safe current.	Ohms per metre.	Ohms per metre.
		amps.					amp.		
12	·0032	15·0	·077	·041	**30**	·222	·4	5·45	2·90
14	·0054	9·8	·131	·070	**32**	·293	·3	7·18	3·83
16	·0083	6·8	·204	·109	**34**	·404	·2	9·90	5·27
18	·0148	4·2	·361	·193	**36**	·590	·15	14·5	7·74
20	·0260	2·6	·645	·345	**38**	·950	·1	23·2	12·4
22	·0435	1·7	1·07	·57	**40**	1·48	·06	36·3	19·4
24	·070	1·1	1·73	·92	**42**	2·10	·05	53·4	27·8
26	·105	·7	2·58	1·38	**44**	3·30	·03	81·7	43·5
28	·155	·5	3·82	2·02	**46**	5·90	·02	145·5	77·4

EUREKA or CONSTANTAN.						PLATINOID (Martino's).			
S.W.G.	Ohms per metre.	20° C. temp.-rise caused by	S.W.G.	Ohms per metre.	20° C. temp.-rise caused by	S.W.G.	Ohms per metre.	S.W.G.	Ohms per metre.
		amps.			amps.				
12	·086	12·2	**20**	·722	1·5	**20**	·622	**28**	3·69
14	·146	8·2	**22**	1·20	·7	**22**	1·03	**30**	5·25
16	·228	4·9	**24**	1·93	·3	**24**	1·67	**32**	6·81
18	·405	2·7	**26**	2·89	·1	**26**	2·50	**34**	9·55

FUSES

The fusing currents are for wires mounted horizontally.

	Fusing current.	1 amp.	3	5	10	20	30	40	50
Tin . .	**S.W.G.**	37	28	24	21	18	16	14	13
Copper .	**S.W.G.**	47	41	38	33	28	25	23	22

DIELECTRIC CONSTANTS

The inductivity, dielectric constant, or specific inductive capacity k of a material may be defined as—

(1) The ratio of the capacity of a condenser with the material as dielectric to its capacity when the dielectric is a vacuum.

(2) The square of the ratio of the velocity of electromagnetic waves in a vacuum to their velocity in the material. This ratio is dependent on the wave-length, λ, of the waves; in most cases k increases with λ. Unless otherwise stated, the inductivities below are for very long waves ($\lambda = \infty$) and at room temperatures.

If μ is the refractive index, then on Maxwell's theory of light, $k = \mu^2$, provided the frequency of the electrical oscillations is the same as that of the light vibrations. In practice we cannot find k for vibrations as rapid as those of the visible rays; the alternative is to obtain (by extrapolation) the refractive index for waves of very great wave-length, *e.g.* by the use of Cauchy's formula, p. 82. When such data are available Maxwell's relation is found to hold fairly exactly in the case of a number of gases and liquids, though there are many substances which provide marked exceptions.

In general, a rise of temperature diminishes the inductivity. The **temperature coefficient** α between t° and T° is defined by $k_T = k_t\{1 - \alpha(T - t)\}$. In the case of water Palmer (1903) finds that α increases slightly with the frequency of oscillation. The **Clausius-Mossotti relation** $\frac{k - 1}{\rho(k + 2)}$ = const. (ρ being the density) has been shown by Tangl (*Ann. d. Phys.*, 1908) to hold from 1 to 100 atmos. in the case of H_2, N_2, and air.

Substance.	k.
Solids—	
Calcite	7·5–7·7
Ebonite	2·7–2·9
Fluorite	6·8
Glass, crown . .	5–7
,, heavy crown	7–9
,, flint . . .	7–10
,, mirror . .	6–7
Gypsum	6·3
Ice (−2°) . . .	93·9
Indiarubber . .	2·1–2·3
Marble	8·3
Mica	5·7–7
Paper, dry . . .	2–2·5
Paraffin wax . .	2–2·3
Pitch	1·8
Porcelain . . .	4·4–6·8
Quartz	4·5
Resin	1·8–2·6
Rock salt . . .	5·6
Selenium (16°) .	6·1
Shellac	3–3·7
Silica, fused . .	3·5–3·6
Spermaceti . . .	*c.* 2·2
Sulphur	3·6–4·3
Sylvin	4·9
Vaseline	2·2
Liquids—	
Alcohol, methyl .	35·4/13°·4
,, ethyl . .	26·8/14°·7
,, amyl . .	16·0/20°
Aniline, α = ·004 .	7·21
Benzene, $\alpha = \cdot 0_3 7$.	2·29/18°

Substance.	k.
Bromine . . .	3·1
Carb. bisulphide .	2·62
,, tetrachloride	2·25/18°
Chloroform, 18° .	5·0
Ethyl acetate . .	6
,, chloride . .	10·9
,, ether, α=·005	4·34
Glycerine, λ=200 .	39·1/15°
Nitrobenzene . .	37/17°
Oil, castor . . .	4·6–4·8
,, olive . . .	3·1–3·2

Substance.	k.
Oil, paraffin . .	4·6–4·8
Paraffin, medicinal	2·2
Petroleum . . .	2·0–2·2
Toluene, α = ·001	2·4
Turpentine . .	2·2–2·3
Vaseline oil . .	1·9
Water, $\lambda=\infty$ . .	81
,, λ=3600 cms.	3·32*
,, λ=1200 ,,	2·79*
,, α_{17}=·0045.	
Xylene, *m*, $\alpha = \cdot 0_3 5$	2·37

Substance.	Temp.	k.	Observer.
		76 cm. Hg.; $\lambda = \infty$	
Gases—			
Air	0°C.	1·000594	C. & H., 1927
,, ...	20	1·000528	Watson, 1934
Hydrogen . . .	0	1·000265	Zahn, 1926
,, . . .	25	1·000252	Watson, 1931
Helium . . .	25	1·000067	,, 1931
Nitrogen . . .	25	1·000538	,, 1934
Nitrous oxide, N_2O	25	1·00103	,, 1934
Carbon monoxide .	25	1·000634	,, 1934
,, dioxide .	25	1·000904	,, 1931
,, bisulphide	29	1·00290	S. & W., 1930
Ethylene . . .	25	1·00132	Watson, 1934
Sulphur dioxide .	22	1·00818	Zahn, 1926
Ammonia . . .	1	1·00713	,, 1926
Alcohol, methyl .	100	1·0057	Pohrt, 1913
,, ethyl . .	100	1·0078	Knowles, 1932
Benzene . . .	100	1·00327	Pohrt, 1913.

C. & H., Carman and Hubbard; S. and W., Schwingel and Williams.
* Beaulard, 1908.

IONIC DISSOCIATION THEORY

On the Dissociation Theory (Arrhenius, 1887), the solute is dissociated into electrically positive cathions and negative anions. For example, KCl in water exists as KCl, K^+, Cl^-; sulphuric acid as H_2SO_4, H^+, H^-, SO_4^{++}, HSO_4^+. Probably, in many cases, these ions are attached to molecules of solvent. **The degree of dissociation** α = (number of dissociated solute molecules)/(total number of solute molecules). α is deduced from the osmotic pressure of the solution, and from its electric conductivity at different dilutions. The osmotic pressure is determined (1) directly, (2) from the raising of the boiling-point, and (3) from the depression of the freezing-point of the solvent by the presence of the solute. The equivalent conductivity (Λ) for different concentrations of any dilute solution is assumed to be proportional to the number of ions present. Λ approaches asymptotically a limiting conductivity (Λ_∞) for extreme dilutions, a state of things when, on this theory, the solute is completely dissociated. $\Lambda_m/\Lambda_\infty = \alpha$ for the equivalent concentration m. The cathion and anion with their charges $+e$ and $-e$ (for monovalent ions) move in unit electric field in opposite directions with speeds or **mobilities** u_+ and u_-. The electrolytic current also obeys Ohm's Law, so that $X\kappa = (u_+ + u_-)ne$ (Kohlrausch, 1879), where X is the potential gradient in volts per cm., n the number of +ive or −ive ions per c.c., κ the conductivity of the solution in $ohm^{-1}\ cm.^{-1}$. This becomes $u_+ + u_- = 1{\cdot}037 \times 10^{-5}\Lambda$ cm./sec., since $\kappa/n = \Lambda/N$, and $Ne = 96{,}740$ coulombs per gm. equivalent of ions.

The mobility of electrolytic ions has been directly observed by Lodge (1886), Whetham, Orme Masson, and D. B. Steele. The ratio $u_-/(u_+ + u_-) \equiv n$ is for the negative ion, the **migration ratio** or transport number of Hittorf (1853–9). n can be determined, when complex ions are absent, from the change of concentration at the anode and cathode during electrolysis. The **mobility** of certain organic ions is approximately inversely proportional to their linear dimension a (Laby and Carse). The existence of this relation of Ohm's Law and of a relation between the viscosity (η) of the solvent and the ionic mobilities (Kohlrausch, Hosking, and Lyle) indicates that the motion of the ion through the solution may follow Stokes' Law ($v = F/6\pi\eta a$, where F is the driving force), with the numerical constant, 6π, possibly changed.

In the theory of Debye and Hückel complete dissociation is assumed, and the variations in conductivity and osmotic pressure are traced to the electrostatic and viscous forces acting on the cluster of molecules which surrounds each ion. (See Davies' "Conductivity of Solutions", Falkenhagen's "Electrolytes" and Newman's "Electrolytic Conduction.")

MIGRATION RATIOS

Hittorf's migration ratio or transport number of the anion, $n = u_-/(u_+ + u_-)$; m = equivalent concentration per litre; $t°$ = temp. of observation.

Solute.	t°C.	**Conc.** m.	**Ratio** n.	**Solute.**	t°C.	**Conc.** m.	**Ratio** n.	**Solute.**	t°C.	**Conc.** m.	**Ratio** n.
KCl .	—	·003	·505, S.D.	$AgNO_3$	17°	·4 to ·02	·526, H.	$CuSO_4$.	18°	·08 to ·02	·625, M.
KBr .	18°	·03 to ·01	·504, B.	NH_4Cl	20	·05	·507, Be.	HCl . .	10	·05 to ·02	·159, N.S.
KI . .	25	·05	·505, Be.	TlCl .	22	·01	·516, Be.	HNO_3. .	18	·25	·17
KNO_3.	8	·1	·497, H.	$CaCl_2$.	—	·005	·562, S.D.	H_2SO_4 .	11	·05	·17, Be.
NaCl .	18	·03 to ·009	·604, B.	$SrCl_2$.	21	·01	·56, Be.	KOH . .	—	·1	·74
$NaNO_3$	19	·05	·629, Be.	$BaCl_2$.	18	·01	·55	NaOH. .	25	·04	·8, Be.
LiCl .	18	·03 to ·008	·67	$MgCl_2$	21	·05	·615, Be.	NH_3 . .	21	·05	·56, Be.
				$ZnSO_4$	—	·05	·64, H.	$AgC_2H_3O_2$	25	·01	·376, L.N.
				$CdBr_2$.	18	·12 to ·007	·57				

B., Bogdan; Be., Bein; H., Hittorf; L.N., Löb and Nernst; M., Metelka; N.S., Noyes and Sammet; S.D., Steele and Denison.

ELECTRICAL CONDUCTIVITY OF SOLUTIONS

κ_{18} = specific electric conductivity (in ohms^{-1} cm.$^{-1}$) of the solution at 18° C.
p = mass of anhydrous solute per 100 gms. of solution.
η = the number of gm. equivalents in 1 c.c. of solution. Gm. equiv. per litre = 1000η. To find η note that $\kappa/\Lambda = \eta$.
v = volume in litres containing one gm. equivalent of solute = $1/1000\eta$.
Λ = equivalent conductivity = κ/η, = the conductivity in reciprocal ohms of 1 gm. equiv. in solution between electrodes 1 cm. apart. The chemical equiv. of, for example, "$1/2CaCl_2$" is 111/2.

Temp. coefficient = $(d\kappa/dt)/\kappa_{18}$. (See Kohlrausch and Holborn, "Das Leitvermögen der Elektrolyten" (Teubner).) K = Kohlrausch; G = Grotrian.

CONCENTRATED SOLUTIONS

1 KCl (K.G.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
5	·0690	99·9	201
10	·1359	95·2	188
15	·2020	91·5	179
20	·2677	88·9	168
21	·2810	87·5	166

1 NaCl (K.G.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
5	·0672	76	217
10	·1211	66·2	214
15	·1642	57·8	212
20	·1957	49·9	216
25	·2135	42·0	227
26·4	·2156	39·8	233

½ $CaCl_2$ (K.G.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
5	·0643	68·6	213
10	·1141	58·3	206
15	·1505	49·2	202
20	·1728	40·6	200
25	·1781	32·1	204
30	·1658	23·9	216
35	·1366	16·1	236

½ $CdCl_2$ (G.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
1	·0055	50·1	222
10	·0241	20·2	217

½ $CdCl_2$ (G.) (*contd.*).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
30	·0282	6·5	252
50	·0137	1·49	353

1 $AgNO_3$ (K.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
5	·0256	83·4	218
10	·0476	74·3	217
15	·0683	67·9	215
40	·1565	45·0	205
60	·2101	31·1	209

1 $(NH_4)_2SO_4$ (K.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
5	·0552	71·0	215
10	·1010	63·1	203
20	·1779	52·7	193
30	·2292	43·1	191

½ $CuSO_4$ (K.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
2·5	·0109	34·0	213
5	·0189	28·7	216
10	·0320	23·1	218
17·5	·0458	17·4	236

½ $CdSO_4$ (G.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
1	·0042	42·9	210
5	·0146	29·0	206
25	·0430	13·8	223
36	·0421	8·25	255

1 HCl (K.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
5	·3948	281·0	158
10	·6302	219·1	156
20	·7615	126·2	154
30	·6620	69·8	152
40	·5152	39·1	—

1 HNO_3 (K.G.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
6·2	·312	307	147
12·4	·542	257	142
18·6	·690	211	137
24·8	·768	169	137
31	·782	133	139
49·6	·634	61	157
62	·496	36·4	157

½ H_2SO_4 (K.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
5	·208	198	121
10	·391	180	128
15	·543	161	136
20	·653	140	145
25	·717	119	154
30	·739	99	162
35	·724	80	170
40	·680	64	178
50	·540	38	193
60	·373	20·3	213

½ H_2SO_4 (K.) (*contd.*).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
70	·216	9·4	256
80	·110	3·9	349
90	·107	3·22	320
100	·0157	—	031

1 KOH (K.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
4·2	·1464	188	187
8·4	·272	169	186
12·6	·376	150	188
16·8	·456	131	193
29·4	·543	81	221
42·0	·421	39	283

1 NaOH (K.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
2·5	·109	170	194
5	·197	149	201
10	·312	112	217
15	·346	79	249
20	·327	53	299
30	·202	20	450
40	·116	8·1	65

1 NH_3 (K.).

p %	κ_{18}	$\Lambda = \frac{\kappa}{\eta}$	Temp. coef.
			·0
·1	·00025	4·25	246
1·6	·00087	·93	238
8	·00104	·23	262
30·5	·00019	·012	—

STANDARD SOLUTIONS FOR CALIBRATING CONDUCTIVITY VESSELS

κ_{18} for the **purest water** in a vacuum = $·04 \times 10^{-6}$ ohms^{-1} cm.$^{-1}$ (Kohlrausch and Heydweiller); κ_{18} for **conductivity water** in air is about 10^{-6} ohms^{-1} cm.$^{-1}$; KCl 1 *n* = normal KCl = 74·59 gm./litre at 18° C.; NaCl sat. = saturated NaCl at temp. *t*. of experiment. **Unit**—ohm^{-1} cm.$^{-1}$. (See Kohlrausch, Holborn, and Diesselhorst.)

Solution.	0° C.	8°	12°	16°	20°	24°
NaCl, sat.	·1345	·1688	·1872	·2063	·2260	·2462
KCl, 1 *n*	·06541	·07954	·08689	·09441	·10207	·10984
KCl, 1/10 *n*	·00715	·00888	·00979	·01072	·01167	·01264
KCl, 1/50 *n*	·00152	·00190	·00209	·00229	·00250	·00271
KCl, 1/100 *n*	·00078	·00097	·00107	·001173	·001278	·001386

EQUIVALENT ELECTRIC CONDUCTIVITY Λ OF DILUTE AQUEOUS SOLUTIONS

Extrapolated numbers are indicated by ( ). Λ for infinite dilution is given under "O." Observers: inorganic solutes, Kohlrausch ; organic, Bredig, *Zeit. Phys. Chem.*, 1894.

Solute at 18° C.	Gm. equiv. per litre = 1000η.			
	0	·0001	·01	·5
KCl .	130·1	129·1	122	102
KBr .	132·3	131·1	124	105
KI .	131·0	129·8	123	106
KF .	111·3	110·5	104	83
KSCN	121·3	120·2	114	95·7
KNO_3 .	126·5	125·5	118	89·2
NaCl .	109·0	108·1	102	80·9
NaF .	90·15	89·3	83·5	60·0
$NaNO_3$	105·3	104·5	98·2	74·0
LiCl .	98·9	98·1	99·2	70·7
$AgNO_3$	115·8	115·0	108	77·5
CsCl .	133·6	132·3	125	—
RbCl .	—	132·3	125	—
NH_4Cl	—	129·2	122	101
TlCl .	131·5	130·3	120	—

Solute at 18° C.	Gm. equiv. per litre = 1000η.			
	·0001	·0002	·01	·5
$\frac{1}{2}$ $CaCl_2$.	115·2	114·5	103	74·9
$\frac{1}{2}$ $SrNO_3$.	111·7	111·1	99	62·7
$\frac{1}{2}$ $BaCl_2$.	[117/·0005]		107	77·3
$\frac{1}{2}$ $MgCl_2$.	109·4	108·9	98·1	69·5
$\frac{1}{2}$ $ZnSO_4$.	109·5	107·5	72·8	—
$\frac{1}{2}$ $CdNO_3$.	[100/·005]		96	63·9
$\frac{1}{2}$ $CuSO_4$.	109·9	107·9	71·7	—
$\frac{1}{2}$ PbN_2O_6	120·7	119·9	103	53·2
	·001	·002	·01	·5
Acids.				
HCl . .	(377)	376	370	327
HNO_3 .	(375)	374	368	324
$\frac{1}{2}$ H_2SO_4 .	361	351	308	205
$\frac{1}{3}$ H_3PO_4 .	(106)	102	85	—
Alkalies.				
KOH .	(234)	(233)	228	197
NaOH .	—	204·5	203·4	174
NH_3 . .	53/·0002	38/·0005	9·6	1·35

Solute at 25° C.	Λ_{1024}	Λ_∞
Na formate . . .	98·1	100·4
Na acetate	85·7	87·5
Na propionate . .	81·0	83·5
Na butyrate . . .	77·4	79·9
Na isobutyrate . .	77·7	80·1
Hydrochlorides of—		
-Methylamine . .	125·1	127·8
-Ethylamine . .	114·3	117·0
-Dimethylamine .	117·5	120·3
-Allylamine . . .	109·2	111·7

Solute at 25° C.	Λ_{1024}	Λ_∞
Hydrochloride of—		
-Propylamine . .	107·5	110·3
$(CH_3)_4PCl$	107·4	109·8
$(C_2H_5)_4PCl$ . . .	98·3	100·8
$(CH_3)_4AsCl$ . . .	105·5	108·2
Hydrochlorides of—	Λ_{256}	
-Aniline	100·3	106·1
-Methylaniline . .	99·4	105·2
-o-Toluidine . .	97·4	103·7

EQUIVALENT ELECTRIC CONDUCTIVITY OF NON-AQUEOUS SOLUTIONS

$v = 1/m$ = volume in litres in which 1 gm. equivalent is dissolved. (See Tower, "Conductivity of Liquids," 1908.)

Solvent.	Solute.	t° C.	v	Λ	v	Λ
NH_3	KBr	−38°	5740	317·6	12410	329·7
,,	$AgNO_3$	−15	94	188	192	110
HCN	KI	0	392	298	1024	308
,,	$S(CH_3)_3I$	0	512	327	1024	332
SO_2 .	KI	0	1024	112·5	2048	134·5
,,	$N(C_2H_5)_4I$	0	512	157·1	1024	167·7
$AsCl_3$	$N(C_2H_5)_4I$	25	150	63·2	750	59·7

Solvent.	Solute.	t° C.	v	Λ	v	Λ
$POCl_3$	$N(C_2H_5)_4I$	25°	750	38·5	1500	44·3
Formic acid	KCl	25	256	58	512	61
	HCl	25	5·86	32·8	46·9	33·2
Acetone	KI	18	1157	155	2315	163
,,	LiCl	18	10	49·8	13·8	99·5
,,	$AgNO_3$	18	288	15·7	576	17·6

MOBILITIES OF IONS IN LIQUIDS

The mobility of the anion = $u_- = 1{\cdot}037 \times 10^{-5} \Lambda n$. ($n$ = Hittorf's number.)

Example.—For KCl, $\Lambda_\infty = 130{\cdot}1$, $n = {\cdot}505$, $\therefore u_- = 1{\cdot}037 \times 10^{-5} \times {\cdot}505 \times 130{\cdot}1 = 6{\cdot}8 \times 10^{-4}$ cm./sec. for Cl ions at 18°. Observers, Kohlrausch and Bredig; the latter's values have been multiplied by $1{\cdot}1 \times 10^{-5}$ to bring them to cm./sec. **Unit**—10^{-6} cm./sec. * ½ Ca, etc.: the actual ionic velocity of the divalent ions is half the value stated here; these values, however, fit the equations given on p. 96.

Ion.	u 18°.	Ion.	u 18°.	Ion.	u 18°.	Ion.	u 18°.	Ion.	u 25°.	Ion.	u 25°.
H .	330	NH_4	66·3	Zn* .	48·4	F .	48·3	HCO_2 . .	56·3	$C_2H_5H_3N$	51·5
Li .	34·6	Tl .	68·4	Cu* .	49	Cl .	67·8	CH_3CO_2 .	42·1	$(C_2H_5)_4P$.	33·7
Na .	45·2	Ca* .	53·7	Ag .	56	Br .	70	$C_2H_5CO_2$.	37·7	$C_6H_5H_3N$ aniline	39·5
K .	67	Sr* .	53·6	Cd* .	49·2	I . .	68·8	n. $C_3H_7CO_2$	33·8		
Rb .	70·5	Ba* .	57·5	Pb* .	63·5	NO_3	64	Iso- „	34·0	C_6H_5HN .	48·5
Cs .	70·5	Mg*	47·7	OH .	180	SO_4*	71	CH_3H_3N .	53·4	$(CH_3)_4As$.	41·8

DIRECTLY OBSERVED MOBILITIES

Deduced from the observed movement of an ionic boundary. m = equivalent concentration. **Unit**—10^{-6} cm./sec. at 18° C. (See Denison and Steel, *Phil. Trans.*, 1906.)

Ion.	m	u	Ion.	m	u	Ion.	m	u	Ion.	m	u	Ion.	m	u	Ion.	m	u
K	·5	55·3	Na	1	31·8	Ba	·5	33	Mg	·2	16·7	Cl	·5	52·9	SO_4	·2	30·4

ELECTROMOTIVE FORCES AND RESISTANCES OF CELLS

The E.M.F.'s given are for cells on open circuit, and are only approximate; in the case of primary batteries they refer to freshly made up cells. The internal resistances quoted are only typical; they vary very widely in practice. With many primary cells the E.M.F. drops and the internal resistance increases as the cell ages. Nearly all modern dry cells are modified Leclanché batteries.

(See Slingo and Brooker's "Electrical Engineering.")

Cell.	Description.	E.M.F.	Resistance.
		Volts.	Ohms.
Bichromate . . .	Zn and C in 1 vol. strong H_2SO_4 and 20 vols. sat. $K_2Cr_2O_7$ sol.	c. 2·0	very low
Bunsen	Zn in 1 vol. H_2SO_4 and 12 vols. H_2O; C in strong HNO_3	1·8–1·9	—
Clark (see p. 15) .	Zn amalgam and Hg in sat. $ZnSO_4$ sol.	1·433	c. 500
Daniell	Zn in $ZnSO_4$ sol. or H_2SO_4 (1 to 12); Cu in sat. $CuSO_4$ sol.	1·07–1·08	c. 4
Grove	Like Bunsen with Pt instead of C	1·8–1·9	—
Leclanché . . .	Zn and C in NH_4Cl, C, and MnO_2	c. 1·5	0·25–4
Secondary . . .	Pb and PbO_2 (etc.) in H_2SO_4 of density 1·2	2·2–1·9	negligible
Tucker	"Hygroscopic cell." Zn and C with sat. $CaCl_2$ sol.	1·4	—
Weston (see p. 15)	Cd amalgam and Hg in sat. $CdSO_4$ sol.	1·018	c. 500

MAGNETIC INDUCTION

The **magnetic induction** B and **intensity of magnetization** J, as well as the **magnetizing force** H on which they depend, are vectors, and may be measured in lines per sq. cm., where the unit is so chosen that 4π lines start from unit magnetic pole. In the case of H, 1 line per sq. cm. is called an Oersted, whilst for B it is a Gauss. On division by H, the relation $B = H + 4\pi J$ becomes $\mu = 1 + 4\pi\kappa$, where $\mu (= B/H)$ is the **permeability** and $\kappa (= J/H)$ the **susceptibility** of the material.

On taking a c.c. of the material through a cycle, the energy dissipated as heat (the **hysteresis** loss) is $(4\pi)^{-1}\int H \,.\, dB$, the induction remaining when H vanishes is the **remanence** B_r and the negative magnetizing force needed to reduce B to zero is the **coercive force**. The coercive force for a cycle which proceeds to saturation is called the **coercivity** H_c.

The magnetic properties of a material depend on such factors as history, state of strain, temperature, grain-size, and perfection of the crystals.

As high purity is approached, the properties of iron become very sensitive to the last traces of impurity; less than 0·01% of oxygen or carbon alters the permeability by a factor as large as two. The maximum permeability of iron has increased with each improvement in its preparation, the highest value so far recorded being 280,000. (Cioffi, 1934.)

For materials which are not ferromagnetic, the susceptibility depends very much on the purity, and especially on the freedom from iron. For diamagnetic substances (κ negative), it is in general independent of the temperature and of the field. For paramagnetic substances, Curie's law is $\chi = A/T$ where χ is the mass susceptibility κ/ρ, ρ being the density and T the absolute temperature. Ferromagnetic substances become paramagnetic above their critical temperatures, and then follow the Weiss law $\chi_m = C_m/(T - T_o)$, which also applies more accurately than Curie's law to paramagnetics. In this formula, χ_m refers to one gm. molecule of the substance, and C_m is then known as Curie's constant. (References: Wilson, "Modern Physics"; Stoner, "Magnetism and Atomic Structure"; Spooner, "The Testing and Properties of Magnetic Materials.")

CURIE POINTS OF FERROMAGNETIC MATERIALS

The Curie point is the temperature at which a substance ceases to be ferromagnetic, and becomes paramagnetic. It is approximately equal to the constant T_o in Weiss' law.

Pure Metal.	Curie Point.	Alloy.	Curie Point.
Iron	770° C.	Nickel-iron (Fe 70%, Ni 30%) . .	70° C.
Cobalt	1150	Permalloy (Fe 22%, Ni 78%) . . .	550
Nickel	360	Nickel-copper (Thermalloy, Thermo-perm, etc.)	10 to 70

PROPERTIES OF FERROMAGNETIC MATERIALS

(Since the properties may vary considerably from specimen to specimen, the values below are only to be regarded as typical of the materials mentioned.)

Material.	Induction B (Gauss).							H_c (Oersted).	B_r (Gauss).	Hysteresis loss	
										Joule /kg/ Cycle	at $B_{max.}$
	H=	**0·5**	**1·0**	**2**	**5**	**20**	**50**				
Electrolytic iron (annealed)		7500	10,200	—	16,200	—	17,100	0·35	10,800	0·02	10,000
Very pure iron (99·99%) (Yensen)		14,500	15,100	15,400	—	—	—				
Swedish iron		2000	7000	10,500	13,000	15,200	—	0·9	13,000	0·04	10,000
Armco iron		400	4200	12,000	—	—	—				
	H=	**2·5**	**20**	**50**	**100**	**200**	**500**				
Cast iron (annealed) . .		900	6800	9000	10,500	12,200	14,200	5	5,500		
Cast steel		—	13,800	16,000	17,300	18,900	20,400				
Constructional steels—	H=	**10**	**50**	**100**	**300**						
0·3% C, 1% Ni . .		12,400	16,300	17,700	19,800				10,500		
0·2% C, 5% Ni, 1% Cr		10,000	16,800	18,700	—						
0·4% C, 3% Ni, 1·5% Cr		6500	16,200	17,400	18,900						

PROPERTIES OF FERROMAGNETIC MATERIALS—*contd.*

Material.	Induction B (Gauss).						H_c (Oersted).	B_r (Gauss).	Hysteresis loss.	
									Joule /kg/ Cycle.	at $B_{max.}$
	H= **20**	**50**	**100**	**200**	**500**					
Dynamo steel	15,800	16,500	17,500	19,000	21,000		0·8	11,000	0·04	20,000
Silicon steels—	H= **0·5**	**1·0**	**2·0**	**10**	**50**	**100**				
2·5%	—	5880	10,500	14,000	—	—			0·025	10,000
4·3%	4500	9000	10,000	—	15,300	17,900	0·8	8,000	0·015	10,000
Nickel iron alloys—	H= **0·02**	**0·05**	**0·10**	**0·40**	**1·0**					
Permalloy (22% Fe, 78% Ni)	500	1850	4200	9500	10,300		0·1	8,000	0·002	9,000
Hypernik *—(50% Fe, 50% Ni)	180	1800	5500	10,300	11,300		0·4	8,000	0·01	10,000
(65% Fe, 35% Ni)	—	—	1100	—	2200	7000				
(72% Fe, 28% Ni)	Almost non-magnetic ($\mu \leqslant 1·01$)									
Mumetal (73% Ni, 22% Fe, 5% Cu)	1400	3400	4400	6500	7500	8400	0·03	—	0·001	5,000
Isoperm (Fe with 40 to 50% Ni and Al or Cu)	μ (of the order 60) varies only 10% up to H=200						0·17			
	H= **0·001**	**0·01**	**0·02**	**0·1**	**1·0**	**10**				
1040 alloy	36	800	2600	4900	6000		0·011	3,000	0·0002	5,000
Perminvar (45% Ni, 30% Fe, 25% Co)				2100	8600	11,000	1·8	3,500		
	H= **5**	**20**	**50**	**100**	**500**	**1000**				
Cobalt iron (65% Fe, 35% Co)	15,000	18,000	21,000	23,300	25,200	26,000	0·48	—	0·017	10,000
Annealed carbon steel (1% C)	1800	10,600	—	15,500	19,000	—	7·5	10,000		
Magnet steel (0·9% C)	200	900	—	11,700	16,600	—	65	8000 to 11,000		
Tungsten steel (5 to 6% W, 0·8% C)	—	—	—	—	—	—	60 to 80	9,500 to 11,000		
Chrome steel (2% Cr, 1% C)	—	—	—	—	—	—	65	9,500 to 10,500		
	H= **100**	**500**	**1000**	**2000**						
K.S. steel (35% Co, 7% W, 2% Cr, 0·6% C)	1300	13,000	16,000	18,500			240	10,000		
New K.S. steel (25% Co, 15% Ni, 60% Fe)	—	—	—	—			up to 800	6,000		
M.K. steel (65% Fe, 25% Ni, 10% Al)	—	—	—	—			up to 800	3,000 to 7,000		
	H= **5**	**10**	**20**	**50**	**100**					
Heusler alloy (61% Cu, 27% Mn, 13% Al)	800	2300	3200	3800	4100		7	2,550		
	H= **0·4**	**0·8**	**1·2**	**5**	**100**	**1000**				
Nickel	200	400	600	3500	5400	7000	5·5	2,800	0·07	4,000
Cobalt	—	—	—	500	9500	—	12	3,400	—	—

* Also known as Invariant and Hyperm 50.

STEINMETZ'S COEFFICIENT

Values of η in Steinmetz's formula $\eta B_{max.}^{1·6}$ for the hysteresis loss in ergs per c.c. per cycle. $B_{max.}$ is the maximum value of the induction.

Substance.	η	Substance.	η
3½% Silicon iron (Stalloy)	·0007	Grey cast iron	·013
Good transformer iron	·0011	Nickel	·012 to ·038
Dynamo cast steel	·0026	Cobalt	·012
High carbon steel, hardened	·025		

MAGNETIC SUSCEPTIBILITIES OF ELEMENTS AND COMPOUNDS

(For Elementary gases, the values are per c.c. ; for solids, per gm.)

Gas.	κ	Observer.
Argon	$-0{\cdot}75 \times 10^{-9}$	Hector, 1924
Hydrogen	−0·164	Wills, 1898
Helium	−0·078	Hector, 1924
Nitrogen	−0·49	”
Neon	−0·28	”
Oxygen	139	Soné, 1919
Air	28·7	”

Substance.	χ	Observer.
Silver	$-0{\cdot}20 \times 10^{-6}$	Honda, 1912
Aluminium	0·65	”
Gold	−0·15	”
Bismuth	−1·38	”
Carbon (Diamd.)	−0·49	”
Copper	−0·09	”
Mercury	−0·19	”
Potassium	0·52	”
Platinum	1·10	”
Sulphur	−0·49	”
Tungsten	0·33	”
Water	−0·72	Mean
H_2SO_4	−0·44	Endo, 1925
NH_3 (gas)	−1·1	Pascal, 1908
CO_2 (gas)	−0·42	Soné, 1919
Silica	−0·49	Pascal, 1913
Nitric oxide (gas)	48·7	Soné, 1919

Substance.	χ	Observer.
Cupric chloride (anhydrous)	$9{\cdot}10 \times 10^{-6}$	Ishiwara, '14
Copper sulphate (anhydrous)	8·6	Fetis, 1913
Manganese oxide MnO	76	Honda and Soné, 1913
Manganese dioxide	38	”
Manganese chloride	107	Ishiwara, '14
Ferric hydroxide	157	Meyer, 1899
Ferrous chloride	101	Ishiwara, '14
Ferric chloride	86	”
Nickel oxide	54	Wilson, 1921
Sodium chloride	−0·50	Ishiwara, '14
Cæsium chloride	−0·36	Pascal, 1913
Potassium ferricyanide $K_3Fe(CN)_6$	7·08	Ishiwara, '14
Methane	−2·5	Mean
Ethylene	−1·6	”
Glycerine	−0·54	Meslin, 1906
Ebonite	0·6	Wills, 1898
Glass	−1	—
Paraffin	−0·6	—

TERRESTRIAL MAGNETIC CONSTANTS

Magnetic observatories no longer remain in large cities owing to electric tram disturbances, and thus many of the places for which reliable data exist are not generally known. The general locality of the station is indicated in many cases below.

Magnetic constants obtained in most physical laboratories are usually abnormal owing to the proximity of iron in some form.

Much of the data below is derived from the Reports of Kew Observatory, and the publications of the United States Coast and Geodetic Survey.

A W declination means that the N-seeking end of the magnetic needle points west of true north ; a N inclination means that the same end of the needle points downwards. H and V are the horizontal and vertical components of the earth's magnetic field. The axis of the doublet which best represents the earth's field does not coincide with the line joining the magnetic poles ; it intersects the surface at about 78° 32′ and 69° 08′. See Chree, "Terrestrial Magnetism," Encyc. Brit., 11th edit., 1911 ; and "Studies in Terrestrial Magnetism" (Macmillan). Also the article in Glazebrook's "Dictionary of Applied Physics."

Place.	Latitude.	Longitude.	Year.	Declination.	Inclination.	H.	V.
	° ′	° ′		° ′	° ′	c.g.s.	c.g.s.
North magnetic pole	70 5 N	96 45 W	—	—	90 0 N	0	—
South magnetic pole*	72 25 S	154 E	1908	—	90 0 S	0	—
British Isles—							
Aberdeen (University)	57 9 N	2 7 W	1909	16 34 W	70 39 N	·163	·464
Eskdalemuir (Dumfries)	55 19 N	3 12 W	1920	16 49 W	69 40 N	·1671	·4509
Falmouth (Cornwall)	50 9 N	5 5 W	1912	17 24 W	66 27 N	·1880	·4312
Abinger	51 11 N	0 23 W	1933	11 52 W	66 39 N	·1852	·4290

* Mawson and David (with Shackleton), 1908.

TERRESTRIAL MAGNETIC CONSTANTS (*contd.*)

Place.	Latitude.	Longitude.	Year.	Declination.	Inclination.	H.	V.
	° ′	° ′		° ′	° ′	c.g.s.	c.g.s.
British Isles—*contd.*							
Kew	51 28 N	0 19 W	1918	14 50 W	66 58 N	·1843	·4336
Leeds (University) . .	53 48 N	1 33 W	1909	18 2 W*	68 35 N	·176	·449
St. Helier (Jersey) . .	49 12 N	2 5 W	1907	16 27 W	65 35 N	—	—
Stonyhurst (Lancs.) .	53 51 N	2 28 W	1924	15 05 W	68 42 N	·1728	·4428
Valencia (S. W. Ireland)	51 56 N	10 15 W	1920	19 18 W	68 5 N	·1784	·4435
Africa—							
Cape Town	33 56 S	18 29 E	1885	30 15 W	56 0 S	·199	·295
Helvan (Cairo) . . .	29 52 N	31 21 E	1913	2 17 W	40 48 N	·3003	·2592
Mauritius	20 6 S	57 33 E	1923	10 49 W	52 34 S	·2298	·3002
America—							
Agincourt (Toronto) .	43 47 N	79 16 W	1924	7 06 W	74 44 N	·1575	·5773
Cheltenham (Maryland)	38 44 N	76 50 W	1925	6 39 W	71 00 N	·1887	·5480
Fairhaven (Mass.) . .	41 37 N	70 54 W	1908	12 27 W	73 8 N	·1736	·5724
Goat Island (California)	37 49 N	122 22 W	1909	17 53 E	62 11 N	·2525	·4786
Ithaca (New York) . .	42 27 N	76 28 W	1925	8 59 W	73 37 N	·1640	·5580
Rio de Janeiro . . .	22 55 S	43 11 W	1906	8 55 W	13 57 S	·2477	·0616
Santiago (Chili) . .	33 27 S	70 42 W	1906	14 19 E	30 12 S	—	—
Sitka (Alaska) . . .	57 3 N	135 20 W	1916	30 24 E	74 26 N	·1559	·5597
Waukegan (Chicago) .	42 21 N	87 51 W	1908	2 39 W	72 46 N	·1830	·5898
Asia—							
Alibag (Bombay) . .	18 39 N	72 52 E	1922	0 13 E	25 05 N	·3697	·1730
Barrackpore (Calcutta).	22 46 N	88 22 E	1914	0 32 E	30 59 N	·3740	·2246
Hong Kong	22 18 N	114 10 E	1924	0 24 E	30 43 N	·3729	·2216
Australasia—							
Christchurch (N.Z.) .	43 32 S	172 37 E	1923	17 12 E	68 12 S	·2221	·5553
Honolulu (Hawaii) . .	21 19 N	158 4 W	1925	10 02 E	39 26 N	·2871	·2361
Melbourne	37 50 S	144 58 E	1916	8 7 E	67 49 S	·2300	·5640
Sydney	33 52 S	151 12 E	1885	9 30 E	62 30 S	·268	·515
Europe—							
Arctic Regions (Norway) .	69 56 N	22 58 E	1903	0 43 W	76 21 N	·1258	·5178
Arctic Regions (Spitzbergen)	77 41 N	14 50 E	1903	10 55 W	80 8 N	·0942	·5417
Odessa	46 26 N	30 46 E	1910	3 36 W	62 27 N	·2171	·4161
Pawlowsk (Petrograd) .	59 41 N	30 29 E	1924	3 16 E	71 08 N	·1582	·4629
Potsdam	52 23 N	13 4 E	1923	6 57 W	66 36 N	·1856	·4292
Rude Skov (Copenhagen)	55 51 N	12 27 E	1921	7 45 W	69 07 N	·1710	·4482
Uccle (Brussels) . .	50 48 N	4 21 E	1916	12 28 W	66 3 N	·1897	·4270
Val Joyeux (Paris) . .	48 49 N	2 1 E	1922	12 31 W	64 40 N	·1966	·4152

* 1907.

SECULAR CHANGES AT GREENWICH †

Year.	Decln.	Incln.	Year.	Decln.	Incln.	H.
	° ′	° ′		° ′	° ′	
1580	11 17 E	72 0 N	1875	19 21 W	67 42 N	0·1797
1660	0 0	73 15 N	1907	16 0 W	66 56 N	0·1855*
1720	13 0 W	74 40 N*	1919	14 18 W	66 53 N	0·1845
1815	24 27 W*	70 30 N	1925	13 10 W	66 51 N	0·1841
1851	22 18 W	68 40 N	1925†	13 23 W	66 35 N	0·1860
			1933†	11 52 W	66 39 N	0·1852

* Maximum. † Replaced since 1925 by Abinger Magnetic Station, near Dorking, Surrey (51° 11′ 5″ N, 0° 23′ 12″ W).

SPARKING POTENTIALS

The work of Peek and others has shown that a spark gap between spherical electrodes of equal size is a convenient means of measuring high voltages. The spark between points is now generally discredited for high voltages on account of its inconsistent dependency on atmospheric humidity and frequency of discharge. By reason of its time-lag, its readings may be 300 or 400 per cent. in error, in the case of high frequency steep impulses.

On the other hand, frequency and wave shape have no appreciable effect in the case of the sphere gap, and the effects of variation in the atmospheric conditions are well known, and can be readily corrected for.

The size of the spheres is important. A good rule is not to use a gap bigger than the diameter of either of the balls, though some latitude may be permitted in this direction. The main point is to avoid the break-down discharge being preceded by brush-discharge or corona, otherwise a pulsating discharge will, in general, give gap readings much too high.

With the above precaution, a sphere gap is capable of measuring (peak) voltages from say, 10,000 volts to 500,000 to an accuracy of about 2 per cent.

The table below is based on Dr. A. Russell's formula, and incorporates the latest results of the American Institute of Electrical Engineers (1918). It includes also for convenience a column of figures for a needle point gap (No. 00 new sewing needles), which furnish a rough notion of the voltages for an instrument which is still much used. The A.I.E.E. recommend that for voltages above 70,000 (and preferably above 40,000) a sphere gap should always be employed.

The gap should not be exposed to any extraneous ionizing influence, such as an arc or an adjacent spark, nor should the gap be enclosed. The first spark is the one for which the reading should be taken.

SPARK-GAP VOLTAGES AT 760mm. PRESSURE AND 25° C.

Where any gap is being used outside its recommended limits, the figures are shown in brackets. The blank spaces indicate that the gap is no longer suitable. The gaps are given to 3 significant figures for interpolation purposes.

TABLE A.

Kilo Volts (peak).	**DIAMETER OF SPHERES.**						
	Needle Points		**2·5 cms.**	**5 cms.**	**10 cms.**	**25 cms.**	**50 cms.**
	cms. gap.	inches. gap.	cms. gap.	cms. gap.	cms. gap.	cms. gap.	cms. gap.
5	(0·42)	(0·17)	(0·13)	(0·15)	(0·15)	(0·16)	(0·17)
10	(0·85)	(0·33)	0·27	0·29	0·30	0·32	0·33
15	1·30	0·51	0·42	0·44	0·46	0·48	0·50
20	1·75	0·69	0·58	0·60	0·62	0·64	0·67
25	2·20	0·87	0·76	0·77	0·78	0·81	0·84
30	2·69	1·06	0·95	0·94	0·95	0·98	1·01
35	3·20	1·26	1·17	1·12	1·12	1·15	1·18
40	3·81	1·50	1·41	1·30	1·29	1·32	1·35
45	4·49	1·77	1·68	1·50	1·47	1·49	1·52
50	5·20	2·05	2·00	1·71	1·65	1·66	1·69
60	6·81	2·68	2·82	2·17	2·02	2·01	2·04
70	8·81	3·47	(4·05)	2·68	2·42	2·37	2·39
80	(11·1)	(4·36)	—	3·26	2·84	2·74	2·75
90	(13·3)	(5·23)	—	3·94	3·28	3·11	3·10
100	(15·5)	(6·10)	—	4·77	3·75	3·49	3·46
110	(17·7)	(6·96)	—	5·79	4·25	3·88	3·83
120	(19·8)	(7·81)	—	(7·07)	4·78	4·28	4·20
130	(22·0)	(8·65)	—	—	5·35	4·69	4·57
(contd.)							

Kilo Volts (peak).	DIAMETER OF SPHERES.						
	Needle Points.		2·5 cms.	5 cms.	10 cms.	25 cms.	50 cms.
(contd.)	cms. gap.	inches. gap.	cms. gap.	cms. gap.	cms. gap.	cms. gap.	cms. gap.
140	(24·1)	(9·48)	—	—	5·97	5·10	4·94
150	(26·1)	(10·3)	—	—	6·64	5·52	5·32
160	(28·1)	(11·1)	—	—	7·37	5·95	5·70
170	(30·1)	(11·9)	—	—	8·16	6·39	6·09
180	(32·0)	(12·6)	—	—	9·03	6·84	6·48
190	(33·9)	(13·3)	—	—	10·0	7·30	6·88
200	(35·7)	(14·0)	—	—	11·1	7·76	7·28
210	(37·6)	(14·8)	—	—	(12·3)	8·24	7·68
220	(39·5)	(15·5)	—	—	(13·7)	8·73	8·09
230	(41·4)	(16·3)	—	—	(15·3)	9·24	8·50
240	(43·3)	(17·0)	—	—	—	9·76	8·92
250	(45·2)	(17·8)	—	—	—	10·3	9·34

AIR-DENSITY CORRECTION TO SPARKING POTENTIALS

Applicable only to sphere gaps. The following table gives the relative air density under different conditions. The figures are relative to dry air at 25° C. and 760 mm. pressure :

Temp.	Press. 720mm.	Press. 740mm.	Press. 760mm.	Press. 780mm.
0° C.	1·04	1·06	1·09	1·12
10	1·00	1·02	1·05	1·08
20	0·96	0·99	1·02	1·04
30	0·93	0·96	0·98	1·01

Within the limits of the above table, the correction factor for a sphere gap agrees substantially with the relative air density and so is small for normal conditions. Thus for a given length of spark gap, the tabulated kilovoltage in Table A must be multiplied by the appropriate correction factor.

THE RÖNTGEN

The röntgen (*r*) is the quantity of X or gamma radiation such that the associated corpuscular emission per 0·001293 gramme of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign (0·001293 gramme is the mass of 1 c.c. of dry atmospheric air at 0° C. and 76 cm. of mercury pressure).

LATTICE CONSTANTS OF CRYSTALS

A crystal may be considered as a lattice generated by the continued repetition in three dimensions of a unit cell which in general contains only a small number of atoms or molecules. The crystal belongs to one or other of the seven classes—cubic, tetragonal, hexagonal, rhombohedral, orthorhombic, monoclinic or triclinic—according as one or more of the ratios between the sides is unity or not, and the angles are or are not right angles. A crystal face is denoted by a triad of integers (h, k, l), and is parallel to planes making intercepts a/h, b/k, c/l, on the three sides a, b, c of the unit cell. The distance d between successive members of the family of planes (h, k, l) is given for the triclinic crystal by the formula

$$\frac{1}{d^2} = \frac{\Sigma(h^2 . b^2c^2 \sin^2 \alpha) + 2\Sigma[kl . bca^2(\cos\beta \cos\gamma - \cos\alpha)]}{[a^2b^2c^2(1 - \cos^2\alpha - \cos^2\beta - \cos^2\gamma + 2\cos\alpha\cos\beta\cos\gamma]}$$

where a, b, c ; α, β, γ are the sides and angles of the unit parallelopiped.

Among important values of *d* are 2·8140 × 10^{-8} cm. for the (200) planes of rock-salt and 3·02904 × 10^{-8} cm. for the cleavage face of calcite. Since comparative measurements of X-ray wave-lengths can be made with higher precision than that reached in determining *d*, a new unit of length, the X unit (approx. 10^{-11} cm.) has been defined, such that *d* for calcite is exactly 3029·04 X.U. (See W. H. and W. L. Bragg, "The Crystalline State" (Bell).)

CHARACTERISTIC X-RAY SPECTRA

The characteristic line spectrum of an element consists of several groups—the K series, containing in general 5 main lines, the L series with at least 16 lines associated in three groups, the still more complicated M series, and finally the N and O series, which only occur in elements of high atomic number. The wave-lengths of a number of lines are given below in X.U., and are mainly due to Siegbahn. (See his book, "The Spectroscopy of X-rays.")

K AND L SERIES

At. No.	Element.	K series.			L series.			
		α_2	α_1	β_1	α_1	α_2	β_1	γ_1
11	Na	11885		11594	—		—	—
12	Mg	9869·0		9539	—		—	—
13	Al	8320·5		7965	—		—	—
14	Si	7109·8	7112·4	6754·5	—		—	—
15	P	6142·5		5792·1	—		—	—
16	S	5361·3	5361·3	5021·1	—		—	—
17	Cl	4721·2	4718·2	4394·2	—		—	—
19	K	3737·1	3733·68	3446·8	—		—	—
20	Ca	3354·95	3351·69	3083·4	—		—	—
21	Si	3028·40	3025·03	2773·9	—		—	—
22	Ti	2746·81	2743·17	2509·0	—		—	—
23	V	2502·13	2498·35	2279·7	24200		—	—
24	Cr	2288·91	2285·03	2080·6	21530		21190	—
25	Mn	2101·49	2097·51	1906·20	19390		19040	—
26	Fe	1936·012	1932·076	1753·013	17580		17220	—
27	Co	1789·19	1785·29	1617·44	15940		15620	—
28	Ni	1658·35	1654·50	1497·05	14530		14240	—
29	Cu	1541·232	1537·395	1389·35	13306		13030	—
30	Zn	1436·03	1432·17	1292·55	12230		11960	—
31	Ga	1340·87	1337·15	1205·20	11270		11010	—
32	Ge	1255·21	1251·30	1126·71	10415		10153	—
33	As	1177·43	1173·44	1055·10	9652		9395	—
34	Se	1106·52	1102·48	990·13	8972		8718	—
35	Br	1041·66	1037·59	930·87	8358		8109	—
36	Kr	978		875	—		—	—
37	Rb	927·76	923·64	826·96	—		—	—
38	Sr	877·61	873·45	781·30	6848·6		6610·0	—
39	Y	831·32	827·12	739·19	6435·7		6203·9	—
40	Zr	788·51	784·30	700·28	6056·7		5823·6	5373·8
41	Nb	748·89	744·65	664·38	5712·0	5718	5480·3	5024·8
42	Mo	712·805	707·831	630·978	5395·0	5401	5166·5	—
44	Ru	646·06	641·74	571·31	4835·7	4843·7	4611·0	4172·8
45	Rh	616·37	612·02	544·49	4587·8	4595·6	4364·0	3935·7
46	Pd	588·63	584·27	519·47	4358·5	4366·6	4137·3	3716·4
47	Ag	562·67	558·28	496·01	4145·6	4153·8	3926·6	3514·9
48	Cd	538·32	533·90	474·08	3947·8	3956·4	3730·1	3328·0

K AND L SERIES (*contd.*)

At. No.	Element.	K series.			L series.			
		α_2	α_1	β_1	α_1	α_2	β_1	γ_1
49	In	515·48	511·06	453·58	3763·7	3772·4	3547·8	3155·3
50	Sn	494·02	489·57	434·30	3592·2	3601·1	3377·9	2994·9
51	Sb	473·87	469·31	—	3431·8	3440·8	3218·4	2845·1
52	Te	454·91	450·37	—	3282·0	3291·0	3070·0	2706·5
53	I	457·03	432·49	383·15	3141·7	3150·7	2930·9	2577·5
54	Xe	417		360	—	—	—	—
55	Cs	404·11	399·59	353·62	2886·1	2895·6	2677·8	2342·5
56	Ba	388·99	384·43	340·22	2769·6	2779·0	2562·2	2236·6
57	La	374·66	370·04	327·26	2659·7	2668·9	2453·3	2137·2
58	Ce	361·10	356·47	315·01	2556·0	2565·1	2351·0	2044·3
59	Pr	348·05	343·40	303·60	2457·7	2467·6	2253·9	1956·8
60	Nd	335·95	331·25	292·75	2365·3	2375·6	2162·2	1873·8
62	Sa	313·02	308·33	272·50	2195·0	2205·7	1993·6	1723·1
63	Eu	302·65	297·90	263·07	2116·3	2127·3	1916·3	1654·3
64	Gd	292·61	287·82	253·94	2041·9	2052·6	1842·5	1588·6
65	Tb	282·86	278·20	245·51	1971·5	1982·3	1772·7	1526·6
66	Dy	273·75	269·03	237·10	1904·6	1915·6	1706·6	1469·7
67	Ho	264·99	260·30	—	1841·0	1852·1	1643·5	1414·2
68	Er	256·64	251·97	222·15	1780·4	1791·4	1583·4	1362·3
69	Tm	248·61	243·87	214·87	1722·8	1733·9	1526·8	1312·7
70	Yb	240·98	236·28	208·34	1667·8	1678·9	1472·5	1264·8
71	Lu	233·58	228·82	201·71	1615·51	1626·36	1420·7	1220·3
72	Hf	226·53	221·73	195·15	1566·07	1577·04	1371·1	1176·5
73	Ta	219·73	214·88	189·9	1518·85	1529·78	1324·23	1135·58
74	W	213·45	208·62	184·2	1473·36	1484·38	1279·17	1096·30
75	Re	—	—	—	1429·97	1441·0	1236·03	1058·7
76	Os	210·31	196·45	173·6	1388·59	1398·66	1194·90	1022·96
77	Ir	195·50	190·65	168·5	1348·47	1359·8	1155·40	988·76
78	Pt	190·04	182·23	163·70	1310·33	1321·55	1117·58	955·99
79	Au	184·83	179·96	159·02	1273·77	1285·02	1081·28	924·61
80	Hg	—	—	—	1238·63	1249·51	1046·52	894·6
81	Tl	174·66	169·80	150·11	1204·93	1216·26	1042·99	865·71
82	Pb	170·04	165·16	146·06	1172·58	1184·08	980·83	838·01
83	Bi	165·25	160·41	142·05	1141·50	1153·01	950·02	811·43
90	Th	136·8	132·3	116·9	954·05	965·85	763·56	651·76
91	Pa	—	—	—	930·9	942·7	740·7	632·5
92	U	130·95	126·40	111·87	908·74	920·62	718·51	613·59

X-RAY ABSORPTION SPECTRA

The absorption of a beam of X-rays by any substance varies in a complex manner with the wave-length or frequency, and in particular, a number of discontinuities characteristic of the chemical elements are found. One of these occurs at a wave-length very slightly less than that of the Kβ_2 emission line, and is known as the K absorption edge. X-rays of shorter wave-length than the absorption edge are strongly absorbed, whilst for those of longer wave-length, the absorption is only slight. Similarly, associated with the L emission spectrum, is a group of three L absorption edges, and with the M series, a group of five edges. The fact that the absorption suddenly increases on the higher frequency side of the edge, is in harmony with the explanation that the edges mark the points at which the quantum energy of the rays is just sufficient to remove an electron from the K, L, or M shell as the case may be.

K ABSORPTION EDGE

At. No.	El.	λ(X.U.).	At. No.	El.	λ(X.U.).	At. No.	El.	λ(X.U.).	At. No.	El.	λ(X.U.).
12	Mg	9496·2	29	Cu	1377·4	48	Cd	463·13	67	Ho	222·64
13	Al	7935·6	30	Zn	1280·5	49	In	442·98	69	Tm	208·5
14	Si	6731·0	31	Ga	1190·2	50	Sn	423·94	70	Yb	201·6
15	P	5774·9	32	Ge	1114·6	51	Sb	406·09	71	Lu	195·1
16	S	5008·8	33	As	1042·63	52	Te	389·26	72	Hf	190·1
17	Cl	4383·8	34	Se	977·73	53	I	373·44	73	Ta	183·6
18	A	3865·7	35	Br	918·09	55	Cs	344·04	74	W	178·22
19	K	3431·0	37	Rb	814·10	56	Ba	330·70	75	Re	173·5
20	Ca	3064·3	38	Sr	768·37	57	La	318·14	76	Os	167·55
21	Sc	2751·7	39	Y	725·5	58	Ce	306·26	77	Ir	162·09
22	Ti	2491·2	40	Zr	687·38	59	Pr	295·1	78	Pt	157·70
23	Va	2263·0	41	Nb	651·58	60	Nd	284·58	79	Au	153·20
24	Cr	2065·9	42	Mo	618·48	62	Sa	264·4	80	Hg	148·93
25	Mn	1891·6	44	Ru	558·4	63	Eu	254·8	81	Tl	144·41
26	Fe	1739·4	45	Rh	533·03	64	Gd	246·2	82	Pb	140·49
27	Co	1604·0	46	Pd	507·95	65	Tb	237·6	83	Bi	136·78
28	Ni	1483·9	47	Ag	484·48	66	Dy	230·1	90	Th	112·70
									92	U	(106·58)

L ABSORPTION EDGES

At. No.	El.	L_{I}.	L_{II}.	L_{III}.	Observer.	At. No.	El.	L_{I}.	L_{II}.	L_{III}.	Observer.
37	Rb	5985	—	6841	C.M.	63	Eu	1533	1623	1772	N.
38	Sr	5571	6162	6362	C.M.	64	Gd	—	1559	1706	C.N.W.
39	Y	5222	5737	5944	C.M.	65	Tb	1418	1498	1645	N.
40	Zr	4857	5366	5561	C.M.	66	Dy	1365	1441	1587	C.N.W.
41	Nb	4572	—	5212	C.M.	67	Ho	1315	1387	1532	N.
42	Mo	4290	4712	4904	C.M.	68	Er	1266	1335	1480	C.N.W.
44	Ru	—	4165	4358	C.M.	69	Tm	1220	1285	1430	C.N.W.
45	Rh	3621	3932	4118	C.M.	70	Yb	1176	1238	1383	E.
46	Pd	3421	3715	3901	D.L.	71	Lu	1136	1194	1338	E.
47	Ag	3245	3506	3693	C.M.	72	Hf	1097	1152	1293	C.
48	Cd	3071	3322	3495	C.M.	73	Ta	1057	1110	1252	N.
49	In	2919	3140	3316	D.L.	74	W	1022	1072	1212	Cr.
50	Sn	2770	2972	3149	D.L.	75	Re	987	1034	1174	B.
51	Sb	2632	2822	2991	C.L.	76	Os	952	998	1138	Ck.
52	Te	2504	2679	2846	C.L.	77	Ir	920	965	1104	Ck.
53	I	2384	2548	2714	C.L.	78	Pt	891	932	1071	S.
54	Xe	2272	2425	2587	L.D.	79	Au	862	901	1038	S.
55	Cs	2160	2307	2468	L.	80	Hg	834	870	1007	D.P.
56	Ba	2062	2199	2357	N.	81	Tl	806	842	978	D.P.
57	La	1969	2099	2254	C.N.W.	82	Pb	781	813	949	D.Sh.
58	Ce	1886	2007	2160	C.N.W.	83	Bi	756	788	922	S.
59	Pr	1807	1920	2073	N.	88	Ra	—	670	802	B.
60	Nd	1732	1839	1991	N.	90	Th	605	629	760	D.P.
62	Sm	1595	1699	1841	N.	92	U	569	592	722	D.P.

B., de Broglie, 1919 ; C., Coster, 1922 ; Ck., Cork, 1923 ; C.L., Chamberlain and Lindsay, 1927 ; C.M., Coster and Mulder, 1926 ; C.N.W., Costa, Nishina, and Werner, 1923 ; Cr., Crofutt, 1926 ; D.L., van Dyke and Lindsay, 1927 ; D.P., Duane and Patterson, 1920 ; D.Sh., Duane and Shimizu, 1919 ; E., Eddy, 1925 ; L., Lindsay, 1922 ; L.D., Lepape and Deauvillier, 1923 ; N., Nishina, 1925 ; S., Sandström, 1930.

COEFFICIENTS OF RECOMBINATION α

α is given below in terms of 1000e, where e is the numerical value of the ionic charge: $4·7 \times 10^{-10}$ in electrostatic units. For air, $\alpha = 3320e = 1·56 \times 10^{-6}$ cm.^{3} sec^{-1}. Room temp. and pressure.

Gas.	Air.	O_2	CO_2	H_2
α	3·42, T.; 3·38, Mc.; 3·2, L.; 3·3, H.; 3·32 *, E.	3·38, T.	3·5, T.	3·02, T ; 2·94, Mc.

E., Erikson, *P.M.*, 1909; H., Hendren, *P.R.*, 1905; L., Langevin, *A.C.P.*, 1902; Mc., McClung, *P.M.*, 1902; T., Townsend, *P.T.*, 1899. * 17° C., 760 mm. Hg.

α IN AIR AND PRESSURE

Press. in atmos. . . .	·2	·5	1	2	3	5	L., Langevin, '02. H., Hendren, '05. T., Thirkill, '13.
α (relative values), L. .	0·21 T.	0·51 T.	1·00 L.	1·11 L.	0·97 L.	0·67 L.	

Press. in cms.	76	45	25	15	10	5	3·5	2	1
α (absolute values), H. .	3·3	2·65	2·07	1·75	1·55	1·31	1·25	1·15	1·00

α IN AIR AND TEMPERATURE

Air at constant density. (E., Erikson ; P., Phillips, *Electrician*, 1909.)

Temp. ° C.	−179°	−68	12	64	100	155	Temp. ° C.	15°	100	155	176
α (in terms 1000e), E.	7·5	5·64	3·47	2·31	1·73	1·38	α (relative values), P.	1	·50	·40	·36

IONIC COEFFICIENTS OF DIFFUSION D

Rate of interdiffusion (in cm.^{2} sec^{-1}) of gaseous ions in dry air: D+ for positive, D− for negative ions. (Townsend, *Phil. Trans.*, 1899, 1900.)

Ionization	Röntgen Rays.	β and γ Rays.	Ultra-violet light.	Point discharge.
D+ at 76 cm.	·028	·032	—	·0247, ·0216
D− at 76 cm.	·043	·043	·043	·037, ·032

GASES IONIZED BY RÖNTGEN RAYS

Air, CO_2, and hydrogen at 15° C. and 760 mm.

Dry Gas.	D+	D−	Dry Gas.	D+	D−	Moist Gas.	D+	D−	Moist Gas.	D+	D−
Air (dried by $CaCl_2$)	·028	·043	CO_2 (dried by $CaCl_2$)	·023	·026	Air (sat. with H_2O)	·032	·035	CO_2 (sat. with H_2O)	·024	·025
O_2 (dried by $CaCl_2$)	·025	·04	H_2 (dried by $CaCl_2$)	·123	·19	O_2 (sat. with H_2O)	·029	·036	H_2 (sat. with H_2O)	·128	·142

AIR IONIZED BY β AND γ RAYS

Press. p. in cms.	77·2	55	40	30	20	Press. p. in cms.	77·2	55	40	30	20
D+ at 15° C.	·0317	·042	·0578	·078	·118	D− at 15° C.	·0429	·0542	·078	·103	1·55
pD+ ,,	2·45	2·31	2·31	2·34	2·36	pD− ,,	3·3	2·98	3·12	3·09	3·1

A.C.P., Ann. de Chim. et de Phys.; P.M., Phil. Mag.; P.R., Physical Review; P.T., Phil. Trans.

MOBILITIES OF IONS IN GASES

Velocities of ions are in cm. per sec. for unit field, or in cm.^{2} sec.$^{-1}$ volt^{-1} at temp. and press. of room. K_+ = mobility of positive ion, K_- of negative.

For **moist air** (*i.e.* saturated with H_2O), $K_+ = 1·37$, $K_- = 1·51$.

For **dry air** (dried by $CaCl_2$), $K_+ = 1·36$, $K_- = 1·87$. (Zeleny (air blast method), *Phil. Trans.*, 1900.)

For mobilities of natural ions in air, see p. 119. * Mean = $(K_+ + K_-)/2$.

Dry Gas.	K_+ 76 cm. Hg	K_- 76 cm. Hg	Ionization and Observer.
Air.	1·32	1·80	Point disch., Chattock, *P.M.*, 1899, 1901.
,, .	1·23	1·93	X-rays, Wellisch, 1915.
,, .	1·40	1·70	,, Langevin, *A.C.P.*, 1903.
,, .	1·39	1·78	,, Phillips, *P.R.S.*, 1906.
,, .	1·36	1·87	,, Zeleny, *Phil. Trans.*, 1900.
H_2 .	5·4	7·43	Point disch., Chattock.
,, .	6·7	7·9	X-rays, Zeleny, 1900.
,, .	5·9	8·3	,, Rothgieser, '13.
He .	5·09	6·31	,, Franck and Pohl, *V.D.P.G.*, '07.
N_2 .	1·6*	—	X-rays, Rutherford, *P.M.*, 1897.
O_2 .	1·36	1·80	,, Zeleny, 1900.
,, .	1·3	1·85	Point disch., Chattock.
CO.	1·1	1·14	X-rays, Wellisch, '09.
CO_2	0·83	0·92	Point disch., Chattock.

Dry Gas.	K_+ 76 cm. Hg	K_- 76 cm. Hg	Ionization and Observer.
CO_2 . . .	0·76	0·81	X-rays, Zeleny, 1900.
,, ...	0·84	1·05	,, Lattey & Tizard, '13.
,, ...			
HCl . . .	1·27*		,, Rutherford.
SO_2 . . .	0·44	0·41	,, Wellisch, '09.
Cl_2	1·0*		,, Rutherford.
N_2O . . .	0·82	0·90	,, Wellisch, '09.
NH_3 . . .	0·74	0·80	,, ,,
Me. acetate .	0·33	0·36	,, ,,
Me. bromide	0·29	0·28	,, ,,
Me. iodide .	0·21	0·22	,, ,,
Et. alcohol .	0·34	0·27	,, ,,
Et. acetate .	0·31	0·28	,, ,,
Et. aldehyde	0·31	0·30	,, ,,
Et. chloride .	0·33	0·31	,, ,,
Et. ether . .	0·29	0·31	,, ,,
Et. formate .	0·30	0·31	,, ,,
Et. iodide .	0·17	0·16	,, ,,
$C.Cl_4$ . . .	0·30	0·31	,, ,,
Pentane . .	0·36	0·35	,, ,,
Acetone . .	0·31	0·29	,, ,,

IONIC MOBILITY AND PRESSURE

Air ionized by Röntgen rays. (Langevin, *A.C.P.*, 1903.)

Press. cm.	7·5	20	41·5	76	143·5	Press. cm.	7·5	20	41·5	76	142
K_+	14·8	5·45	2·61	1·40	0·75	K_-	21·9	7·35	3·31	1·7	0·9

IONIC MOBILITY AND TEMPERATURE

Air at 76 cm. press. ionized by Röntgen rays. (Phillips, *P.R.S.*, 1906.)

Temp. ° C.	138°	126°	110°	100°	75°	60°	12°	−64°	−179°
K_+	2·00	1·95	1·85	1·81	1·67	1·60	1·39	0·945	0·235
K_-	2·49	2·40	2·30	2·21	2·12	2·00	1·785	1·23	0·235

IONIC MOBILITIES IN LIQUIDS AND SOLIDS

Ionized by radium rays. (Bohm-Wendt and v. Schweidler, *Phys. Zeit.*, 1909; Bialobjeski, *Compt. Rend.*, 1909.)

Substance.	$(K_+ + K_-)$	Substance.	$(K_+ + K_-)$
Petroleum ether	$3·8 \times 10^{-4}$	Ozokerite at 100° . . .	$5·1 \times 10^{-4}$
Vaseline	$5·3 \times 10^{-6}$	,, ,, 80° . . .	$35·0 \times 10^{-4}$

A.C.P., Ann. de Chim. et de Phys., *P.M.*, *Phil. Mag.*; *P.R.S.*, *Proc. Roy. Soc.*; *V.D.P.G.*, *Verh. Deutsch. Phys. Gesell.*

IONIC MOBILITIES AT HIGH TEMPS

K in cm. sec.$^{-1}$ per volt cm.$^{-1}$ for coal-gas flames in most instances. The ionic mobility is independent of the acid of the salt. Gold's and Wilson's values for K_- agree the best with existing theory, which makes $K_- = Xe\lambda/mu = 17{,}000$ at 1800° C. (Gold). X is the electric field per cm., λ is the mean free path, and u the velocity of the corpuscle.

Salt.	Temp.	K_+	K_-	Observer.
Cs, Rb, K, Na, Li . .	Flame, *c.* 2000° C.	62	*c.* 1000	H. A. Wilson, *P.T.*, 1899
1/20 normal KCl . .	Flame	260	1400	Marx. *Ann. der Phys.*, 1900
NaCl	”	340	1800	
1/256 normal K salt .	Flame, *c.* 2000°	—	1320	Moreau, *Journ. de Phys.*, 1903
1/16 normal Na salt .	” ”	—	1280	
Concentrated sols. of alkalies	” ”	80	—	
Cs, Rb, K, Na, Li . .	Air at 1000°	7·2	26	H. A. Wilson, *P.T.*, 1899 and *P.M.*, 1906
Ba, Sr, Ca	” ”	3·8	—	
K, Na	Flame, *c.* 1800°	—	8000	Gold, *P.R.S.*, 1907, ratio of potential grad. to current
K.	Flame, *c.* 1800°	—	13,000	Poten. grad., and gas velocity
K_2CO_3	Bunsen burner	—	9600	H. A. Wilson, *P.R.S.*, 1909
Na	Flame, *c.* 2000°	—	1170	Moreau, *C.R.*, 1909

CONDENSATION OF VAPOURS

Expansion $= v_2/v_1$, where v_1 is the volume of the gas before, and v_2 the volume after expansion. **Supersaturation** of the vapour (at end of cooling by expansion) necessary for condensation = S = (density of vapour when drops are formed)/(density of saturated vapour at the same temp.). (See J. J. Thomson, "Conduction of Electricity through Gases.")

CONDENSATION ON NATURAL IONS AND MOLECULES

Dust-free gas saturated with water-vapour. (C. T. R. Wilson, *P.T.*, '97, '99, '00.)

Gas.	Rain-like Condensation.		Cloud-like Condensation.		Gas.	Rain-like Condensation.		Cloud-like Condensation.	
	v_2/v_1	S.	v_2/v_1	S.		v_2/v_1	S.	v_2/v_1	S.
Air . .	1·252	4·2	1·38	7·9	CO_2 . .	1·365	4·2	1·535	7·3
O_2 . .	1·257	4·3	1·38	7·9	Cl_2 . .	1·3	3·4	1·45	5·9
N_2 . .	1·262	4·4	1·38	7·9	H_2 . .	—	—	1·38	7·9

CONDENSATION IN AIR IONIZED BY RÖNTGEN AND RADIUM RAYS

(L., Laby, *Phil. Trans.*, 1908; P., Przibram, *Wien Ber.*, 1906.)

Vapour and Observer.	Ion.	v_2/v_1	S.	Vapour and Observer.	Ion.	v_2/v_1	S.
Water (C. T. R. Wilson)	−	1·25	4·15	n-Butyric acid, L. . . .	?	1·38	15·0
Water (C. T. R. Wilson)	+	1·31	5·8	iso-Butyric acid, L. . .	?	1·36	13·3
Et. acetate, L.	+	1·48	8·9	iso-Valeric acid, L. . .	?	1·22	6·0
Me. butyrate, L. . . .	+	1·33	5·3	Methyl alcohol, P. . .	+	1·25	3·1
Me. iso-butyrate, L. . .	?	1·35	5·2	Ethyl alcohol, P. . . .	+	1·17	2·3
Propyl acetate, L. . . .	+	1·31	5·0	Propyl alcohol, P. . . .	?	1·18	3·0
Et. propionate, L. . . .	?	1·41	7·8	iso-Butyl alcohol, P. . .	?	1·2	3·6
Formic acid, L. . . .	?	1·78	25·1	iso-Amyl alcohol, P. . .	+	1·22	5·5
Acetic acid, L.	+	1·44	9·3	” ” L. . .	+	1·18	4·1
Propionic acid, L. . . .	?	1·34	9·4	Chloroform, P.	+	1·54	3·0

A.C.P., Ann. de Chim. et de Phys.; C.R., Compt. Rend.; P.M., Phil. Mag.; P.R.S., Proc. Roy. Soc.; P.T., Phil. Trans.

THE FARADAY

The faraday, F, is the charge carried by 1 gm. molecule (mole) of electrolytic ions: F = NE, where N is the number of molecules per gm. molecule and E is the charge carried by an ion. For a monovalent ion $E = e$, where e is the electronic charge, and for a bivalent ion $E = 2e$. $F = 2{\cdot}89224 \pm {\cdot}0003 \times 10^{14}$ e.s.u. mole^{-1} = 96494 int. coulomb mole^{-1} = 9648·0 e.m.u. mole^{-1}.

Antecedent data:—1 int. coulomb deposits ·00111800 gm. Ag. At.Wt.Ag = 107·880.

Ne FOR GASEOUS IONS

N is the number of molecules per c.c. of **air** at room temp. and 76 cm. Hg; e is the ionic charge in E.S.U., e_- for negative and e_+ for positive ions.

Ionization.	Ne_-	Ne_+	Observer.
X rays . .	$1{\cdot}23 \times 10^{10}$	$2{\cdot}41 \times 10^{10}$	Townsend, *P.R.S.*, 1908, 1909.
Ra rays . .	$1{\cdot}24 \times 10^{10}$	$1{\cdot}26$ to $1{\cdot}37 \times 10^{10}$	Haselfoot, *P.R.S.*, 1909.

Ne CALCULATED

In E.S.U., $Ne = 3{\cdot}04 \times 10^8 \times K/D = 3{\cdot}04 \times 10^8 \times 1{\cdot}40/0{\cdot}028 = 1{\cdot}52 \times 10^{10}$ for positive air ions at 76 cm. and room temp. For D and K, see pp. 109, 110.

Gas.	Ne_+	Ne_-	Gas.	Ne_+	Ne_-		Ne_+	Ne_-
Air	$1{\cdot}52 . 10^{10}$	$1{\cdot}26 . 10^{10}$	H_2 .	$1{\cdot}50 . 10^{10}$	$1{\cdot}23 . 10^{10}$	Mean	$1{\cdot}42 . 10^{10}$	$1{\cdot}22 . 10^{10}$
O_2.	$1{\cdot}62 . 10^{10}$	$1{\cdot}38 . 10^{10}$	CO_2 .	$1{\cdot}07 . 10^{10}$	$1{\cdot}02 . 10^{10}$		$1{\cdot}32 . 10^{10}$	

NUMBER OF MOLECULES IN A GAS

N = the number of molecules in a **gram molecule** of gas (Perrin, *Compt. Rend.*, 1908; Perrin and Dabrowski, *C.R.*, 1909—by observations on colloidal particles). The theoretical value is

$$N = NE/e = 2{\cdot}89224 \times 10^{14}/4{\cdot}805 \times 10^{-10} = 6{\cdot}022 \times 10^{23}.$$

Method.	Gum mastic.	Gamboge.	Method.	Gum mastic.	Gamboge.
Counting by ultra microscope . .	$N = 7 . 10^{23}$	$N = 7{\cdot}05 . 10^{23}$	Brownian movements	$N = 7{\cdot}3 . 10^{23}$	$N = 7 . 10^{23}$

e/m FOR α-RAYS

e/m in E.M.U. gm.$^{-1}$. The calculated value of e/m for α-ray is $2F(1 - \beta^2)^{\frac{1}{2}}/(M_{He} - 2m) = 4823$ e.m.u. gm.$^{-1}$ where F is the faraday. The electrostatic and electromagnetic deflections of α-particles have been observed by Rutherford and Robinson (1914), giving e/m: 4820, 4830, 4824 for RaC, RaA and Rn respectively. Mean 4825 e.m.u. gm.$^{-1}$.

WORK (ϕ) REQUIRED TO EXTRACT AN ELECTRON FROM A METAL

The work function χ erg is the least energy which if added to that already possessed by the fastest electrons in the metal at absolute zero would enable them to escape. The thermionic work function, ϕ, is found by determining Richardson's equation

$$i = aT^{\frac{1}{2}}\epsilon^{-\phi/kT}$$

for **the thermionic current,** i, as a function of T the absolute temperature.

Calorimetric measurement also gives ϕ.

Another expression for this current in agreement with observation is

$$i = AT^2\epsilon^{-\chi/kT}, \text{ A being tabulated below.}$$

It follows from these relations

$$\chi = \phi - \frac{3}{2}kT,$$

where k is Boltzmann's constant, 1·381 × 10⁻¹⁶ erg deg.⁻¹. In e-volt $\chi_v = \phi_v - T/7733$.

$$1\ e - V = e\,.\,10^8/c \text{ erg} = 1{\cdot}6019\,.\,10^{-12} \text{ erg} = 7733 \text{ deg. per molecule.}$$

Einstein's expression for the **photoelectric effect** is $hv = \frac{1}{2}mv^2 - \chi$, and therefore the photoelectric work function is $h\nu_0$, where ν_0 is the minimum frequency to eject an electron at the absolute zero of temperature. $\chi = h\nu_0 = hc/\lambda_0$ and $\chi_v = 12384{\cdot}6/\lambda_0$. λ_0 in A unit.

Reference: Reimann, "Thermionic Emission," 1934, from which the following table is abstracted.

Metal.	A amp. cm.$^{-2}$ deg.$^{-2}$	Work function χ_v.		Metal.	A amp. cm.$^{-2}$ deg.$^{-2}$.	Work function χ_v.	
		Therm-ionic.	Photo-electric.			Therm-ionic.	Photo-electric.
Li	—	—	2·28 volt	Mo	55	4·15	4·15 volt
Na	—	—	2·46	W	60–100	4·54	4·54
K	—	—	2·24	Fe	—	4·77	4·77
Rb	—	—	2·16–2·19	Ni	1380	5·03	5·01
Cs	1·62	1·81	1·87–1·96	Rh	—	4·58	4·57
Ba	60	2·11	—	Pt	17,000	6·27	6·30
Zr	330	4·12	—	Ag	—	—	4·74
Th	70	3·38	—	Au	—	—	4·90
Ta	60	4·12	4·11				

T. H. L., V. D. H.

ELECTRONIC e/m AND VELOCITY

m_0 is the electromagnetic mass of the negative electron for infinitely small velocities, m the transverse mass for a velocity v; $v/c = \beta$, where c is the velocity of light. On the **theory of Lorentz** and the **relativity theory of Einstein** (*A.d.P.*, 1905), $m = m_0(1 - \beta^2)^{-\frac{1}{2}}$.

β	m/m_0	β	m/m_0	β	m/m_0	β	m/m_0	β	m/m_0	β	m/m_0	β	m/m_0
0·01	1·045	**0·34**	1·063	**0·48**	1·140	**0·62**	1·274	**0·76**	1·538	**0·90**	2·294	**0·97**	4·113
0·05	1·001	**0·36**	1·072	**0·50**	1·155	**0·64**	1·301	**0·78**	1·598	**0·91**	2·412	**0·98**	5·025
0·10	1·005	**0·38**	1·081	**0·52**	1·171	**0·66**	1·331	**0·80**	1·667	**0·92**	2·552	**0·99**	7·089
0·20	1·020	**0·40**	1·091	**0·54**	1·188	**0·68**	1·364	**0·82**	1·747	**0·93**	2·721	**0·999**	22·36
0·25	1·033	**0·42**	1·102	**0·56**	1·207	**0·70**	1·400	**0·84**	1·843	**0·94**	2·931		
0·30	1·048	**0·44**	1·114	**0·58**	1·228	**0·72**	1·441	**0·86**	1·960	**0·95**	3·203		
0·32	1·056	**0·46**	1·126	**0·60**	1·250	**0·74**	1·487	**0·88**	2·105	**0·96**	3·571		

Hρ AND v: MAGNETIC DEFLECTION

When negative rays of velocity v are deflected by a uniform magnetic field H (at right angles to their direction) into a circular path of radius ρ, then $\rho H = m_0 v/e = v\phi(\beta)/(e/m_0)$, where $\phi(\beta) = (1 - \beta^2)^{-\frac{1}{2}}$ on Lorentz's theory (see above), and $e/m_0 = 1{\cdot}7589 \times 10^7$ e.m.u. gm.$^{-1}$, v is in 10^8 cm. sec.$^{-1}$. ρH in gauss cm. **Example.**—If $\rho H = 2114{\cdot}0$ gauss cm., then $v = 2{\cdot}3309 \times 10^{10}$ cm./sec. Reference for Table: Miss N. C. B. Allen, *Proc. Roy. Soc.* of Victoria (1918), recalculated using latest value of e/m_0.

$v \times 10^{-8}$ cm./sec.

Hρ	0	10	20	30	40	50	60	70	80	90
0	0	1·758	3·518	5·276	7·034	8·790	10·546	12·302	14·055	15·808
100	17·559	19·308	21·055	22·799	24·541	26·282	28·019	29·753	31·515	32·215
200	34·94	36·65	38·37	40·87	41·79	43·50	45·20	46·90	48·60	50·28
300	51·97	53·64	55·31	56·98	58·64	60·30	61·95	63·59	65·23	66·86
400	68·49	70·10	71·72	73·33	74·93	76·52	78·11	79·68	81·25	82·82
500	85·37	85·92	87·47	89·00	90·53	92·05	93·56	95·07	96·55	98·04
600	99·53	100·99	102·45	103·91	105·35	106·79	108·22	109·64	111·05	112·46
700	113·85	115·24	116·18	117·99	119·35	120·70	122·05	123·38	124·71	126·03
800	127·33	128·63	129·93	131·20	132·47	133·74	135·00	136·23	137·47	138·70
900	139·91	141·13	142·33	143·52	144·70	145·88	147·05	148·21	149·36	150·49
1000	151·63	152·74	153·86	154·96	156·06	157·14	158·23	159·30	160·37	161·41
1100	162·46	163·50	164·53	164·55	166·56	167·57	168·57	169·54	170·53	171·50
1200	172·46	173·42	174·36	175·30	176·24	177·17	178·08	178·99	179·89	180·79
1300	181·68	182·55	183·42	184·28	185·14	185·99	186·84	187·66	188·49	189·31
1400	190·13	190·93	191·73	192·52	193·31	194·09	194·86	195·62	196·38	197·13
1500	197·88	198·62	199·34	200·07	200·79	201·51	202·22	202·93	203·62	204·29
1600	204·98	205·66	206·33	207·00	207·66	208·31	208·96	209·60	210·24	210·87
1700	211·49	212·11	212·72	213·34	213·94	214·54	215·14	215·73	216·32	216·89
1800	217·44	218·01	218·57	219·13	219·69	220·24	220·78	221·32	221·85	222·38
1900	222·90	223·42	223·94	224·45	224·96	225·46	225·96	226·45	226·94	227·43
2000	227·90	228·38	228·75	229·32	229·78	230·24	230·70	231·15	231·60	232·05
2100	232·47	232·91	233·35	233·78	234·21	234·63	235·04	235·47	235·88	236·29
2200	236·68	237·18	237·48	237·87	238·27	238·65	239·04	239·42	239·80	240·17
2300	240·53	240·90	241·27	241·64	242·00	242·35	242·70	243·06	243·40	243·75
2400	244·08	244·42	244·75	245·09	245·42	245·75	246·08	246·42	246·72	247·04
2500	247·35	247·76	247·97	248·27	248·88	249·18	249·48	249·48	249·78	250·07
2600	250·36	250·84	250·42	251·21	251·49	251·77	252·05	252·33	252·50	252·87
2700	253·13	253·40	253·66	253·92	254·18	254·43	254·69	254·95	255·19	255·44
2800	255·68	255·93	256·16	256·41	256·65	256·89	257·13	257·37	257·60	257·83
2900	258·06	258·28	258·51	258·73	258·96	259·18	259·40	259·61	259·83	260·04

	0	100	200	300	400	500	600	700	800	900
3000	260·24	262·28	264·16	265·92	267·56	269·07	270·49	271·82	273·06	274·23
4000	275·31	276·33	277·29	278·19	279·05	279·84	280·60	281·32	281·99	282·63
5000	283·22	283·80	284·34	284·86	285·34	285·81	286·36	286·68	287·18	287·47
6000	287·82	288·17	288·51	288·83	289·13	289·42	289·70	289·97	290·23	290·47
7000	290·70	290·93	291·15	291·36	291·56	291·75	291·94	292·12	292·30	292·46
8000	292·62	292·78	292·93	293·08	293·22	293·35	293·48	293·60	293·72	293·84
9000	293·95	294·07	294·18	294·28	294·38	294·48	294·57	294·66	294·75	294·84

NUMBER OF α-PARTICLES FROM Ra

Number of α-particles from Ra without its radioactive product $= 3{\cdot}62 \times 10^{10}$ per gm. per sec.

Reference: Rutherford, Chadwick and Ellis (1935).

RANGES OF ALPHA-PARTICLES IN VARIOUS GASES

Alpha-particles from Radium C′ in gases at atmospheric pressure. (Taylor, *Phil. Mag.*, 1911 ; Bates, *Proc. Roy. Soc.*, 1924.)

Gas.	**He.**	**H_2.**	**Ne.**	**A.**	**Air.**	**O_2.**	**Kr.**	**Xe.**
Range (cm.) .	39·7	31·12	11·9	7·5	6·97	6·29	5·24	3·86

STOPPING POWERS OF MATERIALS

If a layer of air of density ρ and thickness t decreases the range of an α particle by the same amount as aluminium foil of density ρ_a and thickness t_a, then the **atomic stopping power,** S, of Al relative to air is given by $S = 27t\rho/14{\cdot}4t_a\rho_a$) = (number of atoms per cm.^{2} in air layer)/(number of atoms per cm.^{2} in Al foil) (Bragg and Kleeman, *Phil. Mag.*, 1905 ; Bragg, *Phil. Mag.*, 1906).

Material.	**S.**	**Material.**	**S.**	**Material.**	**S.**	**Material.**	**S.**	**Material.**	**S.**
(Air at 20° C., 76 cm.)	**1·00**	Ag . .	3·17	Ni . .	2·46	O_2 . .	1·055	C_2H_2 .	1·11
		Sn . .	3·37	Au . .	4·45	N_2O .	1·46	Ethylene	1·35
Al . . .	1·45	Pt . .	4·16	Pb . .	4·27	CO_2 .	1·47	Benzene	3·37
Cu . . .	2·43	Fe . .	2·26	H_2 . .	0·20	CS_2. .	2·18	Methane	0·86

NUMBER OF IONS MADE BY AN α PARTICLE

Total number of ions produced by the complete absorption of an α particle with various initial velocities. Observer assumed $e = 4{\cdot}65 \times 10^{-10}$ E.S.U. (Geiger, *Proc. Roy. Soc.*, 1909).

	Ra	**RaEm**	**RaA**	**RaC**	**RaF**
Range in air at 20° C., 76 cm. . .	3·5 cm.	4·33	4·83	7·06	3·86
Number of ions	$1{\cdot}53 \times 10^5$	$1{\cdot}74 \times 10^5$	$1{\cdot}87 \times 10^5$	$2{\cdot}37 \times 10^5$	$1{\cdot}62 \times 10^5$

IONS PRODUCED AT DIFFERENT VELOCITIES BY AN α PARTICLE

Number of ions made per mm. of path in **air** by an α particle from RaC at various distances from its source. Total number $= 2{\cdot}20 \times 10^5$ (Rutherford, Chadwick, Ellis (Cambridge), 1930.

Distance from RaC in cm.	**1**	**2**	**3**	**4**	**5**	**6**	**6·5**	**7**
Ions per mm. of path in air at 12°C. and 76 cm. .	2480	2540	2680	2880	3440	4800	6000	4500

RELATIVE VOLUME IONIZATIONS FOR β, γ, AND X RAYS

Relative ionization = $I_r = iP/Ip$, where i is the amount of ionization per unit volume for the gas at a press. p, and I that for air at press. P, the other experimental conditions being the same. In the experiments with γ rays (column headed γ), β rays would also be present. Observers: for β and γ rays, Kleeman, *P.R.S.*, 1907; X rays, C., Crowther, *P.C.P.S.*, 1909; *P.R.S.*, 1909; Mc., McClung, *P.M.*, 1904. I_r for secondary γ rays is much the same as for X rays (see Kleeman, *P.R.S.*, 1909).

Gas.	β	γ	Hard X.	Soft X.	Gas.	β	γ	Hard X.	Soft X.
Air . . .	**1·00**	**1·00**	**1·00**	**1·00**	Me. alcohol .	1·69	1·75	—	—
H_2 . . .	0·16	0·16	0·42	0·11	Me. bromide	3·73	3·81	—	71, C.
O_2 . . .	1·17	1·16	1·17, Mc.	1·3, Mc.	Me. iodide .	5·11	5·37	13·5	72
NH_3 . .	0·89	0·90	—	—	Chloroform .	4·94	4·93	4·6	31·9
N_2O . .	1·55	1·55	—	—	CCl_4 . . .	6·28	6·33	4·9	45·3
CO_2 . .	1·60	1·58	1·49, C.	1·57, C.	Et. aldehyde .	2·12	2·17	—	—
C_2N_2 . .	1·86	1·71	—	—	Et. bromide .	4·41	4·63	118	72, C.
SO_2 . . .	2·25	2·27	2·3	7·97	Et. chloride .	3·24	3·19	17·3, C.	18, C.
CS_2 . . .	3·62	3·66	—	—	Et. ether . .	4·39	4·29	—	—
Pentane .	4·55	4·53	—	—	Et. iodide .	5·90	6·47	—	—
Benzene .	3·95	3·94	—	—	Ni. carbonyl .	—	5·98	97, C.	89, C.
Me. acetate	—	—	3·90, C.	4·95, C.	Hg dimethyl	—	—	—	425, C.

P.C.P.S., Proc. Camb. Phil. Soc.; P.M., Phil. Mag.; P.R.S., Proc. Roy. Soc.

RELATIVE IONIZATION PER UNIT VOLUME BY α RAYS

Relative ionization = (total ionization) × (stopping power), Metcalfe, *P.M.*, 1909.

Air .	**1·00**	He .	·211	CO .	1·00	HCl .	1·4	Propane	3·05	Pentane	4·83
H_2 .	·233	Br_2 .	3·9	NO .	1·28	Ethane	2·08	Butane .	4·02		

For calculated **total ionization** when **Röntgen Rays** are completely absorbed in various gases, see Crowther, *Proc. Roy. Soc.*, 1909.

HEATING EFFECT OF RADIUM

Heat liberated by metallic Ra, Rn, etc., in cal. $sec.^{-1}$ $gm.^{-1}$. The calculated total energy E of the radiations is $E = \frac{1}{2}MQ\Sigma(1 + M/m)v^2 + E_1$, where M is the mass of the α-particles, m the mass of the radium atom, v the velocity of each group present, Q the number of α-particles emitted per sec. by 1 gm. of radium and its products. E_1 is the energy of β- and γ-rays absorbed. Heating effect is independent of temperature and pressure.

References: Rutherford, Chadwick and Ellis, 1935. International Critical Tables.

Product.	α-rays.		Pro-duct.	α-rays.		β.	γ.
	Calc.	Obs.		Calc.	Obs.		
Ra .	$6·92 \times 10^{-3}$	$7·00 \times 10^{-3}$	RaB RaC	$11·17 \times 10^{-3}$	$10·42 \times 10^{-3}$	$1·75 \times 10^{-3}$	$2·61 \times 10^{-3}$
Rn .	$7·92 \times 10^{-3}$	$8·28 \times 10^{-3}$					
RaA .	$8·67 \times 10^{-3}$	$8·86 \times 10^{-3}$	Total	$34·68 \times 10^{-3}$	$34·56 \times 10^{-3}$	$1·75 \times 10^{-3}$	$2·61 \times 10^{-3}$

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HEAT EMISSION FROM RaEm, AND THORIUM

The 6×10^{-4} c.c. of **RaEm** (with its products) in equilibrium with 1 gm. Ra emit ·75 of the ·0328 calories emitted per sec. by the radium. Thus the total quantity of heat given out by 1 c.c. of RaEm during its whole life = $·75 \times ·0328\ (\lambda \times 6 \times 10^{-4})$ = $1·9 \times 10^7$ calories.

For old (mineral) **thorium** metal, the heat emitted is 5×10^{-9} calories per sec. per gm. (Pegram and Webb, *Phy. Rev.*, 1908).

RADIUM EMANATION

Γ is the **period of decay** (in days) to half initial activity. Taking $\Gamma = 3{\cdot}82$ days, then the decay coefficient $\lambda = 2{\cdot}10 \times 10^{-6}$ sec.$^{-1}$ (see p. 121).

Γ in days.	Observer, etc.	Γ in days.	Observer, etc.
3·77	Rutherford and Soddy, *P.M.*, 1903.	3·75	Rümelin, *P.M.*, 1907.
3·88	Bumstead and Wheeler, *A.J.S.*, 1904.	3·58	For first 5 days.
3·8 to 4·1	Debierne, *C.R.*, 1909.	3·75	During period 5 to 20 days.
3·86	Sackur, *Ber. C.G.*, 1905.	3·85	20 to 40 days' old emanation.
		4·4	One sample Rutherford and Tuomikoski, *P.M.*, 1909.

EQUILIBRIUM VOLUME OF RADIUM EMANATION

Final **volume of radium emanation** at 0° C. and 76 cm. Hg in equilibrium with 1 gm. of metallic radium. **Theoretical** volume = (number of radium atoms breaking up per sec.)/$\lambda N = 3{\cdot}62 \times 10^{10}/2{\cdot}688 \times 10^{19} \times 2{\cdot}097 \times 10^{-6} = 6{\cdot}42$ c.c. $\times 10^{-4}$. (Rutherford, " Radioactivity "). The volume of the emanation changes anomalously after it is first formed.

Observed vol.	Observer.	Observed vol.	Observer.
·58 cub. mm.	Rutherford, *P.M.*, 1908.	·58 cub. mm.	Debierne, *C.R.*, 1909.
·601 ,,	Gray & Ramsay, *J.C.S.*, 1909.		

A.J.S., Amer. Journ. Sci.; C.R., Compt. Rend.; J.C.S., Journ. Chem. Sci., P.M., Phil. Mag.; C.G., Chem. Ges.

VAPOUR PRESSURE OF RADIUM EMANATION

Vapour pressure of liquid RaEm. in cm. Hg; melting-point, −71° C. (R., Rutherford, *Nature*, February, 1909; G. & R., Gray and Ramsay, *J.C.S.*, June, 1909.)

Temp. ° C.	R.	−127°	−101°	−78°	−65° = B.P.
Vap. press. cm. Hg		·9	5	25	76

Temp. ° C.	G. & R.	−70°·4	−62° = B.P.	−60°·6	−55°·8	−38°·5	−17°·7	−10°·2	+104°·5 crit. t.
Vap. press. cm. Hg		50	76	80	100	200	400	500	4745 crit. press.

IONIZATION DUE TO ELECTRONS AND X-RAYS

The number of ions produced when a beam of electrons or X-rays is absorbed varies linearly with the energy of the beam. The mean energy (in electron-volts) per ion-pair produced, tabulated below, is greater than the ionization potential of the molecule, owing to other sources of energy loss.

Electrons in Air.		X-rays in Air.	
Author.	**Mean energy for ionization.**	**Author.**	**Mean energy for ionization.**
Schmitz . . .	45 volts	Steenbeck	28 volts
Eisl	32 ,,	Gaertner	36 ,,
Wilson. . . .	26 ,,	Crowther and Bond . .	42·5 ,,
Mean . .	34 ,,	Mean . .	35·5 ,,

EQUILIBRIUM ACTIVITIES IN MINERALS

Relative activity of radioactive products in minerals. Boltwood (*A.J.S.*, April, 1908) found U 2·22 times as active as the Ra alone in minerals (see McCoy and Ross, *A.J.S.*).

Product	U	Io	Ra	RaEm.	RaA	RaB	RaC	RaF	Ac	Total.
Relative activity . .	1	·34	·45	·62	·54	·04 ?	·91	·46	·28	4·64

$3\cdot4 \times 10^{-7}$ gm. Ra is in equilibrium with 1 gm. U (Rutherford and Boltwood, *A.J.S.*, 1906). $7\cdot3 \times 10^{6}$ gms. U equal in activity 1 gm. of Ra + its products to RaC. *i.e.* Ra just over 30 days old (corrected by Boltwood, *A.J.S.*, 1908).

RADIUM AND THORIUM IN ROCKS

Rutherford and Soddy (*P.M.*, May, 1903) and W. E. Wilson (*Nature*, July, 1903) suggested that the heat liberated by radioactive changes is one of the sources of the Earth's heat. Thus the distribution of radium and thorium in the Earth's crust is of geophysical importance. Loss of heat from the Earth's surface = temperature gradient × thermal conductivity of crust × area of Earth's surface = $(1/3200) \times \cdot004 \times 5\cdot1 \times 10^{18} = 6 \times 10^{12}$ calories per sec. Now, elementary radium in radioactive equilibrium (*i.e.* whole U family) gives out 6×10^{-2} cal./sec. gm. (Rutherford §), and therefore $1\cdot1 \times 10^{14}$ grms. of radium, or $10^{14}/10^{27} = 10^{-13}$ gm. per c.c., throughout the Earth's volume would maintain it at a steady temperature. Thorium contributes 5×10^{-9} cal. /sec. gm. The **total heating effect** in calories per gram of rock per hour is for the lava indicated below by *, 30×10^{-10}; and for the rock indicated by †, $2\cdot9 \times 10^{-10}$; for average igneous rock, 11×10^{-10}.

(See Strutt, *Proc. Roy. Soc.*, 1906–7 ; Joly, "Radioactivity and Geology," 1909.)

Rock, etc.	**Obs.**	**Ra**	**Th**
		gm. per gm. of rock.	
		$\times 10^{-12}$	$\times 10^{-5}$
Igneous rocks	St., 1906	1·7	—
Sedimentary rocks	"	1·1	—
Sandstone	E. M., 1907	·16	—
Clays	" "	·79	—
Devonian	" "	1 to 4	—
Ordovician	" "	·9	—
Lavas ejected since 1631 * . . .	J., 1909	12·3	2·3
Lava, Mount Erebus	F. F., 1909	2·4	—
126 igneous rocks	J., 1909	7·01	—
64 " "	other obs.	1·3	1·3
Italian igneous rocks	B., 1909	mean	5
Campbell and Auckland Islands, N.Z.	F. F., 1909	1·6 ·5	igneous sedimentary
St. Gothard Tunnel—			
granite	J., 1909	7·7	1·9
schists and altered sedimentary rocks	"	3·4 to 4·9	·5 to 1·2
Simplon Tunnel ‖	"	7·6	—
Transandine Tunnel †	Fl., 1910	·8	·56
Calcareous and dolomitic European rocks	J., 1910 "	mean of 7 27 samples	·16 <·05
Deep-sea deposits—			
Globigerina ooze [1]	"	7·2	—
Radiolarian ooze [2]	"	36·7	—
Red clay [3]	"	27	---

Extent :—[1] 50, [2] 2·5, [3] 51 million square miles. † 1000 feet below the surface. § Assuming that the heat due to each member of the family is proportional to the ionization it produces. ‖ Preliminary result. B., Blanc., *P.M.* ; E.M., Eve and McIntosh, *P.M.* ; F.F., Farr and Florance, *P.M.* ; Fl., Fletcher ; J., Joly, *P.M.* ; S., Strutt (above). *A.J.S.*, *Amer. Journ. Sci.* ; *P.M.*, *Phil. Mag.*

RADIUM IN SEA-WATER

In grams per gram of sea-water. Deduced from the observed amount of Ra Em.

Amount.	Place.	Observer.	Amount.	Place.	Observer.
2·3 × 10^{-15}	—	Strutt, *P.R.S.*, '06	4 × 10^{-16}	Nile	Joly, *P.M.*, 1908
·3–·6 "	Mid. N. Atlantic	Eve, *P.M.*, 1907	14 "	Mediterranean	" " 1909
·9 "	Atlantic	" " 1909	5 "	Indian Ocean	" " "
16 "	"	Joly, *P.M.*, 1908			

RADIUM EMANATION IN ATMOSPHERE

RaEm. per cubic metre of air, expressed in terms of the number of grams of radium with which it would be in equilibrium. The observers below absorbed the emanation by charcoal.

RaEm.	Place.	Observer.	RaEm.	Place.	Observer.
24–27 × 10^{-12}	Montreal	Eve, *P.M.*, 1907	35–350 × 10^{-12}	Cambridge	Satterly, *P.M.*, 1908 and 1910
60 "	"	" 1908	Mean 105 "		
86–200 "	Chicago	Ashman, *A.J.S.*, '08			

MOBILITIES OF NATURAL IONS IN AIR

Mobility or speed K is in cm.^{2} sec.$^{-1}$ volt^{-1} at room temperature and 76 cm. (see p. 110). The ions are named from their velocities: the small ions are assumed to have the velocity of X-ray ions. (See Pollock, *Science*, 1909; Eve, *Phil. Mag.*, 19, 1910; Lusby, *Proc. Camb. Phil. Soc.*, 1910.)

Ion.	Mean K.	Observer.	Ion.	Mean K.	Observer.
Small . . .	$K_+ = 1·4$ $K_- = 1·7$	Langevin, '03	Large . .	·0003	Langevin, *C.R.*, '05
			Large . .	·0003 *	Pollock, 1908
Intermediate	*c.* ·01	Mean	Large . .	·0008 †	" "

* Humidity, 19 grms. H_2O per cubic metre. † ·5 grm. H_2O per cubic metre of air. Pollock, *Austl. Ass. Adv. Sci.*, 1908.

ELECTRIC ARCS

Mrs. Ayrton's formula for carbon arcs, $E = \alpha + \beta l + \frac{\gamma + \delta l}{i}$, has been shown by Guye and Zébrikoff (*Compt. Rend.*, 1907) to hold for short stable arcs between metals. E is the voltage across the arc, *i* is the current in amperes, and *l* the length in mms. of the arc in air at atmospheric pressure. Mrs. Ayrton's formula does not hold for very long arcs, nor for cored carbons. For stability, an arc requires an external resistance R which must be less than $\frac{\{E_x - (\alpha + \beta l)\}^2}{4(\gamma + \delta l)}$ ohms, where E_x is the total available voltage; *or* E_x must exceed $\alpha + \beta l + 2\sqrt{R(\gamma + \delta l)}$. If R is too small the arc hisses, in which case the current is independent of the voltage across the terminals. The constants for carbon refer only to the particular sizes and quality used by Mrs. Ayrton.

(See J. J. Thomson, "Conduction of Electricity through Gases.")

Metal.	α	β	γ	δ	Metal.	α	β	γ	δ
C.	38·88	2·074	11·66	10·54	**Pd** . . .	21·64	3·70	0	21·78
Fe . . .	15·73	2·52	9·44	15·02	**Ag** . . .	14·19	3·64	11·36	19·01
Ni . . .	17·14	3·89	0	17·48	**Pt** . . .	24·29	4·80	0	20·23
Co . . .	20·71	2·05	2·07	10·12	**Au** . . .	20·82	4·62	12·17	20·97
Cu . . .	21·38	3·03	10·69	15·24					

A.J.S., *Amer. Journ. Sci.*; *C.R.*, *Compt. Rend.*; *P.M.*, *Phil. Mag.*; *P.R.S.*, *Proc. Roy. Soc.*

GENERAL AND ATOMIC CONSTANTS

The following table contains a number of the general constants of physics. The basis of the values given below is explained on other pages of this book, referred to in the third column below.

References: Birge, " General Physical Constants " (*Rev. Mod. Phys.*, 1929), Birge's 1939 revision of his 1929 values, and Wensel (*J. Res. Nat. Bur. St.*, 1939).

Symbol.	Quantity.	Page.	Value.		
	Fundamental				
e	Electron	127	$4{\cdot}805 \pm {\cdot}001 \times 10^{-10}$ e.s.u.	$1{\cdot}6029 \times 10^{-20}$ e.m.u.	
e/m	Electron	128	$5{\cdot}2728 \pm {\cdot}0015 \times 10^{17}$ e.s.u. gm.$^{-1}$	$1{\cdot}7589 \times 10^{7}$ e.m.u. [gm.$^{-1}$	
h	Planck's action quantum	128	$6{\cdot}622 \pm {\cdot}007 \times 10^{-27}$ erg. sec.		
c	Velocity of light	84	$2{\cdot}99774 \pm {\cdot}00011 \times 10^{10}$ cm. sec.$^{-1}$		
G	Gravitation constant	17	$6{\cdot}659 \pm {\cdot}006 \times 10^{-8}$ gm.$^{-1}$ cm.^{3} sec.$^{-2}$		
N	Number of molecules per mole, Avogadro's number	112	$6{\cdot}0192 \pm {\cdot}0014 \times 10^{23}$ mole.$^{-1}$ chemical scale		
k	Boltzmann's constant	7	$1{\cdot}3813 \pm {\cdot}0002 \times 10^{-16}$ erg. deg.$^{-1} = R/N$		
R	Gas constant $= pv/T$	7	$8{\cdot}3142 \pm {\cdot}0010 \times 10^{7}$ erg. deg.$^{-1}$ mole.$^{-1}$ Chm. Sc.		
V	Volume perfect gas		$22415{\cdot}2 \pm {\cdot}8$ cm.^{3} mole.$^{-1}$ ($g = 980{\cdot}665$)		
F	Faraday $= Ne$ chem. sc.	112	$2{\cdot}89224 \pm {\cdot}0003 \times 10^{14}$ e.s.u. (gm. equiv.)$^{-1}$		
	,, chem. sc.	112	$9648{\cdot}0$ e.m.u. (gm. equiv.)$^{-1}$		
	Specific Charge				
e/M_P	Proton $= F/M_P$		$2{\cdot}8712 \times 10^{14}$ e.s.u. gm.$^{-1}$	$9578{\cdot}0$ e.m.u. gm.$^{-1}$	
e/M_D	Deuteron $= F/M_D$		$1{\cdot}4359 \times 10^{14}$ e.s.u. gm.$^{-1}$	$4790{\cdot}0$ e.m.u. gm.$^{-1}$	
e/M_H	Hydrogen in electrolysis		$2{\cdot}8692 \times 10^{14}$ e.s.u. gm.$^{-1}$	$9571{\cdot}4$ e.m.u. gm.$^{-1}$	
$2e/M_{He}$	α-ray		$1{\cdot}4450 \times 10^{14}$ e.s.u. gm.$^{-1}$	$4820{\cdot}4$ e.m.u. gm.$^{-1}$	
	Atomic Mass			**Physical scale.**	**Chemical scale.**
M_{H^1}/m	H^1 atom : m. electron		$1837{\cdot}7 = e/(e/m)$		
m	Electron $= e/(e/m)$		$9{\cdot}113 \pm {\cdot}003 \times 10^{-28}$ gm.	·0005486	·0005484
M	Unit atomic mass $= 1/N$		$1{\cdot}6613 \times 10^{-23}$ gm.	1·00027	1·00000
M_P	Proton $= M_P/N$		$1{\cdot}6734 \times 10^{-24}$ gm.	1·00758	1·00731
M_H	Chemical hydrogen	171	$1{\cdot}6746 \times 10^{-24}$	1·00827	1·00800
M_{H^1}	H^1 atom	171		1·00813	1·00786
M_N	Neutron	171	$1{\cdot}6756 \times 10^{-24}$	1·0089	1·0086
M_{H^2}	Deuterium	171		2·01473	2·01418
M_{He}	Helium	171		4·00389	4·00281
M_{Ag}	Silver	171			107·880
	Spectroscopy				
R_H	Rydberg's number H^1	129	$109677{\cdot}75 \pm {\cdot}01$		
R_{He}	,, ,, He		$109722{\cdot}403 \pm {\cdot}01$ cm.$^{-1}$		
R_∞	,, ,,		$109737{\cdot}43$ $R_\infty = 2\pi^2 e^4 m/h^3 c^2$		
α	Fine structure const.		$7{\cdot}3002 \times 10^{-3}$; $1/\alpha = 136{\cdot}98 = \{4\pi Re(e/m)/c\}^{-\frac{1}{3}}$		
	Heat, Radiation				
T_0	Temperature Ice Pt.	54	0° C. $= 273{\cdot}16 \pm {\cdot}02$° K.		
c_1	First radiation const.	75	$3{\cdot}77 \times 10^{-5}$ erg. cm.^{2} sec.$^{-1}$		
c_2	Second radiation const.	75	$1{\cdot}4361$ cm. deg. $= ch/k$		
$\lambda_m T$	Wien's law const.	75	${\cdot}2892$ cm. deg. $\lambda_m T \times 4{\cdot}965 = c_2$		
σ	Stefan's const.	75	$5{\cdot}75 \times 10^{-5}$ erg. cm.$^{-2}$ deg.		
J_{15}	Mech. equiv. heat	65	$4{\cdot}18526 \times 10^{7}$ erg. cal.$^{-1}$ at 15° C.		
J'_{15}	Elect. equiv. heat	65	$4{\cdot}1850 \times 10^{7}$ erg. cal.$^{-1}$ at 15° C.		
	X-Rays				
a_{18}	Grating space calcite	127	$d_{18} = 3029{\cdot}45$ X unit (I XU $= 1{\cdot}00218 \times 10^{-11}$ cm.)		
ρ_{18}	Density calcite		$2{\cdot}71047 \pm {\cdot}00003$ gm. cm.$^{-3}$		
$\phi(\beta)$	Structure factor		1·09594		
a_1	Grating space calcite		3029·04 X unit 1st order spectrum		
	,, ,, quartz		4244·92 ,, ,, ,,		
	,, ,, gypsum		7579·06 ,, ,, ,,		
	,, ,, mica		9927·50 ,, ,, ,,		
$\lambda g/\lambda c$	X unit in cm.	127	1 XU $= 1{\cdot}00218 \times 10^{-11}$ cm. $\lambda g/\lambda c = 1{\cdot}00218$		
	Wavelength equivalent to 1 eV energy for X-rays	126	$12384{\cdot}6 \times 10^{-8}$ cm. abs. volt^{-1}		

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RADIOACTIVITY

RADIOACTIVE ELEMENTS AND SERIES

Rate of Decay.—If N is the number of molecules of a radioactive element at a time t sec., then $N = N_0e^{-\lambda t}$, where N_0 is the initial number of atoms when $t = 0$. If T sec. is the period in which the number of atoms initially present decreases to one half (*i.e.* $N/N_0 = \frac{1}{2}$), then $\lambda T = ·69315$. (When T is in minutes, hours, days or years then $\lambda T = 1·155 \times 10^{-2}$, $1·925 \times 10^{-4}$, $8·021 \times 10^{-6}$ or $2·196 \times 10^{-8}$ respectively, where λ is the disintegration constant in sec.^{-1}).

Change of Atomic Mass and Number.—In the radioactive disintegration of an atom either an α- or β-particle is emitted from the nucleus. In the first case the mass of the atom A relative to $O \equiv 16$ decreases by approximately four units and the nuclear charge $+Ze$ decreases by $2e$, that is the atomic number Z decreases by 2. In the second case the atomic mass A remains practically unchanged and the atomic number Z increases by one unit.

Radioactive Series.—Three radioactive families of elements have been found in nature ; they are known as the thorium ($A = 4n$), the uranium ($A = 4n + 2$) and the actinium ($A = 4n+3$) families. The uranium series was early recognized to originate from UI, and the thorium series from thorium. There was some doubt as to the origin of the actinium series. Recently, however, the determination (by Grosse 1935) of the atomic weight of protactinium as 231 and the observation of the presence of an isotope of mass 235 (actino-uranium) in uranium (Dempster, 1935) have definitely proved the latter to be the parent element of the actinium

Chemical properties of the elements are the same as those of their isotopes which are :

Z . . .	92	91	90	89	88	87	86	84	83	82
Isotope . .	U	Pa	Th	Ac	Ra	(AcK)	Rn	Pa	Bi	Pb

Element.	A	Z	T	Ray.
Uranium Series				
U1 . .	238	92	$4·6\times10^9$ y.	α
UX1 . .	234	90	24·5 d.	β
UX11 . .	234	91	1·14 m.	β
UZ . .	234	91	6·7 h.	β
U11 . .	234	92	3×10^5 y.	α
Io . . .	230	90	$8·5\times10^4$ y.	α
Ra . .	226	88	1590 y.	α
Rn . .	222	86	3·82 d.	α
RaA . .	218	84	3·05 m.	α
RaB . .	214	82	26·8 m.	β
RaC . .	214	83	19·7 m.	β, α
RaC′ . .	214	84	10^{-6} s.	α
RaC″ . .	210	81	1·32 m.	β
RaD . .	210	82	22·3 y.	β
RaE . .	210	83	5·0 d.	β
RaF . .	210	84	139 d.	α
RaG . .	206	82	Stable	
Actinium Series				
AcU . .	235	92	7×10^8 y.	α
UY . .	231	90	24·6 h.	β
Pa . .	231	91	$3·2\times10^4$ y.	α
Ac . .	227	89	13·5 y.	β, α (?)
RAc . .	227	90	18·9 d.	α
(AcK) . .	223	87	21 m.	β
Actinium Series (*cont.*)				
AcX . .	223	88	11·2 d.	α
An . .	215	86	3·92 s.	α
AcA . .	215	84	2×10^{-3} s.	α
AcB . .	211	82	36·0 m.	β
AcC . .	211	83	2·16 m.	α, β
AcC′ . .	211	84	10^{-3} s.	α
AcC″ . .	207	81	4·76 m.	β
AcD . .	207	82	Stable	
Thorium Series				
Th . . .	232	90	$1·4\times10^{10}$y.	α
MsTh1 .	228	88	6·7 y.	β
MsTh11 .	228	89	6·13 h.	β
RTh . .	228	90	1·90 y.	α
ThX . .	224	88	3·64 d.	α
Tn . . .	220	86	54·5 s.	α
ThA . .	216	84	0·14 s.	α
ThB . .	212	82	10·5 h.	β
ThC . .	212	83	60·5 m.	α, β
ThC′ . .	212	84	10^{-10} s.	α
ThC″ . .	208	81	3·1 m.	β
ThD . .	208	82	Stable	
K . . .	40	19	10^{13} y.	β
Rb . . .	87	37	4×10^{11} y.	β
Sm . .	148	62	10^{12} y.	α

s., second ; m., minute ; h., hour ; d., day ; y., year.

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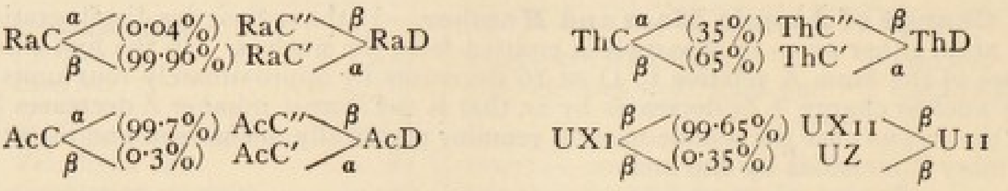
RADIOACTIVITY (*contd.*)

series. The stable end product of each series is always an isotope of lead: Pb^{206} for the uranium series, Pb^{208} for the thorium series, Pb^{207} for the actinium series. These three isotopes are also the main constituents of ordinary lead. The three series exhibit considerable similarity. The elements, RaC, ThC, AcC, exhibit a branching effect, emitting either an α- or a β-particle. Another branching exists in the case of UXI, which emits β-particles to form UXII or UZ. The scheme of the transformations is then:



The numbers in brackets give the percentage of the atoms which disintegrate in the manner shown. Recently Perey, C. R. (1939) has shown a branching effect for Ac and suggests AC→α (0·6%) Ac.K and Ac→β (99·4%) R.Ac.

Three naturally occurring radioactive elements, not members of radioactive series, are K^{40}, Rb^{87} and Sm^{148}. Their half periods are given in the above table.

V. D. H.

α-RAYS ENERGY AND RANGE

References:—Rutherford, Chadwick and Ellis, "Radiations from Radioactive Substances," Cambridge; Gamow, "Atomic Nuclei," Oxford; Briggs, *Proc. Roy. Soc.*

Initial Velocity, Energy and Range.—The velocity, V cm. sec.$^{-1}$, of the α-ray of RaC′ (and other elements) has been measured by Briggs by deflection of the ray in a magnetic field, H oersted.

$$V = H\rho(e/m_0)(1 - \beta^2)^{\frac{1}{2}}$$

where ρ cm. is the curvature of the α-ray path, e/m_0 e.m.u. gm.$^{-1}$, is the ratio of the charge to the rest mass of the particle and $\beta = V/c$. Hρ (observed) = 3·99277.10^5 e.m.u. cm. e/m_0 is calculated from the Faraday 9648·0 e.m.u. (gm. equiv.)$^{-1}$, m_0 = 4·00173 (chemical scale), giving e/m_0 = 4823 e.m.u. gm.$^{-1}$ and V = 1·9215.10^9 cm. sec.$^{-1}$.

The energy, T_α erg, of the α-ray is given by $T_\alpha = \frac{1}{2}(H\rho)^2 (e^2/m_0)(1-\beta^2/4-\beta^4/8)$. In the table T_α is in *e*V, where 1 *e*V = 1·6019 × 10^{-12} erg. Briggs' observations are given in it to five or six figures.

Element.	R_{15} cm.	v × 10^9 cm./sec.	T_αeV × 10^{-6}.	T_TeV × 10^{-6}.	Element.	R_{15} cm.	v × 10^9 cm./sec.	T_αeV × 10^{-6}	T_TeV × 10^{-6}.
UI . .	2·68	1·41	4·1	4·2	ThX .	4·24	1·6533	5·681	5·785
UII. .	3·24	1·51	4·7	4·8	Tn .	4·97	1·7382	6·2818	6·398
Io . .	3·16	1·48	4·6	4·7	ThA .	5·60	1·8048	6·774	6·902
Ra α_0 .	3·26	1·52	4·79	4·88	ThC α_0	4·68	1·7053	6·044	6·161
Rn . .	4·01	1·6247	5·486	5·587	ThC′ α_0	8·53	2·0535	8·776	8·945
RaA .	4·62	1·6987	5·998	6·110	Pa. .	3·63	1·55	4·98	5·06
RaC α_0 .	4·04	1·63	5·51	5·61	RaAc .	4·7	1·71	6·05	6·14
RaC′ α_0	6·87	1·9215	7·680	7·827	AcX .	4·28	1·66	5·72	5·82
RaF .	3·81	1·60	5·31	5·40	An α_0 .	5·66	1·81	6·83	6·95
Th . .	2·57	1·40	4·1	4·2	AcC α_0	5·39	1·78	6·61	6·74
RaTh α_0	3·90	1·61	5·42	5·52	AcC′ α_0	6·52	1·89	7·43	7·58

α-RAYS ENERGY AND RANGE (*contd.*)

Total disintegration energy, T_T erg, of both α-ray and nucleus is given by

$$T_T = T_\alpha(1 + m/M) = T_\alpha(1 + 4/M),$$

where m/M is the ratio of the mass of the α-ray to that of the nucleus after disintegration. It is approximately 4/M if M is the atomic mass of the latter.

Range.—R_{15} cm. is the range of the α-ray in air at 15° C. and 76 cm. Hg.

Geiger's relation. The decrease in velocity of an α-ray in air is approximately given by Geiger's relation $V^3 = a(R - x)$, where a is a constant $= 1{\cdot}011 \times 10^9$, R cm. is the range in air, V cm. sec.$^{-1}$ the velocity of the particle at a distance x cm. from the source. This holds fairly closely for velocities between the initial velocity V_0 and $0{\cdot}75\ V_0$.

Geiger-Nuttall Rule. There is an approximate relationship between the disintegration constant, sec.$^{-1}$ of a radioactive atom and R cm. the range in air of the α-ray which it emits, namely, $\log \lambda = A + B \log R$, A and B being constants, A varying slightly for each radioactive series.

Magnetic spectra of α-rays. Several groups of α-rays having definite energies from one disintegrating element were first observed by Rosenblum in 1930 for ThC and for RaC, AcC by Rutherford, Ward and Wynn Williams, 1930, and later for ThC′, RaC′, RaAc and An. The main group for each element is given in the foregoing table. The following table gives the energy of the group of α-ray and the γ-ray energies from ThC′. It shows that, when an α-particle of less energy than the maximum energy group is emitted, the nucleus is left in an excited state, and its excess energy is emitted as a quantum (or as several quanta) whose energy is the difference in energy of two α-rays.

Element.	T_1 eV.	Energy difference.	hν for γ-ray eV × 10^{-6}.
ThC α_1	$6{\cdot}200 \times 10^6$		
α_2	$6{\cdot}160 \times 10^6$	$\alpha_1 - \alpha_2 = 0{\cdot}400 \times 10^6$	0·399 γ_6
α_3	$5{\cdot}872 \times 10^6$	$\alpha_1 - \alpha_3 = 3{\cdot}278 \times 10^6$	3·267 γ_5
α_4	$5{\cdot}728 \times 10^6$	$\alpha_1 - \alpha_4 = 4{\cdot}724 \times 10^6$	4·709 γ_3
α_5	$5{\cdot}708 \times 10^6$	$\alpha_5 - \alpha_2 = 4{\cdot}518 \times 10^6$	4·511 γ_1
		$\alpha_4 - \alpha_2 = 4{\cdot}324 \times 10^6$	4·317 γ_2
		$\alpha_3 - \alpha_2 = 2{\cdot}878 \times 10^6$	2·869 γ_4

V. D. H.

ARRANGEMENT OF ELECTRONS IN ATOMS

In the following table the electrons in an atom are shown as arranged in shells and sub-shells. The number of electrons in an atom is equal to its atomic number Z, so that the nucleus with a positive charge Ze is surrounded by electrons of total negative charge Ze.

Shells. The electrons with the same principal quantum number n are said to form a shell. Proceeding from the nucleus outwards the shells are called K, L, etc. Thus if $n = 1, 2, 3, 4, 5, 6, 7$ the shell is the K, L, M, N, O, P and Q respectively. This nomenclature had its origin in X-ray spectroscopy in which a K series line is due to an electron transition from an outer to a K shell.

Sub-Groups. The electrons in a shell are arranged (according to convenient terminology) in sub-shells as shown below, where it is shown that L has 3, M has 5, N has 7, O has 5 and P has 5 sub-shells. The electrons in one sub-shell have the same energy, and the differences in the energy levels of the various sub-shells determine the frequency of the X-ray lines emitted by an atom.

Quantum Numbers. Quantum numbers used in the specification of the angular momentum of individual electrons and the assemblage of electrons in an atom are a development of those introduced by Bohr.

ARRANGEMENT OF ELECTRONS IN ATOMS (*contd.*)

Principal quantum number n in Bohr's theory of the H atom is $ma^2\omega = n\hbar$, and this leads to $a_n = (\hbar^2/me^2Z)n^2 =$ const. n^2, where a_n is the radius of the nth orbit, and T_n (Kinetic Energy) $= (\frac{1}{2}me^4Z^2/\hbar^2) \,.\, 1/n^2$, where $\hbar = h/2\pi$, h being Planck's constant.

Reduced quantum number l. $l = k - 1$, where k is the azimuthal quantum number and is introduced to quantize the angular momentum of the electron in the elliptic orbit. $k/n =$ minor axis/major axis of an orbit.

Spin quantum number s. The angular momentum of the spin of the electron is expressed $s\hbar = \frac{1}{2}\hbar$, and therefore $s = \frac{1}{2}$, and its contribution to the total angular momentum is $s = \frac{1}{2}$.

Inner quantum number $j = l + s$ is the angular momentum of a single electron where l and s are vectors. $j\hbar$ is the resultant angular momentum of the electron.

Pauli Exclusion Principle states that no two electrons can have all their four quantum numbers the same.

From the chemical property of the elements as shown in the periodic law, from interpretation of optical and X-ray spectra, and the vector theory of the hydrogen type of atom the electron structure of atoms given below has been deduced. The numerical distribution of electrons in shells of 2, 8, 18, 32, 18 which has been evident for some time is now accounted for by the system of quantum numbers.

Symbols for electrons and spectral terms. The symbols $s = 0$, $p = 1$, $d = 2$, $f = 3$, $g = 4$, $h = 5$, $i = 6$, $k = 7$ . . . are used to denote the value of l. This convention has its origin in Rydberg's formula for the sharp, principal, diffuse, and fundamental series of the alkali spectra. The value of the principal quantum number n is put in front of the symbol, *e.g.* $5d$ represents an electron where $n = 5$. When several electrons have the same values of n and l their number is denoted by a superscript, *e.g.* $2p^3$ represents 3 electrons having $n = 2$, $l = 1$.

Spectral Terms. In several electron configurations, S is the vector sum of their spin moments s. L is the vector sum of their orbital angular momenta. Both L and S couple together to form J. This form of coupling is called Russell-Saunders coupling. As the spin for each electron is $s = \frac{1}{2}$, the resultant spin for x electrons can have all values up to $x/2$, differing by unity. L is obtained by combining two l's and then combining their resultant with a third, etc.

For L . .	0	1	2	3	4	5	6	7 . . .
Symbol .	S	P	D	F	G	H	I	K . . .

There are (2S + 1) values of J provided L $\geqslant$ S and the number (2S + 1) is added as a superscript to the left side of the symbol representing L. The values of J are added as subscripts, *e.g.* ^{3}D is a spectral term having S = 1, L = 2. Possible values of J are 1, 2, 3. The symbol for the energy levels are $^3D_1$, $^3D_2$, $^3D_3$.

References:—Bohr, "Application of Quantum Theory of Atomic Structure," *Camb. Phil. Soc.*, 1924; Stoner, "Distribution of Electrons among Atomic Levels," *Phil. Mag.*, 1924; Main-Smith, "Chemistry and Atomic Structure," 1924; Bacher and Goudsmit, "Atomic Energy States" (1932); White, "Introduction to Atomic Spectra" (1934); Richtmeyer, "Introduction to Modern Physics" (1934).

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ARRANGEMENT OF ELECTRONS IN ATOMS (*contd*).

POSSIBLE STATES OF A ONE-ELECTRON SYSTEM.

Principal quantum number n	1	2			3					4						
Orbital angular momentum l	0	0	1	1	0	1	1	2	2	0	1	1	2	2	3	3
Total angular momentum j	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{1}{2}$
Magnetic quantum number m	$+\frac{1}{2}$ $-\frac{1}{2}$	$+\frac{1}{2}$ $-\frac{1}{2}$	$+\frac{1}{2}$ $-\frac{1}{2}$	$+\frac{3}{2}$ to $-\frac{3}{2}$	$+\frac{1}{2}$ $-\frac{1}{2}$	$+\frac{1}{2}$ $-\frac{1}{2}$	$+\frac{3}{2}$ to $-\frac{3}{2}$	$+\frac{3}{2}$ to $-\frac{3}{2}$	$+\frac{5}{2}$ to $-\frac{5}{2}$	$+\frac{1}{2}$ $-\frac{1}{2}$	$+\frac{1}{2}$ $-\frac{1}{2}$	$+\frac{3}{2}$ to $-\frac{3}{2}$	$+\frac{3}{2}$ to $-\frac{3}{2}$	$+\frac{5}{2}$ to $-\frac{5}{2}$	$+\frac{5}{2}$ to $-\frac{5}{2}$	$+\frac{1}{2}$ to $-\frac{1}{2}$
Number of states	2	2	2	4	2	2	4	4	6	2	2	4	4	6	6	8
Total number of states	2	8			18					32						
Shell	K	L			M					N						
Sub-groups		I	II	III	I	II	III	IV	V	I	II	III	IV	V	VI	VII

THE DISTRIBUTION OF ELECTRONS IN ORBITS CHARACTERIZED BY TOTAL QUANTUM NUMBER n

	$n=$ 1	2	3	4
Period I				
1 H	1			
2 He	2			
Period II				
3 Li	2	1		
4 Be	2	2		
5 B	2	3		
6 C	2	4		
7 N	2	5		
8 O	2	6		
9 F	2	7		
10 Ne	2	8		
Period III				
11 Na	2	8	1	
12 Mg	2	8	2	
13 Al	2	8	3	
14 Si	2	8	4	
15 P	2	8	5	
16 S	2	8	6	
17 Cl	2	8	7	
18 Ar	2	8	8	
Period IV				
19 K	2	8	8	1
20 Ca	2	8	8	2
21 Sc	2	8	9	2
22 Ti	2	8	10	2
23 V	2	8	11	2
24 Cr	2	8	13	1
25 Mn	2	8	13	2
26 Fe	2	8	14	2
27 Co	2	8	15	2
28 Ni	2	8	16	2
29 Cu	2	8	18	1
30 Zn	2	8	18	2

	$n=$ 1	2	3	4	5	6
Period IV (*contd.*)						
31 Ga	2	8	18	3		
32 Ge	2	8	18	4		
33 As	2	8	18	5		
34 Se	2	8	18	6		
35 Br	2	8	18	7		
36 Kr	2	8	18	8		
Period V						
37 Rb	2	8	18	8	1	
38 Sr	2	8	18	8	2	
39 Y	2	8	18	9	2	
40 Zr	2	8	18	10	2	
41 Nb	2	8	18	12	1	
42 Mo	2	8	18	13	1	
43 Ma	2	8	18	14	1	
44 Ru	2	8	18	15	1	
45 Rh	2	8	18	16	1	
46 Pd	2	8	18	18		
47 Ag	2	8	18	18	1	
48 Cd	2	8	18	18	2	
49 In	2	8	18	18	3	
50 Sn	2	8	18	18	4	
51 Sb	2	8	18	18	5	
52 Te	2	8	18	18	6	
53 I	2	8	18	18	7	
54 Xe	2	8	18	18	8	
Period VI						
55 Cs	2	8	18	18	8	1
56 Ba	2	8	18	18	8	2
57 La	2	8	18	18	9	2
58 Ce	2	8	18	19	9	2
59 Pr	2	8	18	20	9	2
60 Nd	2	8	18	21	9	2
61 Il	2	8	18	22	9	2
62 Sa	2	8	18	23	9	2

	$n=$ 1	2	3	4	5	6	7
Period VI (*contd.*)							
63 Eu	2	8	18	24	9	2	
64 Gd	2	8	18	25	9	2	
65 Tb	2	8	18	26	9	2	
66 Dy	2	8	18	27	9	2	
67 Ho	2	8	18	28	9	2	
68 Er	2	8	18	29	9	2	
69 Tu	2	8	18	30	9	2	
70 Yb	2	8	18	31	9	2	
71 Lu	2	8	18	32	9	2	
72 Hf	2	8	18	32	10	2	
73 Ta	2	8	18	32	11	2	
74 W	2	8	18	32	12	2	
75 Re	2	8	18	32	13	2	
	2	8	18	32	14	1	
76 Os	2	8	18	32	14	2	
	2	8	18	32	15	1	
77 Ir	2	8	18	32	15	2	
	2	8	18	32	16	1	
78 Pt	2	8	18	32	17	1	
	2	8	18	32	18		
79 Au	2	8	18	32	18	1	
80 Hg	2	8	18	32	18	2	
81 Tl	2	8	18	32	18	3	
82 Pb	2	8	18	32	18	4	
83 Bi	2	8	18	32	18	5	
84 Po	2	8	18	32	18	6	
85 —	2	8	18	32	18	7	
86 Rn	2	8	18	32	18	8	
Period VII							
87 —	2	8	18	32	18	8	1
88 Ra	2	8	18	32	18	8	2
89 Ac	2	8	18	32	18	9	2
90 Th	2	8	18	32	18	10	2
91 Pa	2	8	18	32	18	11	2
92 U	2	8	18	32	18	12	2

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RESONANCE AND IONIZATION POTENTIALS

When an electron collides with an atom of gas for relative velocities below a certain value, the collision is elastic and the electron rebounds from the atom, but for higher velocities there is an absorption by the atom of the energy of the electron. In general there are two types of inelastic collision, one in which an electron in the atom undergoes an interorbital transition and the other in which an electron is removed from the atom. The work done, measured in electron volts, to ionize the atom is the *ionization potential*, and similarly the work to displace the electron is the *resonance potential*. The *first or principal ionizing potential* is the energy necessary to remove an electron from the lowest state of the atom so as to produce the lowest state of the ion from which it is built, *e.g.* the energy required to remove one of the electrons from the lowest state ($1\ S^2\ {}^1S_0$) of the helium atom is the first ionizing potential of helium. The *second ionizing potential* is the work done in removing the second electron in its lowest state from the atom. That is, for example, the work done in removing the remaining $1\ S\ {}^2S_{\frac{1}{2}}$ electron from the helium atom. Ionizing potentials can be determined (1) by direct observation of the potential required to produce ionization, and (2) indirectly by determining from the convergence limit of the optical spectra the amount of energy given out when an electron drops from infinity to the normal position of the valence electron. $Ve = (c^2h/10^8)\nu$ volt e.s.u., where ν cm.$^{-1}$ is the wave number of the spectral line, *i.e.* $V = 1{\cdot}2385 \times 10^{-4} \times \nu$ volt. Values given in the following table have been calculated by this method.

The meaning of the symbols is given on p. 124, under "Spectral Terms."

References:—Richtmeyer, "Introduction to Modern Physics"; Bacher and Goudsmit, "Atomic Energy States."

FIRST IONIZATION POTENTIALS AND LOWEST SPECTRAL TERMS OF THE ELEMENTS

	Ion. Pot.	Term.		Ion. Pot.	Term.		Ion. Pot.	Term.		Term.		Term.
H	13·584	${}^2S_{\frac{1}{2}}$	Ca	6·11	${}^1S_0$	Y	6·5	${}^2D_{\frac{3}{2}}$	Ce	${}^3H_4$	Os	${}^5D_4$
He	24·564	${}^1S_0$	Sc	6·7	${}^2D_{\frac{3}{2}}$	Zr	6·94	${}^3F_2$	Pr	${}^4K_{\frac{11}{2}}$	Os	${}^5F_5$
Li	5·39	${}^2S_{\frac{1}{2}}$	Ti	6·83	${}^3F_2$	Cb		${}^6D_{\frac{1}{2}}$	Nd	${}^5L_6$	Ir	${}^4F_{\frac{9}{2}}$
Be	9·32	${}^1S_0$	V	6·78	${}^4F_{\frac{3}{2}}$	Mo	7·37	${}^7S_3$	Il	${}^6L_{\frac{11}{2}}$	Pt	${}^3D_3$
B	8·31	${}^2P_{\frac{1}{2}}$	Cr	6·76	${}^7S_3$	Ma		${}^6D_{\frac{9}{2}}$	Sa	${}^7K_4$	Pt	${}^1S_0$
C	11·27	${}^3P_0$	Mn	7·43	${}^6S_{\frac{5}{2}}$	Ru		${}^5F_5$	Eu	${}^8H_{\frac{3}{2}}$	Au	${}^2S_{\frac{1}{2}}$
N	14·54	${}^4S_{\frac{3}{2}}$	Fe	7·85	${}^5D_4$	Rh	7·7	${}^4F_{\frac{9}{2}}$	Gd	${}^9D_2$	Hg	${}^1S_0$
O	13·60	${}^3P_2$	Co	8·5	${}^4F_{\frac{9}{2}}$	Pd	8·3	${}^1S_0$	Tb	${}^8H_{\frac{17}{2}}$	Tl	${}^2P_{\frac{1}{2}}$
F	18·67	${}^2P_{\frac{3}{2}}$	Ni	7·63	${}^3F_4$	Ag	7·56	${}^2S_{\frac{1}{2}}$	Dy	${}^7K_{10}$	Pb	${}^3P_0$
Ne	21·56	${}^1S_0$	Cu	7·70	${}^2S_{\frac{1}{2}}$	Cd	8·98	${}^1S_0$	Ho	${}^6L_{\frac{21}{2}}$	Bi	${}^4S_{\frac{3}{2}}$
Na	5·14	${}^2S_{\frac{1}{2}}$	Zn	9·38	${}^1S_0$	In	5·78	${}^2P_{\frac{1}{2}}$	Er	${}^5L_{10}$	Po	${}^3P_2$
Mg	7·64	${}^1S_0$	Ga	5·99	${}^2P_{\frac{1}{2}}$	Sn	7·32	${}^3P_0$	Tu	${}^4K_{\frac{17}{2}}$	—	${}^2P$
Al	5·98	${}^2P_{\frac{1}{2}}$	Ge	8·11	${}^3P_0$	Sb	8·5	${}^4S_{\frac{3}{2}}$	Yb	${}^3H_6$	Rn	${}^1S_0$
Si	8·15	${}^3P_0$	As	10	${}^4S_{\frac{3}{2}}$	Te		${}^3P_2$	Lu	${}^2D_{\frac{3}{2}}$	—	${}^2S_{\frac{1}{2}}$
P		${}^4S_{\frac{3}{2}}$	Se	9·5	${}^3P_2$	I	10	${}^2P_{\frac{3}{2}}$	Hf	${}^3F_2$	Ra	${}^1S_0$
S	10·3	${}^3P_2$	Br	11·85	${}^2P_{\frac{3}{2}}$	Xe	12·127	${}^1S_0$	Ta	${}^4F_{\frac{3}{2}}$	Ac	${}^2D_{\frac{3}{2}}$
Cl	13·01	${}^2P_{\frac{3}{2}}$	Kr	14·00	${}^1S_0$	Cs	3·88	${}^2S_{\frac{1}{2}}$	W	${}^5D_0$	Th	${}^3F_2$
A	15·75	${}^1S_0$	Rb	4·176	${}^2S_{\frac{1}{2}}$	Ba	5·21	${}^1S_0$	Re	${}^6S_{\frac{5}{2}}$	Pa	${}^4F_{\frac{3}{2}}$
K	4·34	${}^2S_{\frac{1}{2}}$	Sr	5·690	${}^1S_0$	La		${}^2D_{\frac{3}{2}}$	Re	${}^6D_{\frac{9}{2}}$	U	${}^5D_0$

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ELECTRONIC CHARGE

Historical.—The electronic charge, e e.s.u., was measured in 1897 by J. S. Townsend, and in 1898 by J. J. Thomson by finding the average charge in a cloud of drops. The total charge was found, and Stokes's law applied to obtain the average size and total number of drops. H. A. Wilson (1903) pointed out that if v_1 is the velocity of a drop falling freely, and v_2 its velocity when acted upon by a vertical electric field (X), then

$$\tfrac{4}{3}\pi a^3(\rho - \sigma)g = 6\pi\eta v_1 a, \text{ and}$$

$$neX = 6\pi\eta(v_2 - v_1)a = \{162\ \pi^2\eta^3 v_1(v_2 - v_1)^2/(\rho - \sigma)g\}^{\frac{1}{2}}$$

where ne is the charge of the drop.

ELECTRONIC CHARGE (*contd*).

Rutherford and Geiger (1908) counted the number, and measured the charge of a beam of α-rays. Regener, counting scintillations of α-rays, found in a similar experiment, $e = 4{\cdot}79 \times 10^{-10}$. Perrin's (1908) observations of colloid particles verified Einstein's expression for Brownian motion, and gave Avogadro's number. Millikan, in 1917, applying Wilson's theory to single oil drops and correcting for the departure from Stokes's law, found $e = 4{\cdot}774 \times 10^{-10}$ e.s.u., but Bäcklin, in 1928, using a ruled grating to measure the wavelength of X-rays, found $e = 4{\cdot}794 \times 10^{-10}$. This difference and other developments have given rise to much recent discussion of the fundamental atomic constants.

References :—Birge, "General Physical Constants," 1929.

Precision Determinations—Oil Drop Method.—The values of e tabulated below are calculated for $\eta_{23} = (1830 \pm 2{\cdot}5) \cdot 10^{-7}$ gm. cm.^{1} sec.$^{-1}$ for the viscosity of air at 23° C. This is a weighted mean of nine recent determinations. The uncertainty in η gives rise to the main uncertainty in e measured by the oil drop method. The second entry below is found by a method in which the oil drop is laterally deflected by a horizontal electric field. The probable errors given are those of a_{01} in $y = a_{11}x + a_{01}$ calculated by least square theory.

Oil drop method : **Mean value $e = 4{\cdot}804 \times 10^{-10}$ e.s.u.**

Observers.	$e \cdot 10^{10}$ e.s.u.	Observers.	$e \cdot 10^{10}$ e.s.u.
Millikan, 1917 . . .	4·799±0·004	Ishida and others, 1937 . .	4·835
Laby and Hopper, 1940	4·802±0·001	Bäcklin and Flemberg, 1936	4·781±0·018

X-ray Method.—The wavelength, $\lambda_c \cdot 10^{-11}$ cm., of an X-ray line is measured using a ruled grating. Its wavelength, λ_gX unit, is also measured using a crystal grating, where the X unit is defined to be 1/3029·45 of the (100) grating space of calcite at 18° C. $\lambda_c \cdot 10^{-11}$ cm. $= \lambda_g \cdot$ XU, therefore $\lambda_c/\lambda_g = 1\text{XU}/10^{-11}$ cm.

The mass of unit rhombohedron cell of a crystal is $d_{18}\phi(\beta)\rho_{18}$. It is also half the mass of the molecule of the crystal $= \text{M}/2\text{N} = \text{M}e/2\text{F}$, where ρ_{18} is the density and d_{18} the grating space of the crystal, N number of molecules per mole, F the Faraday. Therefore

$$e = 2d_{18}^{3}\phi(\beta)\rho_{18}\text{F}/\text{M}$$

If $d_{18} = 3029{\cdot}45 \times 10^{-11}$ cm., then 1 XU $= 10^{-11}$ cm. and $\lambda_c/\lambda_g = 1$ and $e_0 = 4{\cdot}77306 \times 10^{-10}$ e.s.u., and $e = e_0(\lambda_g/\lambda_c)^3$.

Mean value $e = (4{\cdot}804_4 \pm 0{\cdot}0007) \cdot 10^{-10}$ e.s.u.

Observer.	X-ray line.	λg.	λc.	$\lambda g/\lambda c$.	e e.s.u.
Soderman . . .	Al K∝12	8340·1	8321·35	1·00225	$4{\cdot}805 \times 10^{-10}$
Bäcklin . . .	Al K∝12	8339·5	8321·35	1·00218	$4{\cdot}804 \times 10^{-10}$
Bearden, 1935 .	Cu K∝1	1540·6	1539·397	1·00208	$4{\cdot}803 \times 10^{-10}$
,, 1931 .	Cu K, Cr K	—	—	1·00222	4·805

Mean of oil drop and X-ray methods $e = 4{\cdot}804 \times 10^{-10}$ e.s.u.

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SPECIFIC CHARGE OF THE ELECTRON

e/m for the electron. Methods : **Magnetic** and **electrostatic** deflection give relations of the form $mv/e = \text{H}\rho$ and $\frac{1}{2}mv^2/e = \text{XR}$, which are solved for e/m.

Spectroscopic methods. **Zeeman effect** $e/m = 4\pi c \cdot \Delta\lambda/\text{H}\lambda^2\mu$, where $\Delta\lambda$ is the separation of the components of a triplet in magnetic field H oersted.

Rydberg constant of the atomic spectra can be found with high accuracy. $e/m = \text{F} \cdot \text{R}_{\text{H}}(\text{M}_{\text{He}} - \text{M}_{\text{H}} - m)/(\text{R}_{\text{He}} - \text{R}_{\text{H}})(\text{M}_{\text{He}} - m)(\text{M}_{\text{H}} - m)$ where F e.m.u. (gm. equiv.)$^{-1}$, R cm.$^{-1}$, Rydberg's constants for H and H*e* and M is the mass of the H and He atoms, and m that of the electron relative to $\text{O}^{16} = 16$.

SPECIFIC CHARGE OF THE ELECTRON (*contd.*)

Mean value of e/m = ($1{\cdot}7589_0 \pm {\cdot}0005$) . 10^7 e.m.u.

Author.	Date.	Method.	e/m × 10^{-4}.	Author.	Date.	Method.	e/m × 10^{-4}.
Houston .	1927	He—H	1760·1±·8	Babcock .	1923	Zeeman	1760·5±1·2
S. and S.	1935	H—D	1758·1±·4	P. and Ch.	1930	Defn.	1761·0±1·0
Williams .	1938	H—D	1757·9±·4	Kirchner .	1932	,,	1758·8± ·9
K. and H.	1934	Zeeman	1756·9±·7	Dunnington	1937	,,	1759·7± ·4
				Shaw . .	1938	,,	1757·1±1·3

S. and S., Shane and Spedding ; K. and H., Kinsler and Houston ; P. and Ch., Perry and Chaffee.

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PLANCK'S CONSTANT *h*

Planck's theory postulates that light of frequency, ν sec.$^{-1}$, is emitted in quanta of energy $h\nu$ erg.

In experimental determinations of h the quantity measured A_1 . . . etc., is a function of the natural constants, e, m and h. Thus $A_1 = h/e$, $A_2 = h/(em)^{\frac{1}{2}}$, $A_3 = h/m$, $A_4 = e^2/hm$, $A_5 = me^4/h^3$, $A_6 = e^4/h^3$, $A_7 = e^2/h$. (See J. Du Mond, *Phys. Rev.*, 56, 1939.)

1. High Frequency Limit of X-ray Spectrum h/e.—The highest frequency ν of the continuous X-ray spectrum emitted by an X-ray tube to which a potential V is applied is $h\nu = \mathrm{V}e$ by Einstein's photoelectric equation. Since

$$\nu\lambda = c \text{ and } n\lambda = 2d_n \sin\theta_n$$

$$h/e = 2\mathrm{V}d_n \sin\theta_n/cn, \text{ where } \theta_n \text{ is}$$

the angle of diffraction of the X-rays by a crystal. A number of precision measurements have been made by this method.

2. Photoelectric effect h/e.—Einstein's equation for the kinetic energy, $\frac{1}{2}mv^2$ erg, of a photoelectron ejected by light of frequency, ν sec.$^{-1}$, is $\mathrm{V}e = \frac{1}{2}mv^2 = h\nu - \omega_0$, where ω_0 is the work done by the electron in passing through the surface of the metal from which it is ejected, and V e.s.u. is the retardation potential of the ejected electron. $\mathrm{V}e$ plotted against ν gives a straight line of slope h.

3. Excitation Potential h/e.—When an electron of energy, $\mathrm{V}e$, collides with an atom (if the energy of the electron is sufficient) it may be absorbed by and excite the atom, which emits a light quantum, $h\nu$.

$$h\nu = \mathrm{V}e \text{ and } h/e = \mathrm{V}/\nu.$$

Thermal Radiation Constants.—Planck's law for the radiation (see p. 75) may be written

$$\mathrm{E}_{\lambda\mathrm{T}} = c_1\lambda^{-5}/(e^{c_2/\lambda\mathrm{T}} - 1)$$

where $c_1 = 2\pi c^2 h$, and $c_2 = ch/k = ch\mathrm{F}/\mathrm{R}e$. R = gas constant, F = faraday.

4. Wien's Law h/e. $\lambda_m\mathrm{T} = \text{const.}$—Equating to zero the derivative with respect to λ of Planck's expression

$$\lambda_m\mathrm{T} = c_2/5(1 - e^{-c_2/\lambda_m\mathrm{T}}).$$

The solution of this equation is $c_2 = 4{\cdot}965\lambda_m\mathrm{T}$. By observation $\lambda_m\mathrm{T} = {\cdot}2892$ cm. deg. and $c_2 = 1{\cdot}4361$. Therefore

$$h/e = 1{\cdot}4361\ \mathrm{R}/\mathrm{F}c.$$

5. Stefan-Boltzmann's Law e^4/h^3.—Integrating Planck's equation with respect to λ, Stefan's constant is

$$\sigma = (\pi^4/15)\,.\,(c_1/c_2^4) = 40{\cdot}803\ \mathrm{R}^4e^4/(\mathrm{F}^4h^3c^2)$$

and therefore $e^4/h^3 = {\cdot}0245\sigma c^2\mathrm{F}^4/\mathrm{R}^4$.

By observation $\sigma = 5{\cdot}75\,.\,10^{-5}$ erg. cm.$^{-2}$ sec.$^{-1}$. (See Wensel, *J. Res. Nat. Bur. St.*, 1939).

PLANCK'S CONSTANT *h* (*contd.*)

6. Compton Scattering of X-rays h/m.—The change of wavelength of X-rays when they are scattered in a direction making an angle θ with their initial direction by a free electron is

$$\Delta\lambda = h(1 - \cos\theta)/mc.$$

$\Delta\lambda$ and θ are observed.

7. X-ray Photoelectrons e^2/hm.—X-rays of known energy $h\nu_2$ incident on an atom eject photoelectrons from an electron shell in the atom of energy $h\nu_1$. The kinetic energy of the ejected electron is

$$\tfrac{1}{2}mv^2 = h\nu_2 - h\nu_1.$$

Its momentum is measured by magnetic deflection, and $mv/e = \mathrm{H}\rho$. Therefore

$$e^2/hm = 2(\nu_2 - \nu_1)/(\mathrm{H}\rho)^2.$$

8. Rydberg's Constant $\mathbf{R}_\infty$ me^4/h^3.—Rydberg's constant in Bohr's expression for the frequency of the lines in a hydrogen type of spectrum of an atom of large mass is

$$\mathrm{R}_\infty = 2\pi^2 me^4/ch^3$$

and $\mathrm{R_A}$ for an atom of mass $\mathrm{M_A}$ is $\mathrm{R_A} = \mathrm{R}_\infty/(1 + m/\mathrm{M_A})$, where m is the mass of the electron.

R for $\mathrm{H}^1 = 109677{\cdot}76$, R, $\mathrm{H}^2 = 109707{\cdot}39$, R, $\mathrm{H}e = 109722{\cdot}40$, $\mathrm{R}_\infty = 109737{\cdot}42$ cm.$^{-1}$. The value of h calculated from R_∞ is higher than that obtained by other methods. The difference is unexpectedly large.

9. Electron Diffraction $h/(em)^{\frac{1}{2}}$.—Electrons of energy, Ve erg, produced by the action of an accelerating potential, V, have a wavelength,

$$\lambda = h/mv = h\Big/\left\{2\,em_0\mathrm{V}\left(1 + \frac{e\mathrm{V}}{2m_0c^2}\right)\right\}^{\frac{1}{2}}$$

which is measured by diffraction in a crystal. m_0 is the rest mass, and mv the momentum of the electron.

10. Electron Diffraction h/m.—The velocity and wavelength of the electron are measured. $\lambda = h/mv$ and $n\lambda = 2a \sin\theta_n$.

Omitting the value of h by Rydberg's constant the weighted mean is $6{\cdot}615 \pm {\cdot}005 \times 10^{-27}$. The mean of this and $6{\cdot}630 \pm {\cdot}002 \times 10^{-27}$ is taken as the value of h, *i.e.* $h = 6{\cdot}622 \pm {\cdot}007 \times 10^{-27}$ erg. sec. In the following table, the value of e is taken as $4{\cdot}805 \times 10^{-10}$ e.s.u.

Method.	Observers.	Date.	A$_n$.	$h \times 10^{27}$.
X-ray . . .	Duane, Palmer and Yeh	1921	$h/e\ 1{\cdot}3752 \times 10^{-17}$	$6{\cdot}608 \pm {\cdot}004$
,, . . .	Feder	1929	$h/e\ 1{\cdot}3763 \times 10^{-17}$	$6{\cdot}613 \pm {\cdot}004$
,, . . .	Kirkpatrick and Ross	1934	$h/e\ 1{\cdot}3756 \times 10^{-17}$	$6{\cdot}610 \pm {\cdot}001$
,, . . .	Schaitberger	1935	$h/e\ 1{\cdot}3777 \times 10^{-17}$	$6{\cdot}620 \pm {\cdot}004$
,, . . .	Bollman and Du Mond	1937	$h/e\ 1{\cdot}3765 \times 10^{-17}$	$6{\cdot}614 \pm {\cdot}002$
Excitatn. Potl.	—	'26–'35	$h/e\ 1{\cdot}375 \times 10^{-17}$	$6{\cdot}607 \pm {\cdot}007$
Photo. Effect .	—	'28–'30	$h/e\ 1{\cdot}374 \times 10^{-17}$	$6{\cdot}602 \pm {\cdot}012$
Radiation . .	Wensel (summary)	1939	$h^3/e^4\ 5{\cdot}439 \times 10^{-42}$	$6{\cdot}617 \pm {\cdot}003$
,, . .	,, ,,	1939	$h/e\ 1{\cdot}377 \times 10^{-17}$	$6{\cdot}617 \pm {\cdot}003$
Electron Diff. .	Sten von Frieson	1935	$h/(em)^{\frac{1}{2}}\ 1{\cdot}0006 \times 10^{-8}$	$6{\cdot}621 \pm {\cdot}007$
,, ,, .	Gnan	1934	$h/m\ 7{\cdot}25$	$6{\cdot}607 \pm {\cdot}03$
Compton effect	Ross and Kirkpatrick	1934	$h/m\ 7{\cdot}26$	$6{\cdot}616 \pm {\cdot}01$
Photoelectron .	Robinson	1936	$e^2/mh\ 3{\cdot}823 \times 10^{34}$	$6{\cdot}627 \pm {\cdot}01$
Rydberg const.	—	1940	$me^4/h^3\ 1{\cdot}6665 \times 10^{14}$	$6{\cdot}630 \pm {\cdot}002$

References:—Du Mond, *Phys. Rev.*, 1939; Birge, *Rev. Mod. Phys.*, 1929; Ladenburg, *Ann. d. Phys.*, 1936; Wensel, *Journ. of Res. N.B.S.* (1939).

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PHYSICAL CONSTANTS OF CHEMICAL COMPOUNDS

For properties of the **elements**, see: density, p. 29; melting and boiling points, p. 58. **Metallo-organic** compounds are given under "Organic Compounds," p. 139.

Formulæ.—Hydrated forms (which are often crystalline) are indicated thus: CaI_2(and $+6H_2O$); the properties given are for the anhydrous substance.

Formula (Molecular) Weights are calculated with atomic weights for 1920–21, except in the case of nitrogen where N = 14·01 is used.

Densities.—When no temp. is given, grams. per c.c. at 15° may be assumed. When preceded by "A" the numbers in this column are molecular weights calculated from observed densities relative to air of the substance in the vapour state, using the relation: molecular wgt. = 28·95 density rel. to air. For those gaseous densities known with accuracy, see p. 35. Other densities on pp. 29–35.

Melting and Boiling Points are for anhydrous substances at 760 mms. mercury unless some other conditions are specified. T = temp. of transition or pseudo-"melting" point of hydrated substance.

Solubilities are given as grams of substance in 100 grams of water at the temp. stated. "*p*" indicates grams per 100 grams of solution. "V" means volumes of substance at 0° and 760 mms. per 100 volumes of water at the temp. stated. "Soluble" infers solubility in either hot or cold water; "insoluble" indicates solubility in neither. (See also pp. 145, 146.)

For more complete tables, see Van Nostrand's "Chemical Annual" and Biedermann's "Chemiker-Kalender" for current year; Dammer's "Handbuch der Anorganischen Chemie;" Beilstein's "Handbuch der Organischen Chemie;" Watts' "Dictionary of Chemistry:" F. W. Clarke's "Specific Gravities," and "International Critical Tables," Vol. I.

INORGANIC COMPOUNDS

Substance and Formula.	**Formula weight (0 = 16).**	**Density, gms./c.c.**	**Melting Point, ° C.**	**Boiling Point, ° C.**	**Solubility in Water.**
Aluminium—		at. /temp.	at. /mms.	at./mms.	at. /temp.
bromide, Al_2Br_6(and $+ 12H_2O$)	533·72	2·54; A. 539	97·5°	263°/747	soluble
chloride, Al_2Cl_6(and $+ 12H_2O$)	266·96	A. 270/400°	190°/1910	182·7°/752	69/15°(*p*)
iodide, Al_2I_6 (and $+ 12H_2O$) .	815·72	3·98; A.781·6	191°	360°	soluble
nitrate, $Al(NO_3)_3 . 9H_2O$ . .	375·3	—	T = 73°	dec. 134°	v. soluble
oxide, Al_2O_3	102·2	3·7 − 4	2200°	—	insoluble
phosphate, $AlPO_4$	122·1	2·59	infusible	—	insoluble
sulphate, $Al_2(SO_4)_3 . 18H_2O$.	666·7	1·62	dec. 770°	—	36/20°
Potassium alum, $Al_2(SO_4)_3K_2SO_4 . 24H_2O$	949·0	1·757/20°	84·5°	23H_2O at 190°	9·6/15° 357/100°
Ammonium—					
ammonia, NH_3	17·03	(liq.) ·623/0° A. 17·28	− 75·5°	−33·5°	see p. 145.
acetate, $NH_4C_2H_3O_2$ . . .	77·08	—	89°	—	148/4°
arsenate, $(NH_4)_3AsO_4 . 3H_2O$.	247·1	—	—	—	soluble
bromide, NH_4Br	97·96	2·33/15° A.47·5/440°	diss.	—	66/10° 128/100°
carbonate, $(NH_4)_2CO_3 . H_2O$	114·1	—	diss. 85°	—	100/15°
chloride, NH_4Cl	53·50	1·52/17° A. 25·7	diss. 350°	—	35/15°; see p. 146.
chloroplatinate, $(NH_4)_2PtCl_6$.	444·0	3·06	decomp.	—	·67/20°
chromate, $(NH_4)_2CrO_4$ . . .	152·2	1·88/11°	decomp.	—	decomp.
iodide, NH_4I	145·0	2·5	diss.	—	v. soluble
molybdate, $(NH_4)_2MoO_4$ . .	196·1	2·4—2·9	decomp.	—	decomp.
nitrate, NH_4NO_3.	80·05	1·72/15°	152°	dec. 210°	200/18°

dec. or decomp. = decomposes; diss. = dissociates; v. = very; wh. = white.

INORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	Formula weight (0 = 16).	Density, gms./c.c.	Melting Point, ° C.	Boiling Point, ° C.	Solubility in Water.
Ammonium (*contd.*)—		at./temp.	at./mms.	at./mms.	at./temp.
nitrite, NH_4NO_2	64·05	1·69	decomp.	—	soluble
oxalate, $(NH_4)_2C_2O_4 . H_2O$.	142·1	1·502	—	—	4/15°
persulphate, $(NH_4)_2S_2O_8$.	228·2	—	decomp.	—	58/0°
phosphomolybdate, $(NH_4)_3PO_4 . 12MoO_3 . 3H_2O$	193·1	—	—	—	·03/15°
sulphate, $(NH_4)_2SO_4$ . . .	132·14	1·77/20°	140° †	dec. 250° ‡	76/20°
sulphocyanate, NH_4CNS .	76·12	1·306/13°	159°	dec. 170°	162/20°
Antimony—					
bromide, $SbBr_3$	360·0	4·15/23°	94·2°	280°	decomp.
chloride, tri-, $SbCl_3$ . . .	226·6	306/26° A. 234	73·2°	223°	816/15° ∞/72°
,, penta-, $SbCl_5$ . .	297·5	2·35/20°	2·8°	102°/68	decomp.
hydride, SbH_3	123·2	A. 124·5/15°	− 91·5°	− 18°	20 V.
iodide, tri-, SbI_3	501·0	4·85/26° A. 509·5	170·8° subl. 114°	401°	decomp.
oxide, tri-, Sb_2O_3	288·4	5·2–5·7	red heat	1550°	·002/15°
,, tetr-, Sb_2O_4	304·4	4·07	O/800°	—	insoluble
,, pent-, Sb_2O_5 . . .	320·4	3·8	O/300°	O_2/800°	insoluble
potassium tartrate, $K(SbO)C_4H_4O_6 \cdot \frac{1}{2}H_2O$	332·36	2·6	½H_2O/100°	decomp.	5/9° 36/100°
sulphide tri-, Sb_2S_3 . . .	336·6	4·65	546°	volatilizes	insoluble
,, penta-, Sb_2S_5 . .	400·7	4·12/0°	fusible	—	insoluble
Arsenic—					
bromide, $AsBr_3$	314·7	3·66/15° A. 315·8	31°	221°	decomp.
chloride, $AsCl_3$	181·3	2·17/0°; A.182	− 18°	130·2°	decomp.
fluoride, tri-, AsF_3	132·0	2·7; A. 132	− 8·5°	63°	decomp.
,, penta-, AsF_5 . . .	170·0	—	− 80°	− 53°	soluble
hydride, AsH_3	77·98	A. 78	− 113·5°	− 54·8°	slgtly sol.
iodide, di-, AsI_2	328·8	—	—	—	—
,, tri-, AsI_3	455·7	4·4/13° A. 482	140·7	394–414°	30/100°
,, pent-, AsI_5	709·6	3·93	70°	—	decomp.
oxide, tri-, As_2O_3	197·9	3·86/25° A. 413	subl. 218°	—	1·7/16°
,, pent-, As_2O_5 . . .	229·9	3·9–4·2	red heat	decomp.	245/12°
Barium—					
bromide, $BaBr_2 . 2H_2O$ . .	333·2	3·85/24°	anhy. 880°	$2H_2O$/100°	103/15°
carbonate, $BaCO_3$	197·4	4·3	1360° *	diss. 1450°	·0022/18°
chloride, $BaCl_2 . 2H_2O$ . .	244·3	3·1/24°	anhy. 960°	—	see p. 146.
hydride, BaH_2	139·4	4·2/0°	1200°	1400°	decomp.
iodide, BaI_2	391·2	5·150/25°	740°	—	170/0°
nitrate, $Ba(NO_3)_2$	261·4	3·24/23°	575°	—	5/0°
oxide, BaO	153·4	4·7 − 5·5	BaO_2/450°	—	1·5/0°
,, per-, BaO_2	169·4	4·96	BaO/450°	—	insoluble
sulphate, $BaSO_4$	233·4	4·476, 4·33	1580°	—	·0$_3$23/18°
Beryllium—					
bromide, $BeBr_2$	168·9	—	601°	subl.	soluble
chloride, $BeCl_2$	80·02	—	400°	—	v. soluble
sulphate, $BeSO_4 . 4H_2O$ . .	177·2	1·7/10°	dec. r. ht.	$2H_2O$/100°	44/30°

anhy. = anhydrous; dec. or decomp. = decomposes; r. ht. = red heat; subl. = sublimes;
v. = very; ∞ = soluble in all proportions.

* basic 950° C. † M.P. of NH_4HSO_4. ‡ dec. without melting into NH_4HSO_4.

INORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	Formula weight (O=16).	Density, gms./c.c.	Melting Point, °C.	Boiling Point, °C.	Solubility in Water.
Bismuth—		at./temp.	at./mms.	at./mms.	at./temp.
bromide, $BiBr_3$	447·76	5·6	219°	453°	decomp.
chloride, tri-, $BiCl_3$	314·38	4·6/11°; A. 328	227°	429°	decomp.
nitrate, $Bi(NO_3)_3 . 5H_2O$	484·11	2·8	74°	$5H_2O$/80°	decomp.
oxide, Bi_2O_3	464·0	8·8 – 9	820–860°	—	insoluble
sulphide, Bi_2S_3	512·18	7 – 7·8	decomp.	—	insoluble
Boron—					
chloride, BCl_3	117·28	1·43/0° A. 115·8/17°	– 107°	18·2°	decomp.
fluoride, BF_3	67·9	A. 66·6	– 127°	– 101°	decomp.
oxide, B_2O_3	69·8	1·83/4°	577°	—	16/102°
Borax. *See* Sodium borate.					
Boric acid, H_3BO_3	61·9	1·43/15°	184–186°	H_2O/100°	4/18°
Cadmium—					
bromide, $CdBr_2$	272·24	4·7–4·9/14°	571°	806–812°	48·9/18° *p*.
chloride, $CdCl_2$	183·32	4·05/25°	568°	*c.* 900°	140/20°
nitrate, $Cd(NO_3)_2 4H_2O$	308·48	2·4	59·5°	T. 132°	127/18°
oxide, CdO	128·4	6·9–8·1	—	—	insoluble
sulphate, anhy. $CdSO_4$	208·46	4·7/15°	1000°	—	59/23°
„ hydr. $3CdSO_4 . 8H_2O$	769·51	3·05	—	—	see p. 146.
Cæsium—					
carbonate, Cs_2CO_3	325·62	—	< red heat	dec. 610°	v. soluble
chloride, $CsCl$	168·27	3·97/20°	646°	sublimes	174/10°
hydride, CsH	133·82	2·7	decomp.	—	decomp.
hydroxide, $CsOH$	149·82	4·02	<272·3°	—	soluble
nitrate, $CsNO_3$	194·82	3·636/22°	407°	decomp.	15/10°
Calcium—					
bromide, $CaBr_2$	199·91	3·34/20°	760	*c.* 800°	125/0°
carbonate, $CaCO_3$	100·07	2·7–2·9	dec. 825°	—	·0018 cold
chloride, anhy. $CaCl_2$	111·0	2·3/20°	780°	$4H_2O$/30°	63/10°
„ hydr. $CaCl_2 . 6H_2O$	219·1	1·65	29	$6H_2O$/200°	96/0°
hydride, CaH_2	42·08	1·7	—	—	decomp.
hydroxide, $Ca(OH)_2$	74·09	2·08	H_2O/580°	—	see p. 146.
iodide, CaI_2(and $+6H_2O$)	293·91	4·9/20°	740°	*c.* 710°	192/0°
nitrate, $Ca(NO_3)_2 4H_2O$	236·15	1·82	561°	—	54·8/18°
oxide, CaO	56·07	3·08	*c.* 2000°	—	·13/0°
phosphate, $Ca_3(PO_4)_2$	310·29	3·2	1550°	—	·003–·008
sulphate, $CaSO_4$	136·13	2·96	1360°	—	·18/0°
Carbon—					
Chloride, tetra-, CCl_4	153·84	1·5835/25°	– 23·8°	76·7°	insoluble
oxide, sub- (1906), C_3O_2	68·01	—	—	7°/761	*
„ mon-, CO	28·005	A. 28·001	– 207°/100	– 191·1°	see p. 145.
„ di-, CO_2	44·005	liq. ·772/20° †	– 65°	– 78·2°	see p. 145.
phosgene, $COCl_2$	98·93	1·432/0°	—	8·2°/756	—
sulphide, mono- CS	41·07	1·6–1·83	—	—	insoluble
„ bi-, CS_2	76·12	1·292/0°	– 110°	46·2°	·2/0°
Cerium—					
chloride (cerous), $CeCl_3$	246·63	3·88/15°·5	848°	—	soluble
oxide (cerous), Ce_2O_3	328·5	6·9–7	—	—	insoluble
„ (ceric), CeO_2	172·25	6·74	—	—	insoluble
sulphate (cerous), $Ce_2(SO_4)_3 8H_2O$	712·80	3·22	$8H_2O$/630°	—	16·5/0°
Chlorine—					
oxide, mon-, Cl_2O	86·92	liq. 3·87 A. 87·05	– 20°	– 5°	200V/0°

* Forms malonic acid. † Behn, *Ann. d. Phys.*, 1900. anhy. = anhydrous; dec. or decomp. = decomposes; hydr. = hydrated; liq. = liquid; v. = very.

INORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	Formula weight (0=16).	Density, gms./c.c.	Melting Point, °C.	Boiling Point, °C.	Solubility in Water.
Chlorine (*contd.*)—		at./temp.	at./mms.	at./mms.	at./temp.
oxide, di-, ClO_2	67·46	1·5 ; A. 66·58	− 76°	9·9°/731	20V/4°
Chromium—					
chloride (chromous), $CrCl_2$	122·92	2·75/14°	—	—	v. soluble
„ (chromic), $CrCl_3$	158·38	2·76/15° A. 318/1200°	—	*c.* 1300°	slgtly sol.
oxide, Cr_2O_3	152·0	5·04	*c.* 2060°	—	insoluble
„ tri-, CrO_3	100·0	2·74	190° §	decomp.	62·1/0°(*p*)
sulphate, $Cr_2(SO_4)_3 15H_2O$	662·42	1·867/17°	$15H_2O$/100°	—	120/20°
Cobalt—					
cobaltous chloride, $CoCl_2$(and $+6H_2O$)	129·9	2·94	subl. *c.* 87°	—	29·5/0°
„ hydrate, $Co(OH)_2$	93·02	3·6/15°	—	—	insoluble
„ oxide, CoO	74·98	5·7	2860°	—	insoluble
„ sulphate, $CoSO_4 . 7H_2O$	281·14	1·918/15°	96·8°	—	26/3°
cobaltic chloride, $CoCl_3$	165·35	2·94	sublimes	—	soluble
„ oxide, Co_2O_3	165·95	4·8 − 5·6	·895°	—	insoluble
„ sulphate, $Co_2(SO_4)_3$	406·12	—	—	—	soluble
Columbium. *See* Niobium.					
Copper—					
cuprous chloride, Cu_2Cl_2	198·06	3·7 A. 191/1690°	418°	*c.* 1000°	insoluble
„ oxide, Cu_2O	143·14	5·8–6·1	1210°		insoluble
cupric chloride, $CuCl_2$	134·49	3·05	498°	decomp.	75/17°
„ nitrate, $Cu(NO_3)_2 3H_2O$	241·64	2·17	114·5°	170° dec. r. ht.	60/25°(*p*)
„ oxide, CuO	79·57	6·30–6·43	1148°	—	insoluble
„ sulphate, $CuSO_4 5H_2O$	249·71	2·28/15°	$4H_2O$/100° $5HO_2$/240°	dec. r. ht.	see p.146.
Cyanogen, C_2N_2	52·03	liq. ·866/17° A. 52·32	− 39°	− 22°	4·5V/20°
Deuterium oxide, ^2H_2O	18·03	1·1056/20°	3·8°	101·42°	∞
Erbium—					
oxide, Er_2O_3	383·4	8·6	infusible	—	insoluble
sulphate, $Er_2(SO_4)_3$	767·71	3·18	dec. 950°	—	23/20°
Gadolinium—					
sulphate, $Gd_2(SO_4)_3$	602·78	4·14/15°	—	—	2·3/34°
Gallium—					
chloride, tri-, $GaCl_3$	176·48	A. 353/240°	75·5°	220°	decomp.
Germanium—					
chloride, tetra-, $GeCl_4$	214·34	1·89/18°	—	86°	decomp.
oxide, di-, GeO_2	104·5	4·70/18°	—	—	·4/20°
Glucinum. *See* Beryllium.					
Gold—					
chloride, $AuCl_3$	303·58	—	288° *	dec. 180°	68
Hydrazine, $NH_2 . NH_2$	32·05	1·01/15°	1·4°	113°	v. soluble
„ hydroxide, $NH_4 . H_2O$	50·07	1·030/21°	< − 40°	119°	v. soluble
Hydrobromic acid, HBr	80·93	2·157/-68·7° A. 80·77	− 86°	− 66·8°	221/0° 130/100°
Hydrochloric acid, HCl	36·47	·929/0° †	− 112°	− 84·1°	see p.145.
Hydrocyanic acid, HCN	27·02	·697/18°	− 13·8°	26·1	∞

* Under chlorine at 1520 mms. † Rupert, 1909. dec. or decomp. = decomposes ; § Moissan, 170–172° ; ∞ = soluble in all proportions.

INORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	**Formula weight (O = 16).**	**Density, gms./c.c.**	**Melting Point, ° C.**	**Boiling Point, ° C.**	**Solubility in Water.**
		at./temp.	at./mms.	at./mms.	at./temp.
Hydrofluoric acid, HF . . .	20·01	·988/15° A. 20·04	−83°	19·4°	111/35°
Hydriodic acid, HI	127·93	2·799/−35·7° A. 126·8	−50·6°	−35·6°	42,500 V/10°
Hydrogen—					
peroxide, H_2O_2	34·02	1·458/0°	−2°	80·2°/47	v. soluble
selenide, H_2Se	81·22	A. 81·20	−64°	−42°	331V/13°
sulphide, H_2S	34·08	liq. ·9 A. 34·10	−83·8°	−59·4°	305V/15° see p. 145.
telluride, H_2Te	129·52	A. 127·1	−48°	0	soluble
Hydroxylamine, NH_2OH . .	33·03	1·227/14°	33°	70°/60	soluble
Iodine—					
trichloride, ICl_3	233·3	3·11	33°	dec. 25°	soluble
Iodic acid, HIO_3	175·93	4·63/0°	½H_2O/170°	—	75/16° *p.*
Iron—					
carbonyl, $Fe(CO)_5$	195·86	1·4664/18° A. 188·2	−19·7°	102·7°/764	—
ferrous chloride, $FeCl_2$ . .	126·8	2·99/18°	—	volatilizes	50/19°
„ oxide, FeO	71·84	—	1419°	—	insoluble
„ sulphate, $FeSO_4.7H_2O$	278·01	1·8988/14·4°	64°	$6H_2O$/100°	20·8/10°
„ amm.sulphate, $FeSO_4$ $(NH_4)_2SO_4 6H_2O$	392·14	1·865/15°	—	—	18/0° 78/75°
oxide (magnetic), Fe_3O_4 . .	231·52	5–5·4	1538°	—	insoluble
ferric chloride, $FeCl_3$ . . .	162·22	2·804/10·8° A. 324·2/320°	301°	315°	537/100°
„ nitrate, $Fe(NO_3)_3 9H_2O$	404·01	1·683/20°	47·2°	decomp.	v. soluble
„ oxide, Fe_2O_3	159·68	5·2–5·3	—	—	insoluble
„ sulphate, $Fe_2(SO_4)_3$(and $+9H_2O$)	399·86	3·097/18°	—	—	v.slgt. sol.
Lead—					
acetate, $Pb(C_2H_3O_2)_2 . 3H_2O$	379·32	2·5	$3H_2O$/75°	280°	46/15°
carbonate, $PbCO_3$	267·20	6·43	—	—	decomp.
chloride, $PbCl_2$	278·12	5·873/15°	447°	*c.* 900	·7/0°
iodide, PbI_2	461·04	6·12	375°	861–954	·04/0°
oxide, mon- (litharge), PbO .	223·20	9·37, 8·74	877°	—	·002/20°
„ red lead, Pb_3O_4 . . .	685·6	9·09/15°	dc. 500°-530°	—	insoluble
„ per- (brown), PbO_2 .	239·2	8·91–9·5	decomp.	—	insoluble
sulphate, $PbSO_4$	303·26	6·23	937°	—	·004/18°
Lithium—					
carbonate, Li_2CO_3	73·88	2·11	618–710	—	see p. 146.
chloride, LiCl	42·40	2–2·07	614°	dec. w. ht.	72/0°
nitrate, $LiNO_3$	68·95	2·3–2·4	*c.* 258°	—	35/0°
oxide, Li_2O	29·88	2·10/15°	subl. 1000°	—	5/0°
phosphate, $Li_3PO_4 . H_2O$ . .	133·88	2·4/15°	857°	—	·04
sulphate, Li_2SO_4	109·94	2·21/15°	818–853°	—	26/0°
Magnesium—					
carbonate, $MgCO_3$	84·32	3·04	dec. 350°	—	·01
chloride, $MgCl_2 . 6H_2O$ . .	203·34	1·56/17°	$2H_2O$/100°	decomp.	54/20°
nitrate, $Mg(NO_3)_2 6H_2O$ . .	256·44	1·464	90°	$5H_2O$/330°	42/18° *p.*
oxide, MgO	40·32	3·2–3·7	*c.* 2800°	—	·001
phosphate, $Mg_3(PO_4)_2 . 4H_2O$	335·1	1·64/15°	—	—	·02
sulphate, $MgSO_4 . 7H_2O$ . .	246·49	1·678/16°	$5H_2O$/150°	—	27/0°

atm. = atmospheres ; dc., dec., or decomp. = decomposes ; liq. = liquid ; slgt. = slightly ;
v. = very ; w. ht. = white heat.

INORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	Formula weight (O = 16).	Density, gms./c.c.	Melting Point, ° C.	Boiling Point, ° C.	Solubility in Water.
Manganese—		at./temp.	at./mms.	at./mms.	at./temp.
carbonate, $MnCO_3$	114·93	3·1–3·7	decomp.	—	v. slgt. sol.
chloride, $MnCl_2 . 4H_2O$ . .	197·9	1·91	T. 87·6°	M.P. 650°	107/10°
nitrate, $Mn(NO_3)_2 . 6H_2O$.	287·05	1·82	T. 25·8°	—	54·5/11° *p*.
oxide, -ous, MnO	70·93	5·1	1500°	—	insoluble
„ -ic, Mn_2O_3	157·86	4·3–4·8	O, 1080°	—	insoluble
„ tetr-, Mn_3O_4	228·79	4·7–4·9	—	—	insoluble
„ di-, MnO_2	86·93	4·7–5·0	½ O, 535°	—	insoluble
sulphate,* $MnSO_4 4H_2O$ . .	223·05	2·1	18° and 30°†	M.P. 700°	111/54°
Mercury—					
mercurous chloride, $HgCl$.	236·06	6·48 and 7·2 A. 237·7	sublimes	382·5°	·0002/18°
„ nitrate, $HgNO_3 . 2H_2O$	298·64	4·78	decomp.	—	v. soluble
„ sulphate, Hg_2SO_4	497·26	–7·06/25°	melts.	decomp.	·2 cold
mercuric bromide, $HgBr_2$.	360·44	5·74	235°	subl. *c.* 322°	1/9°
„ chloride, $HgCl_2$.	271·52	5·3–5·5 A. 283	287°	303–307°	5·4/20°(*p*) see p. 146.
„ iodide, red, HgI_2 .	454·44	6·2–6·3 A. 452	241–257°	349°	·003/17°
„ „ yellow, HgI_2	454·44	5·9–6·1	241°	349°	insoluble
„ oxide, HgO . . .	216·6	11·14	dec. r. ht.	—	·005/25°
„ sulphate, $HgSO_4$.	296·66	6·47	dec. r. ht.	—	decomp.
Molybdenum—					
chloride, $MoCl_5$	273·3	A. 275/350°	194°	268°	decomp.
oxide, di-, MoO_2	128·0	6·4/10°	—	—	insoluble
„ tri-, MoO_3	144·0	4·696/26°	759°	sublimes	·2 cold
Nickel—					
carbonyl, $Ni(CO)_4$	170·7	1·318/17°	–25°	43°	insoluble
chloride, $NiCl_2$	129·6	2·56	sublimes	—	35/0° (*p*)
nitrate, $Ni(NO_3)_2 . 6H_2O$ . .	290·8	2·06/14°	56·7°	—	48·5/18° *p*.
sulphate, $NiSO_4 . 7H_2O$ ‡ .	280·85	1·98	98–100°	$6H_2O$/103°	31·5/9°
Niobium—					
chloride, penta-, $NbCl_5$ . .	270·4	4·4–4·5 A. 278/360°	194°	240·5°	decomp.
Nitrogen—					
nitric acid, HNO_3	63·02	1·53/15°	–41·3°	86°	∞
nitrous oxide, N_2O	44·02	1·226/–89°·4 A. 44·28 ‖	–102°	–89·8°	74V/15° see p. 145.
nitric „ NO	30·01	A. 30·011	–160·9°	–153°	5·1V/15° see p. 145.
nitrogen trioxide, N_2O_3 . .	76·02	1·447/–2°	–102°	42·7°/757	soluble
„ peroxide, NO_2 to N_2O_4	46·01	1·49/0° §	–10·8°	21·64°	soluble
„ pentoxide, N_2O_5 .	108·02	1·64/18°	30°	dec. 45–50°	soluble
„ oxychloride, $NOCl$.	65·47	1·367/–8·6°	–60°	–5·6°/751	decomp.
Osmium—					
oxide, tetr-, OsO_4	254·9	A. 257·3	20°	100°	soluble
Ozone, O_3	48·00	·00214 A. 48·03	dec. 270°	–119°	v. slgt. sol.
Palladium—					
chloride, $PdCl_2 . 2H_2O$ . .	213·65	—	501°	—	soluble

* The ordinary salt ; also six other hydrates. † Stable between temps. given.
‡ Also anhy. and $6H_2O$. § Density, p. 35. ‖ ·698/23·7° ; r. ht. = red heat ;
slgt. = slightly ; subl. = sublimes ; v. = very ; ∞ = soluble in all proportions.

INORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	Formula weight (0 = 16).	Density, gms./c.c.	Melting Point, ° C.	Boiling Point, ° C.	Solubility in Water.
		at./temp.	at./mms.	at./mms.	at./temp.
Perchloric acid, $HClO_4$ . .	100·47	1·76/22°	−35°	19°/11	soluble
Phosphorus—					
bromide, tri-, PBr_3	270·8	2·92/0° A. 281	−41·5°	175°	decomp.
chloride, tri-, PCl_3	137·42	1 612/0° A. 141	−112°	76°	,,
,, penta-, PCl_5 . . .	208·34	A. 104·2/296°	148°	162°	,,
fluoride, tri-, PF_3	88·04	A. 87·4	−160°	−95°	—
oxide, tri-, P_4O_6	220·2	liq. 1·94/28°	22·5°	173°	soluble
,, tetr-, P_2O_4	126·1	2·54/23°	>100°	*c.* 180°	,,
,, pent-, P_4O_5	142·1	2·39	800°	subl. r. ht.	v. soluble
Phosphine, PH_3	34·06	A. 34·31	−133°	−85°	slgtly sol.
,, liquid, P_2H_4 . .	66·11	1·007–1·016	<−10°	57/735	insoluble
Phosphonium chloride, PH_4Cl	70·53	—	26°	sublimes	decomp.
Platinum—					
chloride, tetra-, $PtCl_4$	337·04	—	decomp.	—	v. soluble
Potassium—					
bromide, KBr	119·02	2·76/20°	733°	subl. w. ht.	see p. 146.
carbonate, K_2CO_3	138·2	2·29	909° ± 5	dec. 810°	89/0°
chlorate, $KClO_3$.	122·56	2·34/17°	357°	dec. 400°	3/0°
chloride, KCl	74·56	1·99/15°	790°	subl. w. ht.	see p. 146.
chromate, bi-, $K_2Cr_2O_7$ . .	294·2	2·69/4°	400°	dec. 500°	5/0°
cyanide, KCN	65·11	1·52/16°	red heat	red heat	122/103°
ferricyanide, $K_3Fe(CN)_6$. .	329·23	1·8109/17°	decomp.	—	33/4°
ferrocyanide, $K_4Fe(CN)_6 . 3H_2O$	422·38	1·8533/17°	{3H_2O/60° −80°}	—	28/12°
hydroxide, KOH	56·11	2·04	360·4°	subl. w. ht.	see p. 146.
iodate, KIO_3	214·02	3·97/18°	560°	—	8/20°
iodide, KI	166·02	{3·04/24° A. 159/1320°}	678°	1420°	{127/0° see p. 146.
nitrate, KNO_3	101·11	2·1/4°	337°	dec. 400°	see p. 146.
permanganate, $KMnO_4$ . .	158·03	2·70/10°	dec. 240°	—	6·4/15
sulphate, K_2SO_4	174·26	2·66/20°	1066·5°	sublimes	9·2/10°
,, acid, $KHSO_4$ . .	136·17	2·24 * ; 2·61 †	200°	decomp.	36/0°
sulphocyanate, KCNS . .	97·18	1·91	173·8°	—	217/20°
Radium—					
bromide, $RaBr_2$	385·84	—	728°	—	soluble
Rubidium—					
carbonate, Rb_2CO_3	230·9	—	837°	dec. 740°	v. soluble
chloride, RbCl	120·9	2·798/25°	726°	—	84/10°
sulphate, Rb_2SO_4	266·96	3·611/20°	—	—	43/10°
Selenium—					
chloride, Se_2Cl_2	229·32	2·91/17°	—	dec. *c.* 145°	decomp.
oxide, SeO_2	111·2	3·95/15°	390°	sub. *c.* 260°	v. soluble
Selenious acid, H_2SeO_3 . .	129·22	3·91/15·7°	decomp.	—	,,
Selenic acid, H_2SeO_4 . .	145·22	2·95/15°	58°	260°	,,
Silicon—					
chloride, tetra-, $SiCl_4$	170·14	1·520 A. 172	−89°	57·5°	decomp.
fluoride, SiF_4	104·3	A. 103·4	−77° §	−65°/181 §	,,

* Monoclinic. † Rhombic. § Moissan, 1905.

amorph. = amorphous ; cryst. = crystalline ; dec. or decomp. = decomposes ; r. ht. = red heat ; sub. or subl. = sublimes ; v. = very ; w. ht. = white heat.

INORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	Formula weight (O = 16).	Density, gms./c.c.	Melting Point, ° C.	Boiling Point, ° C.	Solubility in Water.
		at./temp.	at./mms.	at./mms	at./temp.
Silicon (*contd.*)—					
oxide (silica), amorph, SiO_2	60·3	2·2/16°	indefinite	—	*c.* ·001
" " quartz. SiO_2	60·3	2·6495/20°	1780°	—	insoluble
Silico chloroform, $SiHCl_3$	135·69	1·65 A. 133·2	−1·3°	34°	decomp.
Silver—					
bromide, $AgBr$	187·8	6·47/25°	398°	dec. 700°	·0$_8$8/20°
chloride, $AgCl$	143·34	5·561 A. 165/1735°	450°	—	·0$_3$15/20°
iodide, AgI	234·8	5·67/25°	*c.* 540	—	·0$_8$3/21°
nitrate, $AgNO_3$	169·89	4·35/19°	218°	dec. r. ht.	see p. 146.
sulphate, Ag_2SO_4	311·82	5·4	660°	decomp.	·77/17°
Sodium—					
borate (borax), $Na_2B_4O_7 \cdot 10H_2O$	381·76	1·694/17°	red heat	—	52·3/100°
bromide, $NaBr$	102·92	3·1	765°	—	77/0°
carbonate, Na_2CO_3	106·0	2·4–2·5	852°	decomp.	see p. 146.
" bi-, $NaHCO_3$	84·01	2·2	CO_2/270°	—	8/10°
chloride, $NaCl$	58·46	2·17/20°	801*	w. heat	see p. 146.
hydroxide, $NaOH$	40·01	2·13	318°	w. heat	63·5/15°
iodide, NaI	149·92	3·65/18°	650°	—	178/20°
nitrate, $NaNO_3$	85·01	2·27/20°	*c.* 313°	—	73/0°
peroxide, Na_2O_2	78·00	2·80	decomp.	—	sol.; dec.
phosphate, di-, $Na_2HPO_4 \cdot 12H_2O$	358·2	1·52/16°	38°	$3H_2O$/*c.*160°	9·3/20°
sulphate, anhy., Na_2SO_4	142·06	2·67/20°	883·2°	—	see p. 146.
" $Na_2SO_4 \cdot 10H_2O$	322·22	1·492/20°	T.32°·383	$7H_2O$/150°	5/0° 50·6/32·7°
sulphite, $Na_2SO_3 \cdot 7H_2O$	252·17	1·594/15°	$7H_2O$/150°	decomp.	25/15°
thiosulphate (hypo'), $Na_2S_2O_3 \cdot 5H_2O$	248·20	1·73/17°	32–48°	dec. 220°	60/10°
Strontium—					
bromide, $SrBr_2$	247·46	4·2/24°	498–630°	—	93/10°
carbonate, $SrCO_3$	147·64	3·6	—	CO_2/1340°	·001/24°
chloride, $SrCl_2$ (and $+ 6H_2O$)	158·55	3·05	830°	$4H_2O$/60° $6H_2O$/100°	48/10° see p.146.
nitrate, $Sr(NO_3)_2$	211·65	3/17°	dec. 645°	—	55/10°
oxide, SrO	103·63	4·45–4·6	3000°	—	35/0°
" per-, SrO_2	119·63	·546	decomp.	—	decomp.
sulphate, $SrSO_4$	183·69	3·7–4	1605°	—	·011/18°
Sulphur—					
dioxide, SO_2	64·06	1·434/0° A. 65·54	−76°	−10·8°	4730 V. 15°; p. 145.
trioxide, SO_3 α form	80·06	1·923/20° A. 80·19	16·79°	44·88°	decomp.
Sulphuretted hydrogen. *See* Hydrogen sulphide.					
Sulphuric acid, H_2SO_4	98·076	1·834/18°	10·5°	dec. 40°	∞
Tellurium—					
chloride, $TeCl_2$	198·42	A. 199·5	175°	327°	decomp.
oxide, di-, TeO_2	159·5	5·9/0°	dull r. ht.	> 700°	·0007
" tri-, TeO_3	175·5	5·07/15°	decomp.	—	insoluble

* Practically same for ordinary table salt as for pure salt (Harker).
anhy. = anhydrous; dec. or decomp. = decomposes; hydr. = hydrated; r. ht. = red heat; w. ht. = white heat; ∞ = soluble in all proportions.

INORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	Formula weight (0 = 16).	Density, gms./c.c.	Melting Point, ° C.	Boiling Point, ° C.	Solubility in Water.
Thallium—		at./temp.	at./mms.	at./mms.	at./temp.
carbonate, Tl_2CO_3 . . .	468·0	7·1	272°	decomp.	4/15°
chloride, tri-, $TlCl_3$ . . .	310·38	—	25°	"	v soluble
" mono-, TlCl . .	239·46	7·02	426°	708°–719°	·2/0°
oxide (thallous), Tl_2O . .	424·0	—	>870°	—	v. soluble
sulphate, Tl_2SO_4	504·06	6·77	632°	decomp.	4·7/15°
Thorium—					
nitrate, $Th(NO_3)_4 . 12H_2O$	696·38	—	—	—	v. soluble
oxide, ThO_2	264·15	9·87/15°	—	—	insoluble
Tin—					
chloride (stannous), $SnCl_2$	189·62	—	249°	620°	270/15°
" (stannic), $SnCl_4$.	260·54	2·279/0° A. 266	−33°	114·1°	soluble
oxide (stannous), SnO . .	134·7	6·3	dec. r. ht.	—	insoluble
" (stannic), SnO_2 . .	150·7	6·6–6·9	1130°	—	"
Titanium—					
chloride, tetra-, $TiCl_4$ . .	189·94	1·76/0° A. 198	−25°	136·4°	decomp.
oxide, di-, TiO_2	80·1	3·7–4·2	1560°	—	insoluble
Tungsten—					
chloride, hexa-, WCl_6 . .	396·76	A. 379/350°	275°	347°	"
oxide, tri-, WO_3	232·0	7·2	red heat	—	"
Uranium—					
oxide, di-, UO_2	270·2	10·9	2176°	—	"
" (green), U_3O_8 . .	842·6	7·3	decomp.	—	"
" (yellow), UO_3 . .	286·2	5·1	decomp.	—	—
" (black), U_2O_5 . .	556·4	8·4–9·2	—	—	—
Uranyl chloride, UO_2Cl_2 .	341·12	—	fusible	decomp.	320/18°
" nitrate, $UO_2(NO_3)_2 . 6H_2O$	502·32	2·81	T. 59·5°	—	200
Vanadium—					
chloride, tetra-, VCl_4 . .	192·84	1·86 A. 193·7	−18°	154°	soluble
oxide, pent-, V_2O_5 . . .	182·0	3·357/18°	658°	—	0·8/20°
Zinc—					
carbonate, $ZnCO_3$ . . .	125·37	4·4	CO_2, 300°	—	0·001/15°
chloride, $ZnCl_2$	136·29	2·91/25°	262°	730°	330/10°
sulphate, $ZnSO_4 . 7H_2O$.	287·54	1·966 3·623/15° anhy.	6H_2O/100°	7H_2O at red heat.	42/0° 80·8/100°
sulphide, ZnS	97·43	4·0	1050°	subl. 1180°	insoluble
Zirconium—					
oxide, ZrO_2	122·6	5·1–5·7	*c.* 2500°	—	"

anhy. = anhydrous ; dec. or decomp. = decomposes ; r. ht. = red heat ; v. = very.

FREEZING MIXTURES

Parts by weight.	Temp.	Parts by weight.	Temp.
1 of NH_4NO_3, 1 of water . .	−15° C.	2 of snow or crushed ice, 1 of NaCl	−18°
8 of Na_2SO_4, 5 of water . .	−17°	3 of snow, 4 of cryst. $CaCl_2$.	−48°
CO_2 and ether	−78·35°		

ORGANIC COMPOUNDS

Formula (Molecular) Weight, Density, Melting and Boiling Points.
For general heading, see p. 130.

Substance and Formula.	**Formula weight ($O = 16$).**	**Density, gms./c.c.**	**Melting Point, ° C.**	**Boiling Point, ° C.**
		at./temp.	at./mms.	at./mms.
Acetaldehyde, $CH_3 . CHO$	44·04	·788/16° C.	−123·6°	20·8°
Acetic acid, $CH_3 . COOH$	60·04	1·05/20°	16·7°	118·5°, Y.
Aceto-acetic ether, $CH_3CO . CH_2CO_2 . C_2H_5$	130·11	1·028/20°	<−80°	181°
Acetone, CH_3COCH_3	58·06	·7900/15°	−95°	56·5°
Acetylene, C_2H_2	26·03	{ ·46/−7° A. 26·34 }	−81·5°/895*	−83·6°
Acrylic acid, $CH_2 : CHCO_2H$	72·05	1·062/16°	10°	140°
Alizarine, $C_6H_4(CO)_2C_6H_2(OH)_2$	240·13	—	290°	430
Allyl alcohol, $CH_2 : CH . CH_2OH$	58·06	·8525/20°	−129	96·7
„ chloride, $CH_2 : CHCH_2Cl$	76·52	·937/19°	−136·4	46
„ thiocyanate, $CH_2 : CHCH_2CNS$	99·13	1·017/10°	liquid	161
Amyl acetate, $C_5H_{11} . CH_3CO_2$	130·15	·879/20°	liquid	148
„ alcohol (n.), $CH_3(CH_2)_3CH_2OH$	88·12	·812/20°	−78·5	137·8
„ „ (act.), $CH_3C_2H_5CHCH_2$-OH	88·12	·825/0°	liquid	129
„ „ (sec.), $C_3H_7CH(OH)CH_3$	88·12	·825/0°	liquid	118·5/753
„ „ (tert.),$(CH_3)_2C(OH)C_2H_5$	88·12	·814/15°	−12°	102·5
Aniline, $C_6H_5 . NH_2$	93·10	1·023/15°	−6·4°	183·9
Anisol, $C_6H_5OCH_3$	108·1	·9925/25°	−37·2°	154
Anthracene, $C_6H_4 : C_2H_2C_6H_4$	178·15	1·15	216	360
Antimony trimethyl, $Sb(CH_3)_3$	165·29	1·52/15°	liquid	80·6
Asparagine(l.)$C_2H_3NH_2CO_2H.CONH_2$	132·1	1·55/4°	decomp.	decomp.
Benzaldehyde, C_6H_5CHO	106·08	1·05/15°	−5·6	179·5
Benzene, C_6H_6	78·08	·87843/20°	5·49	80·2, Y.
Benzoic acid, $C_6H_5 . COOH$	122·08	1·26/21°	121·4	249·2
Benzophenone (α), $(C_6H_5)_2CO$	182·15	1·098/50°	48	305·9
Benzoyl chloride, C_6H_5COCl	140·54	1·212/20°	−1	197
Benzyl alcohol, $C_6H_5CH_2OH$	108·10	1·043/20°	−15·3	206·5
Beryllium ethyl, $Be(C_2H_5)_2$	67·20	—	—	187
Bismuth triethyl, $Bi(C_2H_5)_3$	295·15	1·82	—	107/79
Borneol (i.), $C_{10}H_{17}OH$	154·19	1·01	210	sublimes
Bromo benzene, C_6H_5Br	157·0	1·4948/20°	−30·6	156, Y.
Butane (n.), $CH_3 . CH_2 . CH_2 . CH_3$	58·10	·60/0°	−135	·3
Butyl alcohol (n.),$CH_3(CH_2)_2CH_2$. OH	74·10	·813/20°	−89·8	117·5
„ „ (sec.),$CH_3CHOH . C_2H_5$	74·10	·819/22°	—	99·8
„ carbinol (tert.),$(CH_3)_3C . CH_2OH$	88·12	·812/20°	52	113
„ chloride, $CH_3(CH_2)_3Cl$	92·55	·887/20°	−123	78
„ ether, $(C_4H_9)_2O$	130·18	·77/20°	—	141
Butyric acid (n.), $CH_3(CH_2)_2COOH$	88·07	·96/19°	−7·9	162·3
„ „ (iso), $(CH_3)_2CHCOOH$	88·07	·950/20°	−47	154
Cacodylic acid, $(CH_3)_2AsO . OH$	138·03	—	200	—
Caffeine, $C_8H_{10}N_4O_2 . H_2O$	212·18	1·23/19°	234	sublimes
Camphor, $C_{10}H_{16}O$	152·19	·992/10°	176·4	205·3
Camphoric acid (d.), $C_8H_{14}(COOH)_2$	200·18	1·19	200−2	distin. CO_2
Caproic acid, $CH_3(CH_2)_4COOH$	116·13	·9220/20°	−9·5	202
Carbolic acid. *See* Phenol.				
Carbon bisulphide, CS_2	76·13	1·292/0°	−112, H.	46·2
„ oxysulphide, COS	60·07	2·104	−138	−47°
„ tetrachloride, CCl_4	153·85	1·5936/20°	−22·95	76·7, Y.

* Mackintosh, 1907; decomp. = decomposes; l. = lævo-rotatory (see p. 89). Y., Young, *Journ. de Phys.*, Jan., 1909. H. = Henning.

ORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	Formula weight (O = 16).	Density, gms./c.c.	Melting Point, ° C.	Boiling Point, ° C.
		at./temp.	at./mms.	at./mms.
Cellulose, $(C_6H_{10}O_5)_x$	x162·11	1·27 – 1·61	—	—
Chlor acetic acid, $CClH_2 . COOH$	94·49	1·39/75°	63°	186°
„ benzene, C_6H_5Cl	112·53	1·1062/20°	−45·5 H	132, Y.
Chloral hydrate, $CCl_3 . CH(OH)_2$	165·41	1·90	+47	97·5
Chloroform, $CHCl_3$	119·39	1·49887/15°	−63·3	61·2
Chrysene, $C_{18}H_{12}$	228·19	—	250	448°/760
Cineol, eucalyptol, $C_{10}H_{18}O$	154·19	·9275/16°	−2	176
Cinnamic acid, $C_6H_5CH : CHCOOH$	148·11	1·247	133	300
„ aldehyde, $C_6H_5CH : CHCHO$	132·11	1·05/24°	−7·5	129°/20
Citric acid, $(CO_2HCH_2)_2C(OH)CO_2H + H_2O$	210·11	1·542/18°	153	decomp.
Collidine, α $CH_3 . C_5H_3N . C_2H_5$	121·14	·953/22°	—	180
Coniine (d.), 1 : 2, $C_5H_{10}N . C_3H_7$	127·19	·849/25°	−2·5	170
Cresol (o.), $CH_3C_6H_4OH$	108·1	1·052/15°	30	190·1
Cyanic acid, $HCNO$	43·02	1·14/0°	liquid	dec.
Cyanogen, C_2N_2	52·03	liq. ·866/17° A. 52·3	−35	−20·7
Cymene (p.), $CH_3 . C_6H_4 . C_3H_7$	134·16	·852/25°	−73·5	175
Dextrin, $C_{12}H_{20}O_{10}$	324·22	1·04	—	—
Diacetyl, $CH_3CO . COCH_3$	86·07	·9734/22°	—	87·7
Dichlor acetic acid. $CHCl_2 . COOH$	128·95	1·522/15°	−4	190
Diethyl amine, $(C_2H_5)_2NH$	73·12	·706/20°	−40	55·5
„ aniline, $(C_2H_5)_2NC_6H_5$	149·18	·94/18°	−34	216
„ ketone, $C_2H_5COC_2H_5$	86·11	·8231/12·4°	−42	101·5
Dimethyl amine, $(CH_3)_2HN$	45·08	·686/−6°	−96	7·2
„ tartrate, $(CH_3)_2C_4H_4O_6$	178·11	1·341/15°	48	280
Dinitrobenzene (m.), $C_6H_4(NO_2)_2$	168·08	1·546/17°	91	302·8/770
Diphenyl, $C_6H_5 . C_6H_5$	154·14	1·16	70·5	255
Diphenylamine, $(C_6H_5)_2HN$	169·16	1·159	54	302
Epichlorhydrine, C_3H_5ClO	92·52	1·203/0°	−25·6	116
Erythrite, $(CH_2OH . CHOH)_2$	122·10	1·45/17°	126	330
Ethane, $CH_3 . CH_3$	30·06	liq. ·446/0° A. 30	−172	−88
Ether, $C_2H_5OC_2H_5$	74·10	·7135/20°	−123·3 H	34·6, Y.
Ethyl acetate, $CH_3CO_2 . C_2H_5$	88·07	·9005/20°	−83·4	77·1
„ aceto-acetate, $CH_3COCH_2CO_2 . C_2H_5$	130·11	1·028/20°	< −80	181
„ alcohol, C_2H_5OH	46·06	·79360/15°	−114·9	78·3, Y.
„ amine, $C_2H_5H_2N$	45·08	·699/8°	−81	16·6
„ benzoate, $C_6H_5CO_2 . C_2H_5$	150·13	1·05/16°	−32·7 *	211·2
„ bromide, $C_2H_5 . Br$	108·97	1·45/15°	−116	38·4
„ butyrate, $C_3H_7 . COOC_2H_5$	116·13	·879/20°	−93·3	120·6
„ chloride, C_2H_5Cl	64·51	·921/0° A. 64·22	−140·85	12·5
„ cyanide, $C_2H_5 . CN$	55·07	·794/7°	−92	97
„ formate, $HCOOC_2H_5$	74·06	·9226/20°	−80·5	54·3, Y.
„ iodide, C_2H_5I	156·0	1·944/14°	−110·9	72·3
„ isobutyrate $(CH_3)_2CHCOOC_2H_5$	116·13	·890/0°	−88	110·1
„ mercaptan, C_2H_5SH	62·12	·839/20°	−22	36·2
„ nitrate, $C_2H_5NO_3$	91·06	1·116/15°	−102	87

dec. or decomp. = decomposes.

H., Henning.

Y., Young, *Journ. de Phys.*, Jan., 1909.

* Other form − 40°.

ORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	Formula weight (O = 16).	Density, gms./c.c.	Melting Point, ° C.	Boiling Point, ° C.
		at./temp.	at./mms.	at./mms.
Ethyl propionate, $C_2H_5CO_2C_2H_5$	102·11	·8901/20°	−74·25	99·0°
„ salicylate, $C_6H_4(HO)CO_2 . C_2H_5$	166·13	1·138/15°	1·3	231·5
„ sulphide, $(C_2H_5)_2S$	90·16	·837/20°	−99·5	92·6
„ tartrate (d.), $C_4H_4O_6(C_2H_5)_2$	206·15	1·206/20°	17	280
„ valeriate, $C_4H_9CO_2C_2H_5$	130·15	·876/20°	—	144·5
Ethylene, $CH_2 : CH_2$	28·04	·565/−102·5° A. 28·32	−169	−102·7
„ bromide, di-, $CH_2Br . CH_2Br$	187·88	2·1838/18°	9·97	131·6
„ chloride, di-, $CH_2Cl . CH_2Cl$	98·90	1·28/0°	−35·3	83·7
„ oxide, $<(CH_2)_2O$	44·04	·897/0°	−111	13·5/746
Ethylidene chloride, $CH_3 . CHCl_2$	98·96	1·186/12°	−96·7	59·9
Eucalyptol, $C_{10}H_{18}O$	154·19	·927/20°	−2	176
Eugenol, $C_6H_3 . (OH) . OCH_3 . C_3H_5$	164·15	1·0620/25°	liquid	247·5
Fluor benzene, C_6H_5F	96·07	1·024/20°	−41·2	85·2, Y.
Formic acid, $H . COOH$	46·02	1·218/20°	8·35°	100·5
Formaldehyde, $H . COH$	30·02	·815/−20°A.48	−92	−21
Fructose (d.), $CH_2OH[CHOH]_3CO\text{-}CH_2OH$	180·13	1·55/0°	104	—
Fumaric acid, $(COOH . CH :)_2$	116·05	1·625	286	290
Furfural, $C_4H_3O . COH$	96·06	1·159/20°	−36·5	161
Galactose (d.), $CHO[CHOH]_4CH_2OH$	180·13	—	170	—
Glucose (d.), $CHO[CHOH]_4CH_2OH + H_2O$	198·14	1·54–1·57	146	—
Glutaric acid, $COOH(CH_2)_3COOH$	132·09	—	97·5	303
Glycerine, $OHCH_2 . CHOH . CH_2OH$	92·08	1·26/20°	17	290
Glycocoll, glycine, CH_2NH_2COOH	75·07	1·161	*c.* 234	—
Glycol, $CH_2OH . CH_2OH$	62·06	1·125/25°	−17·4	197·4
Glycollic acid, $CH_2OH . COOH$	76·04	—	78	decomp.
Glyoxal, $CHO . CHO$	58·03	1·14/20°	15°	50·5°
Glyoxalic acid, $CHO . COOH + H_2O$	92·04	syrup	—	with steam
Grape sugar. *See* Glucose.				
Heptane (n.), $CH_3(CH_2)_5CH_3$	100·16	·6836/20°	−90·0	98·4, Y.
Hexane (n.), $CH_3(CH_2)_4CH_3$	86·14	·6595/20°	−94·3	69, Y.
„ di-isopropyl, $[(CH_3)_2CH]_2$	86·14	·6617/20°	−135	58·1, Y.
Hydrocyanic acid, HCN	27·02	·697/18°	−14	26·1
Indigo, $C_6H_4<\begin{smallmatrix}CO\\NH\end{smallmatrix}>C : C<\begin{smallmatrix}CO\\NH\end{smallmatrix}>C_6H_4$	262·18	1·35	390—2	subl. 156°
Indol, $C_6H_4NHCH : CH$	117·11	—	52	253—4
Iodoform, CHI_3	393·77	4·08/17°	119	subl. & dec.
Isatine, $C_6H_4<\begin{smallmatrix}CO\\N\end{smallmatrix}>COH$	147·09	—	201	sublimes
Isoamyl acetate, $CH_3 . COOC_5H_{11}$	130·15	·8708/20°	—	140
„ alcohol, $(CH_3)_2CH(CH_2)_2OH$	88·12	·81/20°	−134	131
Isobutane, $(CH_3)_2CHCH_3$	58·10	—	−145°	−10·2
Isobutyl alcohol, $(CH_3)_2CH . CH_2OH$	74·10	·800/18°	−108·4	108·4
„ amine, $(CH_3)_2CHCH_2NH_2$	73·12	·736/15°	−85·5	68
Isobutyric acid, $(CH_3)_2CH . COOH$	88·08	·9516/20°	−47	155·5
Isopentane, $(CH_3)_2CHCH_2CH_3$	72·12	·6393/0° ·6196/20°	−158·5	27·9
Isopropyl acetate, $CH_3COOCH(CH_3)_2$	102·11	·917/0°	−73·4	90–93
„ alcohol, $(CH_3)_2HC(OH)$	60·08	·789/20°	−85·8	82·8

d., dextro-rotatory (see p. 89) ; dec. or decomp. = decomposes ; subl. = sublimes ; Y., Young, *Journ. de Phys.*, Jan., 1909.

ORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	**Formula weight (O = 16).**	**Density, gms./c.c.**	**Melting Point, ° C.**	**Boiling Point, ° C.**
		at./temp.	at./mms.	at./mms.
Isopropyl amine, $(CH_3)_2CHNH_2$	59·08	·690/18°	−101·2	33°
„ cyanide, $(CH_3)_2CHCN$	69·09	—	liquid	107–108
Isoquinoline, $C_6H_4C_3H_3N$	129·1	1·098/20°	24·6	240
Isovaleric acid, $(CH_3)_2CHCH_2COOH$	102 11	·931/20°	−51	176·3
Lactic acid (i.), $CH_3CHOH . COOH$	90·06	1·248/15°	18	83/1 mm.
Lactose. *See* Milk sugar.				
Maleic acid, $(COOH . CH:)_2$	116·05	1·59	130	decomp.
Malic acid (i.), $COOH . CHOH . CH_2$-$. COOH$	134·07	1·60/20°	130–1	—
Malonic acid, $COOH . CH_2 . COOH$	104·05	—	132	decomp.
Maltose, $C_{12}H_{22}O_{11} + H_2O$	360·25	1·54/17°	—	—
Mercury methyl, $(CH_3)_2Hg$	230·66	3·07	liquid	96
Mesitylene, 1 : 3 : 5, $C_6H_3(CH_3)_3$	120·14	·869/10°	−54·4	164·5
Methane, CH_4	16·04	liq. ·416/−164°	−184	−164
Methyl alcohol, CH_3OH	32·04	·7958/15°	−94·9	64·7, Y.
„ acetate, $CH_3COO : CH_3$	74·06	·9367/16°	−101·2	57·1
„ amine, CH_3H_2N	31·06	{·699/−11° A. 32·4}	−92·5	−6·7/756
„ borate, $(CH_3)_3BO_3$	104·09	·94/0°	—	65
„ chloride, CH_3Cl	50·47	·920/18° A. 50·1	−91·5	−24·1
„ ether, $(CH_3)_2O$	46·06	1·617 A. 46·8	−138·5	−23·6
„ ethyl ether, $CH_3 . O . C_2H_5$	60·08	·697	—	7·9
„ formate, $HCOO . CH_3$	60·04	·9745/20°	−99·75	31·9, Y.
„ iodide, CH_3I	141·95	2·285/15°	−66·1	42·3
„ isobutyrate, $(CH_3)_2CHCOOCH_3$	102·11	·8890/20°	−84·7	92·3
„ mercaptan, $CH_3 . SH$	48·10	·868	−130·5	5·8/752
„ nitrate, $CH_3 . NO_3$	77·04	1·217/15°	liquid	65 explodes
„ nitrite, $CH_3 . NO_2$	61·04	·991/15°	−26·5	−12
„ phosphine, CH_3H_2P	48·09	—	gas	−14
„ propionate, $C_2H_5COO . CH_3$	88·08	·9151/20°	−87·5	79·7
„ salicylate, $C_6H_4(OH)COOCH_3$	152·1	1·182/15°	−8·3	224
„ sulphide, $(CH_3)_2S$	62·11	·845/21°	−83·2	*c.* 38
Methylene bromide, CH_2Br_2	173·86	2·493	−52·8	98·5
Milk sugar, $C_{12}H_{22}O_{11} + H_2O$	360·25	1·525/20°	203 dec.	decomp.
Morphine, $C_{17}H_{19}NO_3 + H_2O$	303·26	1·32	243−4	decomp.
Naphthalene, $C_6H_4 : C_4H_4$	128·11	1·152/15°	80	217·96
Naphthol (*a*), $C_{10}H_7OH$	144·11	1·224/4°	95	*c.* 279
Naphthyl amine (*a*), $C_{10}H_7H_2N$	143·12	1·131	50	300
Nicotine (l.), $C_{10}H_{14}N_2$	162·18	1·01/20°	dec. 250°	246·7/745
Nitro benzene, $C_6H_5NO_2$	123·08	1·19868/25°	5·67	210·85
„ ethane, $C_2H_5NO_2$	75·06	1·056	<-50	114·4
„ methane, CH_3NO_2	61·04	1·144/15°	−29·2	101·7
Octane (n.), $CH_3(CH_2)_6CH_3$	114·18	·7062/15°	−56·6	125·8, Y.
Oleic acid, $CH_3(CH_2)_7CH:CH(CH_2)_7$-$. COOH$	282·38	·891/12°	14	286/100
Palmitic acid, $CH_3(CH_2)_{14}COOH$	256·34	·846/7·6°	62·6	278/100
Paraldehyde, $(CH_3 . HCO)_3$	132·13	·994/20°	10·5	124
Penta methylene, $(CH_2)_5$	70·11	·751/20°	—	50·6
„ „ diamine (cadaverine), $NH_2(CH_2)_5NH_2$	102·16	·917/0°	*c.* 15	178
Pentane (n.), $CH_3(CH_2)_3CH_3$	72·12	·6263/20°	−131·5	36·2°, Y.

dec. or decomp. = decomposes; l., lævo-rotatory (see p. 89); Y., Young, *Journ. de Phys.*, Jan., 1909.

ORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	**Formula weight (O = 16).**	**Density, gms./c.c.**	**Melting Point, ° C.**	**Boiling Point, ° C.**
		at./temp.	at./mms.	at./mms.
Phenetol, $C_6H_5OC_2H_5$	122·12	·963/25°	−34	171
Phenol, $C_6H_5 . OH$	94·08	1·06/33°	42·7	181·5
Phenyl acetic acid, $C_6H_5CH_2COOH$.	136·1	1·23	76·5	265
„ cyanide, C_6H_5CN	103·09	1·008/17°	−17	190
„ hydrazine, $C_6H_5HN . NH_2$.	108·1	1·098/20°	19·35	243·5
Phloroglucin, 1 : 3 : 5.$C_6H_3(OH)_3 2H_2O$	162·11	—	218 anhy.	sublimes
Phthalic acid, o. $C_6H_4(COOH)_2$ . .	166·09	1·59	180–200	—
„ anhydride, $C_6H_4<(CO)_2>O$	148·07	1·53/4°	128	284
Picoline (α), $CH_3 . C_5H_4N$	93·10	·933/22°	−69·9	129
Picric acid, 1 : 2 : 4 : 6, $C_6H_2OH(NO_2)_3$	229·08	1·767/19°	122·5	explodes
Pinene. *See* Turpentine.				
Propane, $CH_3 . CH_2 . CH_3$	44·08	·535	−187·8	−44·1
Propionic acid, $CH_3 . CH_2 . COOH$.	74·06	·9870/20°	−19·3	140
Propyl acetate (n.), $CH_3COO . C_3H_7$.	102·11	·8884/20°	−92·5	101·6
„ alcohol (n.), $CH_3CH_2CH_2 . OH$	60·08	·804/20°	−127	97·2
„ chloride (n.), $CH_3CH_2CH_2Cl$.	78·53	·891/18°	−122·8	46·5
„ formate, $H . COO . C_3H_7$ . .	88·08	·9058/20°	−92·9	80·9, Y.
„ iodide, $CH_3 . CH_2 . CH_2I$ . .	170·0	1·745/20°	−101·4	102
Propylene, $CH_3 . CH : CH_2$	42·06	A.43·36	−185·2	−50·2
Pseudo-cumene, 1 : 2 : 4, $C_6H_3(CH_3)_3$.	120·14	·8748/20°	−57·4	169·8
Pyridine, C_5H_5N	79·08	·985/15°	−42	115·4
Pyrogallol (—ic acid, or "pyro"), 1 : 2 : 3, $C_6H_3(OH)_3$	126·08	1·46/40°	133	293
Pyrrol, $(CH)_4>NH$	67·07	·967/21°	liquid	131
Quinoline,  $C_6H_4<\begin{matrix}CH . CH\\N . CH\end{matrix}>$ . . .	129·11	1·094/20°	−22·6	241
Quinine, $C_{20}H_{24}N_2O_2$	324·31	—	anhy. 174·9	—
„ sulphate, $(C_{20}H_{24}N_2O_2)_2 . H_2SO_4 + 7H_2O$	872·81	—	205, dry	—
Racemic acid, $(COOH . CH(OH))_2 + H_2O$	168·08	1·69/7°	205	—
Rochelle salt (d.), $KNaC_4H_4O_6 . 4H_2O$	282·22	1·77	—	—
Rosaniline (p.), $(C_6H_4NH_2)_3COH$ . .	305·28	—	188–9	—
Saccharin, $C_6H_4<COSO_2>NH$ . .	183·15	—	220 dec.	—
Salicylic acid, $OH . C_6H_4 . COOH$.	138·08	1·48/4°	158/760	sublimes
Sodium ethyl, NaC_2H_5	52·05	—	27	—
Stearic acid, $CH_3(CH_2)_{16}COOH$ . . .	284·38	·843/80°	69·3	291/100
Stearine, $(C_{18}H_{35}O_2)_3C_3H_5$	891·16	·924/65°	71 − 1·5	—
Succinic acid, $COOH(CH_2)_2COOH$.	118·07	1·564/15°	185	235
Sugar, cane-, $C_{12}H_{22}O_{11}$	342·24	1·5877/18°	189	—
Sulphanilic acid (p.), $NH_2.C_6H_4.SO_3H . 2H_2O$	209·18	—	chars	—
Sulphonal, $(CH_3)_2C(SO_2C_2H_5)_2$ . . .	228·22	—	125	300 dec.
Tartaric acid (i. or meso), $COOH-[CHOH]_2COOH . H_2O$	168·08	1·67	142 anhy.	—
„ „ (d.), $COOH(CHOH)_2-COOH$	150·07	1·76/7° P.	170	— —
„ „ (l.), $COOH(CHOH)_2-COOH$	150·07	1·76	170	—
Terephthalic acid (p.), $C_6H_4(COOH)_2$.	166·09	—	sublimes	—
Terpenol (γ), $C_{10}H_{18}O$	154·19	—	70	—

anhy. = anhydrous ; d. = dextro-rotatory (see p. 89) ; P., Perkin ; dec. = decomposes ; l., lævo-rotatory (see p. 89) ; Y., Young.

ORGANIC COMPOUNDS (*contd.*)

For general heading, see p. 130.

Substance and Formula.	Formula weight (O = 16).	Density, gms./c.c.	Melting Point, ° C.	Boiling Point, ° C.
		at /temp.	at./mms.	at./mms.
Terpineol, α, $C_{10}H_{17}HO$	154·19	·936/20°	35°	218°
Tetrabromethylene, $CBr_2 . CBr_2$	343·69	—	53	100/15
Theobromine, $C_7H_8N_4O_2$	180·14	—	330	subl.
Thiocyanic acid, (HCNS)	59·08	—	5	200 dec.
Thiophene, $(CH)_4S$	84·11	1·061/15°	−40	84
Thiourea, $NH_2 . CS . NH_2$	76·12	1·42	180	—
Thymol, 4 : 1 : 3, $(CH_3)_2 : CH . C_6H_3$-$(CH_3)OH$	150·16	·994/0°	50	232
Tin tetramethyl, $Sn(CH_3)_4$	178·82	1·314/0°	—	78
Toluene, $C_6H_5 . CH_3$	92·10	·866/20°	−94·5	111
Toluidine (o.), $CH_3C_6H_4 . NH_2$	107·12	·999/20°	α −21, β −15·5	199·7
,, (p.), $CH_3C_6H_4NH_2$	107·12	1·046/−	45	200·3
Trichloracetic acid, $CCl_3 . COOH$	163·48	1·63/61°	57·5	195
Triethyl amine, $(C_2H_5)_3N$	101·16	·725/15°	−114·8	89
,, arsine, $(C_2H_5)_3As$	162·11	1·15/17°	liquid	140/736 dec.
,, phosphine, $(C_2H_5)_3P$	118·19	·812/15°	liquid	127/744
Trimethyl amine, $(CH_3)_3N$	59·10	·673/0°	−124	3·5
,, arsine, $(CH_3)_3As$	120·05	1·124	—	52·8
,, bismuth, $(CH_3)_3Bi$	253·09	2·30/18°	—	110
,, carbinol, $(CH_3)_3C . OH$	74·10	·786/20°	25	82·9
,, phosphine, $(CH_3)_3P$	76·13	>1	liquid	41
Trinitro benzene (s.), 1 : 3 : 5, C_6H_3-$(NO_2)_3$	213·08	1·688	121·2	decomp.
Turpentine (pinene), $C_{10}H_{16}$	136·18	·865/15°	—	159
Urea, $NH_2 . CO . NH_2$	60·06	1·32	132	decomp.
Valeric acid (n.), $CH_3(CH_2)_3 . COOH$	102·11	·943/20°	−58·5	186·4
Xylene (o.), $C_6H_4(CH_3)_2$	106·12	·8811/20°	−28	142·6
,, (m), ,,	106·12	·8658/20°	−54	139·8
,, (p), ,,	106·12	·8611/20°	15	138
Zinc ethyl, $Zn(C_2H_5)_2$	123·47	1·182/18°	−28	118
,, methyl, $Zn(CH_3)_2$	95·43	1·386/10°	−40	46

dec. or decomp. = decomposes.

ELECTROCHEMICAL EQUIVALENTS

Faraday's laws of electrolysis are expressed by $m = izt$, where m is the mass in grammes of an ion liberated in t secs. by a current of i amperes ; z is the electrochemical equivalent of the ion, *i.e.* the mass liberated by 1 ampere in 1 second.

The exactness of Faraday's laws is obscured in many cases by secondary chemical reactions, and the values of the different electrochemical equivalents are practically always derived by calculation from that of silver, which has been accurately determined (see p. 11). Electrochemical equivalents are proportional to chemical equivalents.

$$\text{Chemical equivalent} = \frac{\text{atomic weight of element}}{\text{valency of element for electrolyte used}}$$

Element.	Chemical equivalent.	z.
Silver	107·88/1	0·001183 gm. sec.$^{-1}$ amp.$^{-1}$
Copper	63·57/2	0·0003295 ,, ,,
Hydrogen	1·008/1	0·00001045 ,, ,, (see p. 112)

SOLUBILITIES OF GASES IN WATER

AIR IN WATER

1000 c.cs. of water saturated with air at a pressure of 760 mms. contain the following volumes of dissolved oxygen, etc., in c.cs. at 0° and 760 mms. Winkler 1904.

	Temperature of Water.						
	0° C.	5°	10°	15°	20°	25°	30°
	c.cs.						
Oxygen	10·19	8·9	7·9	7·0	6·4	5·8	5·3
Nitrogen, argon, etc.	19·0	16·8	15·0	13·5	12·3	11·3	10·4
Sum of above.	29·2	25·7	22·8	20·5	18·7	17·1	15·7
% of oxygen in dissolved air (by vol.)	34·9%	34·7	34·5	34·2	34·0	33·8	33·6

GASES IN WATER

S indicates the number of c.cs. of gas measured at 0° and 760 mms. which dissolve in 1 c.c of water at the temperature stated, and when the pressure of the gas plus that of the water-vapour is 760 mms.

A indicates the same, except that the gas itself is at the uniform pressure of 760 mms. when in equilibrium with water. (For other values, see p. 130) See Constantes Physiques, 1913.

Gas.	0° C.	10°	15°	20°	30°	40°	50°	60°
	c.cs.							
Ammonia, A.	1300	910	802	710	595/28°	—	—	—
Argon, A	·058	·045	·040	·037	·030	·027	—	—
Carbon dioxide, A . .	1·713	1·194	1·019	·878	·66	·53	·44	·36
Carbon monoxide, A . .	·035	·028	·025	·023	·020	·018	·016	·015
Chlorine, S	—	3·09	2·63	2·26	1·77	1·41	1·20	1·0
Helium, A	·0150	·0144	·0139	·0138	·0138	·0139	·0140	—
Hydrogen, A	·0215	·0198	·0190	·0184	—	—	—	—
Hydrochloric acid, S. .	506	474	458	442	411	386	362	339
Nitrogen, A	·0239	·0196	·0179	·0164	·0138	·0118	·0106	·0100
Nitrous oxide, A . .	1·05/5°	·88	·74	·63	—	—	—	—
Nitric oxide, A	·074	·057	·051	·047	·040	·035	·031	·029
Oxygen, A	·049	·038	·034	·031	·026	·023	·021	·019
Sulphuretted hydrogen, A	4·68	3·52	3·05	2·67	—	—	—	—
Sulphur dioxide, S . .	79·8	56·6	47·3	39·4	27·2	18·8	—	—

Ne, ·0147/20° ; Kr, ·073/20° ; Xe, ·1109/20° — Antropoff, 1910.

MUTUAL SOLUBILITIES OF LIQUIDS

The data for the uppermost layer of the two solutions in equilibrium are given in the first line in each case. The pressure in some cases exceeds one atmosphere. Numbers are grams per 100 grams of solution. (From data in Seidell's "Solubilities.")

Liquids.	0°C.	10°	20°	30°	40°	50°	60°	70°	80°	00
Water in ether ; ethereal layer	1·0	1·1	1·2	1·3	1·5	1·7	1·8	2·0	2·2	—
Ether in water ; aqueous layer	12	8·7	6·5	5·1	4·5	4·1	3·7	3·2	2·8	—
Aniline($C_6H_5NH_2$) in water ; aqueous layer	—	—	3·2	—	3·5	—	3·8	—	4·5	6
Aniline in water; aniline layer	—	—	95·5	—	95	—	95	—	93	92
Phenol (C_6H_5OH) in water ; aqueous layer	—	7·5	8·3	8·8	9·6	12	17	33·4	at crit. temp. 68°·3	
Phenol in water ; phenol layer	—	75	72	70	67	63	55	33·4		
Triethylamine in water ; amine layer . .	51·9	at 18°·6	72	97	96	96	96			
Triethylamine[$N(C_2H_5)_3$] in aqueous layer	51·9		14·2	5·8	3·6	2·9	2·2			
CS_2 in methyl alcohol ; alcoholic layer .	—	45	51	58	80·5	at crit. temp. 40°·5				
CS_2 in CH_3OH ; carbon bisulphide layer	—	98	97	96	80·5					

SOLUBILITIES OF SOLIDS IN WATER

s = number of grams of **anhydrous** substance which when dissolved in 100 grams of **water** make a saturated solution at the temperature stated.

p = no. of grams of anhydrous substance per 100 grams of saturated **solution.**

The formula given is that of the solid phase which is in equilibrium with the solution. (See Seidell's "Solubilities," New York, 1916, where the most complete and accurate data will be found for solubilities.) For other solutions, see p. 130.

Substance.		0° C.	10°	15°	20°	40°	60°	80°	100°
Am. chloride, NH_4Cl	*s*	29·4	33·3	35·2	37·2	45·8	55·2	65·6	77·3
Barium chloride, $BaCl_2 . 2H_2O$ . .	*s*	31·6	33·3	34·4	35·7	40·7	46·4	52·4	58·8
Barium hydrate, $Ba(OH)_2 . 8H_2O$.	*s*	1·67	2·48	3·23	3·89	8·22	20·9	101·4	—
Bromine (*liquid*), Br.	*s*	4·22	3·4	3·25	3·20	—	—	—	—
Cadmium sulphate, $CdSO_4 . 8/3H_2O$.	*s*	76·5	76·0	76·3	76·6	78·5	83·7	69·7 *	60·77*
Ca. hydrate, $Ca(OH)_2$	*s*	·185	·176	·170	·165	·141	·116	·094	·077
Copper sulphate, $CuSO_4 . 5H_2O$ . .	*s*	14·3	17·4	18·8	20·7	28·5	40·0	55·0	75·0
Li. carbonate, Li_2CO_3	*s*	1·54	1·43	1·38	1·33	1·17	1·01	·850	·720
Merc. chloride, $HgCl_2$	*p*	3·50	4·50	5·00	5·40	9·30	14·0	23·1	38·0
Potass. chloride, KCl	*s*	27·6	31·0	32·4	34·0	40·0	45·5	51·1	56·7
Potass. bromide, KBr		53·5	59·5	62·5	65·2	75·5	85·5	95·0	104
Potassium iodide, KI	*s*	127·5	136	140	144	160	176	192	208
Potassium hydrate, $KOH . 2H_2O$ . .	*s*	97·0	103	107	112	138 §	—	—	178 §
Potass. nitrate, KNO_3	*s*	13·3	20·9	25·8	32	64	110	169	246
Silv. nitrate, $AgNO_3$	*s*	122	170	196	222	376	525	669	952
Sodium carbonate, $Na_2CO_3 . 10H_2O$.	*s*	7·0	12·5	16·4	21·5	46·1	46·0	45·8	45·5
Sod. chloride, NaCl	*s*	35·7	35·8	35·9	36·0	36·6	37	38	39·0
Sodium sulphate, $Na_2SO_4 . 10H_2O$.	*s*	5·0	9·0	13·4	19·4	49 †	45 †	44 †	42 †
Strontium chloride, $SrCl_2 . 6H_2O$ . .	*s*	43	48	50	53	65	82	91 ‡	101 ‡
Succinic acid, $(CH_2)_2(COOH)_2$.	*s*	2·80	4·50	5·7	6·9	16·2	35·8	70·8	125
Sugar (Cane), $C_{12}H_{22}O_{11}$ . . .	*s*	179	190	197	204	238	287	362	487

* Solid phase becomes $CdSO_4 . H_2O$ at 74°. † Becomes Na_2SO_4 at 32°·38.
‡ Becomes $SrCl_2 . 2H_2O$ at 70°. § Becomes $KOH . \frac{3}{2}H_2O$ at 32°·5 and $KOH . H_2O$ at 50°.
‖ Becomes $Na_2CO_3 . H_2O$ at 35°.

PERCENTAGE COMPOSITION OF DRY ATMOSPHERIC AIR

(Ramsay, *Proc. Roy. Soc.*, 1908; G. Claude, *Compt. Rend.*, 1909.)

	N_2	O_2	A	CO_2	Kr	Xe	Ne	He
By weight .	75·5	23·2	1·3	·046 to ·4	$\cdot0_4 14$	$\cdot0_5 26$	$\cdot0_3 86$	$\cdot0_4 56$
By volume .	78·05	21·0	·95	·03 to ·3	$\cdot0_6 5$	$\cdot0_6 59$	$\cdot0_2 123$	$\cdot0_3 40$

Leduc, 1917, weight % Kr 14×10^{-6}, Xe 3×10^{-6}, Ne $8{\cdot}4\times10^{-4}$, He 7×10^{-8}, H 7×10^{-6}.

MOHS' SCALE OF MINERAL HARDNESS

The numbers are not quantitative, but merely indicate the sequence of hardness.

Hardness.	Mineral.	Hardness.	Mineral.	Hardness.	Mineral.
1	Talc	**5**	Apatite	**9**	Corundum
2	Rock salt	**6**	Felspar	**10**	Diamond
3	Calcspar	**7**	Quartz	*c.* **2·5**	Finger-nail
4	Fluor spar	**8**	Topaz	*c.* **6·5**	Penknife

COMPOSITION, DENSITY, AND HARDNESS OF SOME MINERALS

See Dana's "System of Mineralogy" and Appendices, 1892, 1899, and 1909. Radioactive minerals are indicated thus *; see Szilard, *Le Radium*, August, 1909.

Name and Formula.	Density.	Hardness.
Albite, $Na_2Al_2Si_6O_{16}$ . .	*c.* 2·6	6–7
Amber (fossil resin) . .	1·08	2–2·5
Anhydrite, $CaSO_4$ . .	2·8–2·9	3–3·5
Anorthite, $Ca_2Al_4Si_4O_{16}$.	*c.* 2·7	6–7
Apatite, $Ca_5(Cl,F,OH)(PO_4)_3$	2·9–3·2	5
Aragonite, $CaCO_3$ . . .	2·93	3·5–4
Augite, Mg,Fe,Ca,Al silicate	3·2–3·5	5–6
Barytes, Heavy spar, $BaSO_4$	4·5	3–3·5
Beryl, $Be_3Al_2Si_6O_{18}$ . .	2·6–2·7	7–8
Bröggerite,* a pitchblende which contains thorium	(56–68% U)	(2–8% Th)
Calcite, Calcspar, Iceland spar, $CaCO_3$	2·6–2·7	*c.* 3
Carnallite, $KCl.MgCl_2.6H_2O$	1·6	1
Carnotite,* $K_2O(U_2O_5)_2V_2O_5.3H_2O$	(*c.* 55% U)	(yellow)
Celestine, $SrSO_4$ . . .	3·9	3–3·5
Cerussite, $PbCO_3$ . . .	6·4	3–3·5
Chalcolite,* $Cu(UO_2)(PO_4)_2.8H_2O$;	3·4–3·6 (48% U)	2–2·5
Cléveite*—pitchblende which contains Th & Y	(*c.* 60% U)	(*c.* 4% Th)
Corundum, Al_2O_3 . . .	3·9–4·2	9
Dolomite, $CaMgC_2O_6$.	2·8–2·9	3·5–4
Felspar, $Al_2K_2Si_6O_{16}$ . .	2·4–2·6	6
Flint; agate, SiO_2 . .	2·6	*c.* 6
Fluorspar, Fluorite, CaF_2	3–3·3	4
Galena, PbS	7·4–7·6	2–3
Gummite,* Pb,Ca,U,silic	ate(50–	65% U)
Gypsum, $CaSO_4 2H_2O$.	2·3	1·5–2
Hæmatite, Fe_2O_3 . . .	4·5–5·3	5·5–6·5
Hornblende, Ca,Mg,Fe,Na,Al,silicate	2·9–3·4	5–6
Kainite, $MgSO_4KCl3H_2O$	2·1	—
Kaolin, $H_4Al_2Si_2O_9$ . .	2·5	1
Kieserite, $MgSO_4H_2O$.	2·55	3
Lepidolite (Lithia mica), $(F,OH)_2(Li,K,Na)_3Al_2Si_3O_9$	2·8–3	2·5–4
Limestone, $CaCO_3$ . .	2·5–2·8	—
Magnesite, $MgCO_3$ . .	*c.* 3	3·5–4·5
Magnetite, Fe_3O_4 . . .	4·9–5·2	5·5–6·5
Meerschaum, $2MgO.3SiO_2.2H_2O$.	*c.* 2·6	2–2·5
Mica (common, Muscovite), $K_2O.3Al_2O_3.6SiO_2.2H_2O$	2·7–3·1	2–2·5
Mica (Biotite, Magnesia mica)	2·7–3·1	2·5–3
Monazite,* (CeLaDi)PO_4 (1–16% Th)	5	5·2
Nepheline, $Na_6K_6Al_8Si_9O_{34}$	2·5–2·6	5·5–6
Olivine, $Mg_2Fe_2SiO_4$ . .	3·3–3·5	6–7
Orthoclase, $K_2Al_2Si_6O_{16}$.	2·4–2·6	6
Pitchblende,* U_3O_8 with oxides of Pb, and Ca, Fe,Bi,Mn,Mg,Cu,Si, Al, etc. (25–80% U; 1–6% Th)	6·4 (massive) 9·7 (cryst.)	5·5
Pyrites (iron), FeS_2 . .	4·8–5·1	6–6·5
„ (copper), $CuFeS_2$	4·1–4·3	3·5–4
Pyrolusite, MnO_2 . . .	4·8–5	2–5·5
Quartz, SiO_2	2·5–2·8	7
Rock salt, NaCl . . .	2·1–2·2	2–2·5
Rutile, TiO_2	4·2–4·3	6–6·5
Selenite—cryst. gypsum	—	—
Serpentine, $H_4Mg_3Si_2O_9$	*c.* 2·6	3–4
Spinel, $MgOAl_2O_3$ . .	3·5–3·6	8
Sylvine, KCl	1·9–2	2
Talc, $H_2Mg_3Si_4O_{12}$ . .	2·5–2·8	1
Thorianite,* Th, U oxides, etc.; (4–10% U; *c.* 60% Th) contains He	8–9·7	7 (black cubes)
Thorite,* $ThSiO_4$ (1–9% U; 40–60% Th)	4·6	(tetragonal)
Tourmaline, hydrated silicate and borate of Al, Na with Li or Fe or Mg	2·9–3·3	7–7·5
Trögerite,* $(UO_2)_3As_2O_8 12H_2O$	(53% U)	(yellow)
Uraninite*—crystalline pitchblende (*q.v.*)	(Black	octahedra)
Uranite lime,* $CaO(UO_2)_2(PO_4)_2 8H_2O$ (50% U)	3–3·2	2–2·5
Willemite, Zn_2SiO_4 . .	4	5
Wolfram, (Fe,Mn)WO_4 .	7·1–7·9	5–5·5
Wollastonite, $CaSiO_3$.	2·7–2·9	4·5–5
Zeunerite,* Cu,U arsenate	(*c.* 50% U)	(tetragonal)
Zircon,* $ZrSiO_4$ . . .	4·7	7·5
Zincblende, ZnS . . .	3·9–4·2	3·5–4

FACTORS FOR GRAVIMETRIC ANALYSIS

Calculated with atomic weights for 1938.

Example.—1 gram Al_2O_3 is chemically equivalent to ·5291 gram Al, or 1 gram Al is equivalent to 1/·5291 Al_2O_3. A table of reciprocals is given on p. 157. (See Van Nostrand's "Chemical Annual," London.)

1 part by weight of	is equivalent (by weight) to
Aluminium.	
Al_2O_3	·5291 Al
,,	3·356 $Al_2(SO_4)_3$
Ammonium.	
N	1·216 NH_3
,,	1·288 NH_4
,,	3·819 NH_4Cl
NH_3	2·058 NH_4OH
Antimony.	
Sb	1·1971 Sb_2O_3
,,	1·3285 Sb_2O_5
Sb_2O_3	1·1098 Sb_2O_5
Sb_2O_4	·7919 Sb
,,	·9480 Sb_2O_3
,,	1·0520 Sb_2O_5
Arsenic.	
As_2O_3	·7574 As
,,	1·1618 As_2O_5
As_2O_5	·6519 As
$MgNH_4AsO_4 \cdot \frac{1}{2}H_2O$	·3937 As
,, ,,	·5198 As_2O_3
,, ,,	·6039 As_2O_5
$Mg_2As_2O_7$	·4826 As
,,	·6373 As_2O_3
,,	·7403 As_2O_5
Barium.	
$BaCO_3$	·6960 Ba
,,	·7770 BaO
$BaSO_4$	·5885 Ba
,,	·6570 BaO
,,	·7256 BaO_2
Beryllium.	
BeO	·3605 Be
Bismuth.	
Bi	1·1148 Bi_2O_3
Bi_2O_3	·8970 Bi
BiOCl	·8024 Bi
,,	·8946 Bi_2O_3
Boron.	
B_2O_3	·3107 B
,,	2·7387 $Na_2B_4O_7 \cdot 10H_2O$
Bromine.	
AgBr	·4255 Br
Cadmium.	
CdO	·8754 Cd
Cæsium.	
Cs	1·060 Cs_2O
Cs_2PtCl_6	·3916 Cs
,,	·4151 Cs_2O
Calcium.	
Ca	1·374 CaO
$CaCO_3$	·4076 Ca
,,	·5603 CaO
CO_2	2·274 $CaCO_3$
Calcium (*contd.*)—	
$Ca_3(PO_4)_2$	·5422 CaO
$Mg_2P_2O_7$	1·3934 $Ca_3(PO_4)_2$
P_2O_5	2·1844 $Ca_3(PO_4)_2$
Carbon.	
CO_2	4·4847 $BaCO_3$
,,	2·2743 $CaCO_3$
Chlorine.	
AgCl	·2474 Cl
NaCl	·6066 Cl
Chromium.	
Cr_2O_3	·6843 Cr
,,	1·3158 CrO_3
Cobalt.	
Co	1·2715 CoO
Co_3O_4	·7342 Co
,,	·9336 CoO
$Co(NO_2)_3 \cdot (KNO_2)_3$	·1303 Co
,, ,,	·1657 CoO
$(CoSO_4)_2 \cdot (K_2SO_4)_3$	·1416 Co
Copper.	
Cu	1·2517 CuO
Fluorine.	
CaF_2	·4867 F
Glucinum. *See* Beryllium.	
Gold.	
Au	1·5394 $AuCl_3$
Hydrogen.	
H_2O	·1119 H
Iodine.	
AgI	·5405 I
Iron.	
Fe	1·2865 FeO
,,	1·4298 Fe_2O_3
,,	7·0225 $FeSO_4(NH_4)_2SO_4 \cdot 6H_2O$
FeO	·7773 Fe
,,	1·1114 Fe_2O_3
Fe_2O_3	1·4510 $FeCO_3$
,,	·9666 Fe_3O_4
CO_2	1·6324 FeO
,,	2·6324 $FeCO_3$
Lead.	
Pb	1·0772 PbO
$PbSO_4$	·6832 Pb
,,	·7360 PbO
,,	·7888 PbO_2
,,	·7536 Pb_3O_4
Lithium.	
Li_2CO_3	·1878 Li
,,	·4044 Li_2O
Li_3PO_4	·1797 Li
,,	·3869 Li_2O

J. L.

FACTORS FOR GRAVIMETRIC ANALYSIS (*contd.*)

1 part by weight of	is equivalent (by weight) to
Magnesium.	
MgO	·6032 Mg
$Mg_2P_2O_7$	·2184 Mg
"	·3621 MgO
Manganese.	
MnO	1·1128 Mn_2O_3
Mn_3O_4	·7203 Mn
"	·9301 MnO
"	1·0350 Mn_2O_3
"	1·1399 MnO_2
Mercury.	
Hg	1·1598 HgS
HgS	·8966 Hg_2O
"	·9310 HgO
Nickel.	
Ni	1·2726 NiO
Nitrogen.	
N	3·8555 N_2O_5
Phosphorus.	
P_2O_5	·4368 P
$Mg_2P_2O_7$	·2787 P
"	·8534 PO_4
"	·6379 P_2O_5
Platinum.	
K_2PtCl_6	·4016 Pt
"	·6933 $PtCl_4$
Potassium.	
AgCl	·5201 KCl
AgBr	·6337 KBr
AgI	·7071 KI
AgCN	·4863 KCN
KCl	·5244 K
KBr	·3285 K
KOH	1·2317 K_2CO_3
"	·8394 K_2O
K_2SO_4	·5406 K_2O
Potassium (*contd.*)	
K_2SO_4	1·1604 KNO_3
K_2PtCl_6	·1608 K
Rubidium.	
Rb_2PtCl_6 . . .	·2953 Rb
Silicon.	
SiO_2	·4672 Si
Silver.	
AgCl	·7526 Ag
AgBr	·5744 Ag
AgI	·4595 Ag
Sodium.	
AgCl	·4078 NaCl
$NaHCO_3$ . . .	·3690 Na_2O
Na_2SO_4	·3238 Na
"	·4364 Na_2O
N_2O_5	1·5739 $NaNO_3$
Strontium.	
$SrCO_3$	·7019 SrO
$SrSO_4$	·5641 SrO
Sulphur.	
$BaSO_4$	·1460 H_2S
"	·1373 S
"	·2744 SO_2
"	·3430 SO_3
"	·4115 SO_4
Tin.	
SnO_2	·7877 Sn
Uranium.	
U_3O_8	·8480 U
"	·9620 UO_2
UO_2	·8815 U
Zinc.	
Zn	1·2447 ZnO
ZnO	·8034 Zn

[J. L.

SOME BOILING-POINT MIXTURES

Boiling-points under 760 mms. of mercury. Percentage compositions by weight. A large number of minimum boiling-point mixtures are known.

(Sidney Young, "Fractional Distillation," 1903.)

	Mixture.		Boiling Points.			% of A in mixt.	Observer.
	A.	B.	A.	B.	Mixt.		
Maximum boiling-point mixtures.	Water	Nitric acid	100° C.	86°	125°	32%	Roscoe
	"	Hydrochloric acid	100	*c.* – 80	110	80	"
	"	Formic acid	100	100·8	107	23	"
	Me. ether	Hydrochloric acid	– 23·6	*c.* – 80	– 2	61	Friedel
Minimum boiling-point mixtures.	Water	Ethyl alcohol	100	78·3	78·1	4·4	Y. & F.
	Pyridine	Water	117	100	92·5	59	G. & C.
	Benzene	Methyl alcohol	80·2	64·7	58·3	60	Y. & F.
	Me.alcohol	Acetone	64·7	56·5	55·9	13·5	Pettit

G. & C., Goldschmidt and Constan ; Y. & F., Young and Fortey.

THE EXPONENTIAL e^{-x}

$e = 2·71828$. To derive e^{x} use reciprocals on p. 157. $e^{-·69315} = ·5$.

(Based on Newman, *Trans. Camb. Phil. Soc.*, 13, 1883.)

For values of x from ·0000 to ·0999.											Subtract Differences.								
x	0	·001	·002	·003	·004	·005	·006	·007	·008	·009	·0001	2	3	4	5	6	7	8	9
·00	1·000	·9990	·9980	·9970	·9960	·9950	·9940	·9930	·9920	·9910	1	2	3	4	5	6	7	8	9
·01	·9900	·9891	·9881	·9871	·9861	·9851	·9841	·9831	·9822	·9812	1	2	3	4	5	6	7	8	9
·02	·9802	·9792	·9782	·9773	·9763	·9753	·9743	·9734	·9724	·9714	1	2	3	4	5	6	7	8	9
·03	·9704	·9695	·9685	·9675	·9666	·9656	·9646	·9637	·9627	·9618	1	2	3	4	5	6	7	8	9
·04	·9608	·9598	·9589	·9579	·9570	·9560	·9550	·9541	·9531	·9522	1	2	3	4	5	6	7	8	9
·05	·9512	·9502	·9493	·9484	·9474	·9465	·9455	·9446	·9436	·9427	1	2	3	4	5	6	7	8	9
·06	·9418	·9408	·9399	·9389	·9380	·9371	·9361	·9352	·9343	·9333	1	2	3	4	5	6	7	8	9
·07	·9324	·9315	·9305	·9296	·9287	·9277	·9268	·9259	·9250	·9240	1	2	3	4	5	6	7	8	8
·08	·9231	·9222	·9213	·9204	·9194	·9185	·9176	·9167	·9158	·9148	1	2	3	4	5	6	7	7	8
·09	·9139	·9130	·9121	·9112	·9103	·9094	·9085	·9076	·9066	·9057	1	2	3	4	5	6	6	7	8

For values of x from ·100 to 2·999.											Subtract Differences.								
x	0	·01	·02	·03	·04	·05	·06	·07	·08	·09	·001	2	3	4	5	6	7	8	9
·1	·9048	·8958	·8869	·8781	·8694	·8607	·8521	·8437	·8353	·8270	9	17	26	34	43	52	60	69	77
·2	·8187	·8106	·8025	·7945	·7866	·7788	·7711	·7634	·7558	·7483	8	16	23	31	39	47	55	62	70
·3	·7408	·7334	·7261	·7189	·7118	·7047	·6977	·6907	·6839	·6771	7	14	21	28	35	42	49	56	63
·4	·6703	·6637	·6570	·6505	·6440	·6376	·6313	·6250	·6188	·6126	6	13	19	26	32	38	45	51	57
·5	·6065	·6005	·5945	·5886	·5827	·5769	·5712	·5655	·5599	·5543	6	12	17	23	29	35	40	46	52
·6	·5488	·5434	·5379	·5326	·5273	·5220	·5169	·5117	·5066	·5016	5	10	16	21	26	31	37	42	47
·7	·4966	·4916	·4868	·4819	·4771	·4724	·4677	·4630	·4584	·4538	5	9	14	19	24	28	33	38	43
·8	·4493	·4449	·4404	·4360	·4317	·4274	·4232	·4190	·4148	·4107	4	9	13	17	21	26	30	34	38
·9	·4066	·4025	·3985	·3946	·3906	·3867	·3829	·3791	·3753	·3716	4	8	12	15	19	23	27	31	35
1·0	·3679	·3642	·3606	·3570	·3535	·3499	·3465	·3430	·3396	·3362	4	7	11	14	18	21	25	28	32
1·1	·3329	·3296	·3263	·3230	·3198	·3166	·3135	·3104	·3073	·3042	3	6	9	13	16	19	22	25	29
1·2	·3012	·2982	·2952	·2923	·2894	·2865	·2837	·2808	·2780	·2753	3	6	9	11	14	17	20	23	26
1·3	·2725	·2698	·2671	·2645	·2618	·2592	·2567	·2541	·2516	·2491	3	5	8	10	13	16	18	21	23
1·4	·2466	·2441	·2417	·2393	·2369	·2346	·2322	·2299	·2276	·2254	2	5	7	9	12	14	16	19	21
1·5	·2231	·2209	·2187	·2165	·2144	·2122	·2101	·2080	·2060	·2039	2	4	6	8	11	13	15	17	19
1·6	·2019	·1999	·1979	·1959	·1940	·1920	·1901	·1882	·1864	·1845	2	4	6	8	10	12	13	15	17
1·7	·1827	·1809	·1791	·1773	·1755	·1738	·1720	·1703	·1686	·1670	2	3	5	7	9	10	12	14	16
1·8	·1653	·1637	·1620	·1604	·1588	·1572	·1557	·1541	·1526	·1511	2	3	5	6	8	9	11	13	14
1·9	·1496	·1481	·1466	·1451	·1437	·1423	·1409	·1395	·1381	·1367	1	3	4	6	7	9	10	11	13
2·0	·1353	·1340	·1327	·1313	·1300	·1287	·1275	·1262	·1249	·1237	1	3	4	5	6	8	9	10	12
2·1	·1225	·1212	·1200	·1188	·1177	·1165	·1153	·1142	·1130	·1119	1	2	4	5	6	7	8	9	11
2·2	·1108	·1097	·1086	·1075	·1065	·1054	·1044	·1033	·1023	·1013	1	2	3	4	5	6	7	8	9
2·3	·1003	·0993	·0983	·0973	·0963	·0954	·0944	·0935	·0926	·0916	1	2	3	4	5	6	7	8	9
2·4	·0907	·0898	·0889	·0880	·0872	·0863	·0854	·0846	·0837	·0829	1	2	3	3	4	5	6	7	8
2·5	·0821	·0813	·0805	·0797	·0789	·0781	·0773	·0765	·0758	·0750	1	2	2	3	4	5	5	6	7
2·6	·0743	·0735	·0728	·0721	·0714	·0707	·0699	·0693	·0686	·0679	1	1	2	3	4	4	5	6	6
2·7	·0672	·0665	·0659	·0652	·0646	·0639	·0633	·0627	·0620	·0614	1	1	2	3	3	4	4	5	6
2·8	·0608	·0602	·0596	·0590	·0584	·0578	·0573	·0567	·0561	·0556	1	1	2	2	3	3	4	5	5
2·9	·0550	·0545	·0539	·0534	·0529	·0523	·0518	·0513	·0508	·0503	1	1	2	2	3	3	4	4	5

For values of x from 3·0 to 8·9.											Subtract Differences.
x	0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
3	·0498	·0450	·0408	·0368	·0334	·0302	·0273	·0247	·0224	·0202	Mean differences no longer sufficiently accurate.
4	·0183	·0166	·0150	·0136	·0123	·0111	·0101	·0091	·0082	·0074	
5	·0067	·0061	·0055	·0050	·0045	·0041	·0037	·0033	·0030	·0027	
6	·0025	·0022	·0020	·0018	·0017	·0015	·0014	·0012	·0011	·0010	
7	·0009	·0008	·0007	·0007	·0006	·0006	·0005	·0005	·0004	·0004	
8	·0003	·0003	·0003	·0002	·0002	·0002	·0002	·0002	·0002	·0001	

FOUR-FIGURE LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						4	9	13	17	21	25	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	36
11	0414	0453	0492	0531	0569						4	8	12	15	19	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	18	22	26	30	33
12	0792	0828	0864	0899	0934	0969					4	7	11	14	18	21	25	28	32
							1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	7	10	13	16	20	23	26	30
						1303	1335	1367	1399	1430	3	6	9	13	16	19	22	25	28
14	1461	1492	1523	1553							3	6	9	12	15	18	21	24	27
					1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903					3	6	9	11	14	17	20	23	26
							1931	1959	1987	2014	3	6	8	11	14	17	19	22	25
16	2041	2068	2095	2122	2148						3	5	8	11	13	16	19	21	24
						2175	2201	2227	2253	2279	3	5	8	10	13	16	18	21	23
17	2304	2330	2355	2380	2405	2430					3	5	8	10	13	15	18	20	23
							2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648						2	5	7	10	12	14	17	19	21
						2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878						2	5	7	9	11	14	16	18	20
						2900	2923	2945	2967	2989	2	4	7	9	11	13	15	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

FOUR-FIGURE LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	00000	00432	00860	01284	01703						43	85	127	170	212	255	297	340	382
						02119	02531	02938	03342	03743	41	81	121	162	202	243	283	323	364
11	04139	04532	04922	05308	05690						39	77	116	155	193	232	270	309	348
						06070	06446	06819	07188	07555	37	74	111	148	185	222	259	296	333
12	07918	08279	08636	08991	09342						36	71	106	142	177	213	248	284	319
						09691	10037	10380	10721	11059	34	68	102	136	170	205	239	273	307
13	11394	11727	12057	12385	12710						33	66	98	131	164	197	230	262	295
						13033	13354	13672	13988	14301	32	63	95	126	158	190	221	253	284
14	14613	14922	15229	15534	15836						31	61	91	122	152	183	213	244	274
						16137	16435	16732	17026	17319	30	59	88	118	147	177	206	236	265
15	17609	17898	18184	18469	18752						29	57	85	114	142	171	199	228	256
						19033	19312	19590	19866	20140	28	55	83	110	138	166	193	221	248
16	20412	20683	20951	21219	21484						27	53	80	107	134	160	187	214	241
						21748	22011	22272	22531	22789	26	52	78	104	130	156	182	208	233
17	23045	23300	23553	23805	24055						25	50	76	101	126	151	176	201	227
						24304	24551	24797	25042	25285	24	49	73	98	122	147	171	196	220
18	25527	25768	26007	26245	26482						24	48	71	95	119	143	167	190	214
						26717	26951	27184	27416	27646	23	46	70	93	116	139	162	185	209
19	27875	28103	28330	28556	28780						23	45	68	90	113	135	158	181	203
						29003	29226	29447	29667	29885	22	44	66	88	110	132	154	176	198
20	30103	30320	30535	30750	30963	31175	31387	31597	31806	32015	21	42	64	85	106	127	148	170	191
21	32222	32428	32634	32838	33041	33244	33445	33646	33846	34044	20	40	61	81	101	121	141	162	182
22	34242	34439	34635	34830	35025	35218	35411	35603	35793	35984	19	39	58	77	97	116	135	155	174
23	36173	36361	36549	36736	36922	37107	37291	37475	37658	37840	18	37	56	74	92	111	130	148	166
24	38021	38202	38382	38561	38739	38917	39094	39270	39445	39620	18	35	53	71	89	106	124	142	160
25	39794	39967	40140	40312	40483	40654	40824	40993	41162	41330	17	34	51	68	85	102	119	136	153
26	41497	41664	41830	41996	42160	42325	42488	42651	42813	42975	16	33	49	66	82	98	115	131	148
27	43136	43297	43457	43616	43775	43933	44091	44248	44404	44560	16	32	47	63	79	95	111	126	142
28	44716	44871	45025	45179	45332	45484	45637	45788	45939	46090	15	30	46	61	76	91	107	122	137
29	46240	46389	46538	46687	46835	46982	47129	47276	47422	47567	15	29	44	59	74	88	103	118	133
30	47712	47857	48001	48144	48287	48430	48572	48714	48855	48996	14	28	43	57	71	85	100	114	128
31	49136	49276	49415	49554	49693	49831	49969	50106	50243	50379	14	28	41	55	69	83	97	110	124
32	50515	50650	50786	50920	51054	51188	51322	51455	51587	51720	13	27	40	53	67	80	94	107	120
33	51851	51983	52114	52244	52375	52504	52634	52763	52892	53020	13	26	39	52	65	78	91	104	117
34	53148	53275	53403	53529	53656	53782	53908	54033	54158	54283	13	25	38	50	63	76	88	101	113
35	54407	54531	54654	54777	54900	55023	55145	55267	55388	55509	12	24	37	49	61	73	86	98	110
36	55630	55751	55871	55991	56110	56229	56348	56467	56585	56703	12	24	36	48	60	71	83	95	107
37	56820	56937	57054	57171	57287	57403	57519	57634	57749	57864	12	23	35	46	58	70	81	93	104
38	57978	58092	58206	58320	58433	58546	58659	58771	58883	58995	11	23	34	45	56	68	79	90	102
39	59106	59218	59329	59439	59550	59660	59770	59879	59988	60097	11	22	33	44	55	66	77	88	99
40	60206	60314	60423	60531	60638	60745	60853	60959	61066	61172	11	21	32	43	54	64	75	86	97
41	61278	61384	61490	61595	61700	61805	61909	62014	62118	62221	10	21	31	42	52	63	73	84	94
42	62325	62428	62531	62634	62737	62839	62941	63043	63144	63246	10	20	31	41	51	61	72	82	92
43	63347	63448	63548	63649	63749	63849	63949	64048	64147	64246	10	20	30	40	50	60	70	80	90
44	64345	64444	64542	64640	64738	64836	64933	65031	65128	65225	10	20	29	39	49	59	68	78	88
45	65321	65418	65514	65610	65706	65801	65896	65992	66087	66181	10	19	29	38	48	57	67	76	86
46	66276	66370	66464	66558	66652	66745	66839	66932	67025	67117	9	19	28	37	47	56	65	75	84
47	67210	67302	67394	67486	67578	67669	67761	67852	67943	68034	9	18	27	37	46	55	64	73	82
48	68124	68215	68305	68395	68485	68574	68664	68753	68842	68931	9	18	27	36	45	54	63	72	81
49	69020	69108	69197	69285	69373	69461	69548	69636	69723	69810	9	18	26	35	44	53	61	70	79
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

FIVE-FIGURE LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
50	69897	69984	70070	70157	70243	70329	70415	70501	70586	70672	9	17	26	34	43	52	60	69	77
51	70757	70842	70927	71012	71096	71181	71265	71349	71433	71517	8	17	25	34	42	51	59	67	76
52	71600	71684	71767	71850	71933	72016	72099	72181	72263	72346	8	17	25	33	41	50	58	66	74
53	72428	72509	72591	72673	72754	72835	72916	72997	73078	73159	8	16	24	32	41	49	57	65	73
54	73239	73320	73400	73480	73560	73640	73719	73799	73878	73957	8	16	24	32	40	48	56	64	72
55	74036	74115	74194	74273	74351	74429	74507	74586	74663	74741	8	16	23	31	39	47	55	63	70
56	74819	74896	74974	75051	75128	75205	75282	75358	75435	75511	8	15	23	31	39	46	54	62	69
57	75587	75664	75740	75815	75891	75967	76042	76118	76193	76268	8	15	23	30	38	45	53	60	68
58	76343	76418	76492	76567	76641	76716	76790	76864	76938	77012	7	15	22	30	37	44	52	59	67
59	77085	77159	77232	77305	77379	77452	77525	77597	77670	77743	7	15	22	29	37	44	51	58	66
60	77815	77887	77960	78032	78104	78176	78247	78319	78390	78462	7	14	22	29	36	43	50	58	65
61	78533	78604	78675	78746	78817	78888	78958	79029	79099	79169	7	14	21	28	36	43	50	57	64
62	79239	79309	79379	79449	79518	79588	79657	79727	79796	79865	7	14	21	28	35	42	49	56	63
63	79934	80003	80072	80140	80209	80277	80346	80414	80482	80550	7	14	21	27	34	41	48	55	62
64	80618	80686	80754	80821	80889	80956	81023	81090	81158	81224	7	13	20	27	34	40	47	54	61
65	81291	81358	81425	81491	81558	81624	81690	81757	81823	81889	7	13	20	27	33	40	46	53	60
66	81954	82020	82086	82151	82217	82282	82347	82413	82478	82543	7	13	20	26	33	39	46	52	59
67	82607	82672	82737	82802	82866	82930	82995	83059	83123	83187	6	13	19	26	32	39	45	51	58
68	83251	83315	83378	83442	83506	83569	83632	83696	83759	83822	6	13	19	25	32	38	44	51	57
69	83885	83948	84011	84073	84136	84198	84261	84323	84386	84448	6	12	19	25	31	37	44	50	56
70	84510	84572	84634	84696	84757	84819	84880	84942	85003	85065	6	12	18	25	31	37	43	49	55
71	85126	85187	85248	85309	85370	85431	85491	85552	85612	85673	6	12	18	24	31	37	43	49	55
72	85733	85794	85854	85914	85974	86034	86094	86153	86213	86273	6	12	18	24	30	36	42	48	54
73	86332	86392	86451	86510	86570	86629	86688	86747	86806	86864	6	12	18	24	30	35	41	47	53
74	86923	86982	87040	87099	87157	87216	87274	87332	87390	87448	6	12	17	23	29	35	41	47	52
75	87506	87564	87622	87679	87737	87795	87852	87910	87967	88024	6	12	17	23	29	35	40	46	52
76	88081	88138	88195	88252	88309	88366	88423	88480	88536	88593	6	11	17	23	29	34	40	46	51
77	88649	88705	88762	88818	88874	88930	88986	89042	89098	89154	6	11	17	22	28	34	39	45	50
78	89209	89265	89321	89376	89432	89487	89542	89597	89653	89708	6	11	17	22	28	33	39	44	50
79	89763	89818	89873	89927	89982	90037	90091	90146	90200	90255	6	11	17	22	28	33	39	44	50
80	90309	90363	90417	90472	90526	90580	90633	90687	90741	90795	5	11	16	22	27	32	38	43	49
81	90848	90902	90956	91009	91062	91116	91169	91222	91275	91328	5	11	16	21	27	32	37	43	48
82	91381	91434	91487	91540	91593	91645	91698	91751	91803	91855	5	11	16	21	26	32	37	42	47
83	91908	91960	92012	92064	92117	92169	92221	92273	92324	92376	5	10	16	21	26	31	36	42	47
84	92428	92480	92531	92583	92634	92686	92737	92788	92840	92891	5	10	15	21	26	31	36	41	46
85	92942	92993	93044	93095	93146	93197	93247	93298	93349	93399	5	10	15	20	26	31	36	41	46
86	93450	93500	93551	93601	93651	93702	93752	93802	93852	93902	5	10	15	20	25	30	35	40	45
87	93952	94002	94052	94101	94151	94201	94250	94300	94349	94399	5	10	15	20	25	30	35	40	45
88	94448	94498	94547	94596	94645	94694	94743	94792	94841	94890	5	10	15	20	25	29	34	39	44
89	94939	94988	95036	95085	95134	95182	95231	95279	95328	95376	5	10	15	19	24	29	34	39	44
90	95424	95472	95521	95569	95617	95665	95713	95761	95809	95856	5	10	14	19	24	29	34	38	43
91	95904	95952	95999	96047	96095	96142	96190	96237	96284	96332	5	9	14	19	24	28	33	38	43
92	96379	96426	96473	96520	96567	96614	96661	96708	96755	96802	5	9	14	19	24	28	33	38	42
93	96848	96895	96942	96988	97035	97081	97128	97174	97220	97267	5	9	14	19	23	28	33	37	42
94	97313	97359	97405	97451	97497	97543	97589	97635	97681	97727	5	9	14	18	23	28	32	37	42
95	97772	97818	97864	97909	97955	98000	98046	98091	98137	98182	5	9	14	18	23	27	32	36	41
96	98227	98272	98318	98363	98408	98453	98498	98543	98588	98632	5	9	14	18	23	27	32	36	41
97	98677	98722	98767	98811	98856	98900	98945	98989	99034	99078	4	9	13	18	22	27	31	36	40
98	99123	99167	99211	99255	99300	99344	99388	99432	99476	99520	4	9	13	18	22	26	31	35	40
99	99564	99607	99651	99695	99739	99782	99826	99870	99913	99957	4	9	13	17	22	26	31	35	39
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

	0	1	2	3	4	5	6	7	8	9	Subtract Differences.								
											1	2	3	4	5	6	7	8	9
10	1000	9901	9804	9709	9615	9524	9434	9346	9259	9174	Mean differences not sufficiently accurate.								
11	9091	9009	8929	8850	8772	8696	8621	8547	8475	8403									
12	8333	8264	8197	8130	8065	8000	7937	7874	7813	7752									
13	7692	7634	7576	7519	7463	7407	7353	7299	7246	7194									
14	7143	7092	7042	6993	6944	6897	6849	6803	6757	6711									
15	6667	6623	6579	6536	6494	6452	6410	6369	6329	6289	4	8	13	17	21	25	29	33	38
16	6250	6211	6173	6135	6098	6061	6024	5988	5952	5917	4	7	11	15	18	22	26	29	33
17	5882	5848	5814	5780	5747	5714	5682	5650	5618	5587	3	6	10	13	16	20	23	26	29
18	5556	5525	5495	5464	5435	5405	5376	5348	5319	5291	3	6	9	12	15	17	20	23	26
19	5263	5236	5208	5181	5155	5126	5102	5076	5051	5025	3	5	8	11	13	16	18	21	24
20	5000	4975	4950	4926	4902	4878	4854	4831	4808	4785	2	5	7	10	12	14	17	19	21
21	4762	4739	4717	4695	4673	4651	4630	4608	4587	4566	2	4	7	9	11	13	15	17	19
22	4545	4525	4505	4484	4464	4444	4425	4405	4386	4367	2	4	6	8	10	12	14	16	18
23	4348	4329	4310	4292	4274	4255	4237	4219	4202	4184	2	4	5	7	9	11	13	14	16
24	4167	4149	4132	4115	4098	4082	4065	4049	4032	4016	2	3	5	7	8	10	12	13	15
25	4000	3984	3968	3953	3937	3922	3906	3891	3876	3861	2	3	5	6	8	9	11	12	14
26	3846	3831	3817	3802	3788	3774	3759	3745	3731	3717	1	3	4	6	7	8	10	11	13
27	3704	3690	3676	3663	3650	3636	3623	3610	3597	3584	1	3	4	5	7	8	9	11	12
28	3571	3559	3546	3534	3521	3509	3497	3484	3472	3460	1	2	4	5	6	7	9	10	11
29	3448	3436	3425	3413	3401	3390	3378	3367	3356	3344	1	2	3	5	6	7	8	9	10
30	3333	3322	3311	3300	3289	3279	3268	3257	3247	3236	1	2	3	4	5	6	7	9	10
31	3226	3215	3205	3195	3185	3175	3165	3155	3145	3135	1	2	3	4	5	6	7	8	9
32	3125	3115	3106	3096	3086	3077	3067	3058	3049	3040	1	2	3	4	5	6	7	8	9
33	3030	3021	3012	3003	2994	2985	2976	2967	2959	2950	1	2	3	4	4	5	6	7	8
34	2941	2933	2924	2915	2907	2899	2890	2882	2874	2865	1	2	3	3	4	5	6	7	8
35	2857	2849	2841	2833	2825	2817	2809	2801	2793	2786	1	2	2	3	4	5	6	6	7
36	2778	2770	2762	2755	2747	2740	2732	2725	2717	2710	1	2	2	3	4	5	5	6	7
37	2703	2695	2688	2681	2674	2667	2660	2653	2646	2639	1	1	2	3	4	4	5	6	6
38	2632	2625	2618	2611	2604	2597	2591	2584	2577	2571	1	1	2	3	3	4	5	5	6
39	2564	2558	2551	2545	2538	2532	2525	2519	2513	2506	1	1	2	3	3	4	4	5	6
40	2500	2494	2488	2481	2475	2469	2463	2457	2451	2445	1	1	2	2	3	4	4	5	5
41	2439	2433	2427	2421	2415	2410	2404	2398	2392	2387	1	1	2	2	3	3	4	5	5
42	2381	2375	2370	2364	2358	2353	2347	2342	2336	2331	1	1	2	2	3	3	4	4	5
43	2326	2320	2315	2309	2304	2299	2294	2288	2283	2278	1	1	2	2	3	3	4	4	5
44	2273	2268	2262	2257	2252	2247	2242	2237	2232	2227	1	1	2	2	3	3	4	4	5
45	2222	2217	2212	2208	2203	2198	2193	2188	2183	2179	0	1	1	2	2	3	3	4	4
46	2174	2169	2165	2160	2155	2151	2146	2141	2137	2132	0	1	1	2	2	3	3	4	4
47	2128	2123	2119	2114	2110	2105	2101	2096	2092	2088	0	1	1	2	2	3	3	4	4
48	2083	2079	2075	2070	2066	2062	2058	2053	2049	2045	0	1	1	2	2	3	3	3	4
49	2041	2037	2033	2028	2024	2020	2016	2012	2008	2004	0	1	1	2	2	2	3	3	4
50	2000	1996	1992	1988	1984	1980	1976	1972	1969	1965	0	1	1	2	2	2	3	3	4
51	1961	1957	1953	1949	1946	1942	1938	1934	1931	1927	0	1	1	2	2	2	3	3	3
52	1923	1919	1916	1912	1908	1905	1901	1898	1894	1890	0	1	1	1	2	2	3	3	3
53	1887	1883	1880	1876	1873	1869	1866	1862	1859	1855	0	1	1	1	2	2	2	3	3
54	1852	1848	1845	1842	1838	1835	1832	1828	1825	1821	0	1	1	1	2	2	2	3	3
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
											Subtract Differences.								

RECIPROCALS

	0	1	2	3	4	5	6	7	8	9	Subtract Differences.								
											1	2	3	4	5	6	7	8	9
55	1818	1815	1812	1808	1805	1802	1799	1795	1792	1789	0	1	1	1	2	2	2	3	3
56	1786	1783	1779	1776	1773	1770	1767	1764	1761	1757	0	1	1	1	2	2	2	3	3
57	1754	1751	1748	1745	1742	1739	1736	1733	1730	1727	0	1	1	1	2	2	2	2	3
58	1724	1721	1718	1715	1712	1709	1706	1704	1701	1698	0	1	1	1	1	2	2	2	3
59	1695	1692	1689	1686	1684	1681	1678	1675	1672	1669	0	1	1	1	1	2	2	2	3
60	1667	1664	1661	1658	1656	1653	1650	1647	1645	1642	0	1	1	1	1	2	2	2	3
61	1639	1637	1634	1631	1629	1626	1623	1621	1618	1616	0	1	1	1	1	2	2	2	2
62	1613	1610	1608	1605	1603	1600	1597	1595	1592	1590	0	1	1	1	1	2	2	2	2
63	1587	1585	1582	1580	1577	1575	1572	1570	1567	1565	0	0	1	1	1	1	2	2	2
64	1563	1560	1558	1555	1553	1550	1548	1546	1543	1541	0	0	1	1	1	1	2	2	2
65	1538	1536	1534	1531	1529	1527	1524	1522	1520	1517	0	0	1	1	1	1	2	2	2
66	1515	1513	1511	1508	1506	1504	1502	1499	1497	1495	0	0	1	1	1	1	2	2	2
67	1493	1490	1488	1486	1484	1481	1479	1477	1475	1473	0	0	1	1	1	1	2	2	2
68	1471	1468	1466	1464	1462	1460	1458	1456	1453	1451	0	0	1	1	1	1	2	2	2
69	1449	1447	1445	1443	1441	1439	1437	1435	1433	1431	0	0	1	1	1	1	1	2	2
70	1429	1427	1425	1422	1420	1418	1416	1414	1412	1410	0	0	1	1	1	1	1	2	2
71	1408	1406	1404	1403	1401	1399	1397	1395	1393	1391	0	0	1	1	1	1	1	2	2
72	1389	1387	1385	1383	1381	1379	1377	1376	1374	1372	0	0	1	1	1	1	1	2	2
73	1370	1368	1366	1364	1362	1361	1359	1357	1355	1353	0	0	1	1	1	1	1	2	2
74	1351	1350	1348	1346	1344	1342	1340	1339	1337	1335	0	0	1	1	1	1	1	1	2
75	1333	1332	1330	1328	1326	1325	1323	1321	1319	1318	0	0	1	1	1	1	1	1	2
76	1316	1314	1312	1311	1309	1307	1305	1304	1302	1300	0	0	1	1	1	1	1	1	2
77	1299	1297	1295	1294	1292	1290	1289	1287	1285	1284	0	0	0	1	1	1	1	1	1
78	1282	1280	1279	1277	1276	1274	1272	1271	1269	1267	0	0	0	1	1	1	1	1	1
79	1266	1264	1263	1261	1259	1258	1256	1255	1253	1252	0	0	0	1	1	1	1	1	1
80	1250	1248	1247	1245	1244	1242	1241	1239	1238	1236	0	0	0	1	1	1	1	1	1
81	1235	1233	1232	1230	1229	1227	1225	1224	1222	1221	0	0	0	1	1	1	1	1	1
82	1220	1218	1217	1215	1214	1212	1211	1209	1208	1206	0	0	0	1	1	1	1	1	1
83	1205	1203	1202	1200	1199	1198	1196	1195	1193	1192	0	0	0	1	1	1	1	1	1
84	1190	1189	1188	1186	1185	1183	1182	1181	1179	1178	0	0	0	1	1	1	1	1	1
85	1176	1175	1174	1172	1171	1170	1168	1167	1166	1164	0	0	0	1	1	1	1	1	1
86	1163	1161	1160	1159	1157	1156	1155	1153	1152	1151	0	0	0	1	1	1	1	1	1
87	1149	1148	1147	1145	1144	1143	1142	1140	1139	1138	0	0	0	1	1	1	1	1	1
88	1136	1135	1134	1133	1131	1130	1129	1127	1126	1125	0	0	0	1	1	1	1	1	1
89	1124	1122	1121	1120	1119	1117	1116	1115	1114	1112	0	0	0	1	1	1	1	1	1
90	1111	1110	1109	1107	1106	1105	1104	1103	1101	1100	0	0	0	1	1	1	1	1	1
91	1099	1098	1096	1095	1094	1093	1092	1091	1089	1088	0	0	0	0	1	1	1	1	1
92	1087	1086	1085	1083	1082	1081	1080	1079	1078	1076	0	0	0	0	1	1	1	1	1
93	1075	1074	1073	1072	1071	1070	1068	1067	1066	1065	0	0	0	0	1	1	1	1	1
94	1064	1063	1062	1060	1059	1058	1057	1056	1055	1054	0	0	0	0	1	1	1	1	1
95	1053	1052	1050	1049	1048	1047	1046	1045	1044	1043	0	0	0	0	1	1	1	1	1
96	1042	1041	1040	1038	1037	1036	1035	1034	1033	1032	0	0	0	0	1	1	1	1	1
97	1031	1030	1029	1028	1027	1026	1025	1024	1022	1021	0	0	0	0	1	1	1	1	1
98	1020	1019	1018	1017	1016	1015	1014	1013	1012	1011	0	0	0	0	1	1	1	1	1
99	1010	1009	1008	1007	1006	1005	1004	1003	1002	1001	0	0	0	0	0	1	1	1	1
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
											Subtract Differences.								

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
1·0	1·000	1·020	1·040	1·061	1·082	1·103	1·124	1·145	1·166	1·188	2	4	6	8	10	13	15	17	19
1·1	1·210	1·232	1·254	1·277	1·300	1·323	1·346	1·369	1·392	1·416	2	5	7	9	11	14	16	18	21
1·2	1·440	1·464	1·488	1·513	1·538	1·563	1·588	1·613	1·638	1·664	2	5	7	10	12	15	17	20	22
1·3	1·690	1·716	1·742	1·769	1·796	1·823	1·850	1·877	1·904	1·932	3	5	8	11	13	16	19	22	24
1·4	1·960	1·988	2·016	2·045	2·074	2·103	2·132	2·161	2·190	2·220	3	6	9	12	14	17	20	23	26
1·5	2·250	2·280	2·310	2·341	2·372	2·403	2·434	2·465	2·496	2·528	3	6	9	12	15	19	22	25	28
1·6	2·560	2·592	2·624	2·657	2·690	2·723	2·756	2·789	2·822	2·856	3	7	10	13	16	20	23	26	30
1·7	2·890	2·924	2·958	2·993	3·028	3·063	3·098	3·133	3·168	3·204	3	7	10	14	17	21	24	28	31
1·8	3·240	3·276	3·312	3·349	3·386	3·423	3·460	3·497	3·534	3·572	4	7	11	15	18	22	26	30	33
1·9	3·610	3·648	3·686	3·725	3·764	3·803	3·842	3·881	3·920	3·960	4	8	12	16	19	23	27	31	35
2·0	4·000	4·040	4·080	4·121	4·162	4·203	4·244	4·285	4·326	4·368	4	8	12	16	20	25	29	33	37
2·1	4·410	4·452	4·494	4·537	4·580	4·623	4·666	4·709	4·752	4·796	4	9	13	17	21	26	30	34	39
2·2	4·840	4·884	4·928	4·973	5·018	5·063	5·108	5·153	5·198	5·244	4	9	13	18	22	27	31	36	40
2·3	5·290	5·336	5·382	5·429	5·476	5·523	5·570	5·617	5·664	5·712	5	9	14	19	23	28	33	38	42
2·4	5·760	5·808	5·856	5·905	5·954	6·003	6·052	6·101	6·150	6·200	5	10	15	20	24	29	34	39	44
2·5	6·250	6·300	6·350	6·401	6·452	6·503	6·554	6·605	6·656	6·708	5	10	15	20	25	31	36	41	46
2·6	6·760	6·812	6·864	6·917	6·970	7·023	7·076	7·129	7·182	7·236	5	11	16	21	26	32	37	42	48
2·7	7·290	7·344	7·398	7·453	7·508	7·563	7·618	7·673	7·728	7·784	5	11	16	22	27	33	38	44	49
2·8	7·840	7·896	7·952	8·009	8·066	8·123	8·180	8·237	8·294	8·352	6	11	17	23	28	34	40	46	51
2·9	8·410	8·468	8·526	8·585	8·644	8·703	8·762	8·821	8·880	8·940	6	12	18	24	29	35	41	47	53
3·0	9·000	9·060	9·120	9·181	9·242	9·303	9·364	9·425	9·486	9·548	6	12	18	24	30	37	43	49	55
3·1	9·610	9·672	9·734	9·797	9·860	9·923	9·986				6	13	19	25	31	38	44	50	57
								10·05	10·11	10·18	1	1	2	3	3	4	5	5	6
3·2	10·24	10·30	10·37	10·43	10·50	10·56	10·63	10·69	10·76	10·82	1	1	2	3	3	4	5	5	6
3·3	10·89	10·96	11·02	11·09	11·16	11·22	11·29	11·36	11·42	11·49	1	1	2	3	3	4	5	5	6
3·4	11·56	11·63	11·70	11·76	11·83	11·90	11·97	12·04	12·11	12·18	1	1	2	3	3	4	5	6	6
3·5	12·25	12·32	12·39	12·46	12·53	12·60	12·67	12·74	12·82	12·89	1	1	2	3	4	4	5	6	6
3·6	12·96	13·03	13·10	13·18	13·25	13·32	13·40	13·47	13·54	13·62	1	1	2	3	4	4	5	6	7
3·7	13·69	13·76	13·84	13·91	13·99	14·06	14·14	14·21	14·29	14·36	1	2	2	3	4	4	5	6	7
3·8	14·44	14·52	14·59	14·67	14·75	14·82	14·90	14·98	15·05	15·13	1	2	2	3	4	5	5	6	7
3·9	15·21	15·29	15·37	15·44	15·52	15·60	15·68	15·76	15·84	15·92	1	2	2	3	4	5	6	6	7
4·0	16·00	16·08	16·16	16·24	16·32	16·40	16·48	16·56	16·65	16·73	1	2	2	3	4	5	6	6	7
4·1	16·81	16·89	16·97	17·06	17·14	17·22	17·31	17·39	17·47	17·56	1	2	2	3	4	5	6	7	7
4·2	17·64	17·72	17·81	17·89	17·98	18·06	18·15	18·23	18·32	18·40	1	2	3	3	4	5	6	7	8
4·3	18·49	18·58	18·66	18·75	18·84	18·92	19·01	19·10	19·18	19·27	1	2	3	3	4	5	6	7	8
4·4	19·36	19·45	19·54	19·62	19·71	19·80	19·89	19·98	20·07	20·16	1	2	3	4	4	5	6	7	8
4·5	20·25	20·34	20·43	20·52	20·61	20·70	20·79	20·88	20·98	21·07	1	2	3	4	5	5	6	7	8
4·6	21·16	21·25	21·34	21·44	21·53	21·62	21·72	21·81	21·90	22·00	1	2	3	4	5	6	7	7	8
4·7	22·09	22·18	22·28	22·37	22·47	22·56	22·66	22·75	22·85	22·94	1	2	3	4	5	6	7	8	9
4·8	23·04	23·14	23·23	23·33	23·43	23·52	23·62	23·72	23·81	23·91	1	2	3	4	5	6	7	8	9
4·9	24·01	24·11	24·21	24·30	24·40	24·50	24·60	24·70	24·80	24·90	1	2	3	4	5	6	7	8	9
5·0	25·00	25·10	25·20	25·30	25·40	25·50	25·60	25·70	25·81	25·91	1	2	3	4	5	6	7	8	9
5·1	26·01	26·11	26·21	26·32	26·42	26·52	26·63	26·73	26·83	26·94	1	2	3	4	5	6	7	8	9
5·2	27·04	27·14	27·25	27·35	27·46	27·56	27·67	27·77	27·88	27·98	1	2	3	4	5	6	7	8	9
5·3	28·09	28·20	28·30	28·41	28·52	28·62	28·73	28·84	28·94	29·05	1	2	3	4	5	6	7	9	10
5·4	29·16	29·27	29·38	29·48	29·59	29·70	29·81	29·92	30·03	30·14	1	2	3	4	5	7	8	9	10
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

SQUARES

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
5·5	30·25	30·36	30·47	30·58	30·69	30·80	30·91	31·02	31·14	31·25	1	2	3	4	6	7	8	9	10
5·6	31·36	31·47	31·58	31·70	31·81	31·92	32·04	32·15	32·26	32·38	1	2	3	5	6	7	8	9	10
5·7	32·49	32·60	32·72	32·83	32·95	33·06	33·18	33·29	33·41	33·52	1	2	3	5	6	7	8	9	10
5·8	33·64	33·76	33·87	33·99	34·11	34·22	34·34	34·46	34·57	34·69	1	2	4	5	6	7	8	9	11
5·9	34·81	34·93	35·05	35·16	35·28	35·40	35·52	35·64	35·76	35·88	1	2	4	5	6	7	8	10	11
6·0	36·00	36·12	36·24	36·36	36·48	36·60	36·72	36·84	36·97	37·09	1	2	4	5	6	7	8	10	11
6·1	37·21	37·33	37·45	37·58	37·70	37·82	37·95	38·07	38·19	38·32	1	2	4	5	6	7	9	10	11
6·2	38·44	38·56	38·69	38·81	38·94	39·06	39·19	39·31	39·44	39·56	1	3	4	5	6	8	9	10	11
6·3	39·69	39·82	39·94	40·07	40·20	40·32	40·45	40·58	40·70	40·83	1	3	4	5	6	8	9	10	11
6·4	40·96	41·09	41·22	41·34	41·47	41·60	41·73	41·86	41·99	42·12	1	3	4	5	6	8	9	10	12
6·5	42·25	42·38	42·51	42·64	42·77	42·90	43·03	43·16	43·30	43·43	1	3	4	5	7	8	9	10	12
6·6	43·56	43·69	43·82	43·96	44·09	44·22	44·36	44·49	44·62	44·76	1	3	4	5	7	8	9	11	12
6·7	44·89	45·02	45·16	45·29	45·43	45·56	45·70	45·83	45·97	46·10	1	3	4	5	7	8	9	11	12
6·8	46·24	46·38	46·51	46·65	46·79	46·92	47·06	47·20	47·33	47·47	1	3	4	5	7	8	10	11	12
6·9	47·61	47·75	47·89	48·02	48·16	48·30	48·44	48·58	48·72	48·86	1	3	4	6	7	8	10	11	13
7·0	49·00	49·14	49·28	49·42	49·56	49·70	49·84	49·98	50·13	50·27	1	3	4	6	7	8	10	11	13
7·1	50·41	50·55	50·69	50·84	50·98	51·12	51·27	51·41	51·55	51·70	1	3	4	6	7	9	10	11	13
7·2	51·84	51·98	52·13	52·27	52·42	52·56	52·71	52·85	53·00	53·14	1	3	4	6	7	9	10	12	13
7·3	53·29	53·44	53·58	53·73	53·88	54·02	54·17	54·32	54·46	54·61	1	3	4	6	7	9	10	12	13
7·4	54·76	54·91	55·06	55·20	55·35	55·50	55·65	55·80	55·95	56·10	1	3	4	6	7	9	10	12	13
7·5	56·25	56·40	56·55	56·70	56·85	57·00	57·15	57·30	57·46	57·61	2	3	5	6	8	9	11	12	14
7·6	57·76	57·91	58·06	58·22	58·37	58·52	58·68	58·83	58·98	59·14	2	3	5	6	8	9	11	12	14
7·7	59·29	59·44	59·60	59·75	59·91	60·06	60·22	60·37	60·53	60·68	2	3	5	6	8	9	11	12	14
7·8	60·84	61·00	61·15	61·31	61·47	61·62	61·78	61·94	62·09	62·25	2	3	5	6	8	9	11	13	14
7·9	62·41	62·57	62·73	62·88	63·04	63·20	63·36	63·52	63·68	63·84	2	3	5	6	8	10	11	13	14
8·0	64·00	64·16	64·32	64·48	64·64	64·80	64·96	65·12	65·29	65·45	2	3	5	6	8	10	11	13	14
8·1	65·61	65·77	65·93	66·10	66·26	66·42	66·59	66·75	66·91	67·08	2	3	5	7	8	10	11	13	15
8·2	67·24	67·40	67·57	67·73	67·90	68·06	68·23	68·39	68·56	68·72	2	3	5	7	8	10	12	13	15
8·3	68·89	69·06	69·22	69·39	69·56	69·72	69·89	70·06	70·22	70·39	2	3	5	7	8	10	12	13	15
8·4	70·56	70·73	70·90	71·06	71·23	71·40	71·57	71·74	71·91	72·08	2	3	5	7	8	10	12	14	15
8·5	72·25	72·42	72·59	72·76	72·93	73·10	73·27	73·44	73·62	73·79	2	3	5	7	9	10	12	14	15
8·6	73·96	74·13	74·30	74·48	74·65	74·82	75·00	75·17	75·34	75·52	2	3	5	7	9	10	12	14	16
8·7	75·69	75·86	76·04	76·21	76·39	76·56	76·74	76·91	77·09	77·26	2	4	5	7	9	11	12	14	16
8·8	77·44	77·62	77·79	77·97	78·15	78·32	78·50	78·68	78·85	79·03	2	4	5	7	9	11	12	14	16
8·9	79·21	79·39	79·57	79·74	79·92	80·10	80·28	80·46	80·64	80·82	2	4	5	7	9	11	13	14	16
9·0	81·00	81·18	81·36	81·54	81·72	81·90	82·08	82·26	82·45	82·63	2	4	5	7	9	11	13	14	16
9·1	82·81	82·99	83·17	83·36	83·54	83·72	83·91	84·09	84·27	84·46	2	4	5	7	9	11	13	15	16
9·2	84·64	84·82	85·01	85·19	85·38	85·56	85·75	85·93	86·12	86·30	2	4	6	7	9	11	13	15	17
9·3	86·49	86·68	86·86	87·05	87·24	87·42	87·61	87·80	87·98	88·17	2	4	6	7	9	11	13	15	17
9·4	88·36	88·55	88·74	88·92	89·11	89·30	89·49	89·68	89·87	90·06	2	4	6	8	9	11	13	15	17
9·5	90·25	90·44	90·63	90·82	91·01	91·20	91·39	91·58	91·78	91·97	2	4	6	8	10	11	13	15	17
9·6	92·16	92·35	92·54	92·74	92·93	93·12	93·32	93·51	93·70	93·90	2	4	6	8	10	12	14	15	17
9·7	94·09	94·28	94·48	94·67	94·87	95·06	95·26	95·45	95·65	95·84	2	4	6	8	10	12	14	16	18
9·8	96·04	96·24	96·43	96·63	96·83	97·02	97·22	97·42	97·61	97·81	2	4	6	8	10	12	14	16	18
9·9	98·01	98·21	98·41	98·60	98·80	99·00	99·20	99·40	99·60	99·80	2	4	6	8	10	12	14	16	18
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1′	2′	3′	4′	5′
0°	·0000	·0017	·0035	·0052	·0070	·0087	·0105	·0122	·0140	·0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	14
5	·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	11	14
10	·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	11	14
11	·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	·2079	2096	2113	2130	2147	2164	2181	2198	2215	2233	3	6	9	11	14
13	·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	·2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
18	·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	·3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20	·3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	·3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	·3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3	5	8	11	13
23	·3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	13
24	·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	·4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3	5	8	10	13
29	·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30	·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	·5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2	5	7	10	12
33	·5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	9	12
36	·5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	2	5	7	9	12
37	·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	12
38	·6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40	·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	·6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1′	2′	3′	4′	5′

NATURAL SINES

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1′	2′	3′	4′	5′
45°	·7071	·7083	·7096	·7108	·7120	·7133	·7145	·7157	·7169	·7181	2	4	6	8	10
46	·7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2	4	6	8	10
47	·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2	4	6	8	10
48	·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2	4	6	8	10
49	·7547	7559	7570	7581	7593	7604	7615	7627	7638	7649	2	4	6	8	9
50	·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2	4	6	7	9
51	·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2	4	5	7	9
52	·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2	4	5	7	9
53	·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2	3	5	7	9
54	·8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2	3	5	7	8
55	·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2	3	5	7	8
56	·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2	3	5	6	8
57	·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2	3	5	6	8
58	·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2	3	5	6	8
59	·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1	3	4	6	7
60	·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1	3	4	6	7
61	·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1	3	4	6	7
62	·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1	3	4	5	7
63	·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1	3	4	5	6
64	·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1	3	4	5	6
65	·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1	2	4	5	6
66	·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1	2	3	5	6
67	·9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1	2	3	4	6
68	·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1	2	3	4	5
69	·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1	2	3	4	5
70	·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1	2	3	4	5
71	·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1	2	3	4	5
72	·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1	2	3	3	4
73	·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1	2	2	3	4
74	·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1	2	2	3	4
75	·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1	1	2	3	4
76	·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1	1	2	3	3
77	·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1	1	2	3	3
78	·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1	1	2	2	3
79	·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1	1	2	2	3
80	·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0	1	1	2	2
81	·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0	1	1	2	2
82	·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0	1	1	2	2
83	·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0	1	1	1	2
84	·9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0	1	1	1	1
85	·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0	0	1	1	1
86	·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0	0	1	1	1
87	·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0	0	0	1	1
88	·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0	0	0	0	0
89	·9998	9999	9999	9999	9999	1·000	1·000	1·000	1·000	1·000	0	0	0	0	0
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1′	2′	3′	4′	5′

NATURAL COSINES

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Subtract Differences.				
											1′	2′	3′	4′	5′
0°	1·000	1·000	1·000	1·000	1·000	1·000	·9999	·9999	·9999	·9999	0	0	0	0	0
1	·9998	9998	9998	9997	9997	9997	9996	9996	9995	9995	0	0	0	0	0
2	·9994	9993	9993	9992	9991	9990	9990	9989	9988	9987	0	0	0	1	1
3	·9986	9985	9984	9983	9982	9981	9980	9979	9978	9977	0	0	1	1	1
4	·9976	9974	9973	9972	9971	9969	9968	9966	9965	9963	0	0	1	1	1
5	·9962	9960	9959	9957	9956	9954	9952	9951	9949	9947	0	1	1	1	1
6	·9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	0	1	1	1	2
7	·9925	9923	9921	9919	9917	9914	9912	9910	9907	9905	0	1	1	2	2
8	·9903	9900	9898	9895	9893	9890	9888	9885	9882	9880	0	1	1	2	2
9	·9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	0	1	1	2	2
10	·9848	9845	9842	9839	9836	9833	9829	9826	9823	9820	1	1	2	2	3
11	·9816	9813	9810	9806	9803	9799	9796	9792	9789	9785	1	1	2	2	3
12	·9781	9778	9774	9770	9767	9763	9759	9755	9751	9748	1	1	2	3	3
13	·9744	9740	9736	9732	9728	9724	9720	9715	9711	9707	1	1	2	3	3
14	·9703	9699	9694	9690	9686	9681	9677	9673	9668	9664	1	1	2	3	4
15	·9659	9655	9650	9646	9641	9636	9632	9627	9622	9617	1	2	2	3	4
16	·9613	9608	9603	9598	9593	9588	9583	9578	9573	9568	1	2	2	3	4
17	·9563	9558	9553	9548	9542	9537	9532	9527	9521	9516	1	2	3	3	4
18	·9511	9505	9500	9494	9489	9483	9478	9472	9466	9461	1	2	3	4	5
19	·9455	9449	9444	9438	9432	9426	9421	9415	9409	9403	1	2	3	4	5
20	·9397	9391	9385	9379	9373	9367	9361	9354	9348	9342	1	2	3	4	5
21	·9336	9330	9323	9317	9311	9304	9298	9291	9285	9278	1	2	3	4	5
22	·9272	9265	9259	9252	9245	9239	9232	9225	9219	9212	1	2	3	4	6
23	·9205	9198	9191	9184	9178	9171	9164	9157	9150	9143	1	2	3	5	6
24	·9135	9128	9121	9114	9107	9100	9092	9085	9078	9070	1	2	4	5	6
25	·9063	9056	9048	9041	9033	9026	9018	9011	9003	8996	1	3	4	5	6
26	·8988	8980	8973	8965	8957	8949	8942	8934	8926	8918	1	3	4	5	6
27	·8910	8902	8894	8886	8878	8870	8862	8854	8846	8838	1	3	4	5	7
28	·8829	8821	8813	8805	8796	8788	8780	8771	8763	8755	1	3	4	6	7
29	·8746	8738	8729	8721	8712	8704	8695	8686	8678	8669	1	3	4	6	7
30	·8660	8652	8643	8634	8625	8616	8607	8599	8590	8581	1	3	4	6	7
31	·8572	8563	8554	8545	8536	8526	8517	8508	8499	8490	2	3	5	6	8
32	·8480	8471	8462	8453	8443	8434	8425	8415	8406	8396	2	3	5	6	8
33	·8387	8377	8368	8358	8348	8339	8329	8320	8310	8300	2	3	5	6	8
34	·8290	8281	8271	8261	8251	8241	8231	8221	8211	8202	2	3	5	7	8
35	·8192	8181	8171	8161	8151	8141	8131	8121	8111	8100	2	3	5	7	8
36	·8090	8080	8070	8059	8049	8039	8028	8018	8007	7997	2	3	5	7	9
37	·7986	7976	7965	7955	7944	7934	7923	7912	7902	7891	2	4	5	7	9
38	·7880	7869	7859	7848	7837	7826	7815	7804	7793	7782	2	4	5	7	9
39	·7771	7760	7749	7738	7727	7716	7705	7694	7683	7672	2	4	6	7	9
40	·7660	7649	7638	7627	7615	7604	7593	7581	7570	7559	2	4	6	8	9
41	·7547	7536	7524	7513	7501	7490	7478	7466	7455	7443	2	4	6	8	10
42	·7431	7420	7408	7396	7385	7373	7361	7349	7337	7325	2	4	6	8	10
43	·7314	7302	7290	7278	7266	7254	7242	7230	7218	7206	2	4	6	8	10
44	·7193	7181	7169	7157	7145	7133	7120	7108	7096	7083	2	4	6	8	10
											1′	2′	3′	4′	5′
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Subtract Differences.				

NATURAL COSINES

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54	Subtract Differences.				
											1′	2′	3′	4′	5′
45°	·7071	·7059	·7046	·7034	·7022	·7009	·6997	·6984	·6972	·6959	2	4	6	8	10
46	·6947	6934	6921	6909	6896	6884	6871	6858	6845	6833	2	4	6	8	11
47	·6820	6807	6794	6782	6769	6756	6743	6730	6717	6704	2	4	6	9	11
48	·6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	2	4	7	9	11
49	·6561	6547	6534	6521	6508	6494	6481	6468	6455	6441	2	4	7	9	11
50	·6428	6414	6401	6388	6374	6361	6347	6334	6320	6307	2	4	7	9	11
51	·6293	6280	6266	6252	6239	6225	6211	6198	6184	6170	2	5	7	9	11
52	·6157	6143	6129	6115	6101	6088	6074	6060	6046	6032	2	5	7	9	12
53	·6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	2	5	7	9	12
54	·5878	5864	5850	5835	5821	5807	5793	5779	5764	5750	2	5	7	9	12
55	·5736	5721	5707	5693	5678	5664	5650	5635	5621	5606	2	5	7	10	12
56	·5592	5577	5563	5548	5534	5519	5505	5490	5476	5461	2	5	7	10	12
57	·5446	5432	5417	5402	5388	5373	5358	5344	5329	5314	2	5	7	10	12
58	·5299	5284	5270	5255	5240	5225	5210	5195	5180	5165	2	5	7	10	12
59	·5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	3	5	8	10	13
60	·5000	4985	4970	4955	4939	4924	4909	4894	4879	4863	3	5	8	10	13
61	·4848	4833	4818	4802	4787	4772	4756	4741	4726	4710	3	5	8	10	13
62	·4695	4679	4664	4648	4633	4617	4602	4586	4571	4555	3	5	8	10	13
63	·4540	4524	4509	4493	4478	4462	4446	4431	4415	4399	3	5	8	10	13
64	·4384	4368	4352	4337	4321	4305	4289	4274	4258	4242	3	5	8	11	13
65	·4226	4210	4195	4179	4163	4147	4131	4115	4099	4083	3	5	8	11	13
66	·4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	3	5	8	11	14
67	·3907	3891	3875	3859	3843	3827	3811	3795	3778	3762	3	5	8	11	14
68	·3746	3730	3714	3697	3681	3665	3649	3633	3616	3600	3	5	8	11	14
69	·3584	3567	3551	3535	3518	3502	3486	3469	3453	3437	3	5	8	11	14
70	·3420	3404	3387	3371	3355	3338	3322	3305	3289	3272	3	5	8	11	14
71	·3256	3239	3223	3206	3190	3173	3156	3140	3123	3107	3	6	8	11	14
72	·3090	3074	3057	3040	3024	3007	2990	2974	2957	2940	3	6	8	11	14
73	·2924	2907	2890	2874	2857	2840	2823	2807	2790	2773	3	6	8	11	14
74	·2756	2740	2723	2706	2689	2672	2656	2639	2622	2605	3	6	8	11	14
75	·2588	2571	2554	2538	2521	2504	2487	2470	2453	2436	3	6	8	11	14
76	·2419	2402	2385	2368	2351	2334	2317	2300	2284	2267	3	6	8	11	14
77	·2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	3	6	9	11	14
78	·2079	2062	2045	2028	2011	1994	1977	1959	1942	1925	3	6	9	11	14
79	·1908	1891	1874	1857	1840	1822	1805	1788	1771	1754	3	6	9	11	14
80	·1736	1719	1702	1685	1668	1650	1633	1616	1599	1582	3	6	9	11	14
81	·1564	1547	1530	1513	1495	1478	1461	1444	1426	1409	3	6	9	12	14
82	·1392	1374	1357	1340	1323	1305	1288	1271	1253	1236	3	6	9	12	14
83	·1219	1201	1184	1167	1149	1132	1115	1097	1080	1063	3	6	9	12	14
84	·1045	1028	1011	0993	0976	0958	0941	0924	0906	0889	3	6	9	12	14
85	·0872	0854	0837	0819	0802	0785	0767	0750	0732	0715	3	6	9	12	14
86	·0698	0680	0663	0645	0628	0610	0593	0576	0558	0541	3	6	9	12	15
87	·0523	0506	0488	0471	0454	0436	0419	0401	0384	0366	3	6	9	12	15
88	·0349	0332	0314	0297	0279	0262	0244	0227	0209	0192	3	6	9	12	15
89	·0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	3	6	9	12	15
											1′	2′	3′	4′	5′
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Subtract Differences.				

NATURAL TANGENTS

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1′	2′	3′	4′	5′
0°	·0000	·0017	·0035	·0052	·0070	·0087	·0105	·0122	·0140	·0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3	6	9	12	15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3	6	9	12	15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3	6	9	12	15
5	·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3	6	9	12	15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3	6	9	12	15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3	6	9	12	15
8	·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3	6	9	12	15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3	6	9	12	15
10	·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3	6	9	12	15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3	6	9	12	15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3	6	9	12	15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3	6	9	12	15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	3	6	9	12	16
15	·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3	6	9	13	16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3	6	9	13	16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3	6	10	13	16
18	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3	6	10	13	16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3	7	10	13	16
20	·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3	7	10	13	17
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3	7	10	13	17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3	7	10	14	17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3	7	10	14	17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4	7	11	14	18
25	·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4	7	11	14	18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4	7	11	15	18
27	·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4	7	11	15	18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4	8	11	15	19
29	·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4	8	12	15	19
30	·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4	8	12	16	20
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4	8	12	16	20
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4	8	12	16	20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4	8	13	17	21
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4	9	13	17	21
35	·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4	9	13	18	22
36	·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5	9	14	18	23
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5	9	14	18	23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5	9	14	19	24
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	5	10	15	20	24
40	·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5	10	15	20	25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5	10	16	21	26
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5	11	16	21	27
43	·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6	11	17	22	28
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6	11	17	23	29
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1′	2′	3′	4′	5′

NATURAL TANGENTS

	0′	6	12′	18′	24′	30′	36′	42′	48′	54′	1′	2′	3′	4′	5′
45°	1·0000	·0035	·0070	·0105	·0141	·0176	·0212	·0247	·0283	·0319	6	12	18	24	30
46	1·0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	6	12	18	25	31
47	1·0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	6	13	19	25	32
48	1·1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	7	13	20	27	33
49	1·1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	7	14	21	28	34
50	1·1918	1960	2002	2045	2088	2131	2174	2218	2261	2305	7	14	22	29	36
51	1·2349	2393	2437	2482	2527	2572	2617	2662	2708	2753	8	15	23	30	38
52	1·2799	2846	2892	2938	2985	3032	3079	3127	3175	3222	8	16	24	31	39
53	1·3270	3319	3367	3416	3465	3514	3564	3613	3663	3713	8	16	25	33	41
54	1·3764	3814	3865	3916	3968	4019	4071	4124	4176	4229	9	17	26	34	43
55	1·4281	4335	4388	4442	4496	4550	4605	4659	4715	4770	9	18	27	36	45
56	1·4826	4882	4938	4994	5051	5108	5166	5224	5282	5340	10	19	29	38	48
57	1·5399	5458	5517	5577	5637	5697	5757	5818	5880	5941	10	20	30	40	50
58	1·6003	6066	6128	6191	6255	6319	6383	6447	6512	6577	11	21	32	43	53
59	1·6643	6709	6775	6842	6909	6977	7045	7113	7182	7251	11	23	34	45	57
60	1·7321	7391	7461	7532	7603	7675	7747	7820	7893	7966	12	24	36	48	60
61	1·8040	8115	8190	8265	8341	8418	8495	8572	8650	8728	13	26	38	51	64
62	1·8807	8887	8967	9047	9128	9210	9292	9375	9458	9542	14	27	41	55	68
63	1·9626	9711	9797	9883	9970	2·0057	2·0145	2·0233	2·0323	2·0413	15	29	44	58	73
64	2·0503	0594	0686	0778	0872	0965	1060	1155	1251	1348	16	31	47	63	79
65	2·1445	1543	1642	1742	1842	1943	2045	2148	2251	2355	17	34	51	68	85
66	2·2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	18	37	55	73	92
67	2·3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	20	40	60	79	99
68	2·4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	22	43	65	87	108
69	2·6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	24	48	71	95	119
70	2·7475	7625	7776	7929	8083	8239	8397	8556	8716	8878	26	52	78	105	131
71	2·9042	9208	9375	9544	9714	9887	3·0061	3·0237	3·0415	3·0595	29	58	87	116	145
72	3·0777	0961	1146	1334	1524	1716	1910	2106	2305	2506	32	64	96	129	161
73	3·2709	2914	3122	3332	3544	3759	3977	4197	4420	4646	36	72	108	144	180
74	3·4874	5105	5339	5576	5816	6059	6305	6554	6806	7062	41	81	122	163	204
75	3·7321	7583	7848	8118	8391	8667	8947	9232	9520	9812	46	93	139	186	232
76	4·0108	0408	0713	1022	1335	1653	1976	2303	2635	2972					
77	4·3315	3662	4015	4374	4737	5107	5483	5864	6252	6646					
78	4·7046	7453	7867	8288	8716	9152	9594	5·0045	5·0504	5·0970					
79	5·1446	1929	2422	2924	3435	3955	4486	5026	5578	6140					
80	5·6713	7297	7894	8502	9124	9758	6·0405	6·1066	6·1742	6·2432					
81	6·3138	3859	4596	5350	6122	6912	7720	8548	9395	7·0264	Mean differences no longer sufficiently accurate.				
82	7·1154	2066	3002	3962	4947	5958	6996	8062	9158	8·0285					
83	8·1443	2636	3863	5126	6427	7769	9152	9·0579	9·2052	9·3572					
84	9·514	9·677	9·845	10·02	10·20	10·39	10·58	10·78	10·99	11·20					
85	11·43	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95					
86	14·30	14·67	15·06	15·46	15·89	16·35	16·83	17·34	17·89	18·46					
87	19·08	19·74	20·45	21·20	22·02	22·90	23·86	24·90	26·03	27·27					
88	28·64	30·14	31·82	33·69	35·80	38·19	40·92	44·07	47·74	52·08					
89	57·29	63·66	71·62	81·85	95·49	114·6	143·2	191·0	286·5	573·0					
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′					

	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	1'	2'	3'	4'	5'
0°	·0000	·0017	·0035	·0052	·0070	·0087	·0105	·0122	·0140	·0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0367	0384	0401	0419	0436	0454	0471	0489	0506	3	6	9	12	15
3	·0524	0541	0559	0576	0593	0611	0628	0646	0663	0681	3	6	9	12	15
4	·0698	0716	0733	0750	0768	0785	0803	0820	0838	0855	3	6	9	12	15
5	·0873	0890	0908	0925	0942	0960	0977	0995	1012	1030	3	6	9	12	15
6	·1047	1065	1082	1100	1117	1134	1152	1169	1187	1204	3	6	9	12	15
7	·1222	1239	1257	1274	1292	1309	1326	1344	1361	1379	3	6	9	12	15
8	·1396	1414	1431	1449	1466	1484	1501	1518	1536	1553	3	6	9	12	15
9	·1571	1588	1606	1623	1641	1658	1676	1693	1710	1728	3	6	9	12	15
10	·1745	1763	1780	1798	1815	1833	1850	1868	1885	1902	3	6	9	12	15
11	·1920	1937	1955	1972	1990	2007	2025	2042	2059	2077	3	6	9	12	15
12	·2094	2112	2129	2147	2164	2182	2199	2217	2234	2251	3	6	9	12	15
13	·2269	2286	2304	2321	2339	2356	2374	2391	2409	2426	3	6	9	12	15
14	·2443	2461	2478	2496	2513	2531	2548	2566	2583	2601	3	6	9	12	15
15	·2618	2635	2653	2670	2688	2705	2723	2740	2758	2775	3	6	9	12	15
16	·2793	2810	2827	2845	2862	2880	2897	2915	2932	2950	3	6	9	12	15
17	·2967	2985	3002	3019	3037	3054	3072	3089	3107	3124	3	6	9	12	15
18	·3142	3159	3176	3194	3211	3229	3246	3264	3281	3299	3	6	9	12	15
19	·3316	3334	3351	3368	3386	3403	3421	3438	3456	3473	3	6	9	12	15
20	·3491	3508	3526	3543	3560	3578	3595	3613	3630	3648	3	6	9	12	15
21	·3665	3683	3700	3718	3735	3752	3770	3787	3805	3822	3	6	9	12	15
22	·3840	3857	3875	3892	3910	3927	3944	3962	3979	3997	3	6	9	12	15
23	·4014	4032	4049	4067	4084	4102	4119	4136	4154	4171	3	6	9	12	15
24	·4189	4206	4224	4241	4259	4276	4294	4311	4328	4346	3	6	9	12	15
25	·4363	4381	4398	4416	4433	4451	4468	4485	4503	4520	3	6	9	12	15
26	·4538	4555	4573	4590	4608	4625	4643	4660	4677	4695	3	6	9	12	15
27	·4712	4730	4747	4765	4782	4800	4817	4835	4852	4869	3	6	9	12	15
28	·4887	4904	4922	4939	4957	4974	4992	5009	5027	5044	3	6	9	12	15
29	·5061	5079	5096	5114	5131	5149	5166	5184	5201	5219	3	6	9	12	15
30	·5236	5253	5271	5288	5306	5323	5341	5358	5376	5393	3	6	9	12	15
31	·5411	5428	5445	5463	5480	5498	5515	5533	5550	5568	3	6	9	12	15
32	·5585	5603	5620	5637	5655	5672	5690	5707	5725	5742	3	6	9	12	15
33	·5760	5777	5794	5812	5829	5847	5864	5882	5899	5917	3	6	9	12	15
34	·5934	5952	5969	5986	6004	6021	6039	6056	6074	6091	3	6	9	12	15
35	·6109	6126	6144	6161	6178	6196	6213	6231	6248	6266	3	6	9	12	15
36	·6283	6301	6318	6336	6353	6370	6388	6405	6423	6440	3	6	9	12	15
37	·6458	6475	6493	6510	6528	6545	6562	6580	6597	6615	3	6	9	12	15
38	·6632	6650	6667	6685	6702	6720	6737	6754	6772	6789	3	6	9	12	15
39	·6807	6824	6842	6859	6877	6894	6912	6929	6946	6964	3	6	9	12	15
40	·6981	6999	7016	7034	7051	7069	7086	7103	7121	7138	3	6	9	12	15
41	·7156	7173	7191	7208	7226	7243	7261	7278	7295	7313	3	6	9	12	15
42	·7330	7348	7365	7383	7400	7418	7435	7453	7470	7487	3	6	9	12	15
43	·7505	7522	7540	7557	7575	7592	7610	7627	7645	7662	3	6	9	12	15
44	·7679	7697	7714	7732	7749	7767	7784	7802	7819	7837	3	6	9	12	15
	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	1'	2'	3'	4'	5'

RADIANS

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1′	2′	3′	4′	5′
45°	·7854	·7871	·7889	·7906	·7924	·7941	·7959	·7976	·7994	·8011	3	6	9	12	15
46	·8029	8046	8063	8081	8098	8116	8133	8151	8168	8186	3	6	9	12	15
47	·8203	8221	8238	8255	8273	8290	8308	8325	8343	8360	3	6	9	12	15
48	·8378	8395	8412	8430	8447	8465	8482	8500	8517	8535	3	6	9	12	15
49	·8552	8570	8587	8604	8622	8639	8657	8674	8692	8709	3	6	9	12	15
50	·8727	8744	8762	8779	8796	8814	8831	8849	8866	8884	3	6	9	12	15
51	·8901	8919	8936	8954	8971	8988	9006	9023	9041	9058	3	6	9	12	15
52	·9076	9093	9111	9128	9146	9163	9180	9198	9215	9233	3	6	9	12	15
53	·9250	9268	9285	9303	9320	9338	9355	9372	9390	9407	3	6	9	12	15
54	·9425	9442	9460	9477	9495	9512	9529	9547	9564	9582	3	6	9	12	15
55	·9599	9617	9634	9652	9669	9687	9704	9721	9739	9756	3	6	9	12	15
56	·9774	9791	9809	9826	9844	9861	9879	9896	9913	9931	3	6	9	12	15
57	·9948	9966	9983	1·0001	1·0018	1·0036	1·0053	1·0071	1·0088	1·0105	3	6	9	12	15
58	1·0123	0140	0158	0175	0193	0210	0228	0245	0263	0280	3	6	9	12	15
59	1·0297	0315	0332	0350	0367	0385	0402	0420	0437	0455	3	6	9	12	15
60	1·0472	0489	0507	0524	0542	0559	0577	0594	0612	0629	3	6	9	12	15
61	1·0647	0664	0681	0699	0716	0734	0751	0769	0786	0804	3	6	9	12	15
62	1·0821	0838	0856	0873	0891	0908	0926	0943	0961	0978	3	6	9	12	15
63	1·0996	1013	1030	1048	1065	1083	1100	1118	1135	1153	3	6	9	12	15
64	1·1170	1188	1205	1222	1240	1257	1275	1292	1310	1327	3	6	9	12	15
65	1·1345	1362	1380	1397	1414	1432	1449	1467	1484	1502	3	6	9	12	15
66	1·1519	1537	1554	1572	1589	1606	1624	1641	1659	1676	3	6	9	12	15
67	1·1694	1711	1729	1746	1764	1781	1798	1816	1833	1851	3	6	9	12	15
68	1·1868	1886	1903	1921	1938	1956	1973	1990	2008	2025	3	6	9	12	15
69	1·2043	2060	2078	2095	2113	2130	2147	2165	2182	2200	3	6	9	12	15
70	1·2217	2235	2252	2270	2287	2305	2322	2339	2357	2374	3	6	9	12	15
71	1·2392	2409	2427	2444	2462	2479	2497	2514	2531	2549	3	6	9	12	15
72	1·2566	2584	2601	2619	2636	2654	2671	2689	2706	2723	3	6	9	12	15
73	1·2741	2758	2776	2793	2811	2828	2846	2863	2881	2898	3	6	9	12	15
74	1·2915	2933	2950	2968	2985	3003	3020	3038	3055	3073	3	6	9	12	15
75	1·3090	3107	3125	3142	3160	3177	3195	3212	3230	3247	3	6	9	12	15
76	1·3265	3282	3299	3317	3334	3352	3369	3387	3404	3422	3	6	9	12	15
77	1·3439	3456	3474	3491	3509	3526	3544	3561	3579	3596	3	6	9	12	15
78	1·3614	3631	3648	3666	3683	3701	3718	3736	3753	3771	3	6	9	12	15
79	1·3788	3806	3823	3840	3858	3875	3893	3910	3928	3945	3	6	9	12	15
80	1·3963	3980	3998	4015	4032	4050	4067	4085	4102	4120	3	6	9	12	15
81	1·4137	4155	4172	4190	4207	4224	4242	4259	4277	4294	3	6	9	12	15
82	1·4312	4329	4347	4364	4382	4399	4416	4434	4451	4469	3	6	9	12	15
83	1·4486	4504	4521	4539	4556	4573	4591	4608	4626	4643	3	6	9	12	15
84	1·4661	4678	4696	4713	4731	4748	4765	4783	4800	4818	3	6	9	12	15
85	1·4835	4853	4870	4888	4905	4923	4940	4957	4975	4992	3	6	9	12	15
86	1·5010	5027	5045	5062	5080	5097	5115	5132	5149	5167	3	6	9	12	15
87	1·5184	5202	5219	5237	5254	5272	5289	5307	5324	5341	3	6	9	12	15
88	1·5359	5376	5394	5411	5429	5446	5464	5481	5499	5516	3	6	9	12	15
89	1·5533	5551	5568	5586	5603	5621	5638	5656	5673	5691	3	6	9	12	15
	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1′	2′	3′	4′	5′

ATOMIC MASS OF ISOTOPES

The atomic masses given below are in terms of $O^{16} = 16$, *i.e.* they are on the physical scale. (Chemical unit : physical unit = 16·00432 : 16 = 1 : 1·00027.)

The existence of elements with chemically identical properties but of different atomic mass was discovered for the radioactive elements in 1910 by Soddy. The existence of such atoms was independently shown by the mass spectrograph (Thomson, Aston). The mass and abundance of isotopes is measured by means of this instrument and by the analysis of molecular spectra ; the mass of isotopes can also be accurately calculated in a number of cases from the data of nuclear disintegrations. Deuterium lines are observed in the Balmer spectrum of hydrogen and the difference of their wavelengths from the corresponding hydrogen lines enables the mass of the D atom to be calculated.

Mass Spectrograph.—Positive rays (and anode rays) deflected by an electric and a magnetic field are focused to form a line spectrum, in which there is a line for each value of e/m. The O^{16} atom which is the standard with which other lines are compared has lines at 8 for O^{++} (called a second order line), at 16 for O^{+}, and at 32 for O_2^{+}. The methods used in precision determinations of atomic mass are described by Aston " Mass Spectra and Isotopes," London, 1933.

With the electric and the magnetic field constant positive rays of approximately equal e/m can be compared, *e.g.*

CH_4^{+} and $O^{16}+$; $S^{32}++$ and $O^{16}+$; $(O^{16}H^1)^+$ and $(N^{14}H_3^1)^+$; $N^{14}+$ and $(C^{12}H_2^1)^+$ and the three lines $C^{12}++$, $(He^4H^2)^+$, $(H_3^2)^+$.

By changing the electric field in a known ratio (*e.g.* doubling it), the magnetic field being kept constant, the ratio

$H^2 : He$ which is approximately 1 : 2 is compared
$H^1 : H_2^1$ which is exactly 1 : 2. Similarly the mass ratios
$He^4 : O^{16}$ and $H^2\ H^1\ H^1 : He^4$ are assured.

The following equations for the differences in atomic masses are given by Bainbridge and Jordan and they include the estimated error :—

$$H_2^1 - H^2 = {\cdot}00153 \pm {\cdot}00004 = a$$
$$H_3^2 - \tfrac{1}{2}C^{12} = {\cdot}04219 \pm {\cdot}00005 = b$$
$$C^{12}H_4 - O^{16} = {\cdot}03649 \pm {\cdot}00008 = c$$

giving

$$H^1 = \tfrac{1}{16}O^{16} + \tfrac{3}{8}a + \tfrac{1}{8}b + \tfrac{1}{16}c = 1{\cdot}00813 \pm {\cdot}000017$$
$$H^2 = \tfrac{1}{8}O^{16} - \tfrac{1}{4}a + \tfrac{1}{4}b + \tfrac{1}{8}c = 2{\cdot}01473 \pm {\cdot}000019$$
$$C^{12} = \tfrac{3}{4}O^{16} - \tfrac{3}{2}a - \tfrac{1}{2}b + \tfrac{3}{4}c = 12{\cdot}00398 \pm {\cdot}00009.$$

Similar groups of doublets allow the computation of the masses of several other light elements. (See Livingston and Bethe, *Rev. Mod. Phys.*, 1937.)

Nuclear Disintegration Method.—Nuclear disintegrations are produced by the collision of α-particles, protons, deuterons, neutrons or γ-radiation with the nucleus, or by spontaneous disintegration as in the case of radioactive elements.

The collision of a positively charged deuterium ion with the nucleus of the deuterium atom and the production of two isotopes of hydrogen (H^1 and H^3) and the liberation of energy may be taken as an example of such a disintegration. The following equation applies to it :—

$$H^2 + H^2 = H^3 + H^1 + Q$$

$$(2{\cdot}0147 + 2{\cdot}0147 = H^3 + 1{\cdot}00813 + {\cdot}00427)\ 1{\cdot}6604 \times 10^{-24}\ \text{gm.}$$

The energy, Q eV, liberated is $3{\cdot}98 \times 10^6\ eV$, and therefore $H^3 = 3{\cdot}0170$ mass unit.

Conversion of Energy into Mass.—In nuclear disintegrations and integrations mass is converted into energy and energy into mass. Einstein's expression, derived by relativity theory, gives E erg of energy to be equivalent to E/c^2 gm. of mass. In calculations relating to nuclear changes the unit of atomic mass is $\frac{1}{16}$ of the mass of the O^{16} atom.

Unit of Atomic Mass (physical scale) = $1{\cdot}6599 \times 10^{-24}$ gm.

ATOMIC MASS OF ISOTOPES (*contd.*)

Electron Volt.—The energy of X-rays and other radiations is expressed in *e*V.

$$1\ eV = e\ .\ 10^8/c\ \text{erg} = 1{\cdot}6019 \times 10^{-12}\ \text{erg} = 1{\cdot}0739 \times 10^{-9}\ \text{mass unit.}$$

$$9{\cdot}312 \times 10^8\ eV = 1{\cdot}4917 \times 10^{-3}\ \text{erg} = 1\ \text{mass unit.}$$

$$6{\cdot}242 \times 10^{11}\ eV = 1\ \text{erg} = 670{\cdot}37\ \text{mass unit.}$$

Disintegration data gave the first indication of error in earlier accepted nuclear mass values (Oliphant, Kempton and Rutherford (1935)). Recent workers (Cockcroft and Lewis (1936), Bonner and Brubaker (1936)) have given improved disintegration masses and these agree with the accepted mass values. From disintegration data can be deduced the masses of the neutron, of radioactive nuclei and of nuclei too rare to be measured with accuracy by the mass spectrograph.

The **mass of the neutron** has been determined from the reaction: $H^2 + \gamma = H^1 + n^1$. The energy of the gamma ray is known and that of the proton is obtained from the ionization produced by the proton. Since the masses of the neutron and proton are approximately equal their kinetic energies are assumed equal. Using γ-rays from ThC′ (energy of $2{\cdot}623 \times 10^6$ *e*V), the energy of the proton is $\cdot 2186 \times 10^6$ *e*V, giving the binding energy of the deuteron as $2{\cdot}189 \times 10^6$ *e*V, equivalent to ·00235 mass units, that is,

$$H^2 = H^1 + n^1 - \cdot 00235$$

or $$(n^1 - H^1) = -(H^1_2 - H^2) + \cdot 00235,\ \text{since } 2H^1 = H^1_2$$

$$(H^1_2 - H_2) = \cdot 00153,\ H^1 = 1{\cdot}00813\ \text{from mass spectra observations.}$$

Thus $$\boldsymbol{n^1 = 1{\cdot}00895}.$$

References :—Gamow, "Structure of Atomic Nuclei," Oxford, 1937; Feather. "Nuclear Physics," Cambridge, 1936; Livingston and Bethe, *Rev. Mod. Phys.*, 1937. *Authorities for table* :—O. Hahn, *Ber. der Deuts. Chem. Ges.*, 1938; Third Report of the Committee on Atoms, International Union of Chemistry, *Journ. Chem. Soc.*, 1938; Gregoire, *J. de Phys. et le Rad.* (1938).

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ISOTOPES

Z = Atomic number. Atomic mass in terms $O^{16} = 16$.

Symbol.	Z.	Abundance.	Atomic Mass.	Symbol.	Z.	Abundance.	Atomic Mass.	Symbol.	Z.	Abundance.	Atomic Mass.
n	0		1·0089	Cl	17		33·981	As	33	100	74·934
H	1	99·98	1·0081	Cl		76	34·9803	Se	34	0·9	74
D		0·02	2·0147	Cl		24	36·9779	Se		9·5	76
T			3·0171	Cl			37·981	Se		8·3	77
He	2		3·0171	A	18	0·31	35·978	Se		24·0	77·938
He		100	4·0039	A		0·06	37·974	Se		48·0	79·941
He			5·0037	A		99·63	39·9750	Se		9·3	82
Li	3	7·9	6·0169	K	19	93·4	39	Br	35	50·6	78·929
Li		92·1	7·0182	K		0·01	40	Br		49·4	80·926
Li			8·0251	K		6·6	41	Kr	36	0·35	77·9456
Be	4		8·0079	Ca	20	96·76	40	Kr		2·01	80
Be		100	9·0150	Ca		0·77	42	Kr		11·53	81·9395
Be			10·0167	Ca		0·17	43	Kr		11·53	83
B	5	20	10·0163	Ca		2·30	44	Kr		57·11	83·9387
B		80	11·0129	Sc	21	100	45	Kr		17·47	85·9390
C	6	99·3	12·0040	Ti	22	8·5	46	Rb	37	72·8	85
C		0·7	13·0076	Ti		7·8	47	Rb		27·2	87
C			14·0077	Ti		71·3	48	Sr	38	0·5	84
N	7	99·62	14·0075	Ti		5·5	49	Sr		9·6	86
N		0·38	15·0049	Ti		6·9	50	Sr		7·5	87
N			13·0100	V	23	100	51	Sr		82·4	88
N			16·01	Cr	24	4·9	50	Y	39	100	89
O	8		15·0078	Cr		81·6	51·948	Zr	40	48	90
O		99·76	16	Cr		10·4	53	Zr		11·5	91
O		0·04	17·0045	Cr		3·1	54	Zr		22	92
O		0·20	18·0037	Mn	25	100	55	Zr		17	94
F	9	100	19·0045	Fe	26	6·5	54	Zr		1·5	96
F			17·0076	Fe		90·2	56	Nb	41	100	92·926
F			18·0065	Fe		2·8	57	Mo	42	14·2	92
Ne	10	90	19·9988	Fe		0·5	58	Mo		10·0	94
Ne		0·27	20·9997	Co	27	0·2	57	Mo		15·5	95
Ne		9·73	21·9986	Co		99·8	59	Mo		17·8	96
Na	11		22·0002	Ni	28	66·4	57·942	Mo		9·6	97
Na		100	22·9961	Ni		26·7	60	Mo		23·0	97·946
Na			23·9974	Ni		1·6	61	Mo		9·8	99·945
Mg	12	77·4	23·9924	Ni		3·7	62	Mo			102
Mg		11·5	24·9938	Ni		1·6	64	Ru	44	5·0	96
Mg		11·1	25·9898	Cu	29	68	63	Ru			98
Mg			26·9921	Cu		32	65	Ru		12	99
Al	13		25·9929	Zn	30	50·4	63·937	Ru		14	100
Al		100	26·9899	Zn		27·2	66	Ru		22	101
Al			27·9903	Zn		4·2	67	Ru		30	102
Al			28·9904	Zn		17·8	68	Ru		17	104
Si	14		26·9931	Zn		0·4	70	Rh	45	0·1	101
Si		89·6	27·9866	Ga	31	61·2	69	Rh		99·9	103
Si		6·2	28·9866	Ga		38·8	71	Pd	46	0·8	102
Si		4·2	29·9832	Ga			73	Pd		9·3	104
Si			30·9862	Ga			74	Pd		22·6	105
P	15		29·9882	Ga			76	Pd		27·2	106
P		100	30·9843	Ge	32	21·2	70	Pd		26·8	108
P			31·9841	Ge		27·3	72	Pd		13·5	110
S	16	96	31·9823	Ge		7·9	73	Ag	47	52·5	107
S		1	33	Ge		37·1	74	Ag		47·5	109
S		3	33·978	Ge		6·5	76				

ISOTOPES (*contd.*)

Z = Atomic number. Atomic mass in terms $O^{16} = 16$.

Symbol.	Z.	Abundance.	Atomic Mass.	Symbol.	Z.	Abundance.	Atomic Mass.	Symbol.	Z.	Abundance.	Atomic Mass.
Cd	48	1·5	106	La	57	100	139	Hf	72	5	176
Cd		1·0	108	Ce	58		136	Hf		19	177
Cd		15·6	110	Ce			138	Hf		28	178
Cd		15·2	111	Ce		89	140	Hf		18	179
Cd		22·0	112	Ce		11	142	Hf		30	180
Cd		14·7	113	Pr	59	100	141	Ta	73	100	180·928
Cd		24·0	114	Nd	60	25·95	142	W	74	0·2	180
Cd		6·0	116	Nd		13·0	143	W		22·6	182
In	49	4·5	113	Nd		22·6	144	W		17·3	183
In		95·5	115	Nd		9·2	145	W		30·1	184·0
Sn	50	1·1	112	Nd		16·5	146	W		29·8	186
Sn		0·8	114	Nd		6·8	148	Re	75	38·2	185
Sn		0·4	115	Nd		5·95	150	Re		61·8	186·981
Sn		15·5	116	Sm	62	3	144	Os	76	0·02	184
Sn		9·1	117	Sm		17	147	Os		1·58	186
Sn		22·5	118	Sm		14	148	Os		1·64	187
Sn		9·8	119	Sm		15	149	Os		13·3	188
Sn		28·5	120	Sm		5	150	Os		16·2	189
Sn		5·5	122	Sm		26	152	Os		26·4	189·98
Sn		6·8	124	Sm		20	154	Os		40·9	191·98
Sb	51	56	121	Eu	63	50·6	151	Ir	77	38·5	191
Sb		44	123	Eu		49·4	153	Ir		61·5	193
Te	52		120	Gd	64	21	155	Pt	78	0·8	192
Te		2·9	122	Gd		23	156	Pt		30·2	194
Te		1·6	123	Gd		17	157	Pt		35·3	195
Te		4·5	124	Gd		23	158	Pt		26·6	196
Te		6·0	125	Gd		16	160	Pt		7·2	198
Te		19·0	126	Tb	65	100	159	Au	79	100	197
Te		32·8	128	Dy	66	22	161	Hg	80	0·15	196
Te		33·1	130	Dy		25	162	Hg		10·11	198
I	53	100	126·932	Dy		25	163	Hg		17·03	199
Xe	54	0·09	124	Dy		28	164	Hg		23·26	200·016
Xe		0·09	126	Ho	67	100	165	Hg		13·17	201
Xe		1·90	128	Er	68	36	166	Hg		29·56	202
Xe		26·23	128·946	Er		24	167	Hg		6·72	204
Xe		4·07	130	Er		30	168	Tl	81	29·4	203·037
Xe		21·17	131	Er		10	170	Tl		70·6	205·037
Xe		26·96	131·945	Tm	69	100	169	Pb	82	1·5	204
Xe		10·54	134	Yb	70	9	171	Pb		23·5	206
Xe		8·95	136	Yb		24	172	Pb		22·7	207
Cs	55	100	132·933	Yb		17	173	Pb		52·3	208
Ba	56	0·16	130	Yb		38	174	Bi	83	100	209
Ba		0·01	132	Yb		12	176	Th	90	100	232·070
Ba		1·72	134	Lu	71	100	175	U	92	0·4	235·083
Ba		5·7	135	Lu			177	U		99·6	238·088
Ba		8·5	136								
Ba		10·8	137								
Ba		73·1	137·916								

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THE END

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