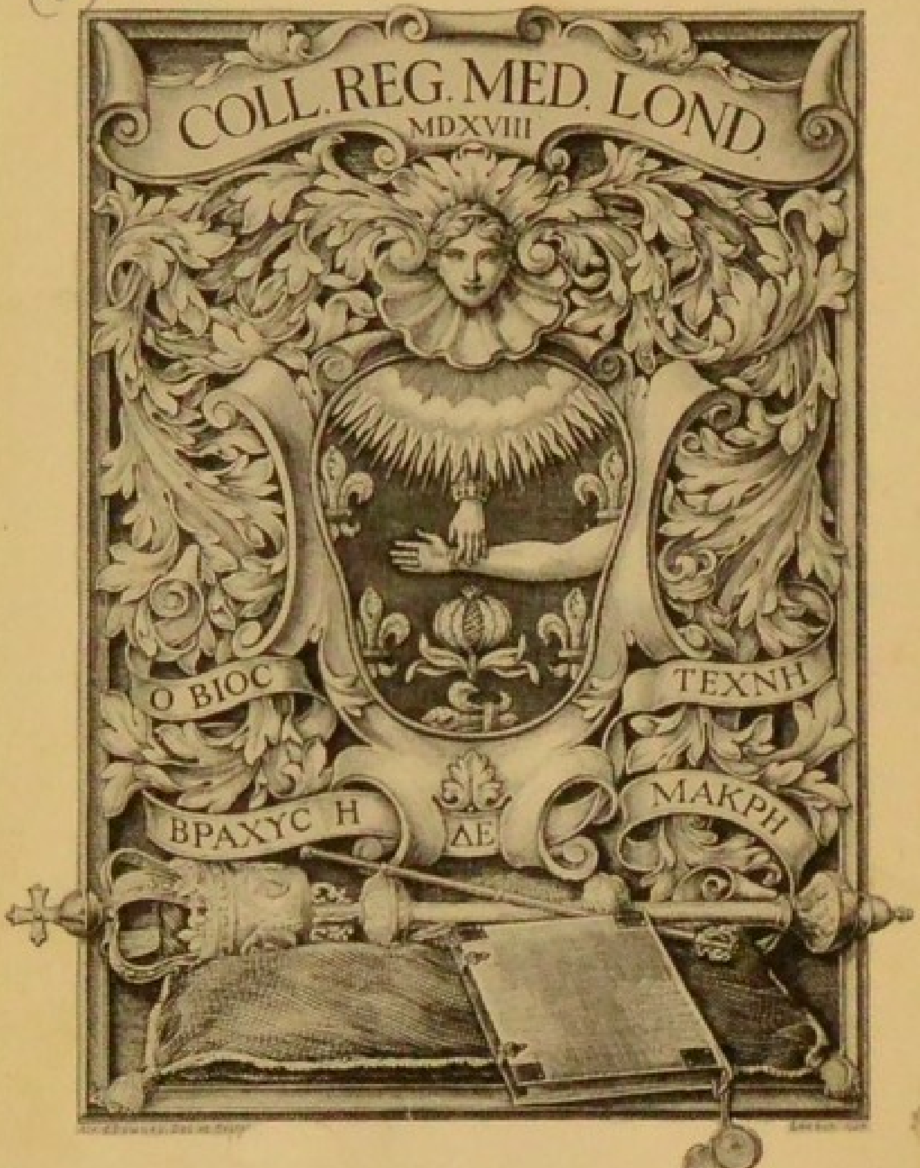
The sources of physical science : being an introduction to the study of physiology through physics. Comprising the connexion of the several departments of physical science, their dependence on the same laws, and the relation of the material to the immaterial / by Alfred Smee.

Smee, Alfred, 1818-1877.
Farre, Arthur, 1811-1887
Royal College of Physicians of London

London : Henry Renshaw, 1843.


COLL. REG. MED. LOND.
MDXVIII
O ΒΙΟϹ ΒΡΑΧΥϹ Η ΔΕ ΤΕΧΝΗ ΜΑΚΡΗ

Arthur Farre M D F R

with the Authors kd Rg

THE

SOURCES OF PHYSICAL SCIENCE.

THE

SOURCES

OF

PHYSICAL SCIENCE.

BEING

AN INTRODUCTION TO THE STUDY OF PHYSIOLOGY THROUGH PHYSICS.

COMPRISING THE
CONNEXION OF THE SEVERAL DEPARTMENTS OF PHYSICAL SCIENCE,
THEIR DEPENDENCE ON THE SAME LAWS,
AND
THE RELATION OF THE MATERIAL TO THE IMMATERIAL.

BY

ALFRED SMEE, F.R.S.

SURGEON TO THE BANK OF ENGLAND, TO THE ROYAL GENERAL DISPENSARY,
TO THE CENTRAL LONDON OPHTHALMIC INSTITUTION, AND TO THE
PROVIDENT CLERKS' MUTUAL BENEFIT ASSOCIATION,
ETC. ETC.

LONDON:
HENRY RENSHAW, 356, STRAND.
M.DCCC.XLIII.

PREFACE.

In former times, when the means of communicating knowledge were limited to the manual labour of writing every separate copy of a work, those who entered into such a difficult task were deservedly recognised as benefactors to mankind; but in these days, when the facility of printing allows such unlimited multiplication of books, that useful knowledge is lost amongst the mass of volumes produced, an apology is required by every writer who adds to the difficulty of learning, by increasing the quantity of books from which knowledge is to be selected.

It has long been a favourite subject with me to endeavour to investigate the physical structure of man, and to endeavour to unravel the mysterious means by which all physical forces, when acting on the human frame, are converted into nervous impressions. To conduct such an inquiry, it be-

London:
Printed by S. & J. Bentley, Wilson, and Fley,
Bangor House, Shoe Lane.

PREFACE.

In former times, when the means of communicating knowledge were limited to the manual labour of writing every separate copy of a work, those who entered into such a difficult task were deservedly recognised as benefactors to mankind; but in these days, when the facility of printing allows such unlimited multiplication of books, that useful knowledge is lost amongst the mass of volumes produced, an apology is required by every writer who adds to the difficulty of learning, by increasing the quantity of books from which knowledge is to be selected.

It has long been a favourite subject with me to endeavour to investigate the physical structure of man, and to endeavour to unravel the mysterious means by which all physical forces, when acting on the human frame, are converted into nervous impressions. To conduct such an inquiry, it became necessary to examine the sources from which the several departments of research, constituting Physical Science, have their origin, so that we might be in a condition to understand the material structure of the body.

For that purpose I intended to draw up a slight sketch of Physical Science, to form an introductory chapter to my inquiries, but when I found that this chapter, notwithstanding my utmost desire to compress and abbreviate it, occupied nearly three hundred pages, I could not allow it to form an introduction to my Physiological Investigations.

Upon consideration I determined to publish it as a separate treatise; believing that the compressed view of physical science which it contained might possibly lead those, who have more time and greater abilities for pursuing these matters than myself, to devote their attention more particularly to the essential nature and mutual relations of the various divisions of physical science.

In this treatise it has been my especial aim to examine the mutual relations, not only of the various conditions of matter, but also of the various physical forces, the independent existence of which mankind have at various times assumed. As the result of my inquiries I have been compelled to admit but three fundamentals — matter, — number, — attraction, — from which under various circumstances, all physical phenomena arise.

The philosopher having these three fundamentals, should be able at will to produce all physical forces and conditions, provided he rightly understands the nature of each separate physical force or condition. In every case it has been my endeavour to point out the exact course to be pursued, in order to produce at will the varieties of physical phenomena.

A work of this character would necessarily have been incomplete without an inquiry into the primary fundamental, Matter itself. A chapter, contemplating its nature, has been added, in which we come by an untrodden road to the proof of the existence of a Creator; the reasoning in support of which is quite independent of the argument of design.

At the commencement of my Physiological Inquiries I had no idea of dedicating a separate volume to the Sources of Physical Science, nor should I have published it if I could have referred to any sufficiently condensed work on these subjects.

But having felt the want of a work considering exclusively the subjects of the sciences, and shewing their relative position, I conceived that my own attempts to forward these inquiries might not be unacceptable to many lovers of scientific knowledge. If I shall hereafter find that my labours have been useful to society, or have induced others to produce a more perfect treatise, I shall feel most amply rewarded.

I have thankfully to acknowledge the assistance which I have derived during the printing of the work, from my much esteemed friend the Rev. EDWIN SIDNEY, M.A. of Acle, who revised many of the proof sheets; and for a revision of the remainder of the work I have to render my best thanks to H. A. GOODWIN, Esq. B.A., of Corpus Christi College, Cambridge, who kindly undertook the completion of the task. For the Analytical Index my readers are indebted to my brother-in-law, Mr. HUTCHISON.

7, Finsbury Circus,
September 1, 1843.

CONTENTS.

CHAPTER I.

THE FUNDAMENTAL SCIENCES.

MATTER.—ARITHMETIC.—ATTRACTION.

Extent of Physical Science (1). — Matter known by its Properties (2).—Matter attracts; Attraction the test of Matter (3). — Light, Heat, &c. tests of Attraction, consequently of Matter (4). — Abstract Physics (5). —Value of Abstractions (6).— Effects of Abstractions (7). — Writings and Conversations, Abstractions (8, 9).—Matter; its Nature (10).—Chemical Elements (11).—Names (12).—Possible Element (13).—Chemical Elements have similar properties to Ultimate Elements (14).— Ultimate Particles of Matter (15). — Number and Arithmetic derived from Matter (16).—Fractions of Units? (17).—Modes of Notation (18). — Arithmetic an Abstraction (19). — Addition and Multiplication (20).—Proportion (21).—Inverse Proportion (22). — Other Properties of Numbers (23). — Further Consideration of the Ultimate Particles of Matter, Algebra (24). Page 1.

CHAPTER II.

ON THE SCIENCES OF MATTER UNDER ATTRACTION.

CHEMISTRY.—CRYSTALLOGRAPHY.—GEOMETRY.—TRIGONOMETRY.—
GRAVITY.—MAGNETISM.

The Attraction of Matter (25).—Activity of Matter (26).—No principle or imponderable attached to Matter (27).—Artificial or

CHAPTER III.

ON THE SCIENCES OF THE DISTURBANCE OF ATTRACTION.

ELECTRICITY.—MECHANICS.—HYDROSTATICS.—PNEUMATICS.

CHAPTER IV.

THE SCIENCES OF ACTIONS AND REACTIONS.

TIME, HEAT, LIGHT, SOUND, ODOUR?

CHAPTER V.

ON THE PERFORMANCE OF HUMAN OPERATIONS.

CHAPTER VI.

ON THE COMPLEX SCIENCES.

CHAPTER VII.

ON THE RELATION OF THE MATERIAL TO THE IMMATERIAL.

INTRODUCTION.

Physical science may be divided for study into various departments. The first comprises those sciences which relate to particles of matter, with their power of attraction. These sciences may be termed the fundamental sciences, because they form the foundation of physical science, and have for their object the study of matter, attraction, and number. Without matter, attraction, and number, we can have no physical phenomena; for we shall hereafter point out that no physical phenomena can be manifested without them. This part of the subject also includes the study of the properties of matter, abstracted from the particular particles which give rise to the effects.

The second division of physical science includes those sciences which have for their object the study of a number of particles of matter under attraction, The attraction of particles into masses, whereby form is given, gives rise to the science called geometry. The attraction of particles of dissimilar character, is studied under the name of affinity, though when the same attraction is exerted between similar elements, the effect is classed under cohesion. When the directions of the attractions are all in one direction, the attraction is investigated under the head of polarity, or magnetism. The study of attractions evinced in a particular manner is comprised under crystallization. The science of gravitation constitutes the science of certain effects, by the agency of which, as causes, position is given to masses of matter.

Proceeding onwards, we arrange under a third division those sciences which have their origin in the action of newly exerted attractions upon attractions previously existing. When there is simply a tendency to this action, we obtain tension, and consequently the electricities of various kinds. When the action is actually evinced, we obtain force; after which the science of dynamics, comprising the phenomena of motion, has to be considered. The phenomena of force and motion, according as they are evinced by solid, fluid, and gaseous bodies, are the subjects, respectively, of the sciences of mechanics, hydrostatics, and pneumatics.

The fourth division into which the sciences may be grouped, contains those which arise more especially from the resistance of old attractions. The first of these is that of time, which it is most important thoroughly to understand, as time is evinced whenever a new attraction is resisted by an old one, as the conflict of the two forces gives rise to the phenomenon. Other phenomena of matter, under the conflict of these two forces, are studied under the respective sciences of waves, heat, light, sound, and probably odour. This division finishes the simple physical sciences; so that under these four divisions of universal physical science, every known possible state of matter is included.

As all physical phenomena are comprised in the preceding four parts, and all have a common relation to matter, number, and attraction, we may expect to find that all human operations may be systematized under a single law, which is actually found to be the case; for we find that in all human operations, some disturbance or destruction of prior attractions ensues, which in every case, when acting on attracted matter, is obedient to the same law.

In this work it may appear almost unnecessary to enter into the consideration of those sciences, the character of which is derived from two or three of the simple sciences acting upon large masses of matter, and, consequently, the compound sciences are very briefly referred to in this treatise.

The sciences of organized beings are excluded from this volume, as their laws and phenomena would require another treatise.

It would be improper, or rather it would render a volume of this kind imperfect, if a few pages were not devoted to the contemplation of the cause of the existence of matter, and the relation of matter to that Immaterial, which has conferred upon matter its power to evince attraction. A chapter on this head has been added to the work; but the subject is so far beyond human comprehension, that we can arrive at little more, by the utmost stretch of physical investigations, than the evidence of the existence of a Great First Cause.

THE

SOURCES OF PHYSICAL SCIENCE.

CHAPTER I.

THE FUNDAMENTAL SCIENCES.

MATTER.—ARITHMETIC.—ATTRACTION.

Extent of Physical Science (1). — Matter known by its Properties (2).—Matter attracts; Attraction the test of Matter (3). —Light, Heat, &c. tests of Attraction, consequently of Matter (4).—Abstract Physics (5).—Value of Abstraction (6).— Effects of Abstractions (7). — Writings and Conversations, Abstractions (8, 9).—Matter; its Nature (10).—Chemical Elements (11).—Names (12).—Possible Element (13).—Chemical Elements have similar properties to Ultimate Elements (14).— Ultimate Particles of Matter (15).—Number and Arithmetic derived from Matter (16).—Fractions of Units? (17).—Modes of Notation (18).—Arithmetic an Abstraction (19).—Addition and Multiplication (20).—Proportion (21).—Inverse Proportion (22).—Other Properties of Numbers (23).—Further Consideration of the Ultimate Particles of Matter, Algebra (24).

(1.) MAN, being composed of the material and immaterial—of body and soul, can have no distinct idea of anything not partaking of the properties of his own constitution. He can form no conception of matter without that which gives it properties; nor can he understand that which gives it properties without the matter. From such considerations, the universe must be studied from effects produced by virtue of properties evinced by the substances of which it is composed. Matter must be considered in connection with that which gives it properties, that which gives it properties in conjunction with the matter.

(2.) All physical bodies are formed of what is termed matter, and physical forces are those which are exhibited by, or appertaining to, this self-same matter. That which men call matter is known by its properties; so that the term matter is given to anything which exerts these peculiar properties.

(3.) In this work we shall shew that all the properties or influences of matter, are dependent upon an ultimate property which confers a power whereby two particles or portions of matter are drawn towards each other, by a force exerted in a particular direction. The power of two particles of matter to generate mutual attraction, as it is its sole property, so it becomes its test; therefore, whatever attracts is matter, and whatever cannot attract is not matter. Ingenious persons, indeed, speculating upon the properties of matter independently of the thing itself, have persuaded themselves, with some show of reason, that matter has no existence. Their minds, however, have been led astray by their mode of arriving at their conclusions. They have not commenced with a sound definition of that which we designate matter. Defining matter to be that which attracts, and allowing attraction to be its test, obviates all difficulty.

(4.) In this work we shall hereafter point out how electricity, galvanism, light, heat, and sound are the effects of the power which generates attraction. Hence, anything which exhibits electrical tension, or the effects of galvanism, or which becomes hot, luminous, or vibrating, or which is capable of being set in motion, is matter; because we shall find that tension, galvanism, light, heat, sound, motion, each presupposes attraction, or is a test of attraction, either at that time, or previously exerted. Any body which exhibits these conditions attracts, and, consequently, is matter.

(5.) Although the human mind can only clearly appreciate matter, and the several effects which different masses under various circumstances can produce, it has been found of the utmost advantage, in all ages, to consider a series of effects produced by matter upon other matter in an abstract form, that is, apart from all material connections. The study, or rather the use of these abstract properties, in order that their real nature may be clearly pointed out, might be well termed Abstract Physics, which would embrace all effects produced by various masses of matter, considered without reference to the specific or particular masses which produce these effects.

(6.) The advantage of abstract physics is seen most prominently in all mathematical and philosophical inquiries, in which our object is to elicit comparative reference between different links of actions and impressions. Thus, when we are desirous to compare the relative force generated by one set of attractions with that generated by another set of attractions, or the relative number of particles composing any body with the number composing any other body, the term force or number is used abstractedly, or apart from the actual particles of matter to which it strictly refers. In a similar manner we employ the abstract terms of attraction, length, breadth, weight, light, heat, sound, time, &c. in all which cases the properties of matter which they denote, are considered without reference to the particular masses of matter the condition of which they point out.

(7.) The right use of abstractions is highly convenient and important, tending to prevent parenthesis and confusion; and in fact we may say, that the capacity to employ abstract ideas in great measures gives to man his superiority over all other created things. If, however, the mind is once led astray to seek some principle or some material essence in the abstraction itself, the greatest confusion and danger results. If we even attempt abstract definitions of abstractions we run into the greatest possible difficulties. The consideration of abstractions in the abstract, that is, apart from all material particles whatever, constitutes metaphysics, which, from its danger, unless carefully qualified, we shall avoid throughout this volume.

(8.) Our intention is to confine ourselves entirely to the effects of matter which give rise to the abstract ideas, which will be used only in the conventional manner, such as universal experience has pointed out to be useful, and everyday conversation sanctions and approves. In no case will abstract definitions be attempted to be given of abstract ideas, but all abstractions will be referred to the matter which gives rise to these properties. Force, for instance, will be referred to the material attractions producing force; and number, in a similar manner, to the juxtaposition of the series of material units which it comprises. In the same way all other material actions will be first considered, and then we shall mention the abstract idea to which these properties give rise.

(9.) In consequence of all writing, and even language itself, partaking more or less of an abstract form, all descriptions are more unintelligible than the inspection of the same things for a single instant. It is upon this account that descriptions of the most simple machines are extremely difficult to be understood by almost all persons, but to persons not thoroughly acquainted with the exact material application of the abstract definitions of the several parts, they are perfectly unintelligible. From this cause truths are acquired and lost, writings are not understood, and we are unable exactly to communicate our ideas and observations. Practice, say all, is so much better than theory; inspection than reading or hearing. Practice and inspection are the direct appreciation of material objects by the mind through the organs of sense; whilst theory, writings, and conversation, are only the abstract ideas of the same material particles.

(10.) The nature of the matter which composes the myriads of worlds which stud the firmament with their wondrous light, we have no means of ascertaining; and it is only in this our planet we can even attempt the investigation. In the examination of the structure of this world such difficulties occur, that even the masses of matter themselves seem to mock the prying eye of that man who attempts to unravel and elucidate the nature of the particles of which it is made up. As it is the property of matter to attract, and attraction is the sole action of matter, we might be led to infer that this great globe is composed of a single element; but, if that be the case, we are not yet in a condition to determine with certainty what that element is. The particles of a single element arranged in different ways, that is, in different relative quantities and positions attracted together, could possibly give the different effects of that variety of elements which up to the present time we so denominate because they are apparently uncompounded.

(11.) Chemists, wisely considering that experiment only is the basis of philosophy, have determined that those bodies should alone be considered elementary which have never been made by compounding other bodies, or which have never been themselves separated by analysis into more primitive portions. We must not, therefore, infer that what we call chemical elementary particles are the ultimate elementary particles; but we must bear in mind that the term element in the former case, that is, in a chemical point of view, refers to whatever has resisted all composition and decomposition by the hand of man. But in a philosophical point of view, the same term is used to designate the ultimate kind of matter, or matters, of which chemical elements, for aught we know, are made up. Chemical investigation should never lose sight of the acquisition of the knowledge of that element, of which philosophy might lead us to suppose that each star, each moon, each world is composed, and which probably fills the expanse, the firmament, the universe; but in all these investigations we should test our inquiries by the general definition of matter, never forgetting that attraction is the test of matter, and whatever attracts is matter.

(12.) Such is the imperfect nature of chemical research at the present time, that we are compelled to admit fifty-five chemical, or undecompounded matters, which, either alone or in combination with each other, compose this great globe. The following is their list:—

Oxygen,
Hydrogen,
Nitrogen,
Chlorine,
Iodine,
Bromine,
Selenium,
Phosphorus,
Carbon,
Boron,
Silicon,
Fluorine?
Sulphur,
Potassium,
Sodium,
Lithium,
Calcium,
Barium,
Strontium,
Magnesium,
Manganese,
Iron,
Zinc,
Tin,
Cadmium,
Cobalt,
Nickel,
Copper,
Lead,
Antimony,
Bismuth,
Uranium,
Titanium,
Cerium,
Lantanum,
Tellurium,
Arsenic,
Molybdenum,
Chromium,
Vanadium,
Tungsten,
Columbium,
Mercury,
Silver,
Gold,
Platinum,
Palladium,
Rhodium,
Osmium,
Iridium,
Glucinum,
Zirconium,
Yttrium,
Thorinum,
Aluminum.

(13.) If, indeed, there be but one ultimate element, hydrogen, being the lightest of the chemical elements, might be supposed to be the ultimate kind of matter of which the rest are composed; and upon that supposition 8 particles of hydrogen could possibly form oxygen, 108 silver, 200 gold, &c.; but we are ignorant whether hydrogen itself is an ultimate element, for each atom of that itself might be composed of several particles of some unknown element of which philosophic reasoning might lead us to infer that all matter is formed. The first idea which supports the doctrine of the unity of matter, is derived from the chemical examination of certain chemical proximate elements, as cyanogen, ferrocyanogen, sulphocyanogen, and perhaps a hundred others. These bodies we know to be compounds, though they behave and act to other bodies exactly as though they were chemical elements. Any number of particles of one element arranged together, and attracted so firmly that chemists could not separate them, would be termed an element; and perhaps the undecompounded bodies are of that nature. There is, indeed, one chemical element that does not seem to exist in the elementary state, but only in a state of combination. This body is fluorine; which, although called by chemists one of their elements, has never been obtained separate from other bodies. There appears to be much greater probability of our increasing the number of these chemical or undecompounded elements than of decreasing them, because there is greater chance of finding bodies incapable of being decomposed, than of decomposing those which have already resisted every attempt.

(14.) It is important to bear in mind, that the fifty-five undecompounded and unformed bodies would have qualities somewhat similar to those of ultimate elements, even if they be really composed of other matter; and therefore, though in theory we have reason to expect there is but one element, yet in practice such consideration is not so important as might at first sight appear.

(15.) Matter, whether of one or of many kinds, is probably divisible into ultimate particles, between which attraction is exerted; and therefore we shall hereafter have to point out that combinations can only be effected by the juxtaposition of these ultimate particles; an inference perfectly consonant with all chemical examination. The discovery of the doctrine of chemical equivalents is doubtless the most brilliant which has enriched science in modern days, for it gives to chemical research and inquiries the facility and certainty of number.

(16.) To the abstract idea of many particles we give the name number; and to the study of numbers we have affixed the term arithmetic. Number may be assumed to be derived from the finite divisibility of matter, and may be said to have relation to a series of indivisible particles usually termed atoms, or units. These units may be arranged together to any extent; eight or ten of one kind may be joined to eight or ten, or any other proportion, of another; but no fractional part of an unit, or atom, can be introduced. In some cases there is an appearance of a fractional part of unity, as when an atom of one substance unites with an atom and a half of another; but nearly all chemists are agreed that the numerical expression in these cases should be two atoms of the first to three of the second body.

(17.) If we assent to the proposition that number has its origin from matter, as consisting of a series of indivisible atoms, it would be impossible to have the fractional part of an atom, or unit, which at first sight appears not to be in conformity with the laws of arithmetic, as we commonly talk of $\frac{1}{2}$, $\frac{1}{8}$, $\frac{1}{10}$, &c. The appearance of divisible units arises from our mode of notation, for we begin by counting our fingers once over, which being ten, we obtain one-ty, or ten; we then count them a second time, and obtain twenty, and so on; and these, of course, will divide into a series of parts. Likewise a large mass of matter is frequently assumed as unity, as one book, one house, one stone, &c., which, being capable of division, gives the idea of a divisible unit. All cases of fractions may be resolved into proportionals; thus we talk of half a body, as bearing the relation to other similar bodies of one to two.

(18.) The mode of notation is almost invariably by ten, that is, by comparison with the fingers of both hands; but although this practice is common to nearly all nations, sometimes the number five has been used, derived from the number of fingers on one hand, which is called the quinary system; and at other times the toes have been counted as well as the fingers, as in the mode of counting by scores, scarcely yet fallen into disuse in all parts of England. Arithmeticians have often lamented that we do not possess twelve fingers instead of ten, because then we should have twelve units before we repeated. We should then have had one-ty, twenty, thirty, &c., with all the advantages of the 10, but at the same time we should have the benefit of the divisibility of the 12 by 6, 4, 3, 2. In a duodecimal scale thus formed, the 10 would stand for 12, 20 for 24, 100 for 144, 1000 for 1728, and so on.

Such a scale is called the duodecimal scale. There are, indeed, some other modes of notation which are not worth consideration, as counting by pairs, threes, &c.

(19.) In all questions of arithmetic we use numbers apart from matter, but we should take great care not to reason upon the character of abstract number without remembering the connection of number with matter. Though the direct utility of abstraction is nowhere more visible than in arithmetic, yet we should continually bear in mind that an unit is a definite thing, meaning one atom of matter; and if we deviate from the material connections of number, we instantly run into confusion and error. It is not strictly correct to talk of a large mass of matter as one, but this mode is forced upon us by the construction of our organs of sense, for we are not endowed with apparatus sufficiently minute to appreciate the ultimate particles of matter.

(20.) The juxtaposition and connection of a series of units we call addition; the juxtaposition and connection of several like series of units we call multiplication; hence multiplication may be regarded as a peculiar mode of addition. Beginning with unity, we can only have addition or its variety, multiplication. But the sum arising from the added units may be decreased. This decrement we call subtraction, which presupposes addition. Division, however, has no relation to subtraction, for the quotient is that number which, multiplied by the divisor, makes up the dividend. If, for instance, we divide 24 by 8, $\frac{24}{8}$, we obtain 3, which is the number which makes up 24, if added together eight times. The quotient number is the relation to unity which the dividend bears to the divisor. Hence, as 24 is to 8, so is 3 to 1. There are numerous cases where the relation of one number to another bears no relation to unity, thus, $\frac{3}{2}$ cannot be made to have relation to a unit, for as $2:3::1:1\frac{1}{2}$. This result introduces a fractional part of unity, which may very conveniently be employed abstractedly in cases relating to masses of matter, though, strictly speaking, it has no existence in reality, the unit being indivisible.

(21.) Next to the addition of units and the diminution or subtraction of the sum so added, the most important knowledge which we can obtain from abstract numbers, or arithmetic, is the proportion or relation of one number to another, so that if we find a mass of matter composed of two other masses of matter, by knowing the relation of one of the primitive masses to another, we, by a certain process which we ridiculously term the Rule of Three, are enabled to find out the exact quantity of each mass of matter required to make a compound mass of any other bulk. For instance, we know that 76 grains of chloride of potassium contain 40 parts of potassium and 36 chlorine, we may require to know how many grains of potassium are contained in a pound of the compound. The quantity of potassium being the problem desired, we place that in the centre to commence proceeding; we then ascertain whether we seek to obtain the quantity of potassium in a larger bulk or a smaller bulk; if in a larger bulk, it is the relation of the known quantity of potassium contained in the smaller bulk to the larger, it is hence $\frac{40}{76}$ of 7000, or as 76·40 : 7000; or, more correctly to state them, as 76 is to 7000 so is 40 to 3684·21; the answer, or exact quantity of potassium contained in the 7000 being the product obtained by multiplying the second and third terms, divided by the first.

(22.) There are cases where number is perhaps not strictly correctly used, as in measuring time, which we shall hereafter find to be a series of actions; for if, when the quantity increases, the time decreases, the Rule of Three, or Proportion, will not be found to be correct if practised in the manner just pointed out, as the proportion will only be correct if the third and first terms are inverted. This inverse proportion seems at first sight to be almost unaccountable, but it is owing to an improper use of number with regard to time; or in other cases where the proportionals are inverted. An example of inverse proportion arises in the following question—If 21 men do a certain excavation in 3 days, how long would 7 men be performing the same operation? In this case the time, as we usually express that term, decreases as the men increase;

therefore we are compelled to invert the first and third proportionals, so that instead of as 21·3 : 7, the question would be as 7·3 : 21. In this case, the undefined use of the word time causes this apparent subversion of the natural orders of numbers.

To show how the erroneous application of number is to time, as we employ it, or rather the assumption of the existence of something absolute in time, to which number may be affixed, causes this inversion of the proportion, we will throw out of consideration the period of three days in the above question, and call the amount of work 1. We should then state the case as follows: as 21 : 1 :: 7 : $\frac{1}{3}$; that is, 7 men would do $\frac{1}{3}$ the work, or give rise to $\frac{1}{3}$ the action, that 21 men would. We next say, as $\frac{1}{3}$ the work is to one series of actions we call a day, so is 3 days to 9, as $\frac{1}{3}$: 3 :: 1 : 9, which is the correct answer. It would be advantageous if the authors of works on arithmetic would discard the term inverse proportion in these cases, but analyse all questions of that nature into the two proportions of which they are made up; for although the inversion of the proportion gives the correct answer, the inversion is an unintelligible operation. In these questions of time, requiring inversion of terms, we have first to discover the relation of the amount of action of one case to the other: in the preceding question, it is the relation of 21 to 7; we then have to refer this relative amount of action to some definite action, as that of the pendulum, or other time meters. The bearing of these questions will be more fully discussed when we have to treat of the modes of measuring, the series of actions we first call "time," and then puzzle ourselves to find out what this "time" is.

(23.) We have already had occasion to mention that all fractions may be looked upon as proportionals, thus $\frac{1}{7}$ is as 1 to 7. One variety of fractions, decimals, refers all these proportions to 10. Thus .1 decimal is as 1 to 10, and so on. To enter into these details would be more in accordance with a treatise on arithmetic than physical science. The properties of series, or logarithms, are also foreign to the purposes of this work, because, although properties of the greatest utility to mankind, yet they have no relation to the finite particles of matter, which constitute the units of numbers.

(24.) The assumption of masses of matter as unity is highly useful, although in some cases it is likely to lead to error if we forget that that unit is only a conventional unit, for 1 is sometimes put for a world, at others to an atom, another time 1 is used for a whole fleet, and again to only one boat.*

---

* The extraordinary accuracy and facility which the application of the abstract properties of numbers gives to artificial units, is perhaps best exhibited in the accounts kept for the management of the vast national debt of this country. Its amount is near 800,000,000. The units of this are assumed to be the sovereign. Portions of the entire amount every six months change hands, and change hands in the most complicated manner. Notwithstanding this difficulty, the accounts are accurately balanced, and an error even of a penny, or the 1 — 192,000,000,000th of the whole amount, is a matter of serious importance,

This conventional assumption of masses of matter as unity, or rather the use of a certain symbol for a large mass of matter, is pre-eminently seen in algebra, where letters are made to represent dissimilar masses of matter. The algebraist uses (a) at one time to denote something approaching infinity; and at another time (a) represents one atom or unit of matter. The value of these letters is well seen where extensive calculations have to be made, for the whole process is conducted by fractional parts or multiples of the assumed letter, or proportionals to other assumed letters, and not till the entire calculations have been conducted, are the values in figures determined; so that in some cases great masses of figures and tedious arithmetical sums are saved. We thus see that arithmetic, as we use it, is not exactly what it ought to be, the denoting of the number of atoms of matter, but it is used to signify masses of matter, and the relation of other masses are referred to some conventional unit which we shall have to describe in the next chapter.

---

and requires detection. An error of a penny may, to the uninitiated, appear to be scarcely worth consideration, especially as it might take many clerks several days to discover it; but it is found that that penny may not be the sole error, but the balance of numerous errors, which all require alteration before the balance is struck. It is contrary to the doctrine of chances that errors should exactly balance each other, otherwise were that frequently the case, it would be impossible to conduct the immense mercantile transactions of this great empire with its present precision and exactness.

Algebra differs only from arithmetic by the algebraist assuming a letter to which he himself gives arbitrary values, differing in each individual case; while arithmetic supposes some common arbitrary value, so that one person may understand the language of another. We shall hereafter see that these arbitrary values are different in each country, so that our arithmetical units of matter throw not the slightest light upon the artificial arithmetical units used by other countries, or even by our own at a different age from the one in which we happen to live. The properties of numbers are due to the relation which different numbers bear to each other, and are therefore the same whatever they refer to. 10 bears the same relation to 5, whether the two numbers refer to sheep or ships, or to any other material connection. These abstract properties of numbers and symbols are very numerous, and are extensively used in algebraical as well as arithmetical problems.

CHAPTER II.

ON THE SCIENCES OF MATTER UNDER ATTRACTION.

CHEMISTRY.—CRYSTALLOGRAPHY.—GEOMETRY.—TRIGONOMETRY.—GRAVITY.—MAGNETISM.

The Attraction of Matter (25).—Activity of Matter (26).—No principle or imponderable attached to Matter (27).—Artificial or Theoretical Principles (28).—Attraction varies in Degree (29).—Weight (30).—Artificial Standard (31).—Natural Standard Units of Weight (32).—Artificial Units (33).—Distant action of Matter (34).—Effect of interposed masses of Matter (35).—Polarity of Attraction (36).—Negative and Positive Ends (37).—Impenetrability (38).—Shapes (39).—Volume (40).—Not absolute Property (41).—Geometry (42).—Specific Gravities (43).—Geometry, its double nature (44).—Measures (45).—Absolute Measures (46).—Artificial Measures—French (47).—English (48).—Best Artificial Measure (49).—Standards Arbitrary (50).—Varieties of Forms (51).—Breadth, Length, Abstractions (52).—Human Measures (53).—The Use of Measures (54).—Quantity of Matter shown by Measures (55).—Intensity of Attraction shown by Measures (56).—Thermometer a Measure of Intensity of Attraction (57).—Value of Comparative Measures (58).—Angles (59).—Kinds of (60).—Angles a material Effect (61).—Curves related to Angles (62).—Points, Edges (63).—Cohesion (64).—Varieties of (65).—Aggregation (66).—Properties of Bodies in Cohesion (67).—Hardness (68).—Brittleness (69).—Elasticity (70).—Mobility (71).—Flexibility (72).—Ductility (73).—Malleability (74).—Miscellaneous Arrangement (75).—Crystals (76).—Crystals, compound (77).—Properties of Cohesion susceptible of change (78).—Chemical Affinity (79).—Affinity exerted by Atoms (80).—Causes different Properties (81).—Proximate Elements (82).—Direction of Attraction (83).—Inducers and Inducees (84).—Examples (85).—List of Inducers (86).—Excited Elements (87).—Neutral Elements (88).—Cohesion an Obstacle to Chemical Affinity (89).—Chemical Affinity an Obstacle (90).—Heterogeneous Adhesion (91, 92).—Capillary Action (93).—Mixture (94).—Gravity (95).—Law of Attraction (96).—Polarity (97).—Magnet (98).—Its mode of Formation (99).—Rationale (100).—Destroyers of Magnetism (101).—Resumé (102).

(25.) The finite particles of matter when simply in apposition, by virtue of a force inherent in themselves, set up a mutual attraction to each other. The particles of matter only exert this power of attraction, and the effect being evinced with various degrees of energy upon various numbers of atoms, and in various directions, gives to masses of matter all the properties which they apparently possess.

(26.) Matter, from the above considerations, is essentially active, as, by the simple apposition of two particles of different, or even of the same nature, effects are produced independent of any external agency. We have no means of ascertaining whether matter ever existed without the power of setting up attraction; and as it is quite impossible for man to conceive matter without this property, we shall not attempt to speculate upon such existence. In fact, matter would cease to be matter if it did not possess it. The property of attraction is the test of matter, as man has given the term matter to that which attracts.

(27.) It is probably unjustifiable to attempt to seek some specific principle attached to matter which causes this act of attraction. Yet if men will not admit the effects of attraction to be manifested by matter without some cause also inherent in it, we had better call the cause of attraction its first property. Indeed, in a former memoir, I alluded to this first property as electricity; but confusion is likely to arise from the assumption. It is preferable in the present state of our knowledge, to treat of the attraction of matter as a primitive fact beyond which human intellect cannot obtain information. We shall again return to this question, and contemplate the probable relation of matter to its first cause at the conclusion of the work.

(28.) Throughout this work, therefore, in speaking of the first property of matter, the term will be used as an abstract idea, having relation to the action of matter considered apart from the particular piece of matter producing this action. We shall not assume any principle or imponderable agent attached to matter which gives rise to attraction. The greatest confusion has already arisen from philosophers having, by exuberant imaginations, manufactured, from abstract ideas, principles or imponderables. As a principle, or imponderable agent, there is neither electricity, affinity, light, heat, sound, scent, &c., each individual term only referring to a great class of actions or effects produced by the activity of matter.

(29.) When two particles of matter are placed in opposition to each other, a certain force of attraction is exerted which varies with every pair of atoms. The force of attraction being different is a most important property, as by the inequality of force we are enabled to perform all our operations, and even nearly all the phenomena of nature may be said to be primarily dependent on this inequality of attraction.

(30.) The energy of the attraction of one particle to another, or to a series of others, is a most important ingredient in all human operations. As we have not the power of appreciating the units, or atoms of matter, we have not the means of obtaining a perfect unit of the force of attraction. The only absolute unit of this power would be the force of attraction exerted between two ultimate particles of matter, an unit which we can never hope to obtain.

(31.) As we have not the power of using the primitive atoms of matter, we take a given mass, and assume that to be a unit. The force exerted between this mass and the whole bulk of the earth at the level of the sea is then obtained. This is assumed as an unit of force which is called an unit of weight, and to which all other weights are referred.* Weights that are greater than this stan-

---

* The weight, correctly speaking, is not the actual force of attraction of a mass of matter, but the attraction lessened by the attraction of the same bulk of air with its accompanying moisture.

dard are represented by 2, 3, 4, 5; that is, by multiplying this force. Weights, on the contrary, that are less than this standard, are represented by fractional parts of this artificial unit of weight. The force of attraction to the earth is not the same at all parts of the earth's surface, in consequence of the globe not being a perfect sphere. On this account it is necessary to give the spot at which the standard attraction is assumed.

(32.) If we compared all weights with the absolute unit of force, or that with which two ultimate particles are attracted, or one ultimate particle to the mass of the earth, every other weight must be a multiple of this absolute unit, because the force generated by two pairs would be twice that of one couple of atoms, or of one atom if compared with its attraction to the earth. On this account, in the latter case, the number of units which represented the weight would be exactly the number of particles attracted.

(33.) In our artificial standards of weight the unit is the grain, which is the force of attraction of a cubic inch of water to the earth at the temperature 62, barometer 30, divided by 252·5. To obtain this comparative unit we must presuppose a knowledge of measure, of heat, of pressure, &c., which have not as yet occupied our attention. It has been recommended, and perhaps is preferable, to take any piece of matter and assume its weight as an arbitrary standard, for philosophers disagree as to the true weight of a cubic inch of water, or indeed of any other body. The utmost limit to human ingenuity in weighing is about $\frac{1}{10,000}$ part of our comparative unit of weight, or grain; but in this quantity so many circumstances lead to error as to render the result very unsatisfactory. The finger held over a scale, which by its warmth causes currents which exert a force contrary to that of the earth, will materially influence the result in very small weights. I have tried this experiment with an excellent pair of scales, made for the Bank of England by Mr. Bate, and found a most sensible disturbance of the equilibrium of the balance, when the finger was held half an inch above one of the scale pans.* There is hardly any limit to the extent of great weights, that may be roughly compared with our comparative unit, or grain. The rough determination of the weight of the earth is an example of a very heavy weight.

(34.) One of the most important points which we have to discuss and settle, is the manner in which this active power of attraction is exerted from body to body, and whether this effect is manifested without the intervention of particles of matter, or whether a layer of matter is actually required. Considering that attraction is manifested

---

* In moderate weights, say that of three or four hundred pounds, the greatest precision in weighing ever obtained, is about $\frac{1}{2,500,000}$ of the entire weight, though the Commissioners for ascertaining the standards in their report consider that the process can only be accomplished to the $\frac{1}{1,000,000}$ of the entire weight.

between celestial bodies hundreds of thousands of millions of miles,—considering, moreover, the various phenomena of heat and light, there appears to be but little doubt, or at any rate strong probability, that attraction is exerted between bodies without any material connexion between them.

(35.) Although, however, attraction is probably exerted between bodies without material connexion, the presence of interposed particles of matter under attraction, greatly influences the result of the force which would otherwise be exerted by the first two bodies.

(36.) The force of attraction is exerted in a certain direction; a series of which attractions, arranged in the same direction, constitutes polarity. This direction of attractions, or polarity, is seen in the Leyden jar, where the inside and outside respectively exhibit the two terminations, or ends, of the force. The magnet, also, well exhibits this polarity of attractions; but not only in these cases, but in every instance where attraction is evinced this direction exists. Even with chemical affinity, the force is always exerted in a definite direction; the force of the combination, for example, of zinc to oxygen, is similar to that of hydrogen to oxygen, and, contrary, to oxygen and hydrogen. This peculiarity in the direction of the force whereby attraction is exerted, is of fundamental importance, for it enables us to oppose one attraction by another. This opposition of attraction enables us to effect decomposition, disintegration, and to give rise to the phenomena of heat, light, sound, &c., at will.

(37.) The terms negative and positive having come extensively into use in electrical effects, which by and by we shall find to be phenomena of attraction, may be conveniently employed to designate the directions of the attraction, or rather, the opposite ends of that direction. In using the terms negative and positive, it must not be assumed that there are two things or principles which are formed by the act of attraction, nor must it be assumed that attraction itself is anything but a material action. The terms negative and positive we employ that the direction of one specific attraction may be referred to the direction of another specific attraction ; and the use of these terms enables us to communicate from one person to another the peculiar direction of any particular attraction, and consequently the mode to be pursued to overcome it.

(38.) The peculiar mode in which attraction is exerted in a definite direction, gives a property to matter which is called impenetrability, which literally means, that where one piece of matter is, another cannot be at the same moment. The reason why impenetrability is conferred on matter by the act of attraction is perfectly evident, if the mode of the generation of attraction be carefully examined. The attraction being exerted in a certain direction, one particle of matter, although capable of being attracted so as to adhere firmly to a second portion, would, if the second passed into the first, instantly be destroyed, because the direction of attraction exerted in one atom would oppose, neutralize, or counterbalance, the attraction in the other; the attraction therefore between two atoms is most violent at contact, but ceases upon one having a tendency to pass into the other. The above observations will be rendered perfectly intelligible by the following notation—

$$\overset{\text{NP}}{\text{O}} \quad \overset{\text{NP}}{\text{O}}$$

If the two O O represent the two atoms, and the NP NP the ends of the forces with which they are held together, then the very moment one atom had a tendency to pass into the other, the two "N," or the two "P" would oppose each other; upon that account the two particles would be firmly attracted till they came in contact, but no further.

(39.) When several particles are attracted together, the mass so formed, according as the number of particles are arranged, assumes various shapes. The shapes, or forms of a mass, or solid, depend upon the number of particles attracted in each way.

(40.) A number of particles attracted together according to the energy of the force with which they are connected, occupies more or less bulk. This energy of the attraction of particles may be termed volume, and the appreciation of volume, measure. Volume, therefore, is rather referrible to a number of particles under a given intensity of attraction, than an absolute property of the primary atoms. By forgetting the relation of size to matter under attraction, metaphysicians have been led into considerable confusion.

(41.) We have at present no proof that matter does possess any absolute volume, for, under different circumstances, the same number of particles exhibits very various volumes. When we consider the enormous bulk that a grain of water may be made to assume, we can hardly assert that the ultimate particles of matter have any absolute volume, for under different circumstances, the same number of particles assumes such various bulks. Many of our most distinguished philosophers, indeed, have supposed that this difference of bulk, assumed by like number of particles, depended on a separation of the finite particles of which the mass was composed; but really this hypothesis, if carefully considered, is somewhat extraordinary, for we cannot readily admit that the particles of water may be separated into steam of *many hundred times* the bulk of the fluid, and still no apparent vacuum be detected. Volume, from the above considerations, seems rather a negative than a positive quality. It is the absence, or the comparative absence, of attraction, for as the force increases, the volume diminishes. The advantages of thus viewing the nature of volume are multifold. It does not require the creation of "Repulsion" to separate particles attracted together, and it overcomes numerous difficulties which arise from the assumption of a certain size to the ultimate particles of matter. From this view, which is forced upon us from multitudinous evidence, one atom of matter, if alone, and unacted upon by any other atom, would fill the universe.

(42.) To the study of the sizes or measures of forms the name geometry has been given. To have a right knowledge of the principles to be pursued in its investigation, its relation to size and form must be fully considered; we have already mentioned that form depends upon the number of particles arranged in each direction, whilst size depends upon the intensity of attraction of that number of particles.

(43.) The same volumes of masses of different substances, in consequence of their particles being attracted together with different energy, or of their containing a different number of particles, have in each case a different weight. The particular weight of each body is called its specific weight, and the weight of one body is assumed as an unit, at a certain temperature and certain condition of external forces, as pressure, &c. To this unit the specific gravity of other bodies is referred. In the table below, the first column is the relation of the respective substances to hydrogen, in the second to distilled water. A description of the mode of obtaining specific gravities is hardly compatible with a work of this nature, though hereafter we shall be compelled to briefly notice some of the modes practised. The value of a complete table of specific gravities is extreme, for, by knowing the weight of a definitive bulk of any one substance, the weight of a corresponding bulk of any other body can be immediately learnt; it is in this manner that architects calculate with great exactness the weight of large structures and buildings, for, having the volume and specific gravity, it is easy to determine the weight of any body.

SPECIFIC GRAVITIES OR RELATIVE WEIGHTS OF EQUAL BULKS OF SOME OF THE CHEMICAL ELEMENTS.

	Hydrogen being taken as unity.	*Water being taken as unity.*
Hydrogen	1	·0,000,846
Oxygen	16	·0,013,641
Chlorine	36	.0,030,692
Potassium	10,220	·865
Sodium	11,290	·972
Water	11,820	1·
Phosphorus	20,920	1·77
Bromine	35,060	3·
Zinc	82,740	7·
Tin	87,470	7·40
Iron	91,960	7·78
Copper	105,190	8·89
Lead	134,160	11·35
Mercury	160,280	13·56
Gold	226,740	19·20
Platinum	247,990	20·98

The above is a specimen of a table of this character, but the specific gravities of nearly every substance known have been accurately determined by philosophers.

(44.) In all geometric operations, if the attraction is uniform, and the same kind of matter attracted, the size is directly as the number of particles attracted; hence, in this respect, geometry and arithmetic are so closely allied that all calculations can be worked geometrically or arithmetically, according to the disposition, convenience, or fancy of the operator. Geometry, as well as arithmetic, owes this function to the divisibility of matter into atoms, and their arrangement by number. Geometric relations can only exactly be treated in two ways, either by having the intensity of attraction fixed, and the size various, which will show the relative number of particles which any two bodies possess, or by having the number of particles fixed and the sizes various, which will show the force of attraction.

(45.) Geometric operations are performed by what are termed measures, which consist of a definite number of particles under a definite attraction, so that a comparative unit is formed, to which all other sizes are referred. The proper unit of measure would be the size occupied by two ultimate particles of matter attracted together, if there be but one kind of matter, or if there be more than one kind of matter, the ultimate particles of one of the kinds of matter. These particles should be attracted together, and have no other attractions to disturb them. Having this standard, a certain number would then form an inch, a certain number of inches a foot, &c.

(46.) But as our organs of sense cannot appreciate the ultimate particles of matter, we never can arrive at, or obtain, an absolute standard of size; on this account we are compelled to take a certain piece of matter under definite conditions of attraction as unity, and by multiplying or sub-multiplying it, we obtain all other measures proportionate to that unit. The legislature formerly thought fit to take three barley-corns from the middle of the ear, from which they formed a measure called an inch. Of course an unit derived from anything so uncertain as three barley-corns is most unsatisfactory, for every measure thus made would doubtless vary.

(47.) The greatest anxiety has been felt by all nations, to find some unit of length to which at any time posterity might be enabled to refer all future measures, but we have already seen that philosophers have been attempting an impossibility. The French have taken that quadrant of the meridian which passes through Fontenara and Greenwich, the middle of which is in the 45th degree of latitude. This measure they have divided into ten million parts, each part of which they constitute a comparative unit. In assuming this measure it is perfectly impossible exactly to obtain the greater measure to divide, and even in fact we do not know whether the earth, in a series of ages, may not slightly alter in form.

(48.) The English have assumed the length of the pendulum vibrating seconds in a particular latitude as a unit of measure, but that assumption is highly objectionable, because it infers the existence of something absolute in time, which is not the fact. It, moreover, first requires us to ascertain or determine the duration of a second, which will be as difficult for posterity as the determination of a measure of length. The length of the pendulum vibrating seconds appears to vary not only in the same latitude, but even slightly, from some unknown cause, in nearly the same spot; and, moreover, no two pendulums of as nearly the same length as human ingenuity can form them, will vibrate in exactly the same time.

(49.) The best mode of making and maintaining a new standard of measure for this country has lately occupied the attention of Government and philosophers, in consequence of the former standards having been destroyed by fire in the Houses of Parliament. Although three or four sets of these standards were then made with the utmost human skill, philosophers cannot determine that these duplicates are exactly similar to those destroyed. This forms an excellent practical proof, not only of the impossibility of possessing an absolute standard, but also the impracticability of using it if we obtained it; because, as we are unable to weigh below $\frac{1}{10,000}$ of a grain, so we are incompetent to measure below a certain amount. Probably in measuring, we can obtain rough results to the $\frac{1}{1{,}000{,}000}$ of an inch, but as the measures decrease in length, so the errors increase, as all measurements must only be regarded as rough comparative approximations to truth.

(50.) Under these circumstances, we find that our standards are purely arbitrary, and therefore the best mode that can be adopted is, to take any arbitrary length, which should be as near the inch now adopted as possible. This measure we should constitute our arbitrary unit, or inch, to which all other measures should be referred. Several copies, that is, as near as human skill and ingenuity can make copies, should then be formed, and deposited in various places of security for reference. This artificial unit, moreover, should be compared by different observers, and by different instruments, with all the most fixed things in the material world, so that if, by any accident, the primitive artificial standard was lost, posterity might be enabled to compare their measures with ours, and though doubtless they would never be able to obtain the exact relative size of our standard, yet they would be able, for all practical purposes, to have ample knowledge of our measures. All other measures would be obtained either by multiplying the inch, or expressing the relation in fractional parts of it.

(51.) Up to the present moment we have only considered the phenomena of size and form arising from a series of particles attracted together, but the varieties of forms now demand our especial attention. When a series of particles are arranged in a row, the mass so formed is called long; when a series of particles are also arranged at right angles to the first row, the mass is called broad, and the degree of length and breadth, provided the attraction is always alike, depends directly upon the number of particles. When the particles producing the breadth are at right angles to those constituting the length, and equal in number, the body is called a square; when a third series of particles are arranged at right angles to those forming the square, and equal in number to those giving the breadth or length, a cube is produced; this third set of particles may be called the depth.

(52.) The terms length, breadth, depth, square, and cube, have only reference to matter, but in ordinary language we employ them in an abstract form, that is, apart from matter, or rather apart from any particular mass of matter, inferring that any mass of matter possesses these properties. Injury has occasionally been done to the harmony and simplicity of physical science, especially in the relation of geometry to the physical sciences, from giving abstract definitions to these abstractions, and then neglecting to consider the material relations of the abstraction itself: in this way the line is spoken of as length without breadth, &c.; from which definition incautious persons might possibly be led to forget that the line primarily depends on matter. However, it is far more useful for the promotion of strict philosophical inquiry, to define length by the material action that gives rise to the phenomenon. Length is the abstract idea of a certain material effect, derived from a series of atoms arranged in the same direction or in a row. The length is proportionate, always supposing equality of attraction, to that of the number of atoms. Relative lengths, or lengths of different extent, can thus be easily referred to each other. Although confusion has arisen by making the abstract material phenomenon of length and breadth immaterial, a more injurious confusion might occur if the perfectly abstract character of these terms were neglected by philosophers. A specimen of such mistake would occur in the definition of a line as length with the least conceivable breadth, which definition would in practice actually overturn the entire science of geometry.

(53.) The measures we employ for the ordinary wants of mankind are, first, measures of length, as the yard measure; secondly, measures of surfaces, which is a measure of length in two directions; the second measure of length being at right angles to the first, and usually termed the breadth. As measures of surface we talk of roods, perches, acres, &c. The third set of measures are those of solids, as of a cubic inch of wood, marble, &c. As a variety of a cubic measure we have measures of capacity, which are empty spaces holding definite cubes; pints, quarts, bushels, &c. are of this character. All measures, however, have relation to the measure of length, hence one artificial standard, the inch, is amply sufficient for all the practical purposes of mankind.

(54.) As measures are in use for almost every purpose of the interchange of property, it is important we should once again advert to what they really shew. We have before stated that measure denotes the relative volumes of masses of particles of matter; but size is influenced by two circumstances, the number of particles attracted, and the intensity of the attractive force. Measure is capable of shewing us by proper management either of these properties separately, provided we take care to obtain uniformity of the other. Thus by measure we are enabled to learn the relative number of particles of any two bodies, and by measure we can also learn the relative intensity of the attraction which holds the particles of any two bodies of the same nature together under different circumstances. We must briefly allude to the practical troubles which arise when we are anxious to obtain either kind of knowledge.

(55.) In the transfer of property from one to another, we generally desire a knowledge of the number of particles sold. With property of great value, as sovereigns, we generally count, but with wheat and other commodities we content ourselves by measuring the quantity. In all cases of measure where we desire to learn quantity, we should be very particular to learn the degree of attraction; for instance, a pint of the vapour of spirits of wine would contain a much less number of particles than a pint of fluid spirit. Whatever interferes with attraction interferes with the number of particles in a given measure; whatever lessens attraction diminishes the number of particles in a given space; whatever increases attraction increases the number of particles in a given space.

(56.) It is, perhaps, almost premature to explain the manner in which heat diminishes attraction, for that will be amply discussed when treating of that part of our subject; but it is necessary here to call attention to the fact, that the slightest deviation in temperature is attended with deviation in the intensity of attraction. The matter of our standard inch is no longer of the same length, and therefore not an inch if the temperature varies ever so little from that point at which the standard was assumed; but let the temperature vary ever so much, the number of particles cannot be multiplied or diminished, it is only the size that varies.* In conducting the ordnance survey of England, the measures were obliged to be most carefully adjusted for temperature or variation in the thermometer. So also in

---

* A variation of $\frac{1}{100}$ of an inch in two different measures would give in the measurement of the circumference of the earth a discrepancy of 240 miles.

adjusting the standard bushel the difficulty was found to be extreme, for it was found that the heat caused by a human body coming near so large a bulk caused a sensible alteration in its exact size. Not only does temperature interfere with attraction, and consequently with the size of bodies, but other forces, such as that of atmospheric pressure, also influence them; hence a pint of gas, at the barometer 30°, would shew twice the number of particles that a pint would contain with the barometer 15°.

(57.) Instances in which we desire to know the force of attraction by the size of bodies are to be found in the construction of thermometers, for there a definite quantity of matter, under different circumstances, exhibits apparently very different numbers of particles of matter, though in reality a different aggregate bulk of the same number. The construction of thermometers will be more fully considered when we treat of heat.

(58.) Although man, unfortunately, is incapable of obtaining absolute standards of attraction or volume, the arbitrary or artificial method is susceptible of such accuracy that he can map the globe with tolerable precision; he can ascertain the distance of celestial bodies from each other, and their relative size to this great globe, or any definite object amongst those of which it is composed. By the application of this knowledge he can circumnavigate the earth with certainty and precision;

and when in unknown seas or untrodden lands he can ascertain his relative position on the earth's surface, and the distance from his native country, provided he had added to his natural resources the mean time in his own climate. In fact, although he cannot obtain that absolute standard of measurement which philosophy teaches does exist, and might be procured, he can obtain a relative measurement sufficient for his preservation, and more than amply sufficient for performing all the operations that his organs are capable of performing. The adaptation of the power of acquiring knowledge to our means of carrying it out, naturally fills our mind with wonder and gratitude; but to shew its bearing in all its various forms, would require more time and more space than can be afforded in this volume, though the subject would form a good thesis for another Bridgewater Treatise.

(59.) When several atoms are attracted together, the mode in which they are conjoined in some cases gives rise to angles, the study of which abstractedly, or apart from the matter, falls within the province of trigonometry. If the force holding together attracted particles lies in one and the same direction, an effect is produced to which the abstract term of length is attached; if the force of the attraction of a second part lies uniformly in a direction different from that of the first, the effect arising from the conjunction of the two series of particles is called abstractedly an angle; and if the second row is perpendicular to the first, the angle is said to be a right angle. In fact, an angle may be defined to be an abstract idea of attracted matter, when the forces holding together the attracted particles form two series, and the direction of those of one series differs from that of the other; hence, if a number of particles are arranged in a row, or in the same direction, the abstract idea of a line arises, if the direction of a part is changed, the idea of an angle occurs.

(60.) If the direction of one part of the particles partakes in any degree of the reverse of the direction of that of the other set of attracted particles, an acute angle is produced; if, on the contrary, it partakes in any manner of the direction of the first particles, an obtuse angle is generated. If, however, the direction varies, but is neither reversed nor continued, a right angle is formed. There are only three kinds of angles—acute, obtuse, and right angles. The extent of deviation of these angles from the original direction is expressed by degrees, of which a right angle is assumed as 90; acute angles are said to be smaller than right angles, hence the size is referred to the units of which the 90 are composed; obtuse angles, on the contrary, are larger, hence they are expressed in units added to 90. This mode of expressing the relation of one angle to another is not strictly perfect in itself, because it requires the intervention of an arc of a circle, of which the vertex is the centre, extending between the two lines, and it is this arc which is divided. The proper material mode of expressing angles, however, is so intimately related to the attraction of the ultimate particles of matter, that we must despair of ever being able to obtain an absolutely perfect mode of expression.

(61.) It would not be consistent with the character of this work to consider more fully the properties of angles, and of those figures called by geometricians triangles. It is sufficient for us to know that angles are dependent upon matter, and have relation to matter; in fact, they are material effects appertaining to the mode in which material particles are attracted; but the terms are abstract, that is, used apart from any particular mass of matter giving these effects.

(62.) To constitute an angle the change of direction in a series of particles only takes place at one point; but there are cases where a slight change in direction takes place at the conjunction of each particle. When this is the case a curve is produced, and if the deviation is equal at the conjunction of every particle the arc of an uniform curve is formed. In some cases the deviation is not equal, and then a series of complicated curves occur.

(63.) We have thus seen, that the arrangement of a single series of particles may be either all in one direction, when the row is said to be in a line, or straight, or there may be an occasional deflection, when angles are said to result; or, lastly, a deflection may arise at the conjunction of every particle, when a curve is produced. The vertex of an angle, or that part where change of direction occurs, is called the angular point. It will be perceived that rows, lines, lengths, breadths, squares, cubes, angles, curves, circles, points, &c. have their origin in certain methods, by which the ultimate particles of matter may be under attraction. Without matter and attraction we could not have had these forms, and therefore those sciences which have for their object the study of those figures, may be reckoned physical sciences. The properties of these several abstract conditions of matter are similar to the properties of number. The properties, for instance, of an angle of the same value is the same wherever situated. These properties have been so fully studied, and are now so extensively known, that they are turned to good account for the purposes of mankind. The three angles of a triangle together, for instance, always are equal to two right angles, or 180°, no matter what the size or the exact shape of the triangle is. These properties do not fall within the province of this work, for it is our business first to show how matter gives rise to each respective science, and then what relation the several sciences have to each other.

(64.) When a number of particles of matter of the same nature are attracted into a mass, and no uniform or definite direction exists in the attractive forces, the body is said to be in a state of cohesion.

Bodies in a state of cohesion resist the action of other bodies presented to them to an extent proportionate to that cohesion. Lead, in an extremely divided state, burns vividly upon simple exposure to atmospheric air, whilst the same metal in a state of cohesion, or in a rolled malleable state, undergoes but little change from long exposure. Spongy platinum, and other metals in a finely divided state, also have very different properties from the same metals in a state of cohesion. There is no more curious instance of the effects of cohesion than in the varieties of coke, for when tinder the slightest spark will inflame it, when soft coke it readily burns, when hard coke it can scarcely be made to ignite, but when a diamond it requires a skilful chemist to inflame. The fine particles of lead, platinum, and carbon, just mentioned, must be under attraction, and cannot be the ultimate particles of matter, otherwise their size would be much larger than it really is. These small particles, perhaps, only differ from larger masses by their consisting of but few primitive atoms attracted together, not that they are absolutely without attraction, or that the attraction which is exerted is of a less intensity than when the same particles are all drawn into a state of cohesion.

(65.) Bodies under cohesion exhibit, under different conditions, three varieties, the solid, fluid, and gaseous states. In each state, even in the gaseous, cohesion exists, for with gases the particles are attracted together. These states may generally be said to differ from the particles of solids, being more intensely attracted than those of fluids, and those of fluids more intensely than those of gases. Hereafter we shall see that there is actually more attraction in solids than in fluids, and fluids than in gases, though in some cases this increase of attraction is not attended with corresponding diminution of volume, and in some cases even with increase of size. The temperature generally may be said to determine these states, which possibly may be owing, in part, to the matter being under the peculiar action called heat, though such an assumption cannot in the least detract from the absolute certainty of there being more attraction in one state than the others. Hereafter we shall find when a gaseous body becomes fluid, or a fluid solid, new attractions are set up, which new attractions will produce all the phenomena of new attractions generally. In like manner it may be stated conversely, that a solid cannot become fluid, or a fluid gaseous, without some force acting which has the power of overcoming attraction.

(66.) In some cases particles of bodies are attracted into little masses, and these little masses are attracted together into greater masses, which effect is called aggregation, which is generally distinguished from cohesion from the force not being equal throughout the mass, so that it more readily breaks in one direction than in others.

(67.) When bodies are in a state of cohesion they have peculiar properties, owing to the attraction which gives rise to that cohesion, thus bodies are hard, soft, brittle, elastic, flexible, ductile, malleable, &c.

(68.) Hardness and softness are two abstract terms, used to designate different degrees of the same condition. Hardness being the positive condition, and softness the absence or lesser degree of that positive property. Hardness arises from an intensity of attraction holding the particles so firmly together that the attraction cannot readily be disturbed or destroyed. The diamond is the hardest body known, it will scratch or destroy the attraction of all other bodies in a coherent state, and can only be used to scratch another diamond.

(69.) Brittleness is an abstract term given to a property of a body in cohesion, which may appertain equally to bodies of all degrees of hardness. Brittle bodies are often aggregated, or made up of other lesser bodies, which do not adhere to each other so firmly as the particles making up the little bodies themselves. Upon that account, when the attractions of the mass are disturbed, the attraction gives way at the junction of these lesser bodies. A lump of sugar is an example of an aggregated body, and at the same time a brittle one. Zinc is a brittle metal under ordinary circumstances, from being of a crystalline texture throughout. Some bodies, however, are brittle without being obviously crystalline, as glass, although even that body is occasionally crystalline.

(70.) Elasticity is the abstract idea of a property of bodies in cohesion, which causes them to reassume, after a disturbance of the attractions, the same attraction which they held before the disturbance, so that the body after a disturbance retains the same form as it possessed previously. Glass is the most elastic of all substances, for after its attractions are disturbed there is so great a tendency to resume them, that the body recovers its former position and shape.

(71.) When the particles of a coherent body suffer change of position upon themselves from slight causes, the body is said to be possessed of mobility. This property exists most pre-eminently in aëriform bodies, less so in liquids, and least so in solid bodies. Mobility is a property of every body, even the hardest solid. Hereafter we shall have to point out instances in which the particles of solid brass have the arrangement of their particles altered by light. Varieties of mobility, or rather instances of mobility of solids, occur in the properties called flexibility, ductility and malleability, which we shall immediately describe.

(72.) Flexibility is a very simple instance of mobility, for when the arrangement of the particles of a solid body are altered from a straight line to a curved one, or to an angle, the arrangement of the particles is altered, and an instance of mobility occurs if the particles retain their new position, for then the relative position of the atoms would have been altered.

(73.) When the particles of a solid body admit of a certain motion upon themselves, whereby the breadth is overcome and the length increased, it is said to be ductile. The extent of the movement, or mobility of the particles, may in some degree be understood, when we mention that a piece of platinum $\frac{1}{8}$ of an inch in width may be drawn till it is so narrow that it is little more than $\frac{1}{200}$ of an inch in diameter. As the length is increased one particle for every particle of the breadth that is decreased, some of the original particles must have been moved from their original position very many yards, in this and other analogous instances.

(74.) When a cubic body can by the application of forces lose its cuboid form, and allow the particles which give it height to be moved in such a way that they increase the length and breadth, the body is said to be malleable, the name being given from the instrument with which the force is directly applied. Malleability infers great mobility, for one grain of gold may be extended to an enormous surface by hammering, that is, the particles constituting the height or depth of the mass may be so moved as to increase its length and breadth.

(75.) The direction of the forces in bodies under cohesion appear not to be arranged in any definite manner, but some forces are in one direction, and some in another; or at any rate, throughout the mass the forces are variously arranged. This miscellaneous arrangement only takes place when the particles very suddenly cohere, but if left to themselves, to cohere gradually, the phenomena of attraction are manifested in a very different manner.

(76.) When a mass gradually coheres into a solid form, the natural tendency of the attractive force is to be exerted in a certain definite manner, and therefore to give rise to a mass of particular and definite form. These definite forms are called crystals, and as their particles are attracted unequally in different directions, their force of cohesion is most easily destroyed in certain positions, which position is termed the cleavage. Heat, from the same cause, makes them expand unequally. The direction of the attraction of the particles causes them to have peculiar properties with relation to light which will hereafter demand attention.

(77.) Crystals invariably appear to be made up of other smaller crystals. The innumerable varieties of carbonate of lime will all split into primitive rhombohedrons. Alum will in the same way break into octohedrons. Crystalline bodies give way with the greatest facility at the lines of junction of the smaller bodies of which they are built up; thus water, by partially dissolving them, will leave those primitive figures. There are a great variety of primitive forms of crystals, which are well described in the various elementary works on chemistry, or more particularly in Brooke's admirable treatise on the subject. In the proper place we shall have to point out the influence of crystallization in producing heat and light, and the influence of heat and light upon crystallization.

(78.) With regard to the properties of particles of matter when held together by the attraction of cohesion, they may be interfered with by forces which in any way disturb attraction. Hence percussion, which will destroy or tend to destroy attraction, will, by destroying old attractions, allow the particles to assume others, and convert a brittle body into a flexible one. Cast-iron, by being well hammered, becomes converted into wrought iron. Rolling, which is analogous to percussion, as being an application of force, will have a similar action on bodies whose particles are in a state of cohesion. Zinc, naturally crystalline, by being rolled may be made both flexible and elastic. Tin in the same way may be similarly altered. A body having its particles in an uniform or miscellaneous condition of attraction, may be made to assume a crystalline texture. A terrific accident occurred on the Paris and Versailles railroad some time ago, by the fracture of the axle of a railway carriage, which was said to be owing to the axle having assumed a crystalline arrangement from the motion of the vehicle. Heat, which (as we shall hereafter shew) disturbs attraction, will make a brittle body flexible, a hard body soft, &c., or again, heat may have the converse effects. Light, in the same way (as we shall hereafter have to notice), will interfere with these properties of cohesion.

(79.) The properties which we have heretofore described of the attraction of the particles of matter only relate to particles of matter of the same nature; but we have now to consider the attraction of particles of dissimilar nature, that is, particles of different chemical or proximate elements. Now, whether these bodies are ultimate or proximate elements, their own particles exert a definite attraction between themselves and the whole body of the earth, which definite attraction is called the equivalent weight. The following table contains the relative weight of some of the ultimate particles of the most important elements as compared with the lightest element, hydrogen.

Hydrogen	1
Carbon	6
Oxygen	8
Silicon	8
Boron	11
Magnesium	12
Nitrogen	14
Phosphorus	16
Sulphur	16
Glucinum	18
Calcium	20
Zirconium	22
Sodium	24
Aluminum	26
Iron	28
Nickel	28
Manganese	28
Cobalt	30
Copper	32
Zinc	32
Chlorine	36
Arsenic	38
Potassium	40
Selenium	40
Strontium	44
Molybdenum	48
Rhodium	52
Palladium	54
Cadmium	56
Tin	58
Thorinum	60
Antimony	65
Vanadium	68
Barium	69
Bismuth	72
Bromine	78
Iridium	96
Platinum	99
Osmium	100
Lead	104
Silver	108
Iodine	126
Columbium	185
Gold	200
Uranium	217

(80.) The union of two elements can only take place by whole particles, or units; therefore, to form any combination between masses of different matter, the quantity of one body to another must be in the proportion that their respective equivalents bear to each other. The attraction of dissimilar elements is called chemical affinity, and the particles so attracted are said to be in chemical combination. Chemical combination is only said to be exerted when two different elements unite together by the proportionals given in the preceding table; thus the relative proportion of the compound of potassium and oxygen is as 40 to 8, the relative equivalents of one body to the other. Sometimes the equivalents are referred to oxygen, which is called the oxygen scale; but the proportion is not so conveniently expressed in that manner. As the equivalent numbers are the combining proportionals, the equivalent of any other body besides hydrogen and oxygen might be employed as a conventional unit, to which all the other bodies might be referred. It is a curious subject for a speculative mind to contemplate the possibility of the properties of all the various elements to be due to different quantities of one kind of matter, which different quantity is expressed by the equivalent number.

(81.) When two atoms, each of a different element, are united together, they give rise to a compound which has neither the functions of either body separately, or any intermediate function between them. The equivalent, or combining number of the compound, is the sum of all the equivalents of the particles in combination; therefore, that of potash, a compound arising from the union of potassium and oxygen, is 48. Potash has neither the properties of potassium or oxygen, or any intermediate properties between them.

(82.) The particles of the fifty-four undecompounded bodies, when united together in the definite proportion already pointed out, have properties varying from such combination. The combinations themselves may be called proximate elements, which we may divide into two classes, neutral and excited. Neutral elements have properties analogous to ultimate elements, uniting with them, and being only distinguishable from them by being formed and decompounded. Cyanogen, sulphocyanogen, &c., are of this class. Excited elements have different properties from neutral elementary bodies, properties attributable to their excitement, properties which we shall presently fully describe.

(83.) When two particles of dissimilar elements are placed in apposition, they set up a peculiar attraction, varying in intensity with each pair of elements. The direction of this force is always with the same pair of elements, exerted in the same manner; thus, If we call the two ends of the direction N, P, the kind of action set up would be similar to that described when treating of attractive directions, and the relation of this direction is always the same with the same elements.

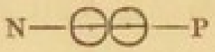
(84.) Upon this fact the particles of different elements may be conveniently arranged into two classes, *inducers* and *inducees ;* that is, bodies capable of exerting the influence of attraction, and bodies capable of receiving the influence. The direction of the force seems to infer this active and passive property in the finite particles; but there is no strict line of demarcation between these two kinds of bodies, for, indeed, the same body may be alternately an inducer and an inducee when placed in relation to particles of different elements, though always the same in this respect when uniting with the same elements.

(85.) As an example of an inducer, hydrogen is the king;—of an inducee, oxygen holds the same rank. Inducers are eminently combustible; inducees supporters of combustion. Inducers are eminently refractive; inducees are distinguished for the absence of that property. Particles of inducers cannot cohere or combine with much strength, because, although there is great capability of exerting power, there is but little power of receiving it. Hence the particles of hydrogen, although a most powerful inducer, cohere so feebly that they are only known in the gaseous form, on account of a want of capability of receiving the attraction. Inducees, for a converse reason, cannot cohere or combine together with firmness, because, although each particle may be pre-eminently in a condition to receive force, there is no desire or power for its exertion; oxygen, on this account, is always seen in a gaseous form. Put, however, oxygen and hydrogen into a condition to exert attraction, that is, prevent other forces from hindering their union, and the inducer will act on the inducee, and combination will take place with tremendous violence.

The following is a short list of inducers and inducees, in which every chemical element is an inducer to those below it, and an inducee to those above it, or at any rate these bodies would be in somewhat similar order. It is a very rough table, but will help to illustrate the mode in which we may assume that some bodies generate a force, and others receive it.

(86.) INDUCERS.
Hydrogen.
Potassium.
Phosphorus.
Sulphur.
Carbon.
Zinc.
Iron.
Tin.
Lead.
Copper.
Mercury.
Silver.
Gold.
Platinum.
Iodine.
Bromine.
Chlorine.
Oxygen.
INDUCEES.

(87.) Particles of different nature, coming in contact, may set up attraction in different ways; thus, if two particles combine together, the force must be generated directly through the length formed by their union, which gives peculiar properties to the compound so formed. In the adjoining diagram we perceive that the two extremities of such a compound would each exhibit the ends of the force, one end (N) being of an opposite character to the other (P).



A compound such as that under consideration may be termed an excited element, of which nature are the compounds of the metals with chlorine, oxygen, &c. Excited elements may be known by their only entering into other combinations with other excited elements, as oxydes with the acids, oxydes with the alkalies, acids with the alkalies, &c. The reason why the term excited is given to these proximate elements is, upon the supposition that the direction of the force is manifested upon the surface of the compound. Thus, at one end the atom of the compound is negative, at the other positive. When excited elements unite a certain increase takes place in the attraction; thus, when nitric acid and potash unite, the resulting nitrate of potash is found to be a compound, in which the nitric acid is far more difficult to be decomposed than when the same acid is acted upon alone.

(88.) It is, however, possible that three, four, or more particles of different chemical elements may mutually attract each other in such a way that no direction of the force should be manifested externally, but the direction of all the ends of the forces may be situated between the primitive units or atoms. In this case the compound so formed may be termed a neutral element, which will act precisely as undecompounded substances, uniting with them freely, but not with excited elements; thus cyanogen will unite with zinc with energy, but not with its oxyde, in consequence of cyanogen being a neutral element. The probable attraction of the particles of a neutral element the following diagram will sufficiently explain.

In the diagram we perceive that the ends of the several forces are situated within the compound so formed, and alternate with each other, so that no external force is manifested at any particular point of the surface of the compound. It is by no means essential, however, that the combination resulting from many elements should be neutral, for in the example of ammonia, a triple compound, it is excited, and the acids, moreover, are multifold compounds and excited elements.

(89.) Chemical affinity is the idea of the exertion of attraction between particles of different bodies, the element which sets up the attraction being called the inducer, the element which receives the impression, the inducee. The term itself is perfectly abstract, that is, has no relation to any particular particles setting up this action. It is the idea of the attraction exerted between what we call dissimilar kinds of matter, because we have not formed or decomposed them. Chemical affinity is not due to any specific principle attached to matter, but is the idea of the attraction of dissimilar elements considered without reference to any particular particles occasioning this action. The obstacles which daily experience shows to be afforded to the exertion of chemical affinity between masses of dissimilar nature are, attractions previously existing between the particles of each mass, or each element, separately. In many cases, the moment the attraction of cohesion of the mass is destroyed, combination, or chemical attraction, will ensue. The influence of cohesion may even be seen in bodies in the aeriform state; for even there, in many cases, the attraction between the particles is quite sufficient to prevent combination till destroyed by a ray of light, or a slight elevation of temperature, when the new attraction will be set up with explosive violence. We have already had occasion to mention, that a ray of light will even interfere with the bodies under crystallization or cohesion, and therefore we cannot be much surprised that it acts in a similar manner on the more feeble attractions of gaseous bodies.

(90.) The attraction of the chemical affinity of one particle to another may be an obstacle to their combining with a third. Gunpowder is an admirable example of this prevention of new attraction by the exertion of others, for as long as the attraction of oxygen for nitrogen in the nitrate of potash, is not interfered with, it may be housed up, transported all over the world, and kept ready for use at any moment. If, however, we destroy or lessen the attractions of oxygen for nitrogen in the nitrate of potash, instantly new attractions are set up by the carbon and sulphur of the mixture with the oxygen of the nitrate of potash, and explosion is the immediate result. In the formation of an explosive powder suitable for the wants of mankind, it is requisite to select with great care a compound that shall resist, with certain force, the new chemical affinity, so that explosion may take place with any desired facility. The experienced pyrotechnist can regulate the facility of explosion with great precision. The common congreve matches form admirable examples of the tendency to the exertion of chemical affinity being balanced by the attraction of cohesion. Its composition only differs essentially from gunpowder by being so regulated that the new power of attraction is barely balanced by the former attractions of those matters of which the composition is made up, from which cause a very slight interference of the attractions will cause explosion.

(91.) The influence of former attractions, *i. e.* the attraction of cohesion on the exertion of the attraction between two bodies, is well seen, and is very curiously exerted in certain cases called heterogeneous adhesion, capillary attraction, and mixture. In these cases there is ample evidence to shew, that an active attraction is exerted between the two kinds of bodies; but the exertion of this attraction is modified by the previous attractions existing between them. From an active attraction being exerted in these cases, all the effects of new attractions may be produced by the power generated when the phenomenon is evinced.

(92.) The first instance of the attraction of masses of matter, held together by attractions, when placed in juxtaposition, is seen when two pieces of clean sheet lead are pressed together, when they cohere. Two pieces of perfectly clean plate glass placed together cohere, frequently so firmly that no force will separate them. Occasionally great losses have occurred at the glass-houses from this cause. Other cases of attraction of masses are seen in the welding of iron, of the adhesion of platinum to glass, &c.

(93.) Capillary action, with its analogues, is the active attraction existing between the particles of a fluid under attraction and the particles of a solid. This force is only exerted between the particles of the fluid actually in contact with the particles of the solid, and consequently the thickness or bulk of the solid or fluid does not influence the result.* This force of attraction is not exerted to an equal extent between all solids and fluids; thus glass and mercury, in many cases, instead of attracting, appear even to repel each other. Doubtless, however, this effect is owing to the prior attraction of the mercury, for sometimes in old thermometers and barometers the mercury is observed to be adherent to the glass, and in the usual process for silvering glasses, mercury is used as the medium for causing the tinfoil to adhere. The active nature of capillary action is occasionally taken advantage of for the production of force, dry pieces of wood driven into rocks will attract water by this property, and rend rocks asunder by virtue of the great force thus generated.

(94.) The phenomena of mixture is, perhaps, similar to adhesion and capillary action. Some very curious results have lately been developed by our great electrical philosopher, Faraday; for in conducting experiments upon the electricity of steam, he discovered that the presence of foreign bodies, such as oil of turpentine, gave to water peculiar effects, which led him to apprehend that

---

* In fact, the attraction between the particles constituting the thickness of the tube and the fluid would be at sensible distances, it would be, consequently, that of gravitation (95). The force of gravitation of so small a bulk, when compared with that of the whole mass of the earth, is so small as to be totally incognizable to our senses.

the primitive particles of water were coated by the oil of turpentine, or other fluid. The phenomenon of mixture from such considerations would be a sort of heterogeneous adhesion of the ultimate particles of two dissimilar bodies. Thus, instead of two masses of dissimilar bodies adhering together, the ultimate particles would adhere. In all these cases a new attraction is generated; but there is a variety of mixture called endosmosis, which especially demands attention, for the mixture of two substances takes place through an intervening body, whose particles are more or less forcibly attracted together. Thus, if two gases are separated by a piece of bladder, or India-rubber, they become mixed together, and even sometimes the same effect appears to take place through the substance of the closest solids. Iron, for instance, will occasionally blister, and in the cavity oxygen is found, which must have permeated the texture of the metal. The intimate nature of the action of endosmosis has been a source of great interest to the natural philosopher; but, perhaps, it may be explained by assuming that the particle of the solid body nearest one gas sets up an attraction with it, the gas so attracted then passes successively to each particle of the solid, and finally enters into an attraction with the gas on the opposite side of the body separating the two gases. Fluids will also pass through solid bodies, probably in a similar manner.

(95.) When masses of matter attract each other at sensible distances, the power of attraction is called that of gravitation. The distance at which this attraction is exerted is vast, when we consider its effects on the planetary bodies; but great, however, as the distance at which the attraction may be exerted, still the distance diminishes the force immensely from the distance at which it is exerted. The general effect of gravitation is, to assign to matter held together in various forms and conditions, by virtue of the attractions called crystallization, cohesion, &c. a certain relative position to other bodies. By gravitation the world retains its form, and everything on it a certain situation, which it keeps in relation to the rest of the earth. The attraction of gravitation tends to keep in its relative position the sun and other planets of our solar system; and by gravitation our system is retained in a certain relative position with other systems.

(96.) The force of attraction, when exerted between distant objects, diminishes in the inverse ratio of the square of the distance, that is, as the distance increases the force lessens by the square of the increase; two bodies exerting a force of 1 at 1 inch would only exert $\frac{1}{4}$ at 2 inches, or $\frac{1}{9}$ at 3 inches, &c. As attraction is the sole force or action of matter, this law is one of fundamental importance in all physical experiments. The cause of this law is extremely easy to be understood; for, when the force is exerted at twice the distance, it is distributed over the square of twice the extent, or, in other words, of four times the space, and in a similar manner for all other distances. Therefore, at any one spot the amount of the force is divided by the increase.

(97.) We have already had occasion to mention, that in all attractions a sort of direction exists; but we have not yet called attention to this property when exerted through an extensive series of particles. This uniformity of the direction of forces holding together a series of particles is called Polarity. Polarity, therefore, is a term which should be confined to the arrangement of the ultimate forces in a row or series, all the forces being in the same direction. A permanent magnet is the best instance of a polar body, the direction of the attractions being arranged longitudinally.

(98.) I have this moment mentioned that a magnet is a good example of a polar solid, and magnetism should literally refer to, or be the abstract idea of, a polar solid. This polarity is principally seen in iron, a metal which most readily takes on that state. When one piece of iron is polar it readily confers that property on other iron. The powerful attractive force exerted by iron when polar, perhaps is in great part owing to its particles exerting a powerful attractive force, and also at the same time being capable of receiving a powerful force; hence iron will weld, a property not appertaining to other metals.* Different varieties of iron take a polarity with very various facilities. Soft pure iron most readily assumes that state. Cast iron, or that alloy of carbon and iron known as steel, on the contrary, takes on the polar state with difficulty. However, the power of maintaining polarity in different species of iron is inversely as the power of assuming it: hence steel, when polar, retains its polarity, whilst soft iron loses it directly. Soft iron, therefore, is used for temporary, hard iron for permanent, magnets.

(99.) Polarity, or magnetism, in a solid, wherein an uniform direction of the attractions exists, may be produced by any new attractions acting in a particular manner; hence the attraction of gravitation may cause it. A bar of iron held upright gradually assumes the magnetic state. Percussion along the long axis of a bar will cause it. The gardener's spade is almost invariably magnetic from the same cause. The attraction producing the phenomena of electricity of tension, may cause magnetism. A flash of lightning will produce it. Animal electricity will cause it; but the best mode of producing it is, the disturbance of attraction produced by the voltaic battery, or, to speak col-

---

* Platinum is stated to be capable of welding; but Mr. Cock, one of the largest manufacturers of platinum in this country, and who is acknowledged to have the most extensive practical knowledge of its properties of any person now living, states, that he has tried the experiment of welding platinum many times, with the greatest care, without any effect.

loquially, the action of the voltaic force tangentially on the bar of iron, which compels its attractions to assume a polar state.

(100.) There are no more obscure phenomena in nature than many of the effects called magnetic; but, at the present time, we have only to consider the polarity which that term infers, and the peculiar effect which that polarity has upon attraction. From the above considerations we are amply in a condition to assert that magnetism, as a principle, is one of the fanciful creations of an exuberant imagination; that the attraction of magnetism is the ordinary attraction existing between the particles of a mass of matter, but arranged polar, that is, with all the forces having the same direction. All the phenomena described under the general head of physics interfere with the attraction of magnetism. In ordinary terrestrial phenomena we perceive that gravitation, the motion of the earth, the aurora borealis, the period of the day, the position of the earth, influence its results. The earth itself, as, indeed, the older philosophers imagined, appears to possess, in some degree, polarity. We have two magnetic poles — a north pole and a south pole; all the phenomena of which would be amply accounted for by the assumption of a slight polarity existing between these two points. That the polarity is very feeble, the structure of the crust of the earth amply proves; but that it is polar, the effects of the action of the magnetic needle seem fully to show. Indeed, when we consider the peculiar motion of the earth on its own axis, and its revolution round the sun, it is difficult to conceive how such a long-continued and uniform force could be exerted without more or less polarity, and therefore we can be but little astonished when we find that it is probably feebly magnetic.

(101.) The mode in which all these actions produce magnetic properties appears to be, that they cause the variety of attractions of the particles of the solid, that is, attractions existing in all manner of ways, to take one uniform, and definite direction. When a body is magnetic and its attractions are disturbed, it may lose its magnetic or polar condition. Hence, percussion may destroy a magnet; lightning may destroy it; the voltaic force may be made to destroy it; heat may destroy it; and, lastly, one magnet may destroy another; because in these cases the attractions which were before polar become undefined as to any certain direction. Solids do not alone become polar, for fluids take a similar condition in certain cases, as when between the poles of a voltaic battery.

(102.) We have now considered the various conditions assumed by particles of matter under attraction, and we perceive that all may be referred to a number of particles under a different intensity, or different arrangements of attraction. Under these circumstances, one ultimate element by a number of its finite particles would produce all the effects which we have now described. In this chapter we have seen that geometry and trigonometry, having for their object the studies of weight, size, and form, and the properties of bodies showing these effects, arise from particles of matter of various number arranged together under different intensities of attraction, and in different directions. We have studied the effects of cohesion, aggregation, and crystallization, arising from the same cause; and the possibility of the so called chemical elements being compounds has been forced upon us. The attraction of chemical elements, or the formation of compounds, has also occupied our attention. The modifications of the attraction of two bodies when their particles are held together by previous attractions, as in capillary attraction and heterogeneous adhesion, has been described. The polarity of attraction called magnetism, and the attraction of masses of bodies to each other, have now also been noticed. All the effects described in this chapter are those in which matter evidences its active nature by attraction. In our next chapter we shall proceed to discuss the power of one attraction to overcome another, and the phenomena to which such destruction gives rise.

CHAPTER III.

ON THE SCIENCES OF THE DISTURBANCE OF ATTRACTION.

ELECTRICITY.—MECHANICS.—HYDROSTATICS.—PNEUMATICS.

Disturbance of Attractions (103–106). — Voltaic Disturbance (105). —Voltaic Battery (106).—Electrolyte (107).—Action (108–113).—Voltaic Phenomena (114).—Positive Pole sole cause of (115).—Obstacles to Voltaic Phenomena (116, 117.) Means of lessening the Attractions of Electrolyte (118). — Obstacles of Cohesion (119).—Obstacles of new Compounds (120).—Intensity (121–126).—Quantity (127). — Power of a Battery (128).—Electro-motive Force? Contact Theory (129, 130). — Polarity of Circuit (131).— Decomposition of Fluids (132, 133).—Solution of Positive Pole (134, 135).—Voltaic Circuit without new attraction in the Fluid (136).—Tension (138–140).—Electrical Machine (141–147).—Electrical Power (148). —Induction (149, 150).—Communication of Electrical Force (151, 152).—Electrical Battery (153).—Lightning (154–160). —Thermo-Electricity (161–163).—Magneto-Electricity (164, 165).—Secondary Coil Machine (166).—Steam Electricity (167). —Discharge of Tension (169–172).—Injury from Discharge (173).—Lightning Discharge (174). — Lightning Conductors &c. (175–177).—Electric Tension, Electric Discharge (178). —Motive Force (179–185).—Motion from direct Attraction (186).—Repulsion a phenomenon of Attraction (187).—Levity a phenomenon of Gravity (188). — Economic production of Force (189–192).—Weight and Distance (193–195).—Inertia (196).—Motion, its mode of production (196, 197).—Action and Reaction (199).—Conditions of Motion (200, 201).—Action of

Force on other Attractions (202).—Accumulation of Force (203–205).—Effects of Force on Bodies in Motion (206–208).—Motion produces Force (209).—Machines (210, 211).—Generation of Force (212).—Accumulation of Force in (213).—(Regulation of Force in (214).—Application of Force in (215).—Direction of Motion (216).—Regulation of Weight and Distance (217).—Levers (218).—Wheels (219).—Screws (220).—Inclined Planes (221).—Brahmah's Press (222)—Hydrodynamics (223).—Generation of Force (224).—Force imparted to Fluids (225).—Equal diffusion of Force in Liquids (226).—Specific Gravity ascertained by the destruction of Force on entering a Fluid (227–229).—Singular cases of Force in Liquids (230).—Hydrostatic Paradox (231).—Powders similar to Fluids (232).—Water Power (233, 234).—Overshot and other Water-wheels (235).—Hydrostatics compared with Mechanics (236).—Pneumatics (237).—Generation of Force (238, 239).—Barometer (240).—Application of Pneumatic Force (241).—Mint (242).—Accumulation of Force in Gases (243).—Effects of Pneumatic Force (244).—Friction (245).—Solids, Fluids, Gases (246, 247).—Resumé (248).

(103.) We have now seen the manner in which matter evidences its active nature, by setting up attraction between its particles. We have shewn the mode in which attraction gives quality by chemical affinity; quantity, by the union of many atoms; form, by the mode in which the particles are united; size, by the intensity of the attractive force; and, lastly, position of masses by gravitation. If these attractions, when once established, could not be suspended or destroyed, we could have no alteration of the form, position, or size, of any body; but, in consequence of the force of attraction being exerted in a particular direction, a second attraction, acting in the opposite direction to the first, may suspend the operation of the first, neutralize, or destroy it.

(104.) As the setting up of a new attraction is essential to the suspension of a former attraction, this act must be manifested when any power, motion, or analysis is evidenced. It will be our business now to consider the different modes or instances of the generation of this new attraction to overcome old ones, either for the generation of force to overcome gravitation, or for the production of electrical and galvanic forces to overcome cohesion or chemical affinity. Before, however, we enter into this inquiry, we must again take notice that attractions are not at all times equally strong, for were all attractions equally intense, the ordinary phenomena of nature could not manifest themselves, and we could not carry on the ordinary business of life; if, for instance, all attractions were as slight as those holding together the particles of chloride of nitrogen, explosions would take place continually from the slightest causes. Again, if the particles of our bodies were not held together by a more intense attraction than that of the particles of the ammoniuret of silver, we should fly to pieces with a slight blow; and, conversely, if the attraction of the particles of our bodies were as strong as those of the diamond, and we were attracted to the earth by a similarly intense force, we could neither move, be moved, or, in fact, breathe or live a single instant.

(105.) In seeking out the new attraction set up in each individual case, where either a change of physical state, either from solid to fluid or from fluid to aeriform, occurs, or where decomposition and disintegration is effected, or where some change in the relative situation of bodies takes place, we shall first commence with the effect of a new attraction acting on a binary compound, whereby a new combination is effected between one body and element of the compound and the second element is set free. The circle of atoms included in this action is called the voltaic circuit, and the entire apparatus in which it is performed the voltaic battery.

(106.) The voltaic battery, being an apparatus in which the attraction of a previously existing chemical affinity is destroyed by a new attraction, set up between one of its elements and a new body to which the compound is exposed, requires of necessity some compound to be decomposed. This compound, or body, the attractions of which are to be disturbed, has been called by our illustrious Faraday the Electrolyte. He has shewn that it is desirable, in most instances, that each primitive atom of this electrolyte should consist of two atoms only; thus water, which is a compound of one atom of hydrogen and one of oxygen, is admirably adapted for this purpose. However, it is not impossible but that compounds of three, four, or more elements are only disadvantageous for the fundamental composition of the voltaic battery from their offering a great resistance to the current. We daily perceive nitric acid or metallic salts decomposed by hydrogen. It is highly desirable, if not absolutely essential, that this compound should be in the fluid state, for it is found that solids, perhaps from the strong cohesion of their particles and gaseous bodies, perhaps from their slight cohesion, are not suitable for electrolytes.

(107.) The electrolyte, then, is the foundation of the battery, and should consist of a fluid made up of two elements. This is the body, the attractions of which have to be destroyed. For the purpose of destroying them we require some other body, but it does not matter whether it is solid, fluid, or gaseous, provided it is capable of setting up a powerful attraction between itself and one element of the electrolyte. This body we call the positive element of the pile or battery, and if it is in a mass, the immediate point at which it comes in contact with the fluid is called the positive pole.

(108.) If we take an atom of water for an electrolyte, and an atom of zinc for a positive element, we perceive that the zinc, by its force of attraction, seizes the oxygen from the water and liberates the hydrogen. This action is invariably taking place in the voltaic battery, for this forms one instance of an universal law, namely, that the positive element of a voltaic battery bears the same relation to the particle it takes from the compound as the element liberated does to the particle seized.

(109.) To illustrate my meaning more fully, water is a compound of hydrogen and oxygen, and we assume that hydrogen is an inducer to oxygen, the inducee; but our positive element zinc, would also be also an inducer to oxygen; it, therefore, follows, that if a particle of water be subjected to the action of zinc, the attraction of zinc for oxygen would be in the reverse direction to that of the oxygen for hydrogen, it consequently has a tendency to overcome or destroy it. Thus, if we suppose the water to be held together by the attractions, as fig. 1,

$$\begin{array}{ccc} 1. & 2. & 3. \\ \overset{n\,\mathrm{P}\quad n\,\mathrm{P}}{\overline{\mathrm{O}\quad\mathrm{H}}} & \overset{\mathrm{P}\,n}{\overline{\mathrm{Z}}}\quad \overset{n\,\mathrm{P}}{\overline{\mathrm{O}}}\quad \overset{n\,\mathrm{P}}{\overline{\mathrm{H}}} & \overset{\mathrm{P}n\mathrm{P}n}{\overline{\mathrm{Z}\;\mathrm{O}}}\qquad \overline{\mathrm{H}} \end{array}$$

when a particle of zinc comes in contact with the oxygen of the water it would have a tendency to generate an attraction in a direction similar to that of hydrogen for oxygen, and consequently opposite to that of oxygen to hydrogen, as in fig. 2; if, therefore, the new attraction of zinc for oxygen is more intense than that of hydrogen for oxygen, the water would be decomposed by the combination of zinc and oxygen, whilst hydrogen is evolved, as represented in fig. 3.

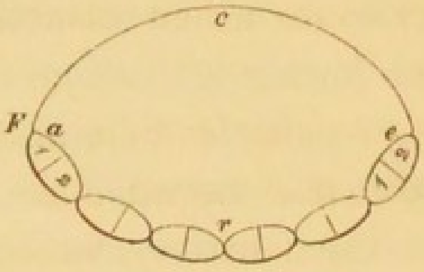
(110.) Such a combination, however, is an atomic circle, which we can conceive but not use; so had we no means of increasing the length of the interval between the abstraction of one element of the electrolyte, by the new attraction exerted between it and the positive pole, and the evolution of the second element, voltaic batteries would be but of little advantage. But we have the power of increasing this interval indefinitely; sometimes miles and miles exist between these two points.

(111.) The mode in which we increase this interval depends upon the power of the new attraction exerted between the zinc and oxygen of the water, to propagate the tendency to the destruction of the old attractions of hydrogen and oxygen through a series of particles of fluid. A second point is then placed, at which the hydrogen, or second element, may be evolved. This second point is the negative element, or, in my battery, the platinized silver; the points actually in contact with the fluid, or the fine particles of platina constituting the negative pole of the battery.

(112.) Not only may this force be propagated through a series of particles of a compound fluid, but also through a series of particles of wires; hence by having a fluid, for instance water, and placing something in it which has affinity for oxygen, that is, has a capacity to set up an attraction with it, the destruction of the former attractions may take place through a series of particles of zinc, through a wire some miles long, to the negative element. In this mode of constructing a battery, we have a series of particles of metal in a state of cohesion, and a series of particles of water, the elements of which are drawn together by chemical affinity. The attraction of the positive pole for oxygen takes place at one point, and the hydrogen is evolved some distance off at the negative pole, the attractions of the entire series of particles in a state of cohesion being at the same time interfered with.

(113.) To recapitulate the construction of a working voltaic battery, an instrument wherein the attractions of chemical affinity holding together a compound are destroyed, and others in opposite directions set up.—First, an interval of compound liquid, the particles of which should themselves be formed of but two elements, and but one atom of each. At one end of the fluid we place a body that shall have such relation, with regard to the direction of its power of generating attraction, to one element of the compound, as the second has to the first. These two points, or poles, are then connected together. From such an arrangement we have a circle, in any part of which voltaic effects are manifested whilst active attraction is going on. The F is the point of abstraction or new combination of the first element of the compound with some new body; the *e* is the point of evolution of the second element. The other letters refer to the connecting parts of the arrangement, which we shall hereafter have occasion to notice.

Fig. 1.



(114.) All voltaic phenomena are phenomena manifested between these two points—the abstraction of one element, and the evolution of the second. Philosophers, not satisfied with referring all these phenomena to the new attraction taking place in the voltaic circuit, have created, or rather assumed the creation of, some definite principle, which they call voltaic electricity. It is most essential, rightly to understand voltaic phenomena, that we should most clearly understand that there is no fluid, or principle or imponderable agent, or any other palpable absurdity, which is really produced or formed by the voltaic battery. Voltaic phenomena entirely derive their characteristics from the new attraction of the positive pole (as zinc for oxygen), overcoming the attraction of hydrogen for oxygen. This new attraction also overcomes the attraction of the particles of metal uniting the poles or points at which one element of the compound enters into a new combination, and the other is set free.

(115.) In the voltaic circuit there is but one source of all the phenomena, and that is at the positive pole. The positive element, or substance attracting one element of the electrolyte, may be either in the solid, liquid, or gaseous state. When that compound is water, almost all the metals, being inducers to oxygen, may be employed. Of liquids, solutions of oxalic acid, syrup, or protosulphate of iron may be used for the same purpose.

Of gases, it has been shown that hydrogen, by its power of inducing attraction with oxygen, will make an efficient and tolerably powerful battery.

(116.) The intensity of voltaic phenomena is directly proportionate to the energy with which the new attraction is set up between the positive pole and one element of the compound. This attraction is that which is termed chemical affinity; therefore, whatever can be an obstacle to chemical affinity, can be a similar obstacle to voltaic action.

(117.) The obstacles to chemical affinity are various; but perhaps the most important is the attraction existing in the compound held together by chemical affinity; hence, the first obstacle in the ordinary voltaic battery to the attraction of zinc for oxygen is the previous attraction of hydrogen for oxygen. But if we place anything with which hydrogen may combine with great readiness, we find that a less power of attraction between the positive pole and oxygen will cause action; hence, if in the voltaic battery we place any highly oxygenated substance at the negative pole, or pole at which the hydrogen has to be manifested, in practice it is found to be equivalent to diminishing the affinity of oxygen for hydrogen. The zinc, inducing a certain force with the oxygen of the water, is balanced by the force being set up from the hydrogen to the oxygen: but when the hydrogen finds another particle of oxygen in an easily reducible compound, with which it can readily unite, it gives up the attempt to maintain its old attraction, and sets up a new one. It is upon this principle, although it has been differently explained, that the sulphate of copper acts in the formation of batteries; and it is in the same manner that nitric acid acts to produce an intense combination.

(118.) The practical effect of giving something with which the hydrogen may combine when the oxygen is abstracted from an electrolyte, is most important; for by it hydrogen, inducing upon the oxygen of the electrolyte a certain force, will overcome the attraction of hydrogen for oxygen previously existing. The gas battery lately proposed by Mr. Grove, our distinguished professor at the London Institution, is a pretty example of this principle; for hydrogen induces an attraction between itself and the oxygen of the water, and the hydrogen in former combination takes on a new attraction with another portion of oxygen placed there for that purpose.

(119.) Nor is the attraction of oxygen for hydrogen the sole obstacle to the new combination taking place; but the force with which the particles of fluid are kept in their situation, the force with which the particles of the solid metal are kept together, also become obstacles to the new attraction. The particles of metal being attracted homogeneously, do not offer a very great resistance, but still a resistance is offered to the new attraction.

(120.) Besides the attraction of oxygen for hydrogen, of that of the particles of the fluid, of that of the particles of the solid, during the working of the voltaic battery, a new compound is frequently formed at the positive pole, which may stop the voltaic circuit by preventing the zinc, or positive pole, from coming in direct contact with the water. In consequence of this the attraction would have to be exerted through the new compound, which, as in the case of sulphate of zinc, is impracticable, and therefore stops the current.

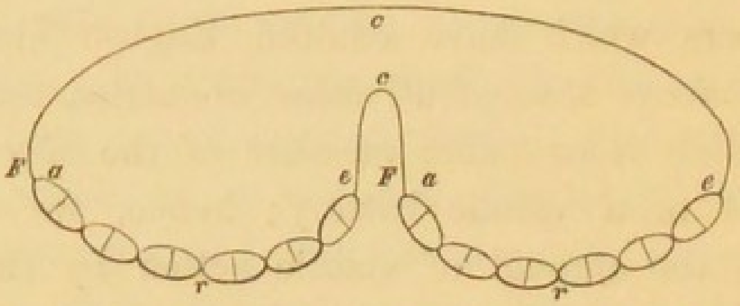
(121.) So much for these four kinds of obstacles which are offered to the generation of the new attractions. When these obstacles are equal to the new force, the new attraction is not exerted, and no change takes place. When the new attraction, or the new tendency to attraction, exceeds the force of the old attractions, which are its obstacles, the difference between the old attractions and the new ones constitutes a certain power, which English philosophers have very wisely called the intensity of the voltaic circuit. The energy of the new attraction, that is, the amount of action as compared with a definite unit of time, is in some manner proportionate to this intensity, so that intensity infers energetic action, energetic action infers intensity.

(122.) The intensity of the current is equal to the affinity of the positive pole, for one element of the electrolyte minus the obstacles to that affinity. The four-fold nature of these obstacles has been already pointed out, so that when the sum of these resistances, or impediments, is sufficient to resist the new attraction of chemical affinity, no action is the result; but when the affinity can overcome the impediments, action takes place.

(123.) It has been shown by Faraday, in a series of papers which have exalted English electrical science above that of all other countries, that this new action is an exact measure of the effects manifested in a voltaic battery; hence, we always express the amount of voltaic action by the new attractions which have taken place.

(124.) When we desire great energy of action, or considerable intensity, there is a plan by which we can introduce two, three, or any other number of attractions into the circle, and the apparatus by which this is effected is called a compound voltaic battery. In a compound voltaic battery, consisting of two batteries, there are two attractions acting in the same direction, and the effects of the voltaic battery are manifested between the point of the abstraction of one element of the electrolyte in the first battery of the series, and the point of evolution of the second element of the electrolyte in the last battery of the series. The compound battery is made by joining the zinc of the first battery to the silver of the second, leaving the silver of the first battery and the zinc of the last not connected, so that they can be applied for whatever purposes the battery may be required. The subjoined diagram sufficiently points out how two or more attractions may be introduced into a voltaic circuit, and by acting in the same direction increase the effect We perceive that, although there is but one circle, two attractions (F) (F) are taking place.

Fig. 2.



(125.) Hitherto we have simply considered the voltaic battery to be made of a single atom, acting at once on a compound fluid, and in such a circle we find that one point alone is the source of power (F) fig. 1, and four parts obstacles to that force—the evolution of the second element (*e*), the resistance of the intervening electrolyte (*r*), the resistance of the connecting part (*c*), and the non-removal of the new compound (*a*). In the practical management of the battery, when any difficulties occur, we have only to direct our attention to these five points, when we shall in a moment be enabled to detect the source of trouble, and instantly be enabled to rectify it. These five points exist in every voltaic battery, or any apparatus which is exhibiting voltaic phenomena; hence, if we have a hundred batteries, we must examine these five points in each separately when we desire to rectify errors.

(126.) It would be useful to have some definite standard, to which all intensities might be referred; but it would be as impossible to obtain any absolute standard as to obtain absolute standards of size or weight, and for the same reason because we cannot employ atoms of matter separately. It would not, however, be difficult to obtain some comparative standard, to which all other intensities might be referred. The obstacles might also be referred to some common standard, so that we might conduct all voltaic proceedings with the certainty and facility given to us by the properties of the abstractions of arithmetic.

(127.) In every voltaic battery there is invariably a number of atoms generating a new attraction, between itself and one element of a corresponding number of particles of an electrolyte. The action of this number of atoms, according as they are more or less numerous, is called the quantity of a battery. We cannot have an absolute measure of the number of atoms acting upon a fluid, therefore we can only have comparative measures of quantity; hence, the actions taking place in two batteries, one twice the size of the other, are said to be respectively as two to one.

(128.) The power of any given battery is dependent on the intensity of the combination of each atom of the positive pole, and the number of atoms setting up the new attraction. It may be said, therefore, to be equal to the intensity multiplied by the quantity. On ascertaining the amount of action taking place in any battery in a given time, we must be careful to remember that we solely learn the power of the battery, from which we can only obtain the values of the quantity or intensity separately, by first ascertaining the value of one of these properties, and then dividing the power by it to obtain the other.

(129.) The Germans, reasoning falsely upon abstractions, have manufactured, or rather improperly assumed, some specific principle, which they call electro-motive power, which is supposed, in some unaccountable way, to arise from one metal looking at another; hence, they think that zinc, by looking at platinum, produces a certain property which they call electro-motive force. This is not the place to enter into scientific debates, much less to discuss one of the most disputed points in the whole range of philosophy; suffice it to say, that the Germans still hold the contact theory for the production of voltaic phenomena. This fanciful assumption is considered by English philosophers to be so erroneous, that further comment is scarcely required. The universally received doctrine of voltaic equivalents, the proof that voltaic equivalents are chemical equivalents, and the experiments shewing that definite actions give rise to definite results, are more than amply sufficient to give us an insight into the true character of voltaic phenomena, and to disprove the theory of the otherwise learned German philosophers.

(130.) The contact theory has given rise to most extraordinary equations by Ohm, the foundation of which has no relation to anything in the voltaic battery, or, indeed, to any voltaic property whatever. Their essentially metaphysical character has caused them to be generally refused admittance in this and other countries for a long period, and though the most powerful exertions have lately been made by two or three of our most ingenious and indefatigable philosophers to support them, and cause their adoption in this country, the attempt has to a certain extent failed, and at the present time scarcely half-a-dozen Ohmites can be enumerated. Had Ohm been better acquainted with, or fully understood the precise and valuable researches of Faraday, there is but little doubt that his important doctrine of resistances would never have been clothed in such metaphysical unintelligibilities.

(131.) During the continuance of the action of the voltaic battery the particles of the compound liquid must not only be arranged in a polar direction, but the element with which the positive pole forms a new combination must be turned towards the positive pole. What determines that polarity we are ignorant, but as water is rendered a better conductor by the addition of acids, alkalies, and neutral salts, there is reason to believe that these bodies favour such an arrangement.

(132.) The voltaic force as it passes through binary compounds in a fluid state, or in a state of solution, has the peculiar property of decomposing the fluid, leaving one element at one pole, the second at the other. This decomposition is owing to the force neutralizing the prior attractions at the moment of which the two extreme particles, being in contact with the poles, set up a more or less powerful attraction with the poles, and consequently are not in so favourable a state for action. The intervening atoms, therefore, immediately unite without those terminal atoms, leaving them uncombined.

(133.) When a fluid is decomposed the same element is always left at the same pole; thus at one pole oxygen is always given off, at the other hydrogen, but not at one time oxygen, at another hydrogen. This phenomena shews clearly that the polarity, or direction of the attractions, is uniformly the same. This polarity appears to depend entirely upon the positive element, that is, the substance generating the new attraction between itself and one element of the electrolyte. It has been determined by Gassiot, that the pole at which oxygen is left when water is decomposed is positive, and where hydrogen is left, negative.

(134.) A metal in a state of cohesion will sometimes not set up a new attraction, in consequence of the former attraction of cohesion being an obstacle to the new attraction of affinity; hence copper in a rolled or malleable state will act but very slightly upon dilute sulphuric acid; but if the voltaic force is propagated through the copper, the cohesion is destroyed at the instant of the passage of the current, or, to speak more correctly, at the moment of the action of the force, and the particle of copper in contact with the oxygen of the liquid combines with it, and forms oxide of copper. If both poles, that is, both negative and positive poles, are formed of copper only, that particle of copper will combine with the one element of the water which is situated, by virtue of the polarity of the water, in contact with that element with which it can set up an attraction.

(135.) The instance of copper forms a good general example of the solution of a positive pole by voltaic electricity, but it extends to all cases where a conducting body is in a state of cohesion. In some cases, however, the particles of metal are capable of exerting a stronger attraction towards each other than towards one element of the liquid, hence platinum, which has a very feeble or scarcely any attraction for oxygen, is not dissolved at the positive pole.

(136.) And here it is proper to mention, that a circuit may be called voltaic whenever a fluid is under decomposition by force, no matter how that force is generated, for as soon as the force is acting upon a liquid it obeys the laws of voltaic phenomena generally; thus, in the electro-magnetic machine lately introduced for the purposes of plating and gilding, the fluid decomposed is subject to the same electro-metallurgical laws as if the fluid was decomposed by the forces originating in the voltaic battery. It is easy to deposit the metal by the machine in three states, the pulverulent, reguline, and crystalline deposits. The reason of these facts is sufficiently obvious; the voltaic battery is an apparatus in which the attractions of a compound fluid are neutralized, and new ones set up in an opposite direction, so whatever apparatus performs these functions may be regarded as a voltaic battery.

(137.) We have now seen that the cause of all voltaic phenomena is referable to a new attraction. This new attraction acts in an opposite direction to the attraction of chemical affinity holding together the particles of the electrolyte, and by neutralizing former attractions of affinity and of cohesion, produces the effects of decomposition and solution of the positive pole. Voltaic action arises, if the new affinity does actually take place; but in certain cases the new force or new attraction is a little below the resistance afforded by its obstacles, and action cannot occur. Though the effects in this case are not actually produced, there is a strong tendency to their production, of which tendency we shall now have to take notice.

(138.) As the available force exerted to overcome obstacles is called the intensity, and this force is the difference between the obstacles to chemical affinity and the force of the new chemical affinity itself, so the amount of tendency to chemical affinity, when resisted by its obstacles, is called tension. Tension, or galvanic tension, is the force of chemical affinity overcome or prevented from taking place by obstacles, we therefore can have no tension without obstacles, and in proportion as the tension increases must the obstacles increase, otherwise the tension would overcome the obstacles and become intensity. Tension, therefore, is a desire for action ungratified, consequently to have tension we must have obstacles. When the force to produce tension remains the same, and the obstacles remain the same, the tension remains uniform; but when tension increases, it at length becomes action, or in the same way, if the obstacles diminish, action takes place.

(139.) A body in a state of tension is generally polar, and the usual effect of tension upon the attractions of chemical affinity, or cohesion, is that of a certain amount of counterbalanced force; hence, the power with which the new body seeks to set up a new attraction is so far evident, that a force which, without the tension, would have produced no effect, may cause immediate action.

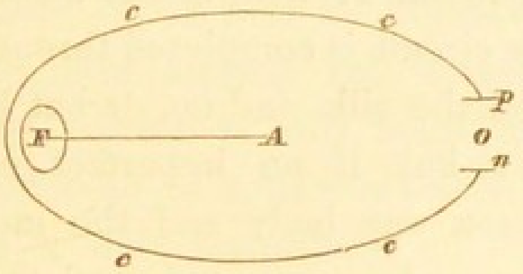
(140.) The effects of tension, or electrical tension, may arise from a variety of causes; for whenever a new attraction is set up, or has a tendency to be set up, which is opposed by some obstacle, the effects of tension are manifested. Tension, however produced, is one and the same; therefore, whether produced by the voltaic battery, the electrical machine, the magneto-electric machine, the secondary coil machine, the stereo-electric apparatus, or the animal apparatus for producing this phenomena, it has for its cause the attempt at a generation of a new attraction resisted by former ones, which prevent its taking place.

(141.) The electrical machine is the instrument by which we produce the greatest tension. It is not very apparent at what precise point the old attractions are interfered with, and the tendency to new ones set up; but it is probable that the pressure exerted to cause frictional tension upon bodies, the particles of which are in a state of cohesion, has an increasing tendency to destroy old attractions, or perhaps actually does destroy them; and these particles again taking on attractions in other directions, causes, by the resistance of the other particles in the state of cohesion, the effects of tension. From this consideration frictional electrical effects derive their properties from the action of new attractions on bodies in a state of cohesion.

(142.) The electrical tension generated by the machine arises from friction. Friction, we shall hereafter show, is the result of force; force, of some new attractions. Friction, therefore, being derived primarily from attraction, may counterbalance other attractions. In the electrifying machine, and all its analogies, where friction is exerted, there must be more or less tendency to the destruction of the attractions. This tendency may be called the desire for action, which is opposed by the attraction of cohesion; this desire for action is the tension.

(143.) Tension, we have before explained, infers an obstacle, and is, especially in high tension, always accompanied by polarity. The effects of tension are consequently only manifested at the two surfaces of the obstacle, and nowhere else; hence, the effects of tension are said to be always resident on the surfaces of bodies. One surface of the obstacle, or one surface of the body in contact with the obstacle, is called positive, the other negative; which terms only designate the direction, or polarity, of the attractions in the body, the particles of which are held together by cohesion.

(144.) To rightly understand the mode of causing tension, we must assume a circle, and call it a frictional one, which we shall find consists of a variety of parts, which must be considered separately. In the first place, it is necessary to have



a body held together by cohesions (*c*, *c*, *c*, *c*). We must then have a point at which friction is exerted, F, the friction being produced by force, which has its origin from some new attractions, A. The body rubbing and the body rubbed may be two imperfect conductors, or one may be an imperfect conductor; but, if both are good conductors, on the application of the friction the new action takes place quietly, and no tension can be produced. In the above diagram, we suppose the body (*c*, *c*) to be an imperfect conductor. When friction is exerted on one point, the desire for new action throws all the attractions into a polar state, and if any breach exists in the continuity of the particles by any imperfect conductor, or obstacle (O), the polarity will then manifest itself by one side of the non-conductor being negative, the other positive.

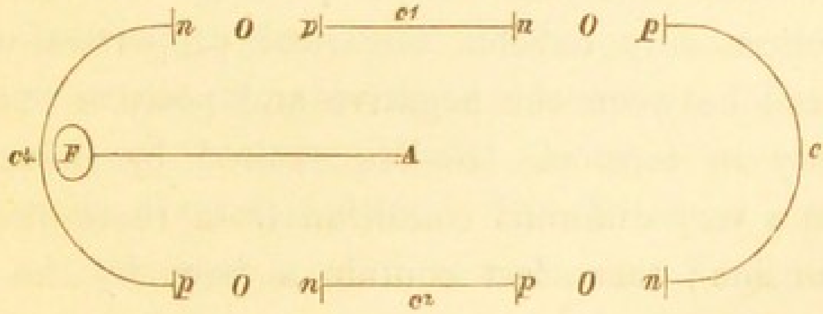
(145.) We have thus seen that electrical, or frictional tension, is identical in effect with galvanic tension; for in both cases it is essential that a non-conductor, or rather an imperfect conductor, should intervene between the parts where the two ends of the direction of the attraction, holding together the particles, manifest the polar condition. If a piece of metal be held in the hand, and rubbed with silk, the circuit is completed through the metal, the body, and the silk, and no, or but little, tension is produced; but if an imperfect conductor be placed between our body and the metal, polarity and tension may be generated, and the metal may show a negative or positive action. This fact, with others, gives us a satisfactory clue to the production of electrical phenomena by friction; for we perceive, that to generate the effects of tension, we must have such an arrangement that obstacles are afforded to the new attraction which the friction had a tendency to cause to be set up.

(146.) If the force, or friction, arising from some new attraction continues to increase, the desire for action becomes irresistible; it at length must be gratified, for it becomes sufficiently great to overcome the obstacle, the impediment conducts under the higher power, and a certain effect, which the learned call a discharge, takes place. The phenomenon called a discharge, therefore, is the propagation of a new action, through a body which does not easily admit that action, which action is caused by some new attraction acting upon particles in cohesion. The discharge is the action taking place through the imperfect conductor, which is essential to the production of the phenomenon of tension. When the discharge takes place, all effects capable of being produced by the disturbance of attractions may be manifested. Hence, light, heat, decomposition, sound, and even odour, may be violently evidenced.

(147.) We have already had occasion to mention, that the tension is only manifested when an obstacle is afforded to a new attraction; and, consequently, it is only manifested on the surface of bodies, or, in other words, upon those points which come in contact with the obstacles. But tension is not only manifested on the surfaces of bodies, but is only evident on that surface which is opposed, or can radiate, to the other surface coming in contact with the intervening or conducting body. Hence, if a frictional circle be formed by connecting the surface of the earth, by means of a good conductor, with the rubber of an electrifying machine, (in practice we connect the rubber with the gas-pipes and water-pipes of all London,) and the air be allowed to be the non-conductor intervening between it and a second body, this second body will exhibit tension at those points only which can radiate, or are opposed to the surface of the earth, or objects situated on it, and contrariwise only that portion of the earth ; or, if the experiment is tried in a room, the walls, the floor, the ceiling, only exhibit at their radiating points the effects of tension. It is on this account that the interior of a sphere does not exhibit tension, the effect only manifesting itself on the surface of the body, which is opposed or radiates to that oppositely electrified.

(148.) In the discharge it is found that the amount of action is not altogether dependent on the energy of the tension. The amount of the effect may be called the electrical power, and depends upon the number of particles in a state of tension, and also upon the degree of tension of each particle. The number of particles may be called the quantity of the electrical force, the energy of tension the intensity, and the intensity multiplied by the quantity constitutes the electrical power on which all effects are dependent. Any definite electrical power may excite a great many particles feebly, or a smaller number intensely; a large power diffused over the surface of a resisting medium will produce but small intensity, a smaller power, however, diffused over a few particles a great intensity. Quantity and intensity, although equally forming a part of electrical power, cannot at all times be made to evince their particular properties as we please from electrical power. For this reason the two properties are better studied separately; although, indeed, the Germans, preferring metaphysical reasoning to straightforward experiments, would persuade us that these two evident components of electric force have no existence.

(149.) In the preceding instances we have only considered a simple frictional circle, that is, a circle where but one obstacle is afforded to the new actions set up by the friction, and consequently but one tension; the two ends, the negative and positive, of which are manifested at each surface. We have now to consider the effect of several new obstacles introduced into the circle, and for this purpose we will conceive a circle thus situated as in the annexed



diagram, the letters of which appertain to the same parts as in the single circle, with this difference, that in the former case but one O or obstacle was present, in this case four obstacles are present. As soon as friction is applied (F) arising from some new attraction (A) tension is exhibited at the ends of the solid body, the particles of which are held together by cohesion, and the attractions of which were interfered with by friction. The body is polar, one end is negative, the other positive. The tension in the first body under cohesion causes polarity on the contiguous bodies, the particles of which are also in a state of cohesion; hence 1*c*, 2*c*, 3*c* all have polarity, and the respective ends of each are alternately negative and positive, as in the conjoined cut. This property of bodies intervening or situated in a non-conductor between two polar ends to become themselves polar by virtue of their situation, is called induction.

(150.) Induction, then, is the polarity of particles held together by cohesion, interposed between the negative and positive ends of a body in a state of tension. There appears to be scarcely any limit to the number of particles which may be so excited when thus situated. The particles excited by induction only exhibit electrical properties when situated between the negative and positive ends of a body in tension. Bodies excited by induction are in a very different condition from those excited by tension; these last contain a force by the disturbance of the attractions which they retain, but bodies under induction only exhibit electrical effects when between the ends of a body in tension. They possess no inherent force, and if removed from the position in which they received their induced effects, exhibit no electrical excitement. Thus we perceive that bodies under induction possess no force, but derive their properties from bodies possessing force.

(151.) A body under electrical tension may communicate its force to other bodies by diffusing the desire for alterations or new actions existing in the tensions over a larger sphere; thus, if an isolated piece of metal be brought in contact with either negative or positive ends of a body in tension, it will be endowed with similar properties; and if a series of bodies be brought successively in contact with either a positively or negatively electrified body, the force, by diffusing itself over a larger surface, may have the tension at any one point so far lessened as scarcely to be evident.

(152.) It is not essential that a body should touch the other under tension to carry the force to it, thus, if the interval of the non-conductor is not too great, nor its conducting power too small, the force may pass by a discharge through the lesser obstacle, and then the intervening solid bodies will not only possess induced electrical properties, but really electrical force. The practical application of this fact is well seen in the Leyden jar, for that is a good instance of a second obstacle afforded to a frictional circle. In this case, the rubber and the earth form the body in cohesion, the air the intervening non-conductor. The force is carried by a discharge from the rubber to the prime conductor, and tension is manifested between this prime conductor and the earth. The Leyden jar is formed of a non-conductor (glass) intervening between two good conductors (tinfoil). When the tinfoil on one side is connected with the rubber, and the tinfoil on the other by means of a knob or any other communication is brought near the prime conductor, a series of little discharges take place through the air intervening between the knob of the Leyden jar and the prime conductor; the force is communicated to the Leyden jar, and the ends of polarity are manifested at the surfaces of the glass; thus, one side is negative, the other positive. In proof that a series of discharges take place through the air intervening between the Leyden jar and the prime conductor, the effects of discharge generally, light, heat, sound, take place in the interval.

(153.) The contrivance called an electrical battery is only a large Leyden jar, or rather a series of Leyden jars, the effect of such an instrument being to greatly accumulate the quantity of electricity by an increase of the number of particles capable of taking on a state of tension, in consequence of which when the discharge takes place greater effects are produced.

(154.) Whenever tension is exhibited by two surfaces, and a negative and positive direction is manifested, it has a curious influence on attraction, and consequently on motion. These phenomena will more fully be considered when we talk of force and motion, but perhaps in this place we should call attention, as all other works when treating of electricity do call attention, to the attraction manifested between oppositely electrified surfaces, that is, between negative and positive surfaces; and the want of attraction of bodies, whenever the direction of the forces opposed to each other is similar, for then the bodies recede from each other. These phenomena form the test of tension. By offering pieces of thin gold leaf, it is found that the surfaces of two pieces of gold leaf oppositely electrified attract, surfaces of gold leaf similarly electrified, repel.

(155.) Having considered galvanic tension, and frictional tension, we have next to describe lightning tension. The tension in this case is evidenced between the surface of the earth on one hand, and a cloud on the other, the air being the imperfect conductor at the surfaces of which the ends of the tension are manifested, that is, one surface is positive, and the other negative. The attraction which is the source of the tension, perhaps present facts have hardly sufficiently proved. Still, when we perceive that a rapid formation of clouds, of rain, and even hail, always accompany the phenomena, we shall not probably much err in attributing the effects to the sudden attraction of aqueous vapour into cloud, rain, or hail. This new attraction, acting upon the air as a non-conductor, causes a polarity of that air, which is communicated between the surface of the cloud on one hand, and that of the earth on the other. Such a mode of the formation of a thunder-cloud agrees well with the natural phenomena. It is apparent from such a cause that the entire surface of the cloud, on the one hand, and the surface of the earth opposed to it on the other, would be in a state of high tension, a result which is in perfect accordance with the fact.

(156.) The electrical power capable of being exerted between the cloud and the earth is enormous. The intensity is so great, that it is capable of passing through a thousand feet, or more, of air during the discharge. The quantity is equally vast; for the cloud and tension may be exerted over very many square miles, occasionally even for 100 square miles. The electrical effects being equal to the intensity (1000 feet of air), multiplied by the quantity, 100 square miles, will produce a result which, when compared with the power of an enormous Leyden jar, the intensity of which is (half-inch air) multiplied by 100 square feet, shows so wide a difference that a comparison can scarcely be made. This difference, while it shows to the presumptuous philosopher the vanity and impossibility of attempting to produce this great phenomenon of nature, yet it amply demonstrates to those who undervalue scientific investigation how, by paying attention to minute experiments in the laboratory, the operations of nature may be explained and comprehended.

(157.) The lightning-cloud almost invariably appears when rain follows long-continued easterly winds, which render the air and earth exceedingly dry; but occasionally the lightning-cloud is formed when the surface of the earth is saturated with wet, and the air highly hygonetric. In this latter case, a dense cloud is generally seen to form in the atmosphere without any apparent cause; with the utmost rapidity, and within a few minutes, and sometimes within a few seconds of its appearance, hail, rain, and lightning follow.

(158.) The lightning-cloud sometimes exhausts itself nearly at the place where it is first formed; and in this case perhaps both the cloud and earth are in an uniformly opposite state, which would have the effect, by virtue of the attraction of oppositely electrified surfaces, of causing the cloud to be retained in its position. Sometimes, however, without any wind, the cloud takes a rapid travelling fit, crossing England in a few minutes, and paying our French neighbours a visit, as we find by the account in the papers the next day, striking and carrying devastation in its progress. Sometimes the cloud will travel away for two or three hours and then travel back; sometimes it will take a circular motion, and, in fact, the freaks which a travelling cloud will play are innumerable. The travelling cloud may possibly owe its properties to an unequal tension at different parts; for if one end of the cloud, or the entire cloud, had an attraction to the earth under this end, and in advance of it, the cloud would be drawn towards that part; but as there is a force which resists its direct downward attraction to the earth, it moves in the diagonal of the force tending to raise the cloud, and the force drawing all the cloud to one point, when a motion more or less rapid must be the result. In this case we must suppose that the earth under one end of the cloud as it advances immediately assumed a violent tension.

(159.) The electrical power of the thunder-cloud is due to the high tension between each particle of the cloud to the earth, and the number of particles of the cloud opposed to the earth. We mimic this effect in our contrivances for obtaining the effects of electricity of friction by connecting the earth with the rubber, in order that we may have an immense number of particles to which our prime conductor, or other body, may be opposed. When the surface of the earth in these experiments exhibits one state of electrical tension, the body opposed to it exhibits the opposite, but only at the parts opposed, or situate opposite to the surface of the earth; hence, if we impart electrical force to a vessel on its inner side, the state of tension would be exhibited at the outer, or part opposite to the earth, and would be in an opposite state to the earth; thus, if one were positive, the other would be negative.

(160.) We have now considered three modes of obtaining the effects of tension, namely, by the galvanic battery, by the electrical machine and its analogies, and the thunder-cloud; we have now to consider how the same effects may be produced by the thermo-electric machine. In the three former cases attraction was evidently the cause of the effects, and in this we shall also find attraction is exerted. In fact, we can have no change of state of any attracted body without some attraction to cause the phenomenon.

(161.) The thermo-electric, or, as some people will have it, stereo-electric apparatus, is a contrivance whereby the attractions of a body in a state of cohesion are disturbed by some new attraction causing heat. The contact of two pieces of the same body, one hot and the other cold, will produce stereo-electric effects; or two bodies that are acted upon equally by heat will exhibit the same properties. Bismuth and antimony soldered together produce these effects most powerfully; but the influence of the solder in this case should be carefully considered.

(162.) That a new attraction is the cause of thermo-electricity we know, because we cannot have heat without attraction; the exact point at which heat acts to produce stereo-electric effects is the point of junction of the metals. As a proof that at this point of junction heat produces the phenomenon, we find that a feeble galvanic current passed through a bar in one direction, causes at this point heat; if passed in the opposite, cold. The effects are probably due to the unequal disturbance by heat of the attractions existing between the two metals and solder; but although we know that the point of soldering is the place where the effects arise, yet the exact mode in which the attractions are thus disturbed we do not at present sufficiently understand.

(163.) The effects of thermo or stereo electricity are exceedingly feeble, as a series of 1000 would not be near so strong as a single voltaic apparatus. It has convulsed the limb of a frog, deflected a magnet; but its effects are lower than any other mode of producing electric phenomena.

(164.) The next apparatus wherein electric phenomena are generated, is the magneto-electric machine. The essential construction of this machine is first a magnet, no matter whether that magnet retains permanently its magnetism, or whether it is only extemporaneously magnetised during the action of the machine. This magnet induces upon a piece of soft iron a certain magnetic state, which acts upon the attractions of a piece of covered copper wire wound round the iron, and produces electric force the moment the polarity of the piece of soft iron is caused by the magnet. The instant the polarity of this piece of iron ceases, the attractions of the particles of the iron returns to the former state, and then the wire assumes its former attractions, and an action in the opposite direction is produced.

(165.) In the magneto-electric machine, the attraction of iron for iron is the new attraction which is the proximate cause of the electric phenomena. This acts upon the particles of wire and disturbs their attraction. The greater the number of particles the attractions of which are interfered with, the greater the result; the less number of particles, the less; therefore the larger the wire, the more energetic the current. The intensity in our ordinary magneto-electric machines is immense; so much so, that it overcomes most obstacles afforded to its passage. Lately the magneto-electric machine has been introduced into the manufactories as a source of voltaic power; and as steam power is cheaper than voltaic power, a great saving was anticipated. By this machine, however, we obtain a much greater intensity than what is necessary, therefore a considerable amount of power is wasted. Doubtless, if the manufacturers ever obtain a large amount of power with but feeble intensity, a result perhaps not very difficult to be effected, the magneto-electric machine might be turned to most profitable account in voltaic reductions of metals.

(166.) In the secondary-coil machine the cause of the generation of the voltaic phenomena is very similar in many respects to the magneto-electric machine. The new attraction which is the proximate cause of the phenomena in this case takes place in the voltaic battery, which acts upon the attractions of the wire, this acts again upon the attractions of a second wire, and causes electric phenomena by disturbing them.

(167.) There has been lately some excitement amongst scientific men upon the production of electric phenomena by steam; but Dr. Faraday having shown in an admirable paper that the results are probably due to friction, the excitement in some degree abated till an extraordinary machine was made for producing these effects, which again caused its renewal.

A most noble apparatus for producing electric action by steam has lately been erected at the Royal Polytechnic Institution, under the direction of Mr. Armstrong, its inventor, who terms it an hydro-electric machine. The steam is generated in a high-pressure boiler, similar to that in use for railway engines, but insulated by glass legs. The steam passes through forty-six curved iron tubes, in which is inserted a small piece of perforated partridge wood. On its emergence from the tubes, it plays upon a series of metallic points, and from the action of the steam the points become positive, the boiler negative. In this arrangement, we have a circle of which the atmosphere is the imperfect conductor, at the surfaces of which the tension is manifested. The partridge wood is the body the attractions of cohesion of which are interfered with.* The circuit cannot be completed through the boiler to the metallic points and rest of the surface of the room in which the operation is performed, in consequence of the imperfect conducting nature of the legs of the boiler.

The action or the effects of the discharge of the tension produced by this machine are extraordinary. A battery of 80 feet surface is discharged with great violence five times in forty seconds, water is decomposed, the metals reduced, the magnetic needle deflected. The power of this machine is characterized by its intensity, the quantity being small. If, however, the inventor succeeds in obtaining by the same means large quantity and small intensity, no one can foresee the importance which the discovery of this instrument may have upon manufactures.

(168.) We have now considered the effect of electric tension, or a desire for the annihilation of attractions existing between bodies in one direction and the assumption of others in the opposite.

---

* The idea has occurred of the possibility of the action being due to the affinity of the iron pipes for the oxygen of the steam, in which case the affinities would be a voltaic circuit, the iron tubes of which would be the positive pole, the metallic points the negative, the steam the electrolyte, and the partridge wood would be simply a non-conductor. Such supposition has arisen from copper not being so favourable as iron to hydro-electric phenomena.

We have considered how such tension may be generated. By the voltaic battery a definite desire is produced to overcome the attraction of chemical affinity. By the electrifying machine, thermo and magneto electric apparatus, and also by the induced current and steam electro apparatus, a similar desire is manifested for disturbing the attractions of cohesion exerted between the particles of which such solid body is made up.

(169.) Tension, however generated, is due to some new attraction acting on and opposed by some previously existing one, therefore, whenever the tension is sufficient to overcome its obstacles, action is produced. Now, from the preceding observations, it will require no extraordinary acumen to understand what the effects of action would be; for as tension is the desire to destroy attraction, action is the act of its destruction. Hence, as attraction produces cohesion, affinity, magnetism, &c., electric action produces the destruction of attraction, and consequently disintegration, decomposition, the destruction of magnetism. These results of electric action are foolishly termed the discharge of tension, a name which has been given upon the assumption of some specific principle in electricity, which we have shown is not the case.

(170.) When action or the discharge takes place through compound bodies, that is, bodies composed of two elements, decomposition is effected in the manner already fully explained when treating of voltaic phenomena. The fact is again only here noticed to afford an opportunity of mentioning that in whatever manner electric phenomena are generated, the effect upon compounds is precisely the same; that is, stereo electricity produces the same effect as voltaic electricity, frictional as magneto electricity, and secondary coil electricity as lightning and steam electricity. In fact, each respectively, when acting upon a compound, produces identical effects if the amount of force is similar.

(171.) The action of the electric force to overcome or modify the attractions of cohesion, is well seen in its powers of fusion, in its tremendous power of shivering the largest trees, in its shattering glass and scattering its fragments. The action of electricity in destroying or altering magnetic polarity, is another instance of its acting upon the direction of the attraction of cohesion.

(172.) All damage done by electric discharge is during the act, and in consequence of that act. Its power of acting upon the animal economy, and destroying life is also during the action. A human being may be in such a state of tension that every hair on the head may straighten, and yet he will not in anywise be injured; but if a powerful electric force be discharged through his body, he is instantly prostrated to the ground, and life perhaps destroyed. This baneful effect only takes place by a large amount of force passing at one instant, so that the same force may pass gradually without causing any injury; hence, when the human body is exposed to tension of great electric forces, it becomes a matter of considerable importance either to prevent the discharge altogether, or to cause it to take place but gradually.

(173.) The great source of danger from electric force is that generated by the lightning cloud, which we have before mentioned may be of great extent and produce enormous power. Last summer, 1842, a violent storm visited the metropolis a little before sunrise, and one of the most violent and long continued peals of thunder followed a flash of lightning that was ever remembered. The discharge which produced these effects appeared to extend over a long distance, for there was scarcely any part of London, or, indeed, of its environs, where some object was not struck and damaged. Every quarter or half mile, for an extent of eight to twelve miles broad and as many long, gave indications of a discharge at that particular moment, for an immense number of dilapidations occurred a few minutes before six, and numbers of individuals at different parts of the district heard, as far as they could describe, a similar peal of thunder. This instance, and many others that might be mentioned, show the enormous amount of electric force which we have to prevent from injuring the delicate fabric of the human body.

(174.) The plans for preventing accidents from this terrific force may be divided into two kinds.

The first is, to surround the body with an imperfect conductor, in the hope that the force will not pass through it. The second is, to discharge the tension through rods of metal called lightning conductors. The first contrivance cannot well be relied on, and when we consider that the intensity is so great in the lightning cloud that it will pass through upwards of 1000 feet of air, the reason why non-conductors are not effective preservatives, seems tolerably apparent. A comparison between the intensity of lightning and of voltaic electricity may be formed, when we state that 5000 batteries arranged as a series will barely discharge their tension through $\frac{1}{4}$ inch of the same air. The discharge of electrical tension by lightning conductors cannot be implicitly relied on, and the application of these supposed averters of destruction may be useful or deleterious in different cases. Whenever a building is struck by lightning, and yet abundantly supplied by protectors, it is assumed that the conductors have not been properly fixed, no matter how carefully that operation was performed. We are afraid, however, in these cases, the mechanic may rather hold the philosopher to blame for promising too much, than allow himself to be blamed for the non-protection of the building.

(175.) If we consider how the lightning tension might be discharged without injury, we shall find that the question is easily answered, but the perfect practice absolutely impossible. To obtain a perfect and safe discharge, the entire air existing between the cloud and earth should be changed for some excellent conductor. This, by affording a ready road for the action, would instantly allow the tension to act, and consequently prevent a high tension from taking place. Possibly the same good result might be obtained by the use of solid thick rods of metal connected between the cloud and the earth at frequent intervals. The surface of the earth, however, is a bad conductor, and the surface of the cloud also an indifferent conductor; therefore these rods would be, when fixed in the earth, nearly in the same condition as a piece of metal inserted in glass, being in every case more or less insulated, the degree depending upon the nature or dryness of the earth at their point of insertion. That difficulty might theoretically be overcome by coating the surfaces of the earth and cloud with metal or some other good conductor. Such a proceeding, although it would doubtless afford protection, would be utterly impossible in practice. As water is a good conductor, the discharge of tension can be better accomplished at sea than on dry land; probably a thick rod carried to a great height, and in contact with the water, might protect bodies for some distance, but the metallic rod should be of great substance. Lightning protectors, if carefully applied, as by Snow Harris, may be of great use to ships at sea. This philosopher is careful to carry the rod from the top of the mast completely into the water, so that if lightning protectors are ever to be of service, it is in this instance, and they are much more likely to be useful here than when applied to protect objects on dry land.

(176.) We have before noticed that the discharge must take place with violence to produce injury, and that the greatest tension without discharge may take place without endangering animal life. For this cause a house may be struck, and the direction of the discharge may be through the chimney, or rather through the soot by virtue of the good conducting power of the soot, and thence pass through a room, with a person in bed, and out by the window, disintegrating the glass in its passage, and yet the individual in bed may escape uninjured. In these cases, the situation of the parties being amongst imperfect conductors, is such, that although their bodies are in a great state of tension, the action takes place so gradually that they are not in the least hurt, although the sheets may be in one or two places slightly scorched. In such a case, the contiguity of a lightning conductor to the human body would cause instantaneous death, for the discharge might then pass with violence through the body. Enough has already been said to show the principles to be pursued for the protection of persons and buildings from violence, and I trust that enough has been said to prevent the unlearned from trusting implicitly to lightning conductors, or placing too much reliance on schemes put forward either by the ignorant or designing.

(177.) Having now described the states of the attraction of solid bodies, which we call tension, an effect produced by some new attraction acting in an opposite direction to those formerly existing; and having, moreover, fully considered the effects of the destruction of the former attractions, which we call action or electric discharges; let us pause for one instant, and consider to what we give the name electricity, which is the apparent cause of these phenomena. We have abundantly shown that there is no immaterial essence, or imponderable attached to matter, to which electric effects are specially due. If electricity is not a thing or principle, that is, neither matter nor any particular property attached to matter, this term is an abstraction having relation to particular material actions or material conditions.

(178.) There are, however, two conditions of matter in which matter is said to be electrified. The first, where a new attraction is seeking to overcome old attractions in a polar state; the second, where the new attraction is actually overcoming the previously existing ones. The first is electric tension, the second electric discharge. What then is electricity? It is the abstract idea of particles of matter, the attractions of which are polar, acted upon by some new attraction exerted in an opposite direction, which tends to destroy, or actually destroys, the previously existing attractions.

(179.) When any number of particles are attracted together, and the attractions remain constantly the same, the body is said to be at rest; but if the attractions are either increased or diminished, or interfered with by other attractions, so that the size, shape, quality, or position of the body is altered, the particles of that body undergoing that action are said to be in motion.

(180.) Although, however, it is manifest that the phenomenon of motion, or an alteration either in the intensity or direction of the attraction may be evidenced in any body the particles of which are attracted together, yet the term motion is generally given to the abstract idea of a disturbance or alteration in the attraction of masses of matter held in a certain position by gravitation, pressure, or other similar causes, so that the mass of matter acted upon leaves the mass of matter with which it was in contact or in some definite relation, and passes to other masses of matter, and assumes thereby a new position. The position of a body is the place of equilibrium, *i. e.* the point where the attractions between it and other bodies are equal, and opposite to each other collectively. When a body changes its position through any alteration of the attractions which kept it in its place, motion is said to result.

(181.) All cases of motion arise from new attractions, and to the abstract idea of the capability of these new attractions to cause motion by acting on attracted matter, the term force is given. Force has only one origin, that is, attraction; and no force can exist without attraction. The extent of manifestation of the effects of force is equal to the intensity of the attractions of each pair of atoms attracted, multiplied by the number of pairs.

(182.) As force arises exclusively from attraction, and attraction is but of one kind, it follows that wherever attraction is exerted, force must arise; hence, in the consideration of the production of force, we should study the position where the attraction is being effected; for instance, in all the varieties of water power, it arises primarily from the action of gravity upon a bulk of water; in steam power the force arises from the attraction of fuel for oxygen; in galvanic power, it is the attraction of the positive element of the battery for the oxygen of the water. We may also obtain power by the attraction of adhesion, the attraction of capillary action, the attraction of endosmosis, for whenever active attraction is generated, force results; that is, a capability or tendency to supersede former attractions, and thus produce motion. From any kind of attraction we may obtain force, which, if rightly used, may produce motion.

(183.) Force arising from some new attractions may destroy any other kind of attraction; hence, it may interfere with the attraction of cohesion. It is by force that a body is beaten out or extended; it is by force that a metal is drawn into wire. Force may also disintegrate a body, as in breaking a lump of sugar. Force arising from some new attraction destroys attractions of cohesion, as in pulverising bodies, force produces the effect. All the modifications of cohesion and crystallisation may be acted upon by force. Moreover, the peculiar polar condition of bodies called magnetism may be either caused or destroyed by the proper application of force.

(184.) The attraction of chemical affinity only differing from the preceding attractions by the force being exerted between elements of dissimilar nature, is capable of being overcome by force. The familiar example of such a destruction taking place from the application of force, is well seen in the chloride of nitrogen, as the slightest force will separate the elements in combination. The ready explosion of the fulminates of silver, of the pure ammoniuret of silver, are also good examples of a similar action; but even a more familiar example may be found in the percussion cap, or even of a lucifer match, for in these cases force decomposes the compounds of chlorine, oxygen, and potassium, called chlorate of potash, and thereon a new combination or detonation ensues.

(185.) In this place, however, we have more especially to consider the disturbance of the attractions of masses of matter by force, and to study the effects of motion, it is preferable to consider the bodies submitted to that force to be at rest, that is, although exposed to a variety of attractions, to have occupied some definite situation between them all. It is not essential for our investigations that the body under consideration should be really at rest, but only at rest with regard to other bodies in its neighbourhood; hence, all bodies on the earth's surface are said to be at rest, although progressing round the sun at a most enormous rate. Force may act upon bodies in motion, but we shall first consider force acting upon bodies at rest.

(186.) The simplest form of motion is seen when two bodies are mutually attracted towards each other. The energy of this attraction is proportionate to the intensity of the attraction acting between the bodies. In this case the attraction of two bodies causes directly the phenomenon of motion, an instance of which is seen in a body falling to the earth. When two unequal bodies are attracted, the lesser body moves through a great space, the greater body through but a small space. Thus, when a stone and the earth mutually attract each other, the stone moves through a great space, but the earth also moves towards the stone through an inappreciable minute space.

(187.) Besides the production of motion from attraction, philosophers have conceived another active property which they call repulsion, because when bodies in a certain state are brought in opposition, one recedes from the other. Two bodies in a polar state, as two magnets, repel each other if two rods of a similar nature are brought near. The phenomenon of repulsion, however, if carefully examined, is only found to be a modification of attraction; for if a body is held in any definite position by a multitude of attractions exerted in different directions, the moment one of the forces is suspended, destroyed, or neutralized, the body moves in the resultant of the others. Hence, the effects of repulsion are either owing to the destruction of one of the attractions holding a body in a certain position, or the action of attractions acting in opposite directions, as in the case of the repulsion of two magnets. Repulsion is not an active property, but only an effect of a new attraction acting contrariwise to a previously existing one. The great Dr. Young, indeed, seems to consider that repulsion is only a modification of attraction, though, unfortunately for science, he did not point out the exact nature of such modification.

(188.) Another fanciful creation of philosophers is to be found in a property which the older writers called levity, and in some respects it is analogous to repulsion. Balloons were supposed to rise in air by a certain something called levity, corks to rise in water from a similar cause; but in these cases the lighter body, or that supposed to be endowed with levity, rises because it is not as heavy as the surrounding medium, which accordingly rushes into its place, so that in reality the heavy body around the lighter one falls, but not the lighter one rises.

(189.) Having now seen that all cases of motion arise either from the body moved being directly attracted to another, or from some new attraction destroying or neutralizing part of the attractions which hold a body in its situation, we have now particularly to point out, that to produce any definite effects of motion by new attractions, the force must be the same in amount. The effect of the above consideration is highly important in practice, for if a certain force is produced by the attraction of any number of atoms of a particular kind of matter; when we change the matter, then will the number of particles of matter required to produce the same force be more or less according as the intensity of the other attractions increase or diminish.

(190.) On this account, when we seek to obtain force, we are careful to select a substance of low equivalent, because but little would contain many atoms. Hydrogen and carbon, whose equivalents are respectively 1 and 6, are peculiarly well adapted for this purpose; but, in this case, in equal weights of the two bodies carbon contains six times a less number of atoms than hydrogen, and consequently, on that score, is only one-sixth as good. If we used gold for the same object, 200 grains would only be equal to one of hydrogen. Having selected a body of low equivalent for the production of force, we should take care that the attraction between it and the substance with which it combines should be as intense as possible. In our ordinary mode of obtaining power, carbon and hydrogen are again preferable, because the energy of their combination with oxygen is very great, and, moreover, the value of the materials is little, nature having kindly afforded us a liberal supply. If we compare carbon and hydrogen with zinc for the production of force, we find a wide difference in these respects, the equivalent of the latter being thirty-two times more than hydrogen, and its energy of combination with oxygen not so intense. The value of zinc is far greater than coals, the usual compound of hydrogen and carbon we employ for our purposes. Carbon is also well adapted for the production of force, because it combines with two portions of oxygen.

(191.) It is upon this principle, and this principle alone, that zinc in a voltaic battery has never been turned to any profitable account for the production of motive power. Zinc is forty times dearer than coals. It has on an average eight times higher equivalent, and its energy of combination with oxygen is, perhaps, one-third that of carbon or hydrogen, and consequently would require three times as much in bulk to produce the same effect. If we multiply these figures together $40 \times 8 \times 3 = 960$, that is, zinc as a source of power is 960 times dearer than coals. In consequence of this, a steam-engine costing one shilling to perform any work, would be 960 times cheaper than a zinc voltaic battery, and therefore the battery would cost for the same work nearly 50*l.* Electro-magneticians have too much neglected these facts, for although year after year patents have been taken out for contrivances to economize and adapt the power, yet the obstacle to the use of electro-magnetic power, namely, the imperfections of the attractions causing the force, is altogether overlooked. The preceding facts are by no means encouraging to those who seek power from electricity; but still, if galvanic power admits of being applied without waste, it is possible that it might be used in some few cases with advantage. In steam force we loose all the power required to raise water from the temperature of the air to the boiling point, and even all the power is wasted in converting water into steam. It is only upon the feeble chance that 1000 times more force is wasted in steam than in electro-magnetic force, that the voltaic battery can supersede the steam-boiler.

(192.) I know nothing that has afforded to me greater pleasure than the considerations that are forced upon us from the mode in which we have shewn that force arises, for it not only proves that the experience of all mankind is correct in using hydrogen and carbon for the production of power, and all effects produced by new attractions, but it shews that nature has accommodated her operations to these principles. She has provided that every plant, every animal, should take advantage of carbon and hydrogen for the conduction of their numerous operations and processes.

(193.) For the production of the phenomena of motion, the power required to cause the effects in a given time, that is, with a definite energy, is directly as the distance moved and the weight of body to be acted on. The same power may either move a great weight through a small space, or a small weight through a large space. For this reason a pound moved through an interval of a foot would require the same force as twelve pounds through an inch. This principle is the basis of mechanics, or the application of combination, that is, the combustion of fuel, or gravity powers; for force only arises from new attractions, and by whatever attractions generated, cannot in any way be subsequently increased. It is the application of force, either to great weights for small distances or small weights for large distances, which alone gives value to levers, screws, inclined planes, and, indeed, all other mechanical contrivances. As a general proposition, to impress the above facts on the mind, it is generally stated, that what is gained in weight is lost in distance, what is gained in distance is lost in weight. The relative energy of one motion through a given space as compared with another is called its velocity; so velocity with regard to the effects of motion is the same as intensity with regard to electrical effects.

(194.) Besides, however, the question of weight and distance, adaptations for the application of force give a certain direction to the action; but in all the mechanical contrivances for giving direction and regulating weight a certain power is wasted with the machinery by friction.

(195.) If we seek for the cause of the possibility of substituting weight for distance, and distance for weight, we find that to overcome the active attractions by which a body is held in any definite situation other attractions, whose force is equal to the former, must be exerted. When a body is moved the active attraction which formerly held it still continues to act, so that if a pound is moved through twelve inches, the active attractive force would be twelve times more than if moved through only one inch. For this reason twelve pounds could be moved by the same force through one inch which was required to move one pound one inch. Philosophers have assumed that a body in motion would go on for ever if not interfered with; but this is to my mind an assumption, for we have already shown that there could be no motion of matter without other matter to attract it or act upon it, for motion either arises directly from the generation of some new attraction; or, secondarily, from new attractions destroying a portion of the old ones, and thereby giving a preponderance to the rest. Under these circumstances a single atom, or even a single mass of matter could not suffer motion if alone in the universe; and if two masses of matter existed, no matter how many millions of miles apart, their mutual action on each other must ultimately cause rest.

(196.) On the application of force to matter certain effects are noticed, which philosophers have supposed to arise from some principle of matter which they call inertia, and define to be, an indifference to either state, rest or motion. These effects are due, when the body is at rest, to the attractions keeping it in position, although exactly counterpoised, being an obstacle to the application of force. When the body is in motion, the force causing that phenomena acts as an obstacle to any attractions seeking to keep it at rest. If, however, force even but slightly exceeds the attractions of situation, or the attractions of situation exceed force, the effort of the new attraction overcomes the previously existing ones, though the action is slow for want of energy. A good example of a very small force acting upon matter, notwithstanding immense inertia, is seen in a delicate pair of scales, where sometimes a grain will overcome the inertia of upwards of a hundred weight of matter. Perhaps it would be correct to say, that the phenomenon called inertia is owing to the difficulty of alteration in the attraction to be transmitted from particle to particle of the mass on which other attractions are acting, and that difficulty, in some cases, is so great as to cause matter, as far as we can see, to resist the application of very minute force.

(197.) If we study the effects of force upon a mass to produce motion from a state of rest, we find, that if that force acted equally on the mass in every direction, no motion would be the result; but if it acted at one point, or in one direction, provided it could overcome the force acting in the opposite direction, the body acted upon would move in the resultant of the other forces. The force acting in one direction is communicated from atom to atom of the whole mass. If, however, the attractions holding together the particles of the mass are largely disproportionate to the new attraction producing the force, they resist the application of the force, and the active attraction which resists the application of force causes (if the force is accumulated and acting through the intervention of a smaller body in motion) a force to react upon that body, and the small body receives an impulse from the larger, as if the force was first communicated to the larger body. This property is called re-action.

(198.) The action of force to interfere with the attractions giving position to any body, is progressive. It begins at one point, and is gradually communicated to the rest of the mass. Hence, attraction being an active and spontaneous property of matter, causes the particles whose attractions were at first interfered with to take on, or endeavour to take on, similar attraction by which it was held in its certain position. The force to destroy these attractions still continues to act, and a sort of conflict arises between the force tending to destroy the old attractions, and their power of generating a similar active attraction to hold it in its situation. These two forces thus conflicting, produce, as the learned call it, action and reaction, which finally ends in equilibrium.

(199.) Action,—a tendency to the destruction of attraction; reaction,—a tendency to maintain them; give rise to a series of effects possessing the deepest interest, for when the energy remains constant it gives rise to the phenomena called vibrations. By these vibrations man is made acquainted with the external world; by vibrations, he sees, he hears, he smells, and, perhaps, even in part feels; by vibrations he measures his life, and the duration of all things; vibrations, therefore, are of the utmost importance, and must be reserved for an ample examination in the next chapter.

(200.) When the phenomenon of motion is produced, it is not necessary that a total destruction of the attractions by which a body is held in equilibrium, or in any definite situation should ensue, but only a partial destruction, or the destruction of one set of forces with which it is held in its situation. Thus, a ball suspended by a cord from a ceiling is kept in its situation by two forces; the force of gravitation towards every other particle of the globe, and the force of cohesion of the string. If the force of gravitation to the earth is destroyed by an impulse from below, all the other forces exist, and now, having the preponderance, it moves by virtue of its attraction to all the particles of the air, ceiling, and even the celestial bodies above it, and it moves in the diagonal between them.

(201.) It is by no means necessary that any destruction of attraction should take place to produce motion, for if any one of the attractions are increased which hold a body in its situation, motion would arise.

(202.) As force arises from new attractions, and possesses the properties whether derived from the attraction of chemical affinity, the attraction of adhesion, or capillary action, the attraction of endomosis, the attraction of gravitation, or magnetism, it may, if sufficiently intense, not only destroy the equilibrium of the position of a body with regard to other substances, but even destroy its attraction of cohesion and aggregation by separating it into the finest powder. It may destroy magnetism, or overcome the attraction of chemical affinity, and compounds may be resolved into their ultimate elements. The much respected Hennell afforded an awful instance of such analysis by being blown literally to pieces from a slight force applied to a chemical compound.

(203.) When force is generated by attraction it may be accumulated or husbanded; thus, a little force acting for a long period, may accumulate till it is capable of producing an enormous force; and, conversely, a great force generated in a few seconds may be economised so as to produce a little force for a long period. A man in less than a minute can wind up a Dutch clock that can go for a fortnight; that is, he accumulates the force by raising the weight, and this weight acts for a long period to keep the clock going. The converse of winding up a clock is seen in contrivances for embossing, where motion is gradually given to a large fly-wheel, which accumulates a moderate force till it becomes an enormous one, and when force is sufficiently accumulated, the blow is struck with an awful crash. A hammer is an instrument for the accumulation of force, for the force is accumulated during the whole time of the strike, but it is applied only when it inflicts the blow. Enormous force is exerted in that manner. A very small stone let fall from a great height accumulates force during the whole time it falls, because the attractions of gravitations are continually being added; from this cause, a small stone falling a yard, would only produce a slight effect if it struck a human being; but if the same stone fell down a deep place, it might kill the person if it should chance to fall upon his head. Well-diggers and miners are very careful to avoid small particles of earth, or even water falling from a great height, as they suffer great inconvenience and injury from the force which those little particles accumulate.

(204.) There are hundreds of other instances of the accumulation of force besides those last mentioned; for, wherever force is being generated without spending itself by the actual destruction of other attractions, it is certainly accumulated. The property of elasticity is frequently taken advantage of to accumulate force; for a spring, which is an elastic body, may be made to accumulate enormous force, and aeriform bodies, which are also elastic, may accumulate power indefinitely. The elasticity depends upon the resistance which the body offers to the destruction of attractions, and therefore is particularly favourable to the accumulation of force. The acts of percussion and rolling are the effects of accumulated force.

(205.) Nothing is more dangerous, or more to be avoided, than an uncontrollable accumulation of force, so that wherever force is generated, care should be taken that it should not over-accumulate, or else the most distressing and fatal accidents might occur. Steam is a good example of the accumulation of force, when under high pressure the force may accumulate till the boiler bursts; hence the great danger of subjecting water to heat without a proper escape for the steam. In casting metals, a few drops of water occasionally from this cause produce terrific explosions. Force is sometimes, in a similar manner, over-accumulated in fly-wheels, so that the wheel at last flies to pieces and destroys every thing in its neighbourhood, resisting all attempts to resist its action.

(206.) Hitherto I have principally called attention to the effects of force on bodies at rest; but if we examine its effects on bodies previously set in motion by other forces, we find a perfect harmony in all the phenomena. If, when a body is in motion, a force acts upon that body in the same direction, the motion is increased; and if an addition of force is continually taking place, the acceleration is uniform, hence called accelerated motion.

(207.) If the new force acts in the opposite direction to the body moving, as much of the motion is destroyed as would have been produced by the force acting on the same body at rest. The reason of these phenomena are so perfectly obvious that they scarce require comment, for where force acts in the same direction as a previous force, the effect is the same as though the body were acted upon by the sum of the forces; if the force acts in an opposite direction the result depends upon the balance of forces; hence, if the opposing force is greater than the force first causing the motion, the difference acts as a force, and produces motion in the opposite direction to that first existing.

(208.) If the force is applied to a body in motion in any other direction besides that of either acting in conjunction or against the previous force, the effect of the two forces is the same as if the two forces acted separately, one following after the other; that is, the body moved occupies, after the action of the two forces conjointly, that spot which it would have taken had the forces been applied separately.

(209.) The energy with which each particle of a body is moved, *i. e.* the velocity, multiplied by the number of particles, is called momentum, which being always the result of new attractions, is force which may produce any other effect of force. Force indeed has been defined to be that which causes motion; but as that is no material thing, or imponderable agent, producing motion, the definition is exceedingly bad, or rather no definition at all; for force is the abstract idea of new attractions acting upon bodies in such a way as to destroy the attractions giving them position, and thereby causing motion.

(210.) Having thus briefly noticed the effects of attractions acting upon attracted matter, the idea of which is called abstractedly force; and having also noticed the particular effect upon the attractions of masses of matter which is called motion, whereby their relation to other masses is interfered with; we must take a short review of mechanical contrivances and instruments for regulating the phenomenon. These possess but few points for consideration and study. All mechanical devices and instruments agree in possessing a point where some new attraction is taking place. In the steam-engine this place is the fire, where fuel is generating a new attraction between itself and the oxygen of the air. The second point, which is not universally present, though common to most machines, is the point where force is accumulated, to be used as it may be required. In the steam-engine force is accumulated by the generation of steam and its subsequent increase in quantity. There are, moreover, contrivances to regulate the force, which in the steam-engine is sometimes the governor. The next point we have to consider is, the point where motion of some body is produced, and the apparatus for regulating the direction and extent of the motion, and lastly, the point where the desired effect is caused through the intervention of the moving body. The accomplishment of this desired effect is the destruction of some attraction, so that in all machines, the first point is the generation of attraction, the last the destruction of other attractions.

(211.) The division of machines into these six points is exceedingly useful, for they exist more or less modified in every case of the application of force. By this division we are enabled instantaneously to analyse any mechanical contrivance whatever, and by an examination of these few parts we are enabled to perceive, no matter how complicated the mechanism, the relative value of any new machine over others before known.

(212.) So much has already been said of the first point, or the generation of force, throughout this chapter, that further details are quite unnecessary, for we have already pointed out that force is the result of new attraction, and its amount is equal to the intensity of such attraction multiplied by the particles attracted.

(213.) The part of the apparatus devoted to the accumulation of force must be so contrived that the force does not over-accumulate, or dreadful disasters may arise; hence, in the steam-boiler the safety-valve is placed, which regulates this with the utmost precision; the moment the pressure is above the amount which the engineer thinks sufficient for his boiler to bear, the extra force is relieved by the escape of the steam. Of course this prevention of too great force by its exhaustion is attended with loss of fuel; consequently, in all contrivances, the force should be generated as nearly as possible at the same rate at which it is consumed, in order that no waste may occur from useless expenditure. Other cases of over-accumulation of force are to be found in the raising of too great a weight to set in motion the wheels of a clock, which would break the string; and hundreds of other cases might be cited were they not sufficiently apparent to the most casual observer.

(214.) The third point, or the regulation of force, is generally effected by some contrivance by which a resistance is offered to the force allowed to act upon the matter receiving the impulse. In a steam-boiler the force is regulated by the quantity of steam admitted by a certain aperture, the size of which is varied by a stop-cock. In a watch the regulator acts upon a spring which counterbalances the force to any desired extent. For the constant regulation of force where machines are put to very irregular amount of work, the force is allowed to accumulate in a fly-wheel, the momentum of which ensures great steadiness in the work. Almost all machines perform their work irregularly; that is, in the course of a minute they perform several operations, all requiring different amounts of force. The effect of the fly-wheel in these cases is, by having more force accumulated than the heaviest work requires, to cause the irregular application of force to be attended with no inconvenience.

(215.) The direction of the application of the force for the production of motion should always be in the direction the motion is wanted, otherwise the force accumulates in the machinery, and requires other force to neutralize that so accumulated. A waste of power in this manner is seen in the piston, for, in being raised, a certain amount of force is accumulated in the piston itself which must be counterbalanced before the down-stroke can take place. On this account it is very advisable to diminish, as much as possible, the bulk of the parts of the machine which exist between the point of the application of force and its immediate use. Hence the oscillating cylinders of Penn's engines, which are so much in use for the river steam-boats, have great advantage, on the score of economy of fuel, and speed, over the old forms of construction. In these engines there is much less weight of metal to waste force by the neutralization of that continually accumulating in the machinery itself. No other plan, with regard to steam power, has come into use, except the up and down, or backward and forward motion, although great power is lost by a reversal of the direction of the application of the force. Upwards of a hundred patents have been taken out for rotatory engines, of which scarcely one is in existence, and none in common operation. The numerous trials made to form engines in which the power should directly be applied in a circular manner, and yet without success, seem to point out that there are not only difficulties in practice, but faults in the rationale of such an attempt. If we seek the cause of the failure of rotatory engines, we find that in no engine of this construction can the power be applied in a right line, so that the same objection exists to that mode of applying power as to the ordinary piston-and-rod motion. There is, however, this difference, that in the latter case the accumulated force is neutralised at each reversal of the direction. In the former, or rotatory engine, the force is continually accumulating and continually being neutralised.

(216.) The apparatus for regulating the direction and extent of motion varies extensively, according as we require great force and a small motion, or a great motion and a slight force. The law to which such contrivances are obedient, is the following, namely, that the number of particles moved multiplied by the extent of motion in the vertical direction, is equal to the weight multiplied by the extent of motion in the vertical direction. The cause of the reference of the motion to the vertical disturbance is very easily understood, for the vertical direction is that in which the force of gravitation is exerted, and as every body is retained in its situation on the earth's surface by the force of gravitation, the extent of disturbance of any number of particles so retained in their situation, point out the extent to which any other number of particles might be moved by the same force.

(217.) A great variety of adaptations are employed by mechanics to regulate the weight or distance moved, for as the weight diminishes, the distance through which it moves may be increased, as the weight increases the distance may be diminished.

(218.) Levers are contrivances for effecting this object; for according as they are arranged to carry the weight or thing moved over a large or a small extent, their peculiar advantages depend. In the consideration of the rationale of levers, their occasional division into three classes, according to the situation of the fulcrum or fixed point, is frivolous and useless, for all follow the same law, and all are of utility to mankind by the power they offer of regulating weight and distance upon the application of force. In every case we can move a great weight through a small space by a moderate force by applying force a sufficient time to carry one end of the lever through a great space. By this means a man, by carrying his animal strength through a great distance, say a yard or two, may lift enormous blocks of stone half an inch, which would resist every attempt to be moved by any other means. Sometimes we are desirous to move a small weight through a great space by the same amount of power which was used for the converse application. This object we can readily obtain by applying the force through a small part of the lever, and arranging the weight in such a manner that it is acted upon through a greater space. However, neither in these instances, nor, indeed, in any other, can the power be increased beyond the force first given by the new attractions. By no contrivance can the force imparted to any body be increased without the further generation of new attractions; and by no complication of mechanical contrivance can force be generated without new attractions; consequently these devices should be esteemed as convenient adaptations for the application of force, and care should be taken that they be not viewed in any other light.

(219.) The wheel is similar to the lever in the principle of its adapting force to the purposes required; for according as motion is required to be evinced in distance or weight, they apply for the purposes of mankind. A small weight playing for a great space over a large wheel, would act in the same way as a great weight playing round a small wheel. When we require the slight motion of a great weight, we apply the force round the circumference of a very large wheel. When we require distance, we apply the same force round a small wheel, connected with some part that can admit extensive motion. We thus see that wheels, like levers, possess the capability of moving great weights a small distance, or of moving smaller weights for a greater distance. The pulley is a beautiful example of small power, by the adaptation of wheels moving a great weight for a small distance. A man may raise enormous weights to the top of a steeple by applying, by means of pulleys, the force of this body through a space six or eight times the height of the steeple; but in so doing we must remember he does not save one tittle of power, but only applies or adapts his available strength at each instant to the best advantage. The windlass is another admirable example of the adaptation of force, for a man applies his animal force, by means of a handle, through a great space, and by the small size of the wheel on which the chain is coiled the weight is only raised a few inches by each revolution.

(220.) Screws are examples of a moderate power exerted over a great distance, producing great force for a short distance. The power of some screws is enormous, especially in those cases where the handle is made to take an extensive revolution, as in the ordinary domestic linen-press. The vertical power of a screw is dependant on the number of revolutions it must take to pass a certain distance.

(221.) Inclined planes act in the same way as screws, for by their means we are enabled, by a long continued small force, to raise enormous weights. The value of the inclined plane for this purpose is the increase of distance traversed of the weight over the vertical motion which we require to give it. Hence the more oblique the inclined plane is to the perpendicular, or the more horizontal the obliquity, the greater weight we are enabled to move by a long continued small power; the more it partakes of the perpendicular, the less, inasmuch as the obliquity to the perpendicular increases the distance over which the force has to be exerted to perform the desired work.

(222.) The Brahmah hydrostatic press is another example of a little force exerted for a long period, or through a great distance, producing the effects of an enormous force for a short distance; to obtain the effects of this force in the most exaggerated manner, we should have a pump with a very small bore to throw the water into the cistern. The effect of such an arrangement is virtually the same as the lever, screw, pulley, and inclined plane, for by it a little water is carried a long distance, which moves a great bulk of water a little distance.

(223.) What mechanics is to the generation of force, by solids, in virtue of their attraction of gravitation, to the action of force on solids, to its propagation through solids, and to the production of motion in solids,* hydrostatics and hydrodynamics are to the same effects in fluids; that is, the generation of force by virtue of gravitation, the action of force on fluids, its propagation through fluids, and the motion of fluids. Hydrodynamics has no different law, no essential distinction, from mechanics, save and except that fluids are the subject of the investigation instead of solids.

(224.) The force generated by fluids, by virtue of gravitation, is like force generated in the same way by solids, the effect being equal to the intensity of the attraction of each particle; *i. e.* the specific gravity multiplied by the number of particles attracted, *i. e.* the bulk. The force of gravitation of water, at a certain temperature, is taken as the standard of power by engineers, and they usually represent the power of any machine by the extent to which it will raise a column of water in a given time.

(225.) Force may be imparted to fluids, and transmitted through them. In many cases it is

---

* Mechanics sometimes is supposed to include hydrostatics and hydrodynamics, &c.

found extremely useful to make fluids the medium of force, for on account of the mobility of fluids the force is exerted equally in every direction. Brahmah's hydrostatic press is an excellent practical example of this property of fluids to have force diffused equally throughout them, whereby the force is exerted equally in every direction. In this machine, pressure exerted on one small spot by the piston of a pump, acts with a certain force on the fluid, say fifteen pound to the square inch. This force is diffused equally over the whole fluid, and an equal force is manifested by every square inch of the cistern; consequently, if the area of the piston of the cistern contains twenty square inches, an effective pressure may be obtained of three hundred pounds, though we must bear in mind, that a pressure to a similar extent is exerted against the sides of the vessel. Practically, it is usual to obtain by the force of a man exerted through a small pump, a pressure of twenty to thirty tons by this machine. We must remember, however, that no more force is produced than what can be accounted for by the new attractions; for although the pressure exerted by the piston of the cistern is so much greater than at the pump, yet the distance moved is proportionally greater at the pump than the cistern.

(226.) The uniform diffusion of force through liquids, or, rather, the exertion of the force of fluids in all directions, is extremely important, and full of curious interest, for many apparently unaccountable phenomena are readily explained upon that fact. Thus, if a body be plunged into a fluid, the force of gravitation of the particles of the fluid being equally diffused through its bulk, will balance the force of gravitation of the new body to the extent of the force which would be generated by the bulk of fluid which it displaces, and consequently the mass of matter immersed is as much lighter as the same quantity of fluid which it displaces and keeps displaced. In this case, the immersion of a body in a fluid requires as much force to displace the fluid which before occupied the same place, as the force of gravitation which that bulk of fluid exerted to keep itself in that situation; consequently, to overcome the former attraction of the fluid a similar amount of the attraction of gravitation of the solid must be exerted. Hence, a body of a less specific gravity than water cannot entirely be immersed by its own weight, though it may partially be immersed by the total attraction of gravity of the mass. If a body is of greater specific gravity than water, as much of its force of attraction to the earth is neutralised, or counterbalanced by the water, and therefore the body is as much lighter, or weighs as much less as the weight of the bulk of water, the former attraction of gravitation of which it overcomes by the act of immersion.

(227.) We practically take advantage of the preceding fact to ascertain the bulk of a body; for the difference of a body weighed first in air and then in water, expresses the weight of the bulk of the fluid it displaces. Hence, by this single process, provided we know the weight of any definite bulk of the fluid, we can readily learn the cubical contents of the most irregular-shaped bodies.

(228.) This elegant operation is continually used to find the specific gravity of bodies; that is, the attraction of a definite bulk to the earth. As the relative specific gravity of any two bodies is directly as the weight of equal bulks, we have only to learn the bulk of the body by the above simple process, and compare its weight with a similar bulk of any other matter. Specific gravities, however, are referred for convenience by philosophers to the specific gravity of water, which is assumed as unity; to find the specific gravity of any given mass of matter, we state as the weight of the same bulk of water, is to the weight of the bulk of matter, so is 1 to its specific gravity. To take an example: a stone weighing in air nine grains, and in water but six, would show that the bulk of water displaced would weigh three grains; therefore, to learn the relative specific gravity of the stone to water, we state, as the bulk of water weighing 3 grains is to the same bulk of stone 9 grains, so is 1, the specific gravity of water, to 3, the specific gravity of stone.

(229.) There is a beautiful mode of ascertaining the specific gravity of a fluid by the relative force which is required to displace any bulk from its situation, for by weighing a solid body in two fluids of unequal density, their loss of weight, that is, the force required to displace the fluids in the two instances, shows the relative specific gravities of the fluids. Hence, if the same stone weighed three grains in water, and nothing in another liquid, the difference of weight in the two cases would be 3 grains; hence, the specific gravity of the two fluids would be as 1 to 3.

(230.) There are other singular cases dependent upon the equal diffusion of forces through fluids, and the necessity for a certain force to be generated to displace a certain number of particles, and to keep them displaced. Although they appear unaccountable on the first examination, they are not so intricate but that the rationale may be readily discovered. A cup full of water will weigh no less if a hollow sphere be immersed in the cup, and cause nearly all the water to be spilt. The reason is obvious—a certain force must be spent to cause the sphere to displace the water, and keep it displaced, and that force must be equal exactly to the force which kept the water in its place; hence the water between the sphere and the cup must be acted upon by a force of a similar amount as before; and therefore the weight of the cup with the hollow sphere with water between it and the cup, is the same as the cup full of water. If a solid mass of platinum be suspended in the cup full of water, the effect is the same as of the hollow space; for why? the greater part of the force of gravitation of the platinum is counterbalanced by the string with which it is suspended, but a certain part is destroyed by the immersion of the platinum in the fluid. The part of the weight lost by displacing the fluid is equal to that which before caused the fluid to be retained in its place, and the remainder of the attraction of gravitation is counterbalanced by the string; hence, no more force acts upon the scale to increase the weight.

(231.) Another phenomenon of great practical importance is, the counterbalancing of a large column of water or other fluid by a small column of equal height; for the sides of the vessel act to the particles of water in the small column, what the fluid itself does to the water of the large column. Whenever the force of gravitation of the water produces motion of its own particles, the particles of the little column of water must move through a great space to move the particles of the large column through a small space. In this respect, the force obtained by the motion of fluids is similar in its action to a force applied either by a lever, screw, inclined plane, or a pulley. A high column of water contained but in a small pipe, will burst everything before it; but this enormous force only produces motion for a small extent. This phenomenon is called the hydrostatic paradox; although, when rightly explained, the puzzle is to discover in what the paradox consists.

(232.) This latter property is not peculiar only to fluids, because occasionally the same result is seen to arise from the force of gravitation of fine powders. The ancients, in building pillars, sometimes filled up the interior with mortar, or light materials, which, after the lapse of centuries, degenerated to powder. This powder has been known in many cases to burst the pillars open by its weight, acting as a column of water. It is, therefore, of great importance to architects to be careful to prevent such a misfortune, or centuries hence their noblest work may be destroyed by the uncontrollable power arising from the gravitation of powders.

(233.) We have already mentioned that the motion of fluids was similar in its general laws to the corresponding motion of solids, for what is gained in weight is lost in distance; what is lost in weight is gained in distance: the distance only having reference to the direction of the force of gravitation, which is exerted in the vertical direction, or to the centre of the globe. This general principle, although to the scientific man perfectly intelligible from the considerations fully pointed out in a former part of this chapter, does not seem to have been generally understood by a class of persons who delight to cloak ignorance under the term practical knowledge, for hundreds of schemes have been put forward by these individuals to obtain power by high columns of water, which they conceived it would be worth while to raise to a great height: but such contrivances have always failed, because it would require as much power to raise the water first, as the water thus raised would subsequently give rise by its attraction to the earth. In the case of the columns of water, although the column of water of small diameter will balance a column of large diameter, if the small column is made the mover of the great column, it then follows the laws of all other instances of motion, namely, that the small force moved through a great space, will only move a great weight through a small space, so that no advantage can be taken of the hydrostatic paradox, as a moving power, beyond that which can be accounted for by the attractions.

(234.) Of the effects of force to put fluids in motion I need say no more; for whether we raise them by pumps, screws, or any other contrivance, they obey the same laws, and the same force will be required to raise a ton, or any other bulk of water, to a given height, as would be produced by the fluid thus raised in falling to the ground. The same remark applies equally to all fluids; but the force required with dissimilar fluids would be proportionate to their specific gravities; hence, a pint of mercury would require thirteen times more force to be raised or moved upwards than a pint of water, because the pint of mercury is attracted to the earth thirteen times stronger than a pint of water. It is no matter how the water is raised; for new attractions must be exerted to raise water, equal to the attractions by which the water was kept in its situation.

(235.) There are many cases in which force obtained by the attraction of fluids to the earth, is transmitted through particles of the same fluid, and being accumulated in the fluid, is finally applied to some machinery to do any definite work. Such cases are technically called cases of water power. The force in these cases is equal to the number of particles of water multiplied by the distance through which the force of gravitation is exerted. The various contrivances for employing water power have different names, according to circumstances. The over-shot wheel, common in hilly and mountainous countries, although it requires but little water, demands a great fall. A noble instance of such a wheel is to be seen on the Dartmoors, where an over-shot of fifty feet diameter produced enormous power by a small stream of water. The breast-wheel, common on low lands, and in the low rivers, is an example somewhat the converse of the over-shot, for it requires a great body of water, though the fall need be but slight. The stream-wheel requires hardly any fall at any one particular point, as the force is derived directly by the rapid motion of the liquid, though that rapid motion must have been given by some fall higher up or lower down the stream, and consequently is derived from the attraction of gravity. There are other ways of obtaining water power by the gravity of masses of fluids, but the above instances are amply sufficient for illustration. In investigating any case of water power, we should look for the distance through which the water or fluid falls, and the bulk of water which acts.

(236.) So much for hydrodynamics, similar to mechanics in its obedience to the laws regulating the production of force by attraction, and the phenomenon of motion by the disturbances of attraction. Unlike mechanics, which only comprises the effect of these laws on solids, Hydrodynamics considers the effect of these laws on fluid bodies. Hydrostatic and mechanical action is like electric action, inasmuch as new attractions destroy others; but unlike electrical action, inasmuch as electrical effects are the effects of attraction acting on chemical attractions, cohesions, &c.; whilst mechanical actions treat of the effect of new attractions, acting on previously existing attractions of gravitation.

(237.) There is one more science which we have to consider in this chapter, which is the science of pneumatics, which is to aeriform bodies what hydrostatics is to fluid, or mechanics to solid bodies. It is useless again to go over the laws of these two sciences; suffice it to say, that the laws of the generation of force, its destruction, &c., are the same for these three sciences. In pneumatics we shall consider the peculiarities of the physical state of aeriform bodies in producing these various phenomena.

(238.) Aeriform bodies have a certain weight, that is, being matter, they are acted upon by the force of gravitation. Gases give a force by gravitation equal to the specific gravity of the gas multiplied by the number of particles attracted. The atmosphere, by its attraction to the earth, is found to give a force equivalent to a column of mercury of about 30 inches, or to a column of water of nearly 33 feet, or we may say that the atmospheric pressure, that is, the attraction of a column of air, exerts a force of about fifteen pounds to the square inch.

(239.) The weight of the atmosphere, or its attraction to the earth, varies under circumstances which are very imperfectly understood; hence the force varies to the extent of $2\frac{1}{2}$ inches of mercury, or nearly three feet of water. These variations are generally followed by extensive motion of the air or wind, hence the weight of the atmosphere is looked upon as an important phenomenon.

(240.) We learn the weight of the atmosphere by finding the height of any fluid which it balances; hence the use of mercurial and water barometers, which are formed of tubes exhausted, that is, containing nothing, or comparatively nothing. These tubes communicate with the fluid in such a manner that the pressure of the air may drive up the fluid to a certain vertical height. The height to which the fluid is raised in the empty tube, is in proportion to the weight of the atmosphere. The marks on the barometer indicate the number of inches, in order that we may by simple inspection ascertain how high the mercury rises in the tube by the atmospheric pressure. Mercury barometers are exclusively used to ascertain the weight of the atmosphere, though there is a water barometer at the Royal Society, fixed as a scientific toy.

(241.) To take advantage of the force produced by the gravity of gases they must act upon a perfect or a partial vacuum, otherwise the force produced by one portion of gas would be counterbalanced by that generated by another. The effect of force derived from the weight of the atmosphere is daily to be witnessed in our ordinary pumps, for we first produce a vacuum in the tube, which then becomes filled with water by the force of the atmospheric pressure. On this account the water will only rise till it counterbalances the atmosphere; hence pumps will not act beyond 36 feet, because the weight of atmosphere never exceeds or even equals that point. In practice no pump should be more than 30 feet from the sucker to the water.

(242.) Another pretty example of the effect of the weight of the atmosphere to produce force is seen in certain machines. At the Mint the air is exhausted from a cylinder, and the pressure of air acting suddenly upon a piston produces a most tremendous blow, and impresses the effigy of the sovereign upon a lump of metal.

(243.) Force is readily accumulated in aeriform bodies by virtue of their compressibility and elasticity. The air-gun is a capital example of such accumulation. The sportsman, before he leaves his habitation, may accumulate sufficient force to fire many bullets. The compression of aeriform bodies is, perhaps, one of the most convenient modes of accumulating force, and is invariably adopted in steam-engines. The law of distance and weight equally applies to gases as to solids; therefore, in the accumulation of force it is necessary, after a certain amount is accumulated, to use a compressor of very small bore, in order that a small quantity may be moved through a considerable space by the small force of our bodies, or else the force of our bodies would be counterbalanced by the accumulated force, and we could not carry on the operation further. In the air-gun, or other apparatus of this nature, the accumulated force at last is sure to counterbalance the force attempting still further to accumulate it.

(244.) The effect of accumulated pneumatic force to produce motion is like other forces, for it may be exerted to overcome a great obstacle for a small distance, or a small weight for a great distance. The blasting of rocks by gunpowder affords a capital example of an enormous weight being moved through a small distance; the discharge of a rifle-ball, however, is an example of a small weight moved through a great distance. The ordinary discharge of a gun admirably shows the last point, block up, however, the muzzle with a piece of paper or a few leaves, and the former property is shewn by its bursting the gun. In a book designed to teach principles the practice may appear improper to be discussed; but the fact of a slight stoppage at the muzzle of a gun rendering the instrument liable to burst, is too important not to require comment. I once placed a few green leaves in a gun with a twisted barrel, made by "Peacock," and on firing it explosion instantly ensued. In this case the force, instead of carrying the shots or small weight a great distance, and killing the bird, carried part of the barrel, or an enormous weight, a short distance. The misapplication of power to weight and distance in this instance might have been important, for the bird which I sought to kill flew away, whilst I, who was desirous of receiving no injury, might have been destroyed.

(245.) In all the sciences which comprise the effects of motion, namely, hydrodynamics, mechanics, and pneumatics, whenever an impediment exists between the point of attraction and its application for any purpose by any other body in its vicinity, that impediment is called friction. If, for instance, a clean piece of iron is in close connection with another piece, an attraction would be set up between the two pieces of iron, and the first would but difficultly move on the second. In these cases, which are the most simple instances of friction, we have a ready remedy, for by interposing a fluid between the two surfaces the particles of which shall adhere to the apposed surfaces of the two pieces of metal, this attraction is prevented from taking place, and in lieu of the attraction of the metal to overcome we only have the attraction of the grease. For this cause the coachman greases his wheel, and he well knows the immense expenditure of force which he saves by the application of a little oil.

(246.) In the motion of fluids through pipes there is also a similar attraction between the fluid and the pipe, which has to be overcome by the loss of a certain amount of force. The friction of fluids is small, and has not demanded attention from philosophers, else, doubtless, it might be much lessened. Indeed, a little turpentine added to water will wonderfully diminish the power of adhesion which is exerted between the water and any solid bodies.

(247.) Not only do solids and fluids manifest the phenomenon of friction, but even gases, in passing through tubes, are retarded by the attraction of the gas to the tube. The friction of gases, however, has not demanded the especial attention of philosophers, as it has not been a particular object to overcome it. In all these cases friction is an active attraction, and demands in all cases where it exists an amount of attraction equal to its own attraction to overcome it. Hence it is of the utmost importance in all machinery to supersede its action in every way we are able.

(248.) We have concluded a brief outline of those sciences which consider the tendency to destroy, or the actual destruction of one attraction by the action of some new attractions. We have seen, that wherever an attraction exists, it can only be overcome by the exertion of another attraction of equal amount. We have seen that electricity is the disturbance of the attraction of cohesion by some new attraction. We have seen that galvanism, in a similar way, is the disturbance of the attraction of chemical affinity. Galvanism, therefore, is like electricity, inasmuch as old attractions are disturbed by new ones, unlike electricity, inasmuch as chemical affinity is destroyed, instead of cohesion, &c. Force is similar to electricity in arising from new attractions, but unlike electricity, inasmuch as it is the tendency to the destruction of the attraction which gives position to masses of matter. Whenever a new attraction is exerted, it will overcome in proportion to its energy, a certain amount of any other attraction; hence the new attractions of electricity, of galvanism, of force, may overcome the attractions of chemical affinity, of cohesion, of crystallisation, of magnetism, of capillary action, of gravitation; for although we speak of these various kinds of forces, they all arise from the same first cause, they all arise from an active attraction.

acting upon attracted matter. There is no difference in the origin of these forces, for all arise from attraction, and when the action is exerted, it matters not what kind of attraction is employed to generate the force. There is no difference in the kind of attraction, and the names which are employed to apparently different kinds, only designate the qualities or conditions of the particles of attracted matter which existed before that particular attraction was exerted. As there is no essential difference in the varieties of attraction which we enumerate, so there is no actual difference between the varieties of force which have their origin, name, and even characteristic peculiarity solely from the state of attracted matter on which the new attractions act. The varieties of electricity and of force only differ from each other by the new attractions acting on matter in different attracted conditions, that is, according as their particles are attracted into the solid, fluid, or gaseous states, into uniform masses or chemical compounds, or masses of matter held in certain positions by gravitation.

(249.) We have now brought the sciences of the disturbance of attractions into a small compass, for we have demonstrated how any kind of attraction may, by acting on matter previously attracted, give rise to any kind of force; and, conversely, we have shown how any kind of force may, by management, be made to destroy every variety of attraction under which the particles of matter may be held.

CHAPTER IV.

THE SCIENCES OF ACTIONS AND REACTIONS.

TIME, HEAT, LIGHT, SOUND, ODOUR.

Action and Reaction (250, 1).—Necessity of Reaction (252).—Time (253).—Units of Time (253).—Commencement of Time (254).—Perfect Units of Time (255).—Pendulum (256).—Different Lengths of (257).—Seconds (259).—Candles (260).—Day (261).—Watches (262).—Hour Glasses (263).—Beginning of Time (264).—Nature of Time (265).—Relation of Time to other Sciences (266).—Waves (267).—Kinds of Waves (268).—Matter in Quiescence (269).—Equilibrium (271).—Evening (272).—Sciences of Vibrations (273).—Heat (274).—Its Nature (275).—Its Causes (276).—Destruction of Attraction causes Cold (277).—Heat from Galvanism (278).—Causes of (280).—Heat from Chemical Affinity (281).—Heat from Percussion, Friction, &c. (282).—Attraction of Capillary Action (285).—Heat from Crystallisation (286).—Heat of different Intensity (287).—Other Sources of Heat (290).—Cold (291).—Radiation of Heat (292).—Diffusion of Heat (293).—Specific Heat (293).—Loss of Heat by Heating Bodies (294).—Force of Heat (295).—Thermometers, Pyrometers (296).—Degree of Heat (299).—Expansion (302).—Latent Heat (307).—Latent Heat of Steam (308).—General Principle of the Manifestation of Heat (309).—Solution of a Solid (310).—Of a Gas (311).—Complex Cases (314).—Communication of Heat (316).—Radiation of Heat (317).—Diathermous Bodies (319).—Mode of Radiation (320).—Radiant Bodies (322).—Reflection of Heat (323.)—Absorption of Radiant Heat (324).—Conduction

(326).—Relation of Heat to the other Sciences (329).—Light (333).—Light, that appreciated by the Eye (334).—The eye the only test of Light (335).—Nature of Light (336—338).—The Production of Light (339).—Light neither an Imponderable nor requires an Ether (340).—Colour (342).—Interference of Light proves the Nature of Colour (343).—Names of supposed Primitive Colours (344).—White Light Compound Colour (345).—Vibrations of Colours (347).—Attracted Matter for the production of Colour (348).—New Attractions acting on Attracted Matter (349, 350).—Voltaic Light (351).—Cause of its Production (352).—Attracted matter necessary for Light (353).—Consumption of Attracted Matter modifies Light (354).—Examples of Lights (357).—Bude Light (358).—Magneto-Electric Light (359).—Other Lights (360, 361).—Monochromatic Bodies (363).—Communication of Light (364, 365).—Law of Action of Light same as that of Attraction (366).—Light destroys Cohesion (367).—Light acts on Crystals (368).—Light destroys Chemical Affinity (369).—Partial Analysis (370).—Chemical Combination (371).—Action of Light on Magnetic Attractions (372).—Action of various Lights (373).—Light causes Heat, Sound (374).—Light a Force (375).—Of the same Nature as Attraction (376).—Opacity and Transparency (377).—Transparency (378.)—Reflection (379-380).—Reflection of Colours (383).—Coloured Bodies (384).—Reflection of Heat similar to that of Light (385).—Refraction (387–405).—Refraction of Colours (406).—Dispersion (407).—Analysis of Light (408).—Diffraction (408).—Similarity of Reflection, Refraction, Diffraction (410).—Similarity of the action of Diaphanous and Diathermous Bodies (412).—Alteration of Light (413, 416).—Double Refraction—Polarization (417–422).—Presence of Light (423).—Relation of Light to the other Sciences (424).—Sun (425).—Sound (426).—Sound a Feeble Force (430).—The production of Sound (431).—New Attraction in Sound (432).—Sounds Musical and Unmusical (433).—Standards of Sound (435).—Octaves (436).—Interference of Sound (438, 439).—Production of Sound (440).—Sound destroys Attractions of Cohesion (441). — Sound acts upon the Attraction of Gravity and Chemical Affinity (442).—Reflection of Sound (443).—Echoes (444).—Propagation of Sound (445).—Relation of Acoustics to the other Sciences (446). — Other Sciences of Vibrations (447, 448).—Science of Scent (449).—Scent due to an action of Matter (450, 451).—On Vibrations generally (452–454).

(250.) We have now fully described the conditions and states which masses of matter take on by virtue of the power of the particles of matter to manifest the act of attraction. We have, moreover, discussed the various manners in which those former attractions may be overcome by some new attractions being set up. We have already had occasion to notice how former attractions might be an impediment to the exertion of new attractions; but we have now particularly to consider all those sciences which depend upon the opposition to the desire for new attractions to be generated, caused by attractions having been previously exerted between these particles which have a tendency to set up the new action.

(251.) The conflict of these two forces may be termed action and reaction. Action being the exertion, or tendency to the exertion of new attractions, reaction the tendency to maintain the old attractions, thereby preventing the action from taking place. Sometimes the action overcomes the reaction, and the new attraction actually does take place. Sometimes the reaction is too much for the action, and the new attraction is prevented from taking place; and sometimes the two forces are nearly balanced, when vibrations ensue. The reaction is thus an active force.

(252.) The partial effect of the power which maintains the attraction of masses of matter being an obstacle to the generation of new attractions, is in the highest degree important in nature; for if, when a mass of matter was placed under circumstances favourable to some new attraction, there was nothing to oppose the force then having a tendency to be generated, the attraction would take place momentarily. The coals in our grates would be consumed instantly; if our house caught light, the whole would be gone in a moment. But, fortunately, the former attractions act as an impediment to the exertion of the new ones; the energy of the desire for combustion of carbon for oxygen in our fires is held at bay by the former attraction of the particles of coals, which is gradually and progressively overcome. Our fires therefore burn regularly and steadily, our candles with slowness and precision, and all other actions, even to the railway engine, take place with an energy proportionate to the smallness of the resistance to the new action which causes the effect.

(253.) The energy with which a new attraction overcomes an old one is called the time of its performance; and, conversely, the energy of the resistance to a new action by an old one is called the time at the attempt of performance. Time, therefore, is the abstract idea of the energy of an action and reaction. Time is, therefore, a strictly material property. Without matter we could not have time; and even with matter the phenomenon of time requires for its manifestation some new attraction to overcome an old one. The tendency of the action of the new attraction to overcome the old one is called the commencement of an unit of time; the actual performance of the new attraction, after the destruction of the old one, or the actual resistance of the new attraction by the old one, is called the termination of an unit of time. The absolute performance or resistance of a new action, that is, its commencement and termination, constitutes an event, and, according to the energy of this event, it is said to be of shorter or longer duration. The science of chronology is a science which treats of the energy of the performance of a series of events; and for the purpose of referring one action to another action we assume, as an unit of time, some definite desire for action opposed by some definite resistance to that action by some previously existing attraction. This unit we call an unit of time, and we multiply or submultiply this to express the relation of other units to it, according as the actions of those units are performed with greater or lesser energy, — in common language, in more or less time. A series of these units we take as our standard, and all events have some relation to that standard.

(254.) Time being a material action opposed by a reaction, must have had its commencement with the first material action so opposed. Time must have been first evidenced immediately matter first existed in an attracted state. Attraction must have preceded time, for at the first exertion of attraction there could have been no reaction to produce that phenomenon, though the moment matter was attracted, time commenced. The end of time, so far as relates to this universe, will be that day when attraction ceases, or, poetically speaking, when "the great globe itself, yea, all which it inherit, shall dissolve."

(255.) Perfect units of time are as impossible to obtain as perfect units of length, size, &c. &c.; because man cannot deal with the units, or finite atoms of matter, although comparative units can be procured with tolerable readiness. Our usual unit, or standard of time, is a second, which is an event obtained by the earth's attraction on a mass of matter, opposed by some resistance which prevents the earth's attraction taking place. The instrument by which the event called a second is performed is called a pendulum.

(256.) The pendulum is a mass of matter of certain length, fixed at one end and moveable at the other, and held in a certain position by two forces, one by which it is suspended, and another by which it is attracted to the earth. If this mass of matter is disturbed from its situation, the reaction of the former attraction to the earth causes it to reassume its old situation. In this case motion is allowed on the application of any force to a certain extent, though the reaction tends to keep it in its former position. It is found that in the same latitude the earth's attraction is nearly the same; and throwing out of consideration local causes, which follow no known law, and are owing altogether to circumstances not understood, we may say that the earth's attraction is exactly the same in the same latitude.

(257.) The longer the pendulum is, the greater, —or, rather, the longer the centre of gravity is from the fixed point; the greater the extent of motion which is allowed, and, consequently, for equal weights, the greater must be the force required to carry it the full distance, or height allowed. But in applying force to cause motion, we always take care to apply less force than sufficient to carry it its full height; consequently, the force acts first stronger, but then less and less till the resistance caused by the attraction to the earth, from the pendulum having been raised a certain distance, is capable of stopping the action. It is of no consequence what is the amount of force applied to a pendulum of a given length, provided it falls short of carrying it to its extreme height; for if a lesser force is applied, the motion is little and the energy is little, so that the oscillation is performed in the same time as if a greater force had been applied, producing more extensive motion, and greater rapidity for equal extent of motion.*

(258.) But although a long pendulum allows motion for a greater height than a short pendulum, the shorter pendulum moves upwards, for each inch of lateral motion, more than the longer pendulum ; hence the comparative energy of resistance to force of two pendulums, of which one is twice that of the other, is in the proportion of their vertical motions in each lateral inch ; therefore two pendulums, one twice the height of the other, would perform their actions and reactions with an energy of which that of the shortest would be twice that of the longest. This energy of action and reaction we call the time of its performance, therefore the short pendulum performs its oscillation twice as fast as the long one.

(259.) In this country, for our unit of measure of time we take the energy of the oscillation in vacuo of a pendulum 39·1392 inches long, at the temperature of 62, barometer 30, at the level of the sea. This energy of action is called a second, of which 60 make a minute ; 60 of these minutes constitute an hour ; and 365 days and a fraction a year. In the measure and record of events we suppose a continued series of some definite event from the beginning of the world to the present time, the total amount of which we suppose to be 5847 years. All

---

* The effects of the atmosphere are disregarded in these observations.

other single or series of events are represented by the relation which the performance bears to a second, and are registered with the corresponding action taking place in the world's events. Thus a series of the world's events is a series of its revolutions on its own axis or round the sun, which are registered as they occur. But whilst this great event is taking place, part of the matter contributing to the event is also undergoing lesser action; thus, whilst I am writing this book, I am also partaking of the greater action, and progressing round the sun. The events, however, are registered by the motion of the earth, so that a series of these are recorded primarily, and then, conjointly with each, the little actions of each part of the matter giving rise to event are also placed down. Thus, in the year 5847, I, a part of the earth, besides going round the sun, am endeavouring to enforce the manner in which the two respective actions, may be registered.

(260.) Many other units of time have been at various periods adopted. We are told that King Alfred used to mark events by the burning of candles, in which case the attraction of the particles of tallow for oxygen, was balanced by the attraction of the particles of tallow for itself, and the energy of the tendency of the body to enter into new attractions being met by the resistance of the tendency of the particles to assume old ones, marked a certain time proportionate to that resistance. This is a very bad standard measure of the energy of an action, for no two candles would give exactly the same result.

(261.) The revolution of the earth upon its axis forms an unit of time which is called a day; this may be multiplied or submultiplied for this purpose. The revolution of the earth round the sun forms another unit, though in these cases the source of the action, and the nature of the resistance, cannot be so clearly demonstrated as in the former cases.

(262.) There are many other methods of obtaining definite energies of action over resistance, of one kind of which our watches and chronometers form an excellent example. In these we have a mainspring to cause action, and a hair-spring to resist action, and the relation which the resistance bears to the tendency to action is called the time required to produce action. When we desire the action to be energetic, we diminish the power of the hair-spring; when less so, we increase it.

(263.) The hour-glass is another note of time. The falling of sand through an aperture in the glass which resists it, forms the essence of this contrivance. If the aperture is small, the resistance is great, and therefore we say the time of the sand passing through is long; if the aperture is great, the resistance is small, therefore we say the time is short.

(264.) We have already mentioned that time being a material property, there must have been a beginning to those series of events which we record.

Our series of events which we chronologically record can be carried back to the first event of the series, so that first event must have had a beginning and an end. If we look to futurity, we see that time may be evidenced as long as material particles are attracted to each other; but if millions of events follow millions of other events, each event must have a beginning and an end, and we see no limit to the possibility of events taking place *ad infinitum.* From natural science, indeed, there is no evidence to show that matter shall lose its power of attraction, and, consequently, that time shall cease; but whilst natural science does not show that time shall cease, it shows at any given instant it may cease. Time cannot cease whilst matter attracts; but if matter lost its power of attraction by the same power by which it first assumed it, time would no longer have an existence — events would cease — succession would end.

(265.) We have so clearly pointed out the true nature of duration, and the material relation of the abstract idea called time, that it may seem almost needless to consider the important subject further; yet, as we are taught in our earliest infancy that time is some reality, that it has some real existence, we are bound most earnestly to caution philosophic inquirers to be careful not to forget the material relation of this phenomenon, which gives rise to the abstraction. In this case, as in many others I have already had occasion to notice, philosophers have been led astray by assuming the abstract to possess the real essence, and forgetting the material effects which give rise to that abstraction. Time, then, is an abstract term, derived from a material phenomenon, and possesses in itself no essence, imponderable, or other immaterial whatever.

(266.) Time cannot be manifested in the simple sciences of attraction, when attraction takes place without opposition, and, therefore, in no time. In all sciences of disturbance of attraction, time is evidenced. All electrical, galvanic, dynamic effects are accompanied by time. We shall hereafter have to show that heat, length, sound, &c. are desires for new actions opposed by former actions; therefore, with these phenomena, time is evidenced. In the present state of the universe, time, be it ever so little, must be present with every material action whatever, for every particle of matter in the great globe, or in the vast universe, is now under attraction; and therefore any other attraction, however intense, overcoming that old attraction, requires time. The rapid explosion of gunpowder requires time to overcome the former attractions of the grains; and even the more terribly rapid detonation of some fulminating powders requires some time for the new attractions to be exerted, although in these cases the time is much diminished.

(267.) We have thus seen that time is owing to an old attraction being an obstacle to a new one:

but actions and reactions following with definite energies, produce other phenomena of great importance. All the cases which I have now to point out are produced by prior attractions being alternately in a state of attraction, and in a state of alteration in the attractions by some force originating in other attractions. This action and reaction, — this alternate attraction and destruction of attraction, produce the motions called vibratory, or, in other words, a vibration, a wave. A capital example of such a motion is seen in a violin-string, which is kept in a certain position by a force applied at each end; but when touched with a bow, the tendency to continue the attraction keeping it in position, and the tendency to its destruction, have peculiar conflicts together, each force alternately getting the mastery, and the string takes certain excursions called waves.

(268.) A body in a state of vibration is said to be in a particular state, according as these vibrations succeed each other with uniform energy, for the energy of the vibrations gives certain effects to attracted matter, which we name according to the frequency of the repetition of the vibration, that is, its energy compared with the definite action and reaction we call a second of time.

(269.) Before we trace these conditions of masses of matter, we must advert to the state of matter simply under attraction, that is, having form, size, figure, quality, or polarity. In those circumstances, if we conceive a mass whose attractions were disturbed by the attractions of no other masses or bodies, it would possess no other quality or property besides that derived from the direct attraction. It would neither exhibit the effects of electrical action or galvanic action. It would not evince the phenomenon of motion. It would, moreover, be absolutely, cold, absolutely dark, without scent or sound, and it would not manifest any colour. Such would be the condition of a body in perfect quiescence, that is, unacted upon by the attractions of any other body.

(270.) But we can neither comprehend nor imagine a body in such a state, nor can philosophers divest a body of any action except that attraction taking place between its own particles, because all bodies, by the power which their particles possess of generating attractions, act upon each other and produce vibrations.

(271.) Every body therefore in nature is in a state of action and reaction, and therefore we can only examine masses of matter in equilibrium, that is equally excited. This equal excitement, or equilibrium, is readily produced, because if a body highly excited be brought into the vicinity of many others in its neighbourhood, it tends to excite all the rest, and all the bodies would become equally excited by the force mutually acting and reacting on each other.

(272.) The most perfect quiet, or absence, of actions and reactions, is perhaps to be found in a still, clear evening, in an open space in the country, for then there are no clouds to return the actions of the earth, which consequently assume, or rather have a tendency to assume, some definite state. In this condition the thermometer goes down, and that chilly coldness is produced which stamps the character and gives that loveliness peculiar to evening. The absence, moreover, of light, of sound, increases the quiet, which continues till the sun, the next morning, causes new commotions, actions, reactions, and heat. The quiet of an evening, however, is but a comparative quiet, and altogether incomparable to that awful quiet which we must acknowledge would exist were all disturbance of attractions to cease.

(273.) Having seen the conditions of matter in a quiet state, we have next to examine its properties when in commotion; and the sciences of commotion, or rather of actions and reactions, which now fall under our notice, are respectively those of heat, light, sound, and scent. All these terms are abstract ideas of material actions and reactions, and there is no imponderable or essence in either heat, light, sound, or scent, to which matter owes its power of being hot, illuminated, noisy, or odoriferous.

(274.) The first science which we have to consider, is that of heat, which, according to the imaginative philosophers, is dependent on an imponderable called caloric. We, however, have already had occasion to call attention frequently to the vain creation of these imponderables, and we look for the cause of heat in some material action, and we regard a hot body as a body in a particular material condition. Without matter there can be no heat, and matter may even exist without that phenomenon being evident.

(275.) If we seek for the material action which primarily is the cause of heat, as matter has but one property, that of attraction, we naturally look for some attraction to be set up to cause the phenomenon, and we actually find that, if we take a review of all sources of heat, the phenomenon is owing to some new attraction acting upon a body, the particles of which are held together by former attractions. A hot body is therefore a body whose attractions are interfered with by other attractions, and heat is the abstract term of this disturbance of attractions in a particular manner.

(276.) Although some new attraction must be exerted to cause heat, yet one simple attraction is not sufficient for that phenomenon, for it is essential that that new attraction should act upon a previously existing one, and the conflict of the new with the old is the kind of action to which we give the abstract term heat. The attraction of gravitation, of capillary action, of magnetism, nay, even of chemical affinity, may be exerted without producing heat, if we take care that no reaction ensues.

(277.) It is from the necessity of the conflict of the two attractions for the production of the phenomenon of heat, that no heat is produced when the old attraction is actually destroyed; as when, for instance, chloride of calcium is thrown into water the attractions of the particles are annihilated, and the phenomenon of heat is not manifested. All these cases we shall more particularly consider hereafter, but in this place the important point we have to enforce is, that the production of the phenomenon of heat is always most intense when a new attraction has a great tendency to the destruction of the attractions of a body, and yet that body resists that tendency. The more energetic these forces, the more intense the heat.

(278.) A new attraction being the primary source of heat, let us consider the various instances in which attraction gives rise to that action; and first let us consider the effects of heat as generated by the voltaic circuit. In this instrument, where a new attraction abstracts one element of an electrolyte or compound, and, therefore, destroys the attractions previously existing, no heat is evidenced when the circuit is completed through sufficiently large conductors, the former attractions being destroyed and new ones assumed without that phenomenon. Not so, however, if any part of the circle is made a great obstacle to an energetic force, for at the point of that resistance heat will be produced. In the first place, heat will be produced if the electrolyte is constricted at one point, or when it is suddenly acted upon by great rapidity by the energetic force of the positive pole. In this way it is not difficult to make tolerably strong mixture of sulphuric acid and water boil. Heat may also be evidenced by the resistance of the former attractions of the electrolyte to the new attraction of the positive pole. Heat may also arise in the electrolyte itself if the impediment is great. Heat may arise from a new attraction taking place at the negative pole by the second element of the electrolyte acting upon some former attraction, which former attraction by reacting may give rise to the phenomenon; and, lastly, heat may be evinced in the solid part of the arrangement where the attraction of cohesion is an obstacle to the attraction acting upon the electrolyte, and the two forces by action and reaction produce that phenomenon.

(279.) In all these cases the amount of heat generated is proportionate to the intensity of the voltaic force multiplied by its quantity; but still no action called heat is produced unless this force is resisted, for heat absolutely requires that the new attraction should be opposed by an old one, and not only opposed, but opposed to a certain amount. Snow Harris has recommended that the phenomenon of heat should be made the test of the power of a battery; but we see that it is not a good test, because the power of a battery does not alone cause that phenomenon. In all cases of the generation of heat, the degree of heat produced in any particular spot or number of particles is inversely as the entire number of particles between which this phenomenon is evidenced. The reason of this is sufficiently obvious, for the force at each part must be more diluted the greater number of particles its action is divided amongst.

(280.) The heat evidenced by the voltaic circuit has for its cause the new attraction of the positive element of the battery, resisted either by the attraction of cohesion or of chemical affinity. Electrical force derived from other attractions will produce heat in the same way as the voltaic force, for whether the peculiar electrical force be that of lightning, frictional electricity, magneto electricity, thermo, or any other kind of electricity, it will produce the effects under certain circumstances of resistance, which are called heat.

(281.) The next source of heat after that derived from new attractions producing electrical forces, is that derived from the attraction of chemical affinity. The phenomenon of heat is not manifested by the chemical union of any two bodies, if the combination takes place without being impeded by the other attractions, or if the other attractions are quietly destroyed. If the combination takes place with great energy, however, the rapid tendency to the destruction of attractions, reacting against the desire for maintaining them, give rise again to the phenomenon called heat. In the combustion of coals, the rapid desire for the particles of the coal to unite with the oxygen of the air acting upon the desire of the particles to maintain their old attractions of cohesion, causes that heat to be manifested which so comforts and cheers us in our dreary winter's night.

(282.) The action of heat may be produced by disturbing the attraction of cohesion, by percussion, friction, &c.; and when we are told that the athletic Indian lights his fire by rubbing together two pieces of wood, we can form some idea of the intense heat which may be so evidenced.

(283.) The mode in which percussion acts to produce that phenomenon is derived from the disturbance of attractions consequent on the performance of those events. It is a matter of every day experience that percussion and friction will destroy the attractions of bodies. It will at one time alter their form, it will at another disintegrate them. Percussion and friction are derived from forces which themselves are derived from some new attraction, so that when a piece of iron is hammered violently on an anvil, a new attraction acts upon the attractions by which the particles are held together. The tendency of this new attraction to destroy the old ones being met by the tendency of the old attractions to be continued, gives rise to the action and reaction called heat. The nail so hammered is thus thrown into the action called heat, and becomes by this process red hot.

(284.) The heat of the nail being derived from a tendency to disintegrate its particles, met by the particles of the mass endeavouring to keep themselves together, may be continued for any time, forming a beautiful link in the long chain of argument which may be adduced to prove that heat is not a thing, or principle, or imponderable produced, but a material action and reaction following each other in rapid succession in the manner which has been already amply described.

(285.) The attraction of capillary action, the attraction of magnetism, and the attraction of gravity, may, with care, by mechanical contrivances, be made to tend to neutralise former attractions; and if these former attractions strenuously endeavour to maintain themselves inviolate, heat, and heat proportionate to the energy of these new attractions, will be produced.

(286.) The attraction of crystallization is another source of heat: if a saturated solution of a salt suddenly be attracted into a solid mass, great heat will arise. Attractions set up in various cases of mixture will cause heat; hence sulphuric acid and water, on being mixed, set up violent attraction, and, consequently, give rise to much heat, the mixture assuming a boiling temperature: spirit and water will also produce similar phenomena.

(287.) In all these cases of the production of heat from attraction, we see that, like the production of force, the degree of heat is equal to the intensity of the new attraction multiplied by the number of attractions, supposing the resistance to that attraction to remain constant. Hence, when we desire to produce heat economically, we use bodies having the lowest equivalent number, because then a greater number of ultimate particles would be contained in the same weight. We next select bodies which generate the most intense attraction: and, lastly, we consider the cheapness of the body used. The atmosphere is always at hand, and at everybody's command, consequently, that is used as one body for the new attraction. Then we find that the two elements which have lowest equivalents are carbon and hydrogen. These we, therefore, select for bodies to enter into combination with the atmosphere. Moreover the combination of these elements with oxygen is very intense, and Nature has contrived that a tolerable abundance should be supplied for the wants of man. And, in addition to all these advantages, carbon actually combines with two portions of oxygen, so that its combination is equal to two attractions. Whilst Science points out that our ordinary mode of obtaining heat by combustion is the best possible, so does History record that mankind, in all ages, has invariably taken advantage of the best mode of obtaining this phenomenon.

(288.) As heat depends upon two attractions, a new attraction acting upon an old one, so the resistance which the old one affords modifies the intensity of the heat. When a gentle heat is required, we select a body whose attractions are not very intense; but when we want a strong heat, we select a body whose attractions are very intense. The practical metallurgist uses, in different cases, carbon of different degrees of cohesion. Light coal, — for instance, the Newcastle,—burns with a gentle heat, suitable for our sitting-rooms; stronger coal burns at a more elevated temperature. Light coke is more suitable for our green-houses; but a very coherent coke, — a strong coke, as the workman calls it, — is suitable for our blast furnaces. But we must take care that the old attraction is not too strong, and does not totally overcome or resist the tendency to the new, or else we obtain no heat at all. Very coherent coke, as gas retort coke is occasionally found to be, is nearly incombustible; and the diamond, which is only carbon more intensely attracted, almost resists the cunning skill of the chemist who attempts its inflammation.

(289.) The practical man should beware that, although a strong reaction produces an intense heat, yet that the effects of heat are not dependent on the intensity of the heat, but on the power of the new attractions, or, in other words, to the number of atoms attracted multiplied by the intensity of the attraction. For this cause the strong coke or coal does no more work in evaporation than the same weight of lighter coal. As the amount of attractions capable of being destroyed is equal to the amount of new attractions, — and, moreover, as heavier coal has more intense attractions than lighter coal, the power of the old attractions of the particles of coal must be subtracted from the effect which can be produced by combustion. Hence, though diamonds, and gas-retort coke, burn at an enormous heat, — on account of the intensity of their attractions requiring much force to throw them into action and reaction, — yet the effect of their combustion is lessened by the extra amount of the attractions of the substances themselves. And we may look at the same phenomena in another light, for those bodies which burn with an intense heat, simply accumulate the force before it acts, but do not in any way increase it for obtaining any effects which mankind requires, so that a strong heat may be regarded as accumulated force, analogous to other cases of accumulated forces.

(290.) We have thus pointed out that the attraction of combination is best suited for the production of heat, and that coals and oxygen are eminently adapted for the exercise of this affinity. But now, when geologists are frightening the world by their prognostications of the exhaustible nature of the coal fields, natural philosophers can console mankind that any other attraction will produce, though not so economically, heat to any extent. The very works which have been written on these subjects, nay, even the authors of those works, the immortal Buckland himself, may, by the force of gravity, be made to produce force which, if rightly applied, may give rise to heat to warm and cheer our habitations. The practical philosopher alone wants attraction, for, having that, he can produce at will all other material conditions.

(291.) Heat is a particular action and reaction. The absence of heat is cold: hence we might suppose that if quiet is cold, the effect of the wind might sometimes, though not necessarily, be heat. This is actually found to be the case, for the coldest day is invariably noticed to be the quietest. Captain Ross found at the North Pole that a wind would raise the thermometer 50 or 60 degrees in a very short space of time; and in this country those frosts known by the name of Wells' radiating frosts are effectually prevented by clouds disturbing the attractions, or by a slight breeze preventing the quiet. In the choice of a situation for a dwelling we should beware of situations favourable for the existence of these destructive night frosts, which do so much damage in Autumn and Spring. Many select the warm valley, as they think that they will be, in that situation, protected from the wind; whilst those very winds, in higher situations, protect them from the great depression of temperature which occurs in the still evening. Valleys favourable for radiating frosts will have the dahlias sometimes cut off at the end of August, whilst on the hill side they will frequently last till November. Wind, indeed, upon the animal frame, will sometimes produce the feeling of cold from the current of air reducing the action or temperature of the surface of the body; still, in intensely cold, frosty days, a little wind will cause a great rise in the thermometer, an instrument hereafter to be described.

(292.) A body in the state of action and reaction has a tendency to throw other bodies into the same condition: thus, in a room, every body is in a similar state of heat, for the force of each body acting upon the attractions of every other, produces and maintains an equal temperature of all the bodies. This property for the equal distribution over all contiguous bodies of the force of heat is called radiation, upon the supposition that bodies emitted particles, or some imponderable essence called heat, the fallacy of which supposition has been already abundantly pointed out.

(293.) A heated body loses the action by diffusing its heat over other bodies to an amount proportionate to the number of atoms contained in the second body; and the amount of action in the first body is also directly proportionate to the number of atoms between which that phenomenon is evinced. In consequence of this very apparent law, equal weights of different substances would contain different amounts of heat, according to the relative number of atoms in the respective masses of matter. The amount of action necessary to raise to the same temperature equal weights of various substances is called the specific heat, which depends entirely on the number of atoms contained in these equal weights. A pound of gold would only require $\frac{1}{200}$ part the heat to raise it to any given temperature, that one pound of hydrogen would require, because the respective weights of the atoms are as 200 to 1.

(294.) When one body excites a second, the first loses as much heat as the second gains; so that when a hot body is brought near a cold, the cold is warmed, the hot is cooled, and the two bodies at last assume the same temperature.

(295.) We thus perceive that the phenomenon of heat contains, or rather depends upon, a force in all respects similar to ordinary force, which we formerly described. The force of heat, like the force of electricity, galvanism, the force of motion, always arises from the manifestation of this new attraction. This new attraction may destroy a previously existing one; and, in fact, so constantly does it more or less destroy some attraction, that we usually take this destruction of attraction as the test of heat, although the effects of heat are not manifest, or, in other words, heat is lost when the attraction is actually destroyed.

(296.) The instruments with which we measure these destructions of former attractions are called thermometers and pyrometers, according to the range of intensity of the heat which they measure. The thermometer is a most elegant instrument for this purpose, and its essential character depends upon the destruction of attraction which ensues on the application of heat, whereby some body of definite volume is enlarged or increased.

(297.) The body to be acted upon by heat may be either a solid fluid or gas. As an example of a solid, the expansion of a bar of metal may be taken; as an example of a fluid, metallic mercury, or spirit of wine, may be taken; and as an example of a gas, air may be taken. Generally speaking, however, fluids are preferred for this purpose, and ordinarily we employ a mercury or spirit thermometer. In these instances the fluid is placed in a bulb, communicating with a tube of very fine bore, so that in proportion as the fluid is raised in temperature the attractions are lessened, its volume is increased, and it rises into the tube. The object of using a large bulb is to obtain the action on a large mass of matter, whereby the expansion, for minute variations in temperature, is rendered more evident.

(298.) To make the measurements of the instrument abstract, — that is, independent of a particular thermometer, to render them intelligible at all parts of the world, the scale, or the tube of the thermometer, is marked at two points, — the freezing point of water, and its boiling point at the pressure of 30 barometer. This interval is divided into a certain number of parts: in the centigrade thermometer into 100 parts, in Reaumur into 80, and in Fahrenheit into 180 parts. Thus, if we say that the thermometer is at any given degree, a philosopher might obtain, in an uninhabited island at any part of the world, without any other thermometer to help him, an exactly similar temperature.

(299.) When philosophers talk of a degree of heat of Fahrenheit's scale, it is the $\frac{1}{180}$ part of the power capable to produce the destruction of attraction which ensues by raising water from 32°, the freezing point, to 212°, the boiling point. In the centigrade and Reaumur it is respectively $\frac{1}{100}$, and the $\frac{1}{80}$ of the same force.

(300.) The pyrometer, in its essential construction, is similar to the thermometer, but it measures very high temperatures. The thermometer takes in a range from -100 to $+600$: at the North Pole it sometimes stands at -54 Fahrenheit, whilst the pyrometer extends to $+2000$ or $+4000$. The measurements of the pyrometer are made by the expansion of a bar of platinum, and a degree upon this instrument is the same as that of the thermometer. The thermometer and pyrometer are only comparative measures of heat, as the degree is but an artificial unit of that action. We can have no absolute standard of heat more than that of force, &c.

(301.) We perceive that the attractions of bodies are lessened by high temperature, and that therefore they occupy a greater bulk relatively to other bodies. This increase of bulk is called expansion.

The converse, or diminution of bulk occurring from a greater intensity of attraction is called contraction. Contraction arising from attraction may be turned to enormous force, which is sometimes applied for the purposes of mankind. The knowing blacksmith heats the iron before he places it round the wheel, so that by its contraction it may firmly grip the wood-work. This property of contraction is occasionally employed to draw together two walls which have been separated by a settlement in a building.

(302.) Expansion arising from the diminution of attraction from the action of other attractions is also sometimes capable of exerting enormous force. The iron bridge crossing the Thames at Southwark, nearly suffered severely from this cause on its being first erected; and we often see in churches and buildings severe damage from the exercise of this force. In some instances, contraction and expansion being alternately exerted produce great injuries.

(303.) Bodies raised or depressed in temperature, do not contract or expand equally, but each body has an expansion peculiar to itself. Silver and platinum, for instance, expand very unequally; so that a compound bar of these metals is bent into a curve upon an alteration of temperature. It is upon this fact that expansion balances, &c. are made. This unequal expansion of bodies is very important, and depends upon the diminution of the power of attraction exerted between the particles of each respective body when subjected to the action of the new attractions in heat.

(304.) Bodies in an uniform state of attraction throughout the mass, as bodies in a state of gas or liquid, or in the state ordinarily called cohesion, expand equally in all directions, in proportion to the number of particles exerting that property in each direction; thus, the expansion of the breadth of a rod is proportionate to the expansion of the length; and the expansion of the length would be as many times more than that of the breadth as the length is greater than the breadth.

(305.) There are some bodies, however, not in an uniform state of attraction, as crystals, which do not expand equally by heat. A crystal is held together by attractions acting far more intensely in one direction than in others, so that we can readily imagine how any force lessening the force of attraction should act unequally upon a body whose particles are so unequally attracted together.

(306.) We have already had occasion to mention that heat depends upon action and reaction, so that if there is no reaction there is no heat. When the action from a new attraction destroys an old attraction, no heat is evidenced because there is no reaction; and if one hot body destroys the attractions of another body, the heat existing in the first ceases to manifest itself, and becomes lost; whilst the attractions of the second body, if they resume their old attractions, produce a force capable of manifesting the effects of heat.

(307.) The phenomenon of heat ceasing and again appearing from the causes already described, is called and described under the general term latent heat. It is an admirable and expressive term; for heat on the destruction of attractions becomes hidden, or latent, but manifests itself again on the resumption of the attractions destroyed.

(308.) The two great classes of instances where heat destroys attractions and becomes latent is, first, the destruction of attraction on change of state from solidity to fluidity; secondly, from fluidity to the gaseous state. A good instance of latent heat is to be found in water; for chemists have proved that as much heat is lost in converting ice into water, by the destruction of the attractions of the ice, as would raise 140 times the bulk of water one degree. In converting water into steam, as much heat is lost as would raise 1000 times the bulk of water one degree.

(309.) If, however, the force of attractions of the solid state requires as much force to overcome them as would give 140 degrees of heat to water, and the attractions of the fluid state require, in a similar manner, 1000 degrees of heat to overcome them; so steam, when it resumes its attractions and becomes water, generates, by virtue of these attractions, as much force as was required in the first instance to overcome them. Hence, when steam becomes water, 1000 degrees of heat are produced, or rather manifested; and, in a similar manner, when the liquid resumes its attractions and becomes solid, as when water becomes ice, 140 degrees of force capable of producing heat are indicated.

(310.) Every solid being held together by attractions of different intensity, has a different capability to render heat latent by becoming fluid; and every fluid by becoming gaseous, in like manner, requires a different amount of heat from water in order that it may change its state. When heat actually acts upon a body, it either destroys its attractions, and thereby becomes latent, or else it is manifest. This very obvious fact has been thus conveniently expressed by those philosophers who have assumed heat to be a reality possessing independent existence attached to matter, for they state the general law that the sum of the latent and sensible heat is always the same in the same body; the cause of which law is sufficiently evident from the facts above stated.

(311.) As a general law, whenever attractions are destroyed, heat, or force which might be heat, is lost; whenever attractions are manifested, heat may show itself by acting on attracted matter. By whatever mode we may compel attractions to be assumed, heat may arise; thus, if we compress gases, and thus cause them to be fluid, heat will appear. If we rarify gases, cold will arise. So that if we desire to know whether heat or cold will be produced, we have only to examine and find out whether any attraction is generated or destroyed. If an attraction is generated, and acts on attracted matter, and still no attraction destroyed, heat will ensue: if an attraction is destroyed without reaction, no heat will be evidenced.

(312.) The phenomenon called solution is a capital instance of the sudden destruction of the attractions of a solid body; hence great cold is produced when salts are dissolved in water. The solution of chloride calcium or of nitrate of potash form capital examples of such diminution of temperature.

(313.) But if we examine the effects of the solution of gas, we perceive that new attractions are set up, and a great heat produced. These two instances are perfectly analogous, inasmuch as something is dissolved in a fluid in both cases. In one, however, attractions are destroyed, and cold results; in the other, attractions are set up, and heat ensues.

(314.) In nature many complicated cases occur where attractions are both destroyed and generated by a single operation. In these cases, if the new attractions take place with much energy, heat is produced; if the old attractions yield with facility, no heat is produced, because there is not sufficient reaction. If the attractions destroyed are more than those generated, cold manifests itself, because then the force to destroy them must have been derived from the heat of neighbouring objects. In the case of gunpowder, the attraction of cohesion is destroyed, but new attractions of carbon and oxygen, sulphur and oxygen, &c. cause the gases produced by its inflammation to be hot, not cold.

(315.) We have now traced the phenomenon of heat. We have seen that the phenomenon is owing to a material action, and not to an imponderable or essence, which is formed or evolved by matter. We have shewn how heat may be produced, and how destroyed; and we have pointed out various instances of action and quiet, or rather the principles which regulate them. It now becomes our especial business to enquire how action is communicated from one body to another, in other words, how heat existing in one body is imparted to a second.

(316.) The phenomenon of heat is usually said to be communicated in two ways, by conduction and by radiation. Heat is said to be conducted when a hot body touches a cold, and the particles of the cold body have an increase in their temperature. Heat is said to be radiated when a cold body becomes hot by being opposed to it, either no layer of matter existing between the two bodies, or the layer of matter interfering but little with the propagation of the phenomenon. Conduction and radiation appear to possess but little essential difference of character, for when heat is conducted through a body a part first becomes heated, say two or three particles. These particles, in that condition, impart that state to their neighbours, or, in other words, to those in contact or opposed to them. These impart that action to the next series, which action is carried on till the entire mass becomes heated. Conduction, therefore, appears to be similar to radiation, inasmuch as the heat is communicated from the hot particles to opposed particles not evincing that action. Conduction, however, differs from radiation, inasmuch as the latter is exerted between only the opposed surfaces of bodies, whilst conduction is a repetition of radiations taking place between the particles of a body more or less in a state of cohesion.

(317.) As radiation can be studied by examining the effects of one set of opposed particles, the transfer of heat by that cause demands attention before the phenomenon of conduction, which requires of necessity the examination of a series of radiations. The term radiation is given to those cases where cold bodies become hot, or, rather, where cooler bodies become hotter by simply being opposed or opposite to them, some distance intervening between them.

(318.) The communication of this action from one body to another does not require the intervention, as far as human means can determine, of any material particles; but, on the contrary, the presence of material particles, by virtue of their attractions, interferes with, diminishes, or prevents, that action, but never promotes it.

(319.) The extent which interposed bodies allow radiation is called the extent of diathermancy, so that bodies which pretty freely admit this property are called diathermous, bodies which resist it are called non-diathermous. There are, however, not two sets of material bodies, one diathermous the other non-diathermous, but all bodies fall into a great scale possessing this property in a more or less eminent degree. As a specimen of a diathermous body air is a capital example, though, even in this case, the more rarefied it is, the more diathermous. Rock salt, talc, &c. are also other examples. As a specimen of a non-diathermous body glass is an excellent example, as it will nearly, if not entirely, stop the radiation of terrestrial heat.

(320.) It does not appear to be a difficult problem to solve, how heat is radiated from one body to another. Heat, we have already proved, is a tendency to the continuing of an attraction and a tendency to a destruction of attraction, alternately reciprocating; therefore, these actions would be alternately induced in the second body, on which the first or hot body acts, so that the second body becomes hot by the action of the first. The interposition of matter is no more required here than in the case of simple attraction; and, in fact, as far as we can see, matter interposed between the radiater and the radiatee invariably diminishes more or less the effect of radiation.

(321.) A good example of radiation is found when we stand before a furnace door, into which cold air is rushing with extreme rapidity, for, in spite of that cold air, which must help materially to cool our bodies, so much heat is felt as to cause great uneasiness. A pretty effect of the danger of radiation was seen some years ago in the Bank of England, where the late Mr. Oldham, a gentleman of great talent and ingenuity, fitted up an apparatus to burn large quantities of cancelled bank-notes. It was fixed on the flag-stones of the court-yard, but ample space was left for the cold air to play underneath the bars, so that the notes might be supplied with air. The draught of cold air, however, though well conceived, was totally inadequate to prevent radiation, and two or three hours after it was first lighted, the flag-stones became so heated as to fly to pieces.

(322.) Heat is not radiated from all bodies with equal facility, as the state of the attractions of the surfaces of bodies materially interfere with the phenomenon. Bodies whose particles are loosely combined, possessing rough surfaces, usually radiate the heat the best; and it is an important and singular fact, that the capacity for receiving heat by radiation in any body is directly as its power of radiating it. Radiation from points is similar to the discharge of polar attraction from points, as witnessed in electricity of tension.

(323.) Some bodies, however, whose particles are in a particular state of attraction, and which are very smooth, resist the force existing in the heated body, and, instead of taking on the action of heat, generally repel it at a certain angle, so that the body resisting the force has the same effect upon all other bodies as if it were a heated body, without, however, being itself at all hot. This repulsion of the force existing in heat is called the reflection of heat, which, following the same laws as that of light, we shall reserve the consideration of till we study the effect of light.

(324.) The absorption of radiant heat (or rather the assumption of the action called heat) by any body, is inversely as its reflection; so that, of any definite amount of heat acting upon any body, the part affecting that body is the difference between that reflected and the heat producing the effect. When, however, a hot body is separated from a cooler by material particles, a certain amount is lost by absorption in that body, and then the quantity acting upon the second body is the difference between the whole of the part reflected and the part absorbed by the intermediate matter. If we suppose a hot body, from whose surface an amount of heat equal to any given amount is acting upon a second body, that second body would become hot, or manifest the effects of heat, not of the entire amount, but of the entire amount diminished by that acting upon the intervening matter, and diminished also by that reflected or that repelled from its own surface.

(325.) The communication of the action of heat by radiation always takes place in right lines when there is either no medium between the bodies, or the intervening medium is of uniform density. When, however, the medium is diathermous, and of unequal density, the attractions of the different densities disturb the course, or act as a counter-force to the force of heat, and a bending or refraction takes place. This refraction is so much better illustrated in the study of light, that we shall not enter into the inquiry in this place. Lenses, prisms, &c. of rock-salt are usually employed for the refraction, or turning aside of the force of heat, as that compound is the most diathermous body known.

(326.) We before mentioned that the propagation of heat by conduction is to be considered as a series of radiations, for one set of particles becoming heated, radiates to the next, then to a third, and so on, till the whole mass become sheated. Now, we can easily imagine that such a propagation must require more or less time to be effected, and as the effect takes place more or less rapidly, the body is said to be a more or less ready conductor. Metals generally are capital conductors; marble, glass, cloth, &c., on the contrary, are very bad conductors.

(327.) If we apply the principle of radiation to the elucidation of conduction, we shall perceive that the action of heat taken on by a remote part of any body from heat previously existing in another part, would be first according to the diathermancy of the intervening particles. On this account, imperfectly diathermous bodies would, at their remote parts, receive no heat from any heated portion. One end of a piece of glass might be red hot, and yet this action would be prevented from being assumed by the other from the non-diathermancy of the intervening particles. This is one species of non-conduction, and perhaps we may say, a very frequent one.

(328.) A body, however, may be highly diathermous, and yet, by virtue of that very diathermancy, a bad conductor. Air, for instance, is diathermous: one portion may be heated, and yet another would not take on that action, because the force would actually act through the remote part, and therefore, not act upon that part of the gas itself. Diathermancy, therefore, is another source of non-conductability. Air is one of our worst non-conductors on this account, and it is only by its expanding by heat, and thereby undergoing motion, so that the heated part is brought into actual contact with others, that the effect of heating a quantity of air is accomplished. When the two actions are in actual contact, the force of heat is enormous; but it follows the laws of all forces, diminishing in the inverse ratio of the square of the distance. We may also expect that a power exists of more or less energy for the particles of bodies to repel in their interior the action of heat, but it is difficult to ascertain the amount of reflection which would take place in the interior of bodies. Probably many non-conductors have two of these impediments combined.

(329.) We have now pointed out that heat can only be evinced by new attractions acting upon old ones. The relation of heat to the other sciences, therefore, is the following:—First attraction, comprised under the fundamental sciences, must have been first exerted, though the simple exertion of that attraction will not produce heat. Some new attraction must act upon this attracted matter to set it into the action of heat, but all other effects of heat are due to the new attraction existing in the action and reaction called heat.

(330.) Heat, containing a new attraction, may destroy or overcome all other former attractions. It may partially or totally destroy that of cohesion. It may disintegrate, fuse, or convert a solid body into gas. It will destroy the attraction of chemical affinity, decomposing the most stable compounds. The familiar example of the reduction of many metallic oxydes may be mentioned as proof of its analyzing power. Heat will interfere, and destroy the polar attractions called magnetic. It will interfere with the attractions of crystallization, decrepitating them, or fusing them. Heat, by destroying attractions, will often allow new attractions to be exerted. Large crystals will break up into a multitude of smaller ones; bodies in cohesion, as sandstone, will become crystalline from the long continued action of heat. Bodies will also become decomposed, and converted into other bodies by heat, as in destructive distillation.

(331.) Heat, inasmuch as derived from new attraction, and containing within itself a new attraction, may give rise to all effects comprised within the range of the sciences of disturbances of attraction. Heat may give rise to electric effects, to force, motion, &c. Heat cannot be manifested without time, because it infers necessarily a resistance; and lastly, heat, by giving rise to vibrations of given intensity, may produce light or sound.

(332.) Such is the connexion between the science of heat and other sciences, and if we consider the range of vibrations which are called heat, some difficulty occurs, for we do not know in what the range of vibrations called heat is comprised. The range appears extremely extensive, and, perhaps, it is better to decide that heat comprises actions and reactions, ranging between light and sound, than to endeavour, in the present state of our knowledge, to point out the exact frequency of the occurrence of the vibrations called heat. We have now shewn that heat may be produced from any kind of attraction, and that so arising it may destroy or interfere with any previously existing one, and we shall at once pass on to the consideration of another set of vibrations.

(333.) The actions and reactions which we have now to consider are those contained within a certain range, which certain range is called light. This range must be confined to those actions and reactions of matter, or, in other words, to those vibrations which are appreciated by the eyes of the human species; for although the physiologist can find abundant fault with the range, yet it is the best which, under our present knowledge, we can adopt.

(334.) In the restriction of light to the actions comprised by the eye, we are not sure that all eyes are acted upon by the same range, and even it is clearly proved that certain vibrations which effect the eyes of some people are not appreciated by others. Thus one person cannot distinguish red from green; and, apart from this supposed physical defect, no two persons express the colour of any definite object in the same words.

(335.) However, if we neglect the eye as a test for light, we have none other that can be relied on, for if the vibration is too quick to be appreciated by the eye, darkness is the result; if the vibration is too slow, darkness is equally produced. Light occupies but a very small space in the universal range of actions and reactions, for we shall hereafter shew that but few vibrations can be appreciated by the eye. Light cannot be determined by any other effects besides that which it produces on the optic nerve, because that which is not seen by the eye produces similar effects; so that if we took the effects of light upon attracted matter as the test of light, we should comprise within the range of light all kinds of forces, and not the specific vibrations which render objects visible.

(336). We have before had occasion to explain the nature of an action and reaction, and we pointed out that when a body was held *in equilibrio* by attractions, and some new attraction acted upon it, that the tendency to the destruction of attractions acting upon the tendency for their continuance, produced the motions called vibratory. The greater the force with which the old attractions were sustained, the greater the force that would be required to overcome them; and, if it resisted the force, the energy or intensity of the vibration would be greater from the conflict of the two forces. Thus, a violin string held in position by a very great force would vibrate very rapidly, because the action and reaction, if set in motion, would be very intense.

(337.) The vibrations called waves occur in every degree of frequency, from twice in a day, the tides of the sea, to hundreds of millions in a moment of time. In this immense scale, a very small portion constitutes light, but this small portion being actions and reactions, do not differ in the cause of their production from all other vibrations.

(338.) Some philosophers have been led astray, have sought some imponderable or essence, some principle or immaterial, to which they refer the effects of light; and some have even supposed that the phenomenon is due to the emission of corporeal particles. We shall hereafter have to point out that light is an abstract idea of a definite material action, that we can have no light without matter, and only matter whose particles are in a certain state of aggregation will give rise to the effects.

(339.) Light, being an action and reaction, requires of necessity a body held together by attractions, on which some new attraction can act. The new attraction is generally called the source of light, for by its action on old attractions, that is, on previously existing ones, the phenomenon arises.

(340.) If we regard the labours of our most distinguished philosophers, we find that they show the impossibility of light consisting of material particles emitted from an illuminated object, for be they ever so small, the rate at which in that case they necessarily must progress is so great, that they would destroy any material body with which they came in contact. Mathematicians, moreover, have shown that light could not be communicated from one body to another by the vibration of material particles. Upon this they straightway assumed some kind of imponderable, which they were pleased to designate an ether, which, after they had created by their imaginations, they made in the same way fill space, and enter into the composition of every body, even of the most dense and heavy, that we are acquainted with. Such gratuitous assumptions, such vain creations of essences and imponderables, must be discarded, and we shall see that nature is even more easily interpreted if we first remove the inventions which human imagination has created, and then examine nature in all its beauty of simplicity.

(341.) We find that all light, the origin of which is known, is produced by some new attraction acting upon some previous one, and that for the production of the phenomenon of light in the most eminent manner, some particular attraction must act upon some particular resistance; and that, if the new attraction is either too small or too great for the old attraction, the phenomenon of light is not evinced. From these facts, the practical bearing of which we shall presently consider, we prove that light is an abstract idea of attracted matter in a peculiar state of disturbance of attraction, which disturbance of attraction is appreciated by man through the organs of sensation called his eyes.

(342.) We find, however, that the eyes recognise a certain variety of light, which variety we call colour. Colour can be readily altered by varying the attraction of matter, and the degree with which new attractions act upon the old ones. As light is the general term for the entire impressions received by the eye, so colour is the term used to designate the particular impressions received by the eye.

(343.) We have not only abundant proof that light is an action and reaction of the illuminated body, but we find that the vibration takes place with each respective colour with the same degree of frequency as compared with that event called a second. That every colour is a regular vibration, is proved by the interference of light; that is, that if the elevation of one wave coincide with the equal depression of another, and act against it, the two forces being opposite, are found to neutralise each other, consequently quiet takes place, and darkness is the result.

(344.) As the frequency of vibrations constitutes what is called colour, it follows that the division of the spectrum into certain colours is entirely an artificial division,—a division by no means to be found in nature; for there are in reality as many colours as the eye can appreciate vibrations: hence the division into colours is different in the eyes of various people. Light is conveniently artificially divided by some people into three colours,—red, yellow, blue; and by others into seven, — red orange, yellow, green, blue, indigo, violet. Let me once again point out that this division has no real existence, being only a conventional one used for convenience. The division into each colour doubtless comprises a great number of vibrations; so if light is divided into three colours, each division takes in a greater range than when divided into seven.

(345.) When the three colours of Brewster, or the seven of Sir Isaac Newton, are received upon a spot of the retina of certain size, the effect communicates a certain impression on the sensorium, which impression is called that of white light. White light is the general impression of all the specific impressions received at once by the eye. It is a compound effect, therefore, depending entirely on the structure of the eye, not on any inherent quality of light itself.

(346.) We perceive the difficulties which continually present themselves to the proper study of natural philosophy; for natural philosophy has been divided into sciences according to impressions received on different organs of the human body. To understand natural philosophy, we should thoroughly understand physiology; and again, physiology cannot be understood without natural philosophy. Nature is single, and cannot be divided; and if we study it by artificial sections, considerable difficulties occur. In the present state of our knowledge, we are compelled to read nature piece by piece, the human mind being unable to grasp it as one, single and indivisible.

(347.) Light, then, comprises the vibrations seen by the eye; colours being the specific vibrations of which white light is made up. The following table, drawn up by the greatest living philosopher, Sir John Herschel, shows the number and frequency of vibrations as compared with a moment of time.

Colours of the Spectrum.	Number of Undulations as compared with a Second.
Extreme red . .	458,000000,000000
Red . . .	477,000000,000000
Intermediate . .	495,000000,000000
Orange . .	506,000000,000000
Intermediate . .	517,000000,000000
Yellow . .	535,000000,000000
Intermediate . .	555,000000,000000
Green . .	577,000000,000000
Intermediate . .	600,000000,000000
Blue . .	622,000000,000000
Intermediate . .	644,000000,000000
Indigo . .	658,000000,000000
Intermediate . .	672,000000,000000
Violet . .	699,000000,000000
Extreme violet . .	727,000000,000000

(348.) We have now seen that light is the abstract idea of matter vibrating with enormous rapidity. It is, therefore, necessary to have matter in the first instance attracted together, on which some new attraction may act to set it vibrating. It is found that the frequency of the vibration of any particle of matter, held together by any definite attraction, depends on the length of the wave; therefore the particle of attracted matter must be a certain size to give any definite colour. It is from this reason that all bodies, no matter what the colours of larger masses, may be brought into a state incapable of showing any colour, and therefore of no light. A beautiful example is mentioned by Brewster, of rock crystal, the particles of which were so small as to be quite black. In a former work on Electro-Metallurgy I have pointed out the manner in which any metal may be reduced as a perfectly black powder. Gold, for instance, is readily rendered black, though when in a coherent state it is yellow. Silver, which is usually seen as a white metal, copper as a red, lead as a white, palladium, platinum, zinc, &c. are all readily obtained as a black powder by depositing them in the state of indefinite division. I have reduced twenty different metals as a black powder, and in every instance the division was so minute as to elude observation by the highest powers of the best microscrope.

(349.) Having obtained attracted matter on which to act, we next have to look for some power by which it may be set in vibration with enormous rapidity, which Sir John Herschel has shown is necessary to render the object visible. This force must arise from some new attractions; and as the time of each action, as compared with the action called a second, is excessively small, so must the force exerted by the new attractions be enormously large as compared with the attraction of the particles previously existing.

(350.) This new attraction is generally regarded as the source of light, and it requires a large quantity of atoms attracted with great force. On this account we only employ, practically, the attraction of chemical affinity, for by other attractions it is difficult to produce a sufficiently energetic force to produce that phenomenon.

(351.) The first source of light that we shall examine, is that produced by the voltaic battery. In this instrument no light is produced unless the attraction taking place at the positive pole, is very intense, and the number of atoms implicated numerous. When this is the case, that is, force produced by large quantity multiplied by large intensity, it will act upon attracted matter in any part of the circuit, and produce, simply by that vibration, any amount of light.

(352.) Light may be produced in a voltaic circuit at any part, provided sufficient force acts upon the attracted matter; thus in the solid part of the arrangement the metals constituting the positive and negative poles, may be made intensely luminous. Fine platinum wires, extending between the poles, are generally used to show this phenomenon. The beautiful experiment of making metallic wires luminous in dilute sulphuric acid, finely illustrates the production of the phenomenon of light by the voltaic force. In these cases no light is evinced unless the actions and reactions are sufficiently active, for if the force is not immensely more powerful than the counter force of the old attractions, the vibrations are not sufficiently rapid to affect the eyes and, therefore, light does not appear.

(353.) The second and most common source of light which we have to notice, is that produced by the attraction of chemical affinity. This attraction is usually very intense, and, therefore, very applicable for the purpose. We must, however, remember that in this, as well as in all other sources of light, the attraction may be exerted without giving rise to that phenomenon; for it is essential that the force should be so great, that it should act upon attracted particles of matter with sufficient energy.

(354.) In all cases of artificial illumination it is important to understand the manner in which that phenomenon may be produced with the greatest effect. To obtain the effect of light we must have attracted particles acted upon by new attractions. It is a beautiful experiment to inflame pure hydrogen, for in that case the attraction of particles of matter being very slight, but little or no light is produced. But if we throw into such a flame a little fine dust, instantly we obtain the most brilliant illumination. It is upon this principle that lime is so efficacious in the lime light. In candles, and other sources of light, we select a compound which, in the act of burning, deposits some solid matter to be acted upon by the attractions of the combustion, and we prefer that this solid matter, after having been illuminated, should itself, by virtue of its powers of entering into new combination, enter into a new attraction, and thus help in the production of force.

(355.) In all ordinary cases of the combustion of hydrocarbons the hydrogen is first consumed, and the carbon deposited. This carbon becomes first illuminated, and then itself is burnt, to assist in the illumination of carbon of other portions of the material. If this carbon is consumed, the instant it is liberated no light, or but very little light, is produced, and it is therefore advisable to regulate the rate of the combustion by a proper supply of oxygen, that the carbon may remain sufficiently long to evince the phenomenon of light. The most carbonaceous, and therefore the best flame, may exhibit no light if the flame be strongly acted upon by the blow pipe, as the carbon is too quickly consumed to be luminous. We thus perceive that the attracted matter that exhibits light must retain its attractions for a certain time to be luminous.

(356.) The rapidity of the consumption of the carbon, or attracted matter, materially interferes with the colour of the flame. If it is consumed with sluggishness we get a red flame, if with greater energy a yellow flame, but if still greater energy we obtain a white light, and lastly, if the energy is further increased we have only a pale, and nearly colourless blue flame.

(357.) The most perfect light that man uses has been generally esteemed to be that derived from wax candles, though the naphthalised street-gas is much whiter and more pleasant. I myself invariably use this invention, for which we are indebted to my neighbour, the celebrated gas-engineer, Mr. Lowe. The gas comes into my residence from the usual street pipes, and thence passes through an apparatus containing a series of sponges saturated with coal-tar naphtha. Gas so charged with carbon should be burned to obtain a white light with rapidity, — that is, a good supply of oxygen should be afforded. This is easily accomplished by the use of the Scotch fish-tail burner, or by the Argand with a consumer. Such a mode of proceeding is a trifling inconvenience, but the quality of the light more than amply compensates the extra expense and trouble. By these means we obtain a most beautiful and brilliant light; and those who esteem the quiet of a night as a period of study rather than repose, should never be without this admirable light, as brilliancy and whiteness, when combined with tolerable intensity, will contribute greatly to the preservation of the eyes of the studious philosopher.

(358.) The bude light is one which is much esteemed for its power of illumination. The bude light differs from ordinary light in the manner in which the gas emanates from the jets, and in the mode in which atmospheric air is supplied for its consumption. It is said to be an economical light, and is especially esteemed for very large rooms. Large public assemblies should invariably employ this mode of lighting. All artificial lights we find to be more or less injurious to the eyes, but in proportion as they are white so does the danger decrease. I find that at the Ophthalmic Institution, to which I am surgeon, that those individuals who work by deficient lights, especially at black colours, are very apt to suffer from indistinctness of vision. The reflection which always takes place from smooth surfaces, as paper for instance, is perfectly destructive to vision when the eye is much exposed to its deleterious influence.

(359.) Light may be produced by the attraction of magnetism, as in the magneto-electric machine, for in this, as in all other cases when definite attraction acts upon other attractions, light evidences itself.

(360.) Any attraction capable of giving rise to force may, by proper management, produce light. The attraction of crystallisation, or even the action of endosmosis might, by contrivances, give rise to light. The attraction of crystallization very curiously produces light, the rapid crystallization of a salt being frequently attended by flashes of light.

(361.) Any force, having been previously derived from attraction, will produce light. Heat which arises from attraction will readily give rise to light, if sufficiently intense. Force, giving rise to motion, may produce light, as in the sparks of the knife-grinder's wheel.

(362.) We have now seen how light requires, in the first place, attracted matter to be acted upon by new attractions. The mass of matter must be of a particular size, or rather of sufficient size to take on a vibration of a definite frequency, and the force originating in the new attractions must be sufficiently great, when acting on the attracted matter, to cause that frequency.

(363.) All attracted bodies do not set up vibrations of a definite energy with the same facility, hence monochromatic lights, as blue, red, yellow lights, which arise from certain bodies taking one particular vibration in preference to others.

(364.) Having now sufficiently considered the origin and nature of light, we have next to examine how, when a body is illuminated, it acts on other bodies in its vicinity, for we find that light has considerable influence on bodies on which it acts.

(365.) If we consider the nature of light, where an attraction alternately has a tendency to destroy a previous attraction, and is repelled by that previous attraction, we may expect that the same force causing the vibrations of light may produce the effect of new attractions on other bodies; and if we ask for instances of that nature, an abundance can be found which help to illustrate in the most forcible manner the true character of that action of matter which we are considering.

(366.) Light arising from new attractions is obedient to the general law of attraction, which decreases in force in the inverse ratio of the square of the distance. The cause of decrement in this particular manner is sufficiently obvious; for if light acts at twice the distance, its force is exerted over the square of the distance, or four times the space; consequently, the illuminating power, or intensity of the force at any one point, is $\frac{1}{4}$ the first effect. If it acts at three times the distance, $\frac{1}{9}$, or four times, $\frac{1}{16}$, and so on for the action it would produce at other distances to that which it would exert at the unit of distance.

(367.) In the first place, light will act upon the attraction of cohesion, and cause a body attracted together in one manner to assume other forms and conditions. Brass, whose particles are drawn together so as to form wires, is rapidly acted upon by light, and the metal becomes so crystalline as hardly to support its own weight. In the absence of light, brass will undergo no change, so that it is important never to use that metal in situations exposed to sunshine.

(368.) The attraction of crystallization may be interfered with by light: the learned Mitschellick has found the internal structure of crystals of sulphate of nickel to be materially interfered with by the force of light. He has known the internal portion of these crystals, which were originally prisms, to assume the form of octohedrons with square bases, which will give an idea of the extent which the original attractions of the body are capable of being interfered with by the agency of the vibrations denominated light. For in these instances the former attractions must have been destroyed before the particles of the body could have assumed new forms.

(369.) However extraordinary the above instances may appear, they fall into insignificance compared with the powerful effect which this force has on the attractions of chemical affinities. Chloride of silver, and other metallic salts, may be readily separated into their component parts by light. Photographic papers are practical instances of such an analysis taking place. The power in all those cases which light possesses of overcoming the attraction is due to the new attractions which give rise to the force, and in proportion to the power, that is, the quantity multiplied by the intensity of the new attractions, so has it a capability of destroying these old attractions.

(370.) In some cases light seems incapable to produce a perfect analysis, but only to so far act upon a body as to put it into a condition to be more readily acted upon by other forces. The calotype of Fox Talbot is a good example of this property, for the sun's rays do not complete the operation, the image being brought out finally by heat. Thus light puts the compound into a condition to be acted upon by heat.

(371.) There are some remarkable and curious instances where light seems to produce chemical action, but in these cases the chemical action may be rather considered as a secondary effect—an effect allowed to take place by the interference of the attractions of cohesion, which before were an obstacle to that affinity. Hydrogen and chlorine will not combine when mixed together, from the attractions of the gases themselves being an obstacle to the chemical attraction. When exposed to light, however, the attraction of the gas is interfered with, and then nothing opposes the chemical affinity, and combination ensues. It has lately been discovered, that if light acts on hydrogen it will retain its power of combination with chlorine for a long period, probably from being thrown into an action which it retains.

(372.) At various times the minds of the scientific have been disturbed by the notification that the polarity of magnetism might be given or might be taken away from iron by light ; the statement has continually been made, and as continually refuted, and up to the present moment the greatest uncertainty attends the matter. It appears to me the inquiry should only be undertaken with polarized light, that is, with light in a peculiar state, which we shall presently have to notice.

(373.) Whenever attractions are capable of being interfered with by light, it is found that the frequency of the vibrations materially influences the phenomenon, which is doubtless owing to the mode and intensity with which the particles are in action. Numerous instances of difference in the effects of different varieties of lights upon various bodies have been discovered by Sir John Herschel, to whose papers I must refer those desirous of consulting the extensive results he has obtained.

(374.) It by no means follows that light acting upon any body should actually destroy attractions. It may be repelled by that body in which it acts; it may not act upon that body at all; or it may throw that body into other vibrations. In this way light, by virtue of the new attractions which it contains, may act upon a body destroying its attraction, which on their resumption may give the effects of heat, and likewise in some cases even to sound. The production of heat from light is so common, that it scarce requires further comment. It is a very important fact to the gardener, for in a bright cold day the light acts through the glass of his frames upon the attracted matter underneath. This attracted matter assumes the vibrations of heat, which cannot again act through the glass.

(375.) We perceive that whenever light is present we have a force, which force, according to its power, must contain new attractions acting upon old ones. The new attractions, according to their energy, may produce all the effects of destruction of old attractions, which we have so frequently pointed out throughout this work. Whenever light acts upon the attractions of other bodies, and does not cause them to set up the actions of light, the light is said to be absorbed; thus, when light causes heat, decomposition, &c., &c., it is said to be absorbed.

Although the term was originally given from the supposition of the material nature of light, yet it may be well retained, only clearly understanding that the absorption of light is a term applying to the action of the force of light in producing other phenomena. Charcoal and other black things are the best absorbers of light.

(376.) As attraction requires no intervening matter between particles evincing that action, so light, whose force is derived by virtue of attraction, appears to require, for the same reason, no intervening matter for an illuminated body to act upon other matter. At least, not only has no proof of such necessity ever been adduced, but on the contrary, every fact seems to prove that such material intervention is not only not required, but is an obstacle to the action. Upon this account we may infer, that when the action of light of any body interferes with a second, that the second is acted upon by virtue of the actions in the first, without the propagation of force through any material particles which may exist between them.

(377.) Indeed, when material particles exist between the light and the lighted body, these particles, according to their number and state of attraction, interfere with the action of light in various manners. When they admit the action of light to be more or less exerted through them they are called transparent. When they prevent the action they are called opaque. All transparent bodies, if sufficiently thick, would be opaque, and all opaque bodies, if sufficiently thin, transparent. Hence transparency and opacity are but different degrees of the same property, that is different degrees of the power of allowing the action of light to be exerted through their substance.

(378.) Transparency is very much to the force of light what diathermancy is to that of heat, and requires for its exertion very similar conditions. It is necessary for a body to be transparent that its attractions, by virtue of the power of reaction, should not entirely repel, or reflect the force inherent in light. Moreover, the force of light must not destroy the attractions of the body, otherwise so much of the force used for that purpose would be annihilated. The light must not make the body hot or luminous, or else that would detract from the force. In a few words, we may state that the transparency of a body is inversely as its power of reflection, as its capability to become luminous, as its capability to become hot, or as it admits destruction of its attractions. No body can be absolutely transparent, because more or less force is sure to be destroyed by some of these means: no body is absolutely opaque, because these properties are never infinite.

(379.) When the force inherent in light is repelled from any body, it is said to be reflected, and its repulsion always takes place at a certain angle; for, from whatever direction the force impinges upon a body, when it is repelled it is repelled or reflected in such a manner that the angle of incidence is equal to the angle of reflection; so that the force, instead of acting upon the body on which it impinges, has its direction changed. Apparently force is exerted from the second body in a particular direction, whilst, in reality, the second body only manifests the effects of force by virtue of its power of repelling the force acting from the illuminated body.

(380.) Upon this very simple principle depends the construction of looking-glasses, mirrors, both concave and convex, as all the properties evinced by these contrivances depend upon the reflection of light, and its reflection in the particular manner just pointed out. The manner in which light is reflected causes the true looking-glass to reflect without distortion; the concave mirror to collect the light, (throwing out of consideration spherical aberration,) into a focus or point; and the convex mirror to reflect the force in such a manner that it diverges from all parts of the surface.

(381.) It is necessary for perfect reflection that the surface of the attracted matter causing that phenomenon, should be as polished and bright as possible, as it is found that an uneven surface reflects, as might be expected unevenly, by reflecting in every possible direction. Moreover, to insure considerable reflection, the surface should be in a state unfavourable to the absorption, or rather the annihilation, of the force, by its destroying other attractions, or giving rise to vibrations of a different character from those comprised within the range of light.

(382.) Philosophers generally believe that this repulsion of the force, not only takes place at the surface of a body whose particles are held together by attraction, but at each layer of ultimate particles of which the body is made up.

(383.) The remarks which, up to the present time, have been made on reflection, have related to light in general; but specific kinds of light, as they contain different degrees of force, allow of reflection from various bodies in very different manners. Thus some bodies which reflect easily a red light, will not at all reflect a blue, or a blue a yellow, and so on for any colour comprised within the range of light, the law regulating the reflection of the specific colour being in accordance with the principles which we have pointed out, as regulating the reflection of light in general.

(384.) We have already noticed, that when the force of light is repelled from any body, it has to all outward appearance the same effect as if it had originated in the repelling body itself; so that when any body reflects any specific kind of light, the body reflecting it appears to originate the kind of light. On that account, when a body only repels one or more varieties of light, it is said to be of that colour. If a body only repels red, it is called red; if yellow, yellow; and so on for any other vibration. It is thus apparent that a coloured body is not coloured by virtue of the existence within itself, or about itself, of any immaterial or imponderable, but simply according as it repels the force of any particular vibration. On this account, the same body, with a different condition of surface, may exhibit a different colour, by reflecting differently.

(385.) In the phenomenon of reflection of heat similar effects are seen to those of light, so that the preceding remarks apply equally, whether the force repelled be originally that of heat or light, for although these terms are given to a different range of actions the force of both is identical; namely, that of new attractions.

(386.) We have before had occasion to notice that light acts from one body on another in straight lines, or, in other words, that the direction of the force was exerted usually in a right line, but sometimes other forces interfere with this direction, in which cases the direction of the ray of light is said to be bent, and this bending has different names according to the manner in which it is produced.

(387.) When the force of light is exerted through transparent bodies, and the attractions of those bodies interfere with the direction, the ray is said to be refracted, and the general phenomenon of this bending is described under the general term refraction.

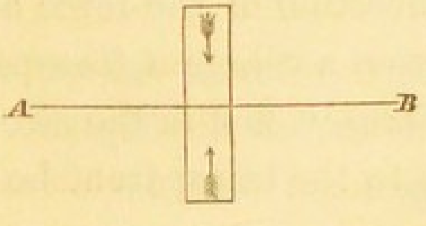
(388.) Refraction can only be exerted by transparent bodies or those which admit the force to be exerted through them, and for the exertion of this property we have already noticed, that the body must neither entirely repel the force, become illuminated, take on other vibrations, nor have its attractions overcome. Transparent bodies even only refract when the force is exerted in a particular manner, which we shall have presently to point out. A body will exhibit refraction even though it admits but the least amount of the force of light to be exerted through it.

(389.) The phenomenon of refraction is always exerted in proportion to the number of atoms of which any definite bulk of the refracting body is made up; or, in other words, refraction depends on the density of the body, the densest body, or that held together by the strongest attraction, and containing in a given volume the most numerous ultimate particles, evincing that property in the most eminent degree.

(390.) In the former part of this work I had occasion to notice that there was reason to believe that, when two atoms were attracted together, one atom was the generator of the force, and therefore may be called an inducer, and the other atom the recipient of the force, or inducee. To the former class we have reason to suspect combustible bodies belong; to the latter, supporters of combustion. Inducers refract violently about three times more than what can be accounted for by their density, whilst inducees refract but very little. Hydrogen is a violent refractor for this reason, whilst oxygen, from the converse cause, refracts but feebly.

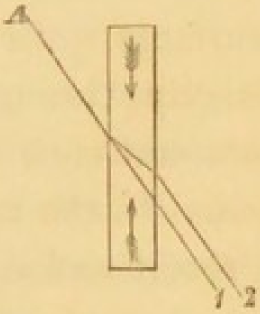
(391.) Having premised that bodies differ in their refracting power, first, according to the energy with which their particles generate attractions; and also secondly, according to the number of particles which are attracted together to make up a definite bulk of the body; we have next to consider in what cases this diversion of the direction of rays of light and this bending or refraction takes place.

(392.) We find that when light is exerted between two bodies, and a transparent body is interposed, as, for instance, a piece of glass between a candle and a book, if the forces of the attractions of the intervening transparent body act laterally to the same amount, no bending or refraction occurs. If, for instance, a piece of glass is ground with its surfaces quite parallel, and the force is exerted directly through it, the lateral force being alike in amount each way, no refraction or bending takes place. In the adjoining figure the two arrows shew the result and direction of the lateral attraction of cohesion, the backward and for-



ward forces are disregarded in this and in subsequent diagrams, because as the force of light is directly opposed to the contrary one, it has no power of deflecting the direction of that force.

(393.) If, however, the force of the ray of light falls obliquely on the glass, the force of cohesion does not act upon it laterally to the same extent, for it is more opposed on one side than the other, inasmuch as the force is partially in the same direction of one lateral force, though partially opposite to the other. On this account the force of one lateral force of cohesion, which is partially opposite to the force of light, acts upon it to a greater extent than the force of cohesion, which is partially in the same direction; and, therefore, the light is not exerted in a straight line but bent or refracted from the opposing force of cohesion, and consequently towards a line perpendicular to the surface of the glass, as in the adjoining diagram.



(394.) The direction of the force of a ray of light falling obliquely on a coherent transparent body having parallel surfaces, is first in the direction of a right line, or straight to the transparent body, that is, in a right line from the illuminated body. As the force traverses, or is exerted through the transparent medium, it is deflected according to the intensity of the attractive power and the number of particles whose attractions are more or less opposed to the force of a ray of light. After the force has ceased to be influenced by the attraction of cohesion, it again follows a right line in the same direction as it emanated, or was exerted from the illuminated object. After the force has passed beyond, or is without the influence of the refracting body, it continues its passage in the same direction that it possessed prior to the refractive power having been exerted. The action of the ray, therefore, beyond the refracting body, is parallel to the direction of the action of the ray before it impinged upon it, though carried to a certain amount to one side by the forces inherent in the refracting body.

(395.) In the preceding account I have described the phenomenon of refraction for the sake of perspicuity, in several stages, prior to refraction, during refraction, and subsequent to refraction, though such description is not strictly correct, for light is a force and cannot be said to travel at all, as really the phenomenon of refraction is simply the diversion of the direction of the force of light by the force of cohesion.

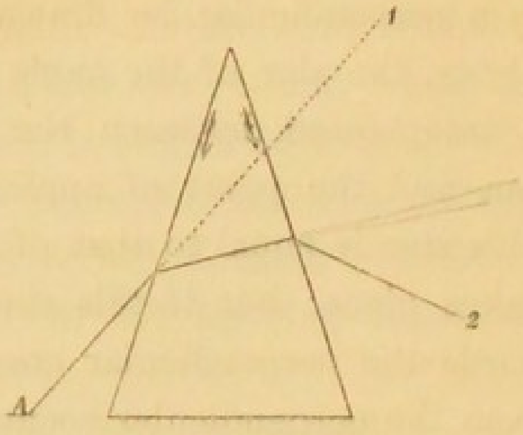
(396.) In the former instance which was given of the effect of transparent bodies under attraction upon the force of light, the bending or refraction was of the most simple kind, for the force was simply carried one way; but, when bodies are of irregular forms, the effect is far more complex.

(397.) The refraction taking place through transparent bodies of any form is referable to the two surfaces, that is, the bending apparently only occurs at its entry and exit. The mode in which the influence of form of bodies of various densities has upon refraction is reduced to simple mathematical laws, and admits of tolerably easy calculation.

(398.) To calculate the influence of the power of particular forms of any body to refract, the refractive power of the body is first obtained, by expressing the relation which the sine of the angle of refraction bears to the sine of the angle of incidence. Having obtained this relation, when force acts upon a body at any given angle, the point of the surface at which the force acts is taken as the centre of a circle, whose plane is determined by the direction of the force being in it, and the condition that it must be perpendicular to the surface of the body; the direction of force is necessarily a diameter of the circle, and a line is drawn from the point where this cuts the circle perpendicular to the surface of the body, the radius of the circle being then considered as unity, the sign of angle of incidence is the line intercepted between the foot of the perpendicular and the point of application of the force; if the direction of the force after refraction be produced to cut the circle, and from the point where it intersects a perpendicular be drawn to the surface of the body, the sine of the angle of refraction is the line intercepted between the foot of this perpendicular, and the point of application of the force. If this sine is equal to that of incidence no refraction takes place; but if this sine is less, refraction towards the perpendicular ensues, if more, refraction from the perpendicular occurs.

(399.) This mode of expressing the refraction of bodies is not an absolute but a conventional one, for the circles and the sines have no connection with the refracting body, but are useful and practically perfect assumptions to enable us, first, to express the refracting power of any body, and thereby ascertain the influence which any definite form of that body would have upon light acting in any direction through various forms.

(400.) All cases of refraction may be referred to a deflection of the direction of the force by other forces acting in other directions, so that the force is exerted in the resultant of the several forces. Perhaps one of the most extraordinary instances of this change of direction is seen in the lens called a prism, for the forces of cohesion act in two different directions upon the force of light when acting in a particular manner. In the adjoined cut the force of light is acting from A to A 1, or upwards and forwards, but is met by two forces of cohesion; the first attempts to carry it downwards and backwards, the other downwards



and forwards. That part of the force acting forwards neutralizes that acting backwards, and the result is, the downward force alone acts, and the force is deflected downwards to an extent proportionate to the refractive power of the matter of which the prism is composed (2).

(401.) In this and in all other cases of refraction, there are often forces of cohesion acting in all directions, but they do not require particular attention, for by all those that act directly contrary to the force of light, the force of light is not refracted, but only lessened, it is only those that act laterally upon it which influence the result.

(402.) The force in acting through the prism or indeed other lenses is resisted, therefore, according to the doctrine of time as previously explained; time is most probably manifested by this act; the time, however, is perhaps so small as compared with a second, that it is uncognisable to our senses. At the present moment I cannot call to mind whether this manifestation of time has ever been experimentally examined by philosophers, nor can I conceive any mode by which such investigation could be conducted.

(403.) Light on being resisted by attractions has its force lessened; so its effect is that of less force after it has acted through a transparent medium. For this reason light, after acting through glass, has not an equally beneficial influence on plants requiring much light; and also, for a similar cause, the action of light cannot under these circumstances so well give rise to the intense attraction of light, but frequently makes the body acted upon hot instead of illuminated. Hence the great heat in graperies and melon-pits, which gardeners take advantage of to give to the choice fruit in colder countries the flavour peculiar to exotic climes.

(404.) It is upon the principle of refraction that all lenses are formed; for, according as they collect a series of rays, or separate them, so their virtues are derived. Convex lenses, for instance, collect a number of parallel rays to a focus; concave, on the contrary, separate parallel rays and cause them to diverge; and so for all the varieties of forms which human ingenuity has at various times contrived.

(405.) For a work like the present it is not suitable to discuss the minutiæ which belong to optical laws, but we must refer our readers to the excellent treatises of Brewster and other professed writers on that subject. We shall, therefore, not enter into the consideration of spherical aberration and other minor properties which belong to refracting bodies.

(406.) Hitherto we have detailed the effects of refraction on light in general, but we have now again to point out that light is composed of several kinds of light,—of lights with different forces,—hence the power of refraction is exerted unequally on these varieties of light. The most intense vibrations, that is, those of greatest frequency, are the most refrangible; the least intense, or those of less frequency, are the least refrangible.

(407.) The different relative degree in which these various vibrations or colours admit refraction with different bodies is called the dispersion of light, and the relative power of various bodies is termed their dispersive power. This dispersion is supposed not to be coequal with the absolute refractive power, that is, the refractive power for the same relative number of ultimate particles; but we can hardly imagine that such should not be the case. Connected with the dispersion of light, however, we find that, under different circumstances, different colours are differently separated, which phenomenon is termed the irrationality of dispersion.

(408.) The separation of all the colours of white light is called the analysis of light; but sometimes refraction takes place without the phenomenon appearing. For instance, light in acting through a pane of glass exhibits no colour, perhaps, from the rays being in some manner not sufficiently under-

Wood's Optics Art. 378 Newt. Opt. P. II. Sect.

stood so collected again as to give the phenomenon of white light when acting upon the visual apparatus. In all refractions the separation of the colours doubtless takes place; but, to produce it in the most eminent way, that particular form of lens called a prism must be employed.

(409.) If the forces by which particles of bodies are held together exert an influence on the force of light, we might *à priori* imagine, that if the force of a ray of light was exerted near a body whose particles are held together by attraction, that that force might influence the force of light. This is actually found to be the case; for, when the force of light is exerted near the edge of bodies, it is deflected, or rather its component rays are deflected from their original direction, and assume others. The action, however, is not called refraction, as in the former case, but inflexion or diffraction. This phenomenon is generally exhibited and studied by the effects which a solid body produces upon the shadow of a solid body interposed between a small aperture admitting a divergent beam into a dark room, and a skreen on which the image is received.

(410.) We have now seen that reflection, refraction, inflexion, or diffraction, are terms used to designate phenomena produced by the attraction of bodies acting upon the direction of the force of light. The respective phenomena, however, are unlike, inasmuch as the deflexion of the light takes place in different manners and different extents.

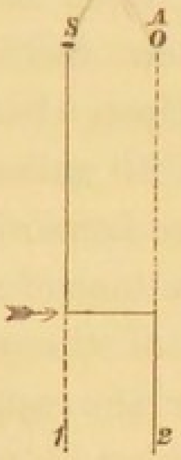
Reflection treats of those cases where the force is repelled or turned back from its original direction, refraction comprises those cases in which light is simply turned on one side, whilst inflexion depends upon a force being exerted from bodies under cohesion upon a ray of light acting near the solid body.

(411.) Before we dismiss the consideration of the influence of transparent bodies, we should not omit the consideration of the effects of transparent bodies on the direction of the force of light, for there is invariably reflection exerted as well as refraction. In fact, the similarity of cause may be inferred from the conjunction of reflection with refraction, and perhaps reflection is not only exerted at the surfaces of bodies, but at each layer of particles of which the mass is made up.

(412.) Heretofore we have only treated of the influence of transparent bodies on vibrations called light, but vibrations which are more frequent than violet light, and less frequent than red light, are obedient to the same laws, and are acted upon by bodies which admit the force being exerted through them. Hence diathermous bodies have similar action on the vibrations of heat that transparent bodies have on light, there being no further difference between the two effects than what is due to the different degree of energy and frequency of the exertion of the several vibrations.

(413.) Light, being a series of alternating actions and reactions, may be interfered with by other actions. Hence light from celestial bodies appears to be interfered with by the rapidity of the earth's motion. "It is observed," says Mrs. Somerville, "that those eclipses of the first satellite of Jupiter which happen when the planet is near conjunction are later by 16′ 26″ 6 than those which take place when the planet is in opposition. But as Jupiter is nearer to us when in opposition, by the whole breadth of the earth's orbit, than when in conjunction, the circumstance was attributed to the time employed by the rays of light in crossing the earth's orbit a distance of about 190,000,000 of miles, whence it is estimated that light travels at the rate of 190,000 miles in one second." However, the time occupied by the passage of light may be explained more satisfactorily in other manners; for, as light decreases in the inverse ratio of the square of the distance, the feeble light of the satellite would have been much more feeble when 190,000,000 miles further off. Upon that account the onward motion of the earth, 19 miles in a second, would assist the light to drive forward the force. The force proceeding in the resultant of the direct force of the light, and the force of the motion of the earth, would give the star the appearance of being in another position to what it really is; and this resistance, according to the general doctrine of resistances, would cause the manifestation of a certain time, which time would be the 16m. 26s. before quoted. Upon this consideration it will probably be hereafter found by astronomers, that the aberration of light will not only be proportionate to the distance the celestial body is off, but also to the intensity of the illuminative power, and the intensity of the force acting upon that original direction.

(414.) The adjoining diagram will serve to illustrate the effect of the force of the motion of the earth on the force of light. S is the star radiating a ray of light in the direction of S to 1. The force, however, at the earth is acted upon by another force at right angles to it. It is, therefore, instead of going on to 1, deflected to a certain extent laterally to E, when, on that force being spent, it proceeds in its original direction to 2. The star, therefore, appears in the direction of E 2, which being prolonged, is apparently at A, whilst in reality the star is at S.



The preceding observations on the action of the force of light by other forces show that we can neither judge accurately of the position nor magnitude of the form of any body by the forces of light acting from it, for those forces may be, and actually are, disturbed, moved from their original direction, and deflected so as to give in some cases the most false and unnatural appearance to bodies, though we are so much in the habit of judging by them that we continually hear of the vulgar proverbs referring to the certainty of what is seen.

(415.) Having now described the effects produced upon the force of light by the forces of cohesion, or, in other words, on the one set of attractions giving origin to light, by another producing cohesion, we have to detail the effects which bodies produce when the direction and intensity of the attractions holding them together are different, in different parts, and in different directions. We might, beforehand, indeed expect that such peculiarity in the direction and attraction of bodies should produce particular effects on the force existing in light.

(416.) In a former part of this work we have had occasion to point out, that there is a peculiar direction in which the force of attraction is manifested. Now we may expect, that, when the attractions of a luminous body act upon another, that the direction of the force of one part of the attractions is in the contrary direction to another, so that in a quantity of light made up of numerous forces acting from different particles, we may expect that it can be analysed not only into its component parts, that is, into forces of definite energies, but into the colours whose forces are exerted in the two directions.

(417.) To this analysis of light into the direction of the exertion of the forces, the term polarization is given, and it is effected generally by means of bodies whose attractions differ in intensity and direction in various parts. Crystalline bodies are bodies of that character, and, according to their structure, they have in certain positions the power of separating the two directions of the forces of the rays of light of which a quantity of light is made up.

(418.) When light, made up of rays having forces in opposite directions, is exerted through crystalline bodies of peculiar structure, one set of rays passes in one direction through the crystal, the other in another, so that a line seen through a crystal of this character appears not as one line, but as two, in consequence of which this separation of the rays is called double refraction, and the two sets of rays so separated are called polarized rays on account of their peculiar properties.

(419.) The properties of polarized rays are very curious if the force is again exerted through another crystal; for instance, a tourmaline cut into plates about the $\frac{1}{30}$ of an inch thick and polished, for the two sets of rays will not exert their force through it at all positions, but each ray only in some definite positions, so that a plate of tourmaline becomes a test of polarity in light when used in the manner just pointed out.

(420.) The two sets of vibrations separated by double refraction may be put together again in such a manner as to lose the character of polarity. Every kind of ray, that is, vibrations of every colour, are in certain directions, and therefore both refracted rays may consist of all the colours which are necessary to make the impression on the sensorium of white light.

(421.) Light may be separated into the rays having various directions not only by refraction, but also by reflection. This similarity of properties must forcibly add to the overwhelming evidence supporting the idea of the analogy, or rather identity of the cause of these two actions on light, but whether a body be polarized either by refraction or reflection, it is only in such a position that the multitude of forces constituting a ray of light are separated into the two directions which they possess by virtue of the direction in the previous force of attraction.

(422.) Most bodies which do not ordinarily doubly refract light, possess that property after their attractions have been interfered with by pressure or unequal expansion, or by any other means which give a peculiar direction to the attractions holding together the particles of any body.

(423.) We have now considered the vibrations which are appreciated by the eye, and are called light. We have pointed out the variety of vibrations constituting colour, which acting collectively upon the eye, produce white light. We have detailed how light arises from new attractions of great energy acting upon particles of matter attracted together. We have discussed the effect of the force of light upon that attraction, and we have found in turn that all attractions may be interfered with by that force. Again, we have seen that all attractions may act upon the force of light; they may repel it at a certain angle, they may turn it on one side, they may separate the rays into their multifold forces of different frequency or intensity, and, lastly, they may analyse them into their two directions.

(424.) But little further is required to point out the relation of light to the other sciences, and the other sciences to that of light. Being a science of vibrations, it requires the study of the sciences of attracted matter before we can study how new attractions can give rise to that phenomenon. Being a science where new attractions are required, any science wherein new attractions are contained, have relation to light, by being capable of producing the phenomena. Hence electrical force of all varieties, dynamical action, heat, &c., may cause the effects of light; and, in like manner, light may give rise to the effects studied under all these sciences. The similarity of heat and light is very close; in fact I have rather bowed to universal custom in treating them separately than to any division really existing in nature. Light is similar to sound in being a vibration, but dissimilar in being of a different range of vibrations, one set being appreciated by the eye, the other by the ear.

(425.) The great source of heat and light to the earth is derived from the sun, whose benefits upon all terrestial creatures is so great, that there have not been wanting human beings who, on its first appearance at the dawn of morning, have fallen down upon their knees and worshiped it for the benefits they derived from its powers. What is this sun, without whose rays we could scarce exist a single day? Some have supposed it a ball of fire, others that it is a mass in a certain state of combustion. If, however, we suppose the particles of the mass of the sun be alternately attracted and in a state of destruction of its attractions, all the effects produced by the sun would arise. How far the sun acting successively on different parts of our planetary system is the cause of their revolution, it is not for me at the present time to consider, and if perchance the influence of the planets causes the vibrations of the particles of the sun, how simple would be the construction of our solar system! When we consider, that, by attraction, the planets are held in their situation, such an idea has some probability. Upon such a view, beautiful for its simplicity, excellent for its grandeur, the sun would cause the alternations of light with darkness, heat with cold, day with night, summer with winter, and source of light, source of heat, source of motion, it would itself derive this power of illumination from the planets, which in turn it illuminates, revolves, and cheers.

(426.) The next set of vibrations which particularly demands our attention, are those which are appreciated by a certain organ in human beings called the ear. The vibrations communicated to the sensorium by means of this organ are called sound; which is, therefore, to the ear what light is to the eye. Without the ear, we can have no knowledge of sound, as without the eye, we can have no knowledge of the specific actions called light.

(427.) The range of vibrations constituting sound is very great. It varies in different cases; but on an average it is stated to be from 8 in a second to 24,000; so that the range of vibrations appreciated by the ear is much greater than that appreciated by the eye, though the vibrations of light are immensely more frequent than the vibrations of sound. A singular difference exists between these phenomena, for it is essential that sound should be promulgated to the ear through material particles. This distinction between light and sound is rather apparent than real, as it depends, perhaps, upon the immense intensity of the vibrations of light over those of sound, and a difference of structure between the ear and the eye.

(428.) Whether the action of sound can be exerted without the intervention of material particles perhaps it is difficult to ascertain, because there is no good test of sound except its action on the human ear. This organ is constructed, not to appreciate delicate sounds, but to withstand the action of heavy sounds. Were it not for its power of diminishing sound, probably the noise produced by the discharge of heavy artillery, when communicated to the sensorium, would produce insensibility, or even instant death. The noise from the merry peal of bells might in the same way cause similar inconvenience to those engaged in producing the joyous sound.

(429.) To show that sound sometimes exists when we cannot hear it, we have only to look around for instances in natural history: and who has not seen the entire fish contained in a pool collect at one spot with open mouths at the sound of a bell usually employed to give notice that food would be thrown into the pond? Although fish can hear in the water with perfect distinctness, I have been informed by good divers, that when under water they could not hear a gun fired close above their heads. This observation only applies to cases where the individual is completely submerged in the water, and not to diving-bells and air-hoods, as it is reported to be customary, especially with diving-bells, to transmit signals by causing the bell to vibrate at a particular place.

(430.) Sound always requires a great number of attracted particles to have their attraction disturbed by a feeble force, so that the force inherent in sound is not only feeble, but distributed over a large surface. On this account the force of sound cannot be readily made to produce the effects of forces of much energy.

(431.) To produce a sound, we must procure a large number of particles attracted together and held in some definite position. Upon this mass the force acts ; and it is by the action and reaction of these forces,—that is, the reaction of the force by which the particles of matter are held in position against the force tending to alter their position, that sound arises.

(432.) The source, or cause of the vibration of sound, manifested in attracted matter, is always derived from a new attraction acting upon it. However that new attraction arises, sound may be produced. At the present part of our work, I need hardly again recount how various attractions may give rise to sound, but only refer to the other sciences which have in a similar manner their origin from new attractions. Suffice it to say, that any kind of attraction may produce a force which, if acting on attracted matter in a particular manner, may give rise to sound. The sound of the mill, which may be heard for miles, is primarily due to the attraction of gravity of the water. The noise of the cataract is due to the same cause. The thrilling sound of the steam-whistle and the roar of the cannon are due to the attraction of chemical affinity. An alarm may be rung by the attraction of magnetism, or an organ played by attractions taking place in a voltaic battery.

(433.) Sound may be defined to be the range of vibrations of attracted matter appreciated by the human ear; but as there are many vibrations so appreciated, there are great variety of sounds. When the vibration is repeated with the same frequency, the sound is a musical sound; when of unlike frequency, it is called an unmusical sound.

(434.) Musical sounds are exceedingly numerous, and are divided for convenience into octaves, notes, and fractional portions of notes, to assist musicians and composers, who use to produce various effects, notes, and combinations of notes, of various lengths, to which all the beauties of melody and harmony are attributable. The duration of a note depends on the number of vibrations of a sound of any definite pitch.

(435.) The only standard of sound, which is deserving the name of a standard of sound, is that derived from a piece of matter taking on a certain number of vibrations, as compared with a second. This standard being doubled, or halved, in the energy of its vibrations, and then again successively doubled and halved, gives the successive octaves, whose relations to the standard are determined by the relative frequency of their vibrations to that of the artificial pitch. A perfectly natural standard of sound would be as impossible to obtain as perfect standards of size, weight, or time. A curious instance occurs, of the difficulties which arise from descriptions of sound not being abstract, in the writings of the Hon. Daines Barrington, where he compares certain notes of birds with that of the great bell of St. Paul's; that learned author having no other means by which he could communicate to the world his observations on the noises and notes of our British birds.*

(436.) An octave in music comprises the vibrations of any particular body, which, being either halved in size or doubled in the force of position, would, on the application of a force, give twice the number of vibrations as compared with a second of time; or conversely, if the particles of the body were doubled, or the force holding them in position, halved, the frequency of the vibrations would be diminished half.

(437.) This octave musicians divide into eight notes, and these notes into semi-tones; but it is important that we should rightly understand that the particular vibration of a semi-tone, — the very smallest division of the whole range of vibrations,— is removed from the next semi-tone by an immense number of vibrations, even when compared with a

---

* "As one should speak of these notes with some precision, the B flat of the spinnet I tried them by was perfectly in tune with the great bell of St. Paul's."—Page 268, Phil. Trans. 1773, vol. lxiii.

second. The number of octaves comprised within the range of sound is about twelve and a half.

(438.) Every vibration coming within the range of sound follows the laws of vibrations generally, and is subject to the phenomenon of interference; that is, if two waves act upon each other they may be either increased or annihilated, according to circumstances. If the elevation of one wave so acts upon the depression of another that the two forces are exerted in the same direction, the force of the sound is increased, that is, the noise is increased, though the pitch of the sound is not altered. If the forces, however, act equally in the contrary direction the force is annihilated.

(439.) On account of this property of interference it has often been a subject of surprise to musicians, that when four or five hundred instruments and voices are apparently producing the same note, that the result is not necessarily a great sound, or an annihilation of sound: but this apparent non-interference may be owing to several causes; first, that the different instruments are not vibrating absolutely with the same frequency, and even in cases where they are so, their distance from each other may make the forces act on each other in every possible manner. Connected with this subject the infinite variety of tones of the same note may be considered, for the same note produced by a flute is very different from that of a violin, or that of a violin from a piano, or a piano from a drum. These varieties of tones are, perhaps, owing to other sounds acting contemporaneously with the principal note.

(440.) When we desire to produce sound we procure portions of attracted matter, and act upon the particles under attraction, so that the action and reaction may be within the range of the ear. When we require to produce any definite pitch, we obtain particles of matter attracted with a particular force, and act upon these attractions by some other definite force. The higher the note the more forcible must be the first attraction, and the greater the force which is required to act upon it. If the attractions of any particular mass give a certain vibration, twice the quantity of matter, or half the attractive power would give the octave lower, or if *vice versâ*, the octave higher. Certain fractional parts of increment or decrement, either of the force of attraction holding together the particles, or of the number of particles constituting the original mass, allow of the vibration of the eight notes, or subdivisions, of the octave.

(441.) Sound, containing within itself a force, and force being the result of new attractions, may interfere with the attractions previously existing in bodies. It may interfere with the attraction of cohesion. The fracture of glass windows after heavy explosions is an excellent example of this action. Upon the explosion of gunpowdermagazines, fracture of glass may take place in windows miles off. A fearful instance of the destruction of cohesion by sound is seen in some Alpine passes, for travellers state, that frequently not only loud explosions, but even the sound of the voice, will determine an avalanche to fall, and carry away and destroy every thing within its reach.

(442.) It may disturb the attraction of gravitation; the rattling of windows from the noise accompanying explosions is a familiar example of this fact. Sound may even disturb or destroy the attraction of chemical affinity; but, in this case, we find that as chemical affinity is generally strong, and the force of sound weak, its analysing power is not strongly marked; still, however, delicate chemical compounds will explode by a strong sound. Sometimes from very heavy explosions of gunpowder there is an appearance of its causing the explosion of contiguous gunpowder. A short time since the government mills at Waltham Abbey exploded, at which time one magazine first blew up, and subsequently the second, which took place without apparent cause. In this case it is not impossible that the explosion of the second might be caused by that of the first, in the same way that a similar effect arises with some delicate compounds.

(443.) Sound acting on old attractions does not necessarily destroy them; it may be, like light, repelled by the force at a certain angle which repulsion is called reflection. Reflection is always exerted in such a way that the angle of incidence is equal to the angle of reflection. It is, therefore, easy to calculate the effect of particular curves for the purpose of collecting sound.* The ear trumpet is a good example of the practical application of the reflection of sound.

(444.) An echo is another example of reflection. In this case the reflecting body must be such a distance from the origin of sound that the two noises are quite distinct. Sometimes by various reflections an echo may repeat many times. A fine instance of frequent repetition is to be found upon the Rhine; but instances of two or three repetitions are not uncommon. In Finsbury Circus, where I reside, there is a quadruple echo in certain situations, which will repeat one word three, four, or more times. A very beautiful single echo is observed off the Great Ormes' Head, a projecting headland between Liverpool and Conway. This will repeat an octave with the greatest precision.

(445.) We have before mentioned that sound appears only to be propagated through the intervention of material particles, at least we can only hear sound so propagated; and we find, therefore, that a bell ringing *in vacuo* is inaudible. Its progression through material particles, like the conduction of heat, requires a certain time, from the obstacle which is afforded to its propagation.

---

* The whispering gallery of St. Paul's is also an excellent illustration of the reflection of sound.

Different bodies allow sound to be propagated through them with different facilities, a property in which respect it is similar to conduction of heat.

(446.) The relation of the science of sound to the other sciences may be easily inferred from the nature of that phenomenon. By containing a force, it is analogous to the sciences of the disturbance of attraction, to the various forms of electrical forces, to dynamic force, &c.; the only difference in this respect being, that with sound a feeble force is distributed over a large mass of matter. In containing a force it is similar to light and heat; but here it presents the further analogy of being the idea of an action and reaction. In fact, philosophers suppose that a string vibrating sound on being continually bisected into octaves, would give at last, on being acted upon by sufficient force, the effects of light. In all probability it would give also the effect of heat; but, we must remember, that as the frequency of the vibrations increases, the amount of force must be also enormously increased.

(447.) The sciences of vibrations, which we have at present considered, treat of but a very few of all the vibrations which might possibly happen. The longest vibration, and slowest, with which we are acquainted, are the tidal waves, of which only two are manifested in a day. The smallest vibration is that of violet light, though we have evidence to shew that even more rapid vibrations than this exist.

(448.) In this enormous range but few are described, and made the subjects of distinct sciences, and these few are tides, sounds, and light. Between these there are an immense mass, either not particularly described, or their limits not exactly known. Heat for instance, we know, is an action and reaction, though we do not know the precise actions and reactions which constitute heat; but, independently of this undetermined range, there must be still a vast number not particularly described.

(449.) Of this undescribed number there is some probability, that another science comprises some of the unknown vibrations. This science, perhaps, comprises the vibrations of odours. Odours, properly, should be referred only to those actions which are appreciated by the nose, or similar difficulties might occur to those which arise from the non-restriction of light to the vibrations perceived by the eye, or sound to those recognised by the ear.

(450.) The best proof that can be given of the non-existence of some principle, or some essence, or some imponderable attached to matter, to which the effects of odour are due, is perhaps seen in the indefinite propagation of odour from small particles of bodies. When we are told that a grain of musk will impart a scent over a large room for many years, we must admit that the effects of odour are rather derived from an action of matter, than from the emission of corporeal particles or immaterial essence.

(451.) Of the nature of the action which causes odour we can never hope to arrive at much knowledge, because man has literally no nose, the organ being only the rudiment of an organ in the human subject. If a philosopher should arise who possessed a nasal apparatus endowed with the same delicacy as the blood-hound, or the exquisite structure of the cat, then, indeed, perhaps we shall find that as many effects are produced by odour as by light, sound, or heat.

(452.) We have thus briefly treated of vibrations, and we find every gradation from the tidal waves to vibrations, more frequent than violet light. Of these vibrations, we have seen that some are called tides ; a second set, sound ; a third, light ; a fourth, heat ; and, perhaps, even a fifth, odour.

(453.) When we consider that the vibrations of sound, light, heat, and perhaps odour, must constitute a very small proportion of all the vibrations which must daily take place, some slight idea may be formed of the multitude of impressions we might perceive had our organs been more highly developed. In studying the phenomena, which are classed under the sciences of vibrations, we have no proof that what is light to us, that is, the particular vibrations which affect our eyes, is light to other animals, or produces effects on them. We cannot tell that the sharp-eyed hawk, or the acute-nosed dog, sees or smells with the particular vibrations which affect our organs.

(454.) The above considerations shew most forcibly the importance of studying physics as a whole, not in divisions. By the investigation of the phenomenon of one science we become more acquainted with its details; but when we are desirous of contemplating the real nature of the phenomena, and the cause of their production, we must study the effects as a whole, to prevent erroneous conclusions and vain creations of imponderables.

CHAPTER V.

ON THE PERFORMANCE OF HUMAN OPERATIONS.

Mode of Performing Operations (455).—Attracted Matter acted upon by Attractions (456—459).—Law for the amount of Action (460).—All Operations destructions of Attractions (461).—Resistance to Action (462—464).—Force only annihilated by destruction of Attractions (464).—Voltaic Force (465).—Attractions without Force (466).—Energy of Action (467—469).—Effects of Forces (470).—Attractions of Forces (471—472).—Misapplication of Forces (473—477).—Resistance (478—484).—General Law of Force (485).—Characteristic of the several Sciences (488).—Economic production of Force (490, 491). — Animal Force (492). — Animate Force compared with the Inanimate (495).

(455.) Having traced the various conditions of masses of matter, and how the particles are attracted to form masses, we have to consider in what manner man conducts his various operations, and performs his duties. Man can only use matter by virtue of its property to act upon other matter. He can neither increase, nor diminish, nor alter the property with which matter is endowed.

(456.) The property of matter, and the sole property of matter which man can employ, is that of attraction; and man can only place particles under circumstances favourable to exert attraction, and the act of attraction is the proof of that property having been exerted. All human operations depend on the effect which the act of attraction has upon other attracted matter; and when any operation is conducted whatsoever, the act of attraction must be exerted to a degree proportionate to the magnitude of the operation performed.

(457.) Every particle of matter in the universe is now under attraction, because the power of attraction, although decreasing enormously with the distance, as far as we can tell, is never extinguished, if not resisted by counter attractions. In consequence of this attraction now being exerted, no operation can be performed, and no mass of matter can be altered in its physical condition, without disturbing some previous attraction, which can only be accomplished by the generation of some new attraction, to counterbalance or counteract the former attraction.

(458.) All human operations, and indeed all other operations, are comprised in the alteration of the former condition of bodies, by one attraction acting upon the previous one, and, therefore, when man seeks to produce electric, galvanic, or dynamic action, new attractions must be generated, and generated to a greater amount than those sought to be destroyed. In the same way to make a body either hot, luminous, or audible, attractions must be generated, because those conditions of matter infer a disturbance of its attractions.

(459.) The great law for all human proceedings, that is, for the production of galvanic and electric effects, of motion, heat, light, and sound, is founded entirely on the laws of attraction of matter. There is not one law for galvanism, a second for electricity, a third for motion, and so on for other physical conditions, but one single law for all these states; and this single law is this: The neutralization of any attraction requires a counter-attraction, or an attraction of superior amount, to be exerted.

(460.) The amount of effect, *i. e.* the amount of disturbance of attractions which man by any operation can perform, depends on the number of particles which he causes to evince the act of attraction, multiplied by the intensity of that act of attraction. To put the law into fewer words, the quantity of the attraction multiplied by the intensity, is equal to the power to produce effects, be the effects those of electricity, galvanism, light, heat, sound, motion, &c.

(461.) When we talk of producing effects, it necessarily infers that the effects are those of the disturbance or destruction of attractions, for throughout this volume we have abundantly shown, that the effects of all these conditions of matter are those of the disturbance and destruction of attraction. Decomposition by electricity, destruction of the attraction of gravitation by force, of cohesion by heat, of chemical affinity by light, are good examples of effects which we have so laboriously enumerated throughout this volume.

(462.) In the sciences of vibrations and of electricity, the propagation of the power of the new attraction is resisted by the attractions previously existing. In these cases, the resistance arising from old attractions, that is, its quantity multiplied by its intensity, must be neutralized before the desire for the exertion of power can be used to produce other effects. By applying new attractions to produce effects, through the medium of either electritricity, galvanism, heat, light, sound, the amount of resistance in the old attractions affords an impediment to the new attraction, and consequently to the effects which the new attraction might otherwise perform.

(463.) Thus we perceive that all effects are primarily due to the act of attraction, and that the act of attraction must be evidenced to the same amount as attractions are destroyed. We shall, for the purpose of elucidation and perspicuity, illustrate our position by a few examples of the generation of power, its application and its loss before being applied.

(464.) We must, however, be careful not to confound a desire for a new attraction with the act of attraction, for the former will produce nothing if the new attraction is not actually exerted. It is only the act of attraction which is operative; and if this act of attraction has taken place, it produces a force, when acting on previously existing attractions, which can never be annihilated without some destruction of attraction.

(465.) In voltaic electrical effects, the quantity of attractions multiplied by the intensity gives the power which is possessed of a capability to destroy attractions exactly proportionate to that amount. In this case, the desire for the exertion of the attraction of the positive pole with the oxygen may be prevented from taking place, and then no effects ensue; but if the act does take place, the attractions resisting the force must be destroyed.

(466.) In all cases, however, we must remember that a new attraction may take place if not resisted by former attractions, and produce no force; for force, although arising from attractions, must to evince itself have other attractions on which to act; and, when there are no attractions on which it can act, the destruction of attraction is not exhibited, and if it acts on but few attractions, the destruction of attraction of only these few is shown.

(467.) The total number of atoms whose attractions are destroyed by force, may or may not be similar to those newly set up. If the intensity of the force of the old attractions is less than that of the new, the energy with which force is evinced is probably proportionate to the relation which the difference of the two forces bears to the resistance of the forces; or, in other words, the time required for the force to be exerted would be in that proportion; the force, however, may be made to act upon a great number of particles attracted together, with less intensity than that of the new attraction, and in that case the time of the exertion of that force is less. We thus see that force, arising from quantity of attractions multiplied by their intensity, may produce, by proper management, the destruction of either a quantity of attractions of low intensity, or a few of high intensity; the time of the performance of that destruction depending on the excess of power of the force, or new attractions, over the counter-force, or old attractions; for were they exactly equal, there would be action and reaction, which would continue till events shall end, till time shall cease.

(468.) We now perceive that although a force may give us a certain amount of work, yet the energy with which it performs its work,—in other words, the time which it requires to execute it,—is dependent on the excess of force over the resistance; for if there were no counter-force it would require no time, and in proportion to that counter-force, so would the time be more extended.

(469.) All forces arise from the superior power of the counter attraction over the old attraction, and the energy of the force is the relation which the difference of the two forces bears to the resistance. Force generated by the voltaic battery,—force generated by combustion,—force generated by heterogeneous adhesions, &c., all have one common origin, attraction acting upon other attractions, and the energy of action of all these forces, or the time in which they would give any required work is obedient to the above general principle.

(470.) We have thus traced effects back to their primary source, attraction; but if we look at the result in other ways we perceive the analogy: thus, if we confine our attention to the forces themselves, for instance to galvanism, to force of motion, to heat, light, sound, we find that, in proportion as these forces are energetic, so we can produce effects by their agency of more or less energy, that is, in a shorter or longer time; though in most cases we can regulate the time of the event by throwing the force over a greater or lesser quantity of matter, and thereby one force produces another of more or less energy. Examples of these changes of forces are to be seen in the changes of the energetic action of a white heat into the moderate one of warm water; of the change of gentle heat into light; of force into sound; of sound into force.

(471.) From the preceding observations it is manifest that the actions of forces may be arranged into classes,—the actions of forces of magnitude, and the actions of forces of energy. The action of a force of magnitude being the action of a definite number of attractions on a large bulk of matter; the action of the force of energy being the action of the same amount of attractions on a small bulk. A good example of such a contrast is seen in the respective motions of a barge and a wherry when acted upon by the power of a man. In a barge the force acts upon perhaps 40 or 50 tons of matter with slowness, whilst in a wherry, where the same force acts upon about two hundred weight, or $\frac{1}{500}$ of the matter usually found in a barge, the locomotion takes place with extreme rapidity.

(472.) These two varieties of actions, however, have no essential difference, they are both derived primarily from attraction, and they both end by destroying attraction. The only manner in which they vary is in the amount of attractions destroyed in each case by the same force; for in proportion as the difference between the amount of the new attraction and the old attraction is great, so the energy of the destruction of the latter is great, and consequently the time of its performance small.

(473.) Having by new attractions obtained the force which we intend to turn to account in the production of certain phenomena in matter previously attracted, we should be careful so to apply that force that we may obtain the desired effect. What should we say to an orchestra, who, after promising the performance of some exquisite piece of music, should so misapply their power as to give rise to electric effects, or, in other words, to give a terrible shock to the persons collected to hear their melodious strains? What should we say to a cook who, instead of producing heat for the purposes of his avocation, should give rise, by the attractions destined for heat, to the most violent noises? And in like manner we should feel ourselves greatly aggrieved when we were desirous of travelling by a railway train, if the engineer should so misapply the power as to destroy the attractions of our bodies, *i. e.* blow us to atoms, instead of destroying the attraction of gravitation, and transporting us to our destination.

(474.) We might bring forward many other exaggerated cases of the misapplication of power,—as the generation of heat in lamps instead of light,—but the exaggerated character of those already adduced might, apparently, almost afford a theme for ridicule to the parties whom we have supposed might so misapply the power generated by new attractions.

(475.) Yet, however, notwithstanding the apparent exaggeration of the above instances, similar results are daily witnessed. In our fires we continually generate light when we require heat, and in our candles heat instead of light, or, what is invariably observed, we produce both phenomena when we require but one.

(476.) Whenever we seek to produce any given phenomenon we lose power if, unfortunately or ignorantly, we give rise to others; thus, when we require illumination, all the force giving rise to heat is wasted, and, in a similar manner, if any other effect is produced besides that required, all the force used for its production is wasted.

(477.) In the attempt to give rise to certain effects men have experience sufficient to prevent their wasting any great amount of fuel, or so grossly to misapply it as to produce effects of a totally different character from what is required. Yet force is hardly ever used for the purposes of mankind but that a large per centage is wasted. A very frequent source of loss of power is the immediate destruction of attractions by which the force is neutralized, as by decomposition, destruction of the attraction of gravity, magnetism, capillary action, or indeed of any other attraction whatever.

(478.) It would extend this volume too far if we attempted to point out the exact laws which regulate the resistance which old attractions afford to new attractions seeking to disturb them. In many cases, the laws could not be stated without throwing the subject into the abstract form of mathematics, hardly suitable to a volume of this nature. In other instances, the resistance increases to a certain extent, as the rapidity of action increases. A case of this kind is to be found in the progression of a vessel through the water, the resistance to which greatly increases with its speed.

(479.) As a matter of common sense, coinciding with experiment, it may be generally stated, that when a certain portion of force overcomes a resistance, the amount of force consumed or employed in overcoming that resistance must be subtracted from the total amount capable of producing active phenomena.

(480.) In this way we perceive the available force, after having passed any resistance, has a certain quantity to be subtracted from it; but this resistance is not constant, for it varies as it is sought to be overcome with more or less energy.

(481.) This increase of resistance according to the time in which the resistance is overcome is highly important; for the resistance can never be assumed as a constant quantity when we are investigating the effects of an increase of force upon the same quantity of matter. If, for instance, a ten horse power engine moved a vessel at a certain rate, a twenty horse engine would not move the same vessel at twice that rate; so, if a voltaic battery, of given intensity, produce any amount of action in a certain time, a battery of twice that intensity would not perform anything like twice the work.

(482.) An ignorance or a forgetfulness of this simple principle has led philosophers into strange blunders. They have tried an experiment on a small scale, and then multiplied that result, and stated to the world the result on the large scale. By these means, these apparent facts have, when tested by other observers, shown the most extraordinary discrepancies.

(483.) In all cases of resistance, however, if this counter-action is taken at a uniform amount, double the force will move, or disturb, or neutralise the attractions of twice the quantity of matter, or a proportionate extent for all other quantities. In all cases where the destruction of former attractions is performed, in more or less time the resistance, or the force required to overcome attractions, varies, and varies in a manner not well understood in the different cases of the application of force.

(484.) We have thus seen that force in its most extended signification arises from the quantity of attraction multiplied by its intensity acting upon attracted matter. This force produces destruction of attractions as compared with an unit of time, in some manner proportionate to the excess of force over the attraction it destroys. A bullet is driven through the air with amazing velocity, on account of the great number of attractions which are exerted in the gun, on the explosion of the powder, acting upon the small amount of attraction with which the bullet is retained in its situation; if the bullet was moved but very slowly, much less force would have been required to transport it the same distance.

(485.) All the sciences which result from force are obedient to the same general conditions, as they apply equally to galvanism, electricity, motion, disintegration, decomposition, light, heat, sound; and conversely, the forces treated of in these respective sciences produce destruction of attractions to an amount bearing some unknown proportion to the time in which they are destroyed.

(486.) It is customary to refer all phenomena to some unit of time; hence we talk of a horse that runs a certain number of miles per hour, an engine that pumps so much water per hour, or day &c. In all these cases, however, the actions are not performed in a unit of time, but in proportion to an unit of time. Thus we see that the running a certain number of miles forms an event, which is proportionate in its magnitude and energy to a certain definite event called an hour.

(487.) From the preceding observations we perceive that the amount of effect is directly as the force, provided the resistance does not vary with the increase of effect. In the sciences of vibrations, consequently, for vibrations of the same frequency, the amount of effect is directly as the force; but if we double the frequency of the vibration, the resistance for the same quantity of matter is much more than doubled, and consequently would require much more than twice the force. The vibrations of light being much more frequent than the vibrations of sound, would require, for the same quantity of matter vibrating, an enormous addition of force beyond what could be accounted for by the increased frequency of the vibrations.

(488.) We thus perceive that a peculiar characteristic appertains to the subjects of the various sciences; for the production of light demands an enormous power to act contrary to the resistance of the previous attractions of matter, whilst heat demands less, and sound but little.

As an illustration of this view, we find that a wire of a given tension — a piano-forte string for instance—may be readily made to give a particular note, a current of air even occasionally causing it to evince the phenomena of sound. But to heat that self-same string, kept in its position by precisely the same attractions, we find that a great increase of power would be required, and if we desired it to be illuminated, a still further enormous increase of force must be used.

(489.) In these cases, however, twice the force producing the particular note of sound would double the force of the noise of that sound; twice the force causing heat would double the effects of heat, and twice the force required to produce any particular colour would double the extent of that colour.

(490.) In former portions of this work we have explained that, for the production of force from masses of different kinds of matter, that mass would produce, by means of attraction of a certain intensity, the most force which contained the greatest number of atoms of attracted particles: thus, a pound of that matter would, on setting up new attractions, produce most force which has the lowest equivalent: consequently, a pound of hydrogen will give two hundred times more force by combination than a pound of gold, supposing, which is not the case, that the gold would attract with the same intensity as hydrogen.

(491.) We have also before noticed that carbon and hydrogen are the two bodies which are invariably, or most commonly, used for the production of force, by means of their capacity to enter into attraction with the atmospheric air. Hydrogen, whose equivalent is but one, is best adapted; yet carbon, which enters into two attractions with oxygen, is nearly as well adapted. Its capacity to take two atoms of oxygen is virtually the same for the production of force as if its equivalent were only three: this additional quantity is, perhaps, also virtually reduced by the intensity of the attraction of carbon with oxygen.

(492.) For all machinery, carbon and hydrogen are used for the production of force; in all cases of illumination and heat the same substances are also employed; but if we look around to organised beings, we also perceive that the force produced by animated beings is also obtained by the consumption of the carbon and oxygen with which they replenish their bodies.

(493.) However, animal bodies, in producing force by the exhaustion of their bodies, and in replenishing their system with food, derive great pleasure, which is not the case with steam-boilers, candles, fires. To the benevolent, such consideration is fraught with curious interest; for how many animated beings might live and enjoy their existence by producing the same force that is constantly produced by the fire of a large steam-engine.

(494.) The manufacturer would say that food containing carbon and hydrogen was dearer than fuel containing the same elements; and the animate, by having a will of their own, might give much more trouble than the inanimate force producers, which can be extinguished at any given moment. These motives invariably cause them to give a decided preference to the inanimate over animate power.

(495.) The natural philosopher, however, must intercede in favour of the animate force with all the pleasures of existence, over the inanimate without consciousness; and he should lose no opportunity, whenever the choice of the two forces is not determined by great additional expense or inconvenience, to entreat the manufacturer to select animated beings as machines for producing his various effects, as by that means he would call into existence innumerable happy beings who might, under proper treatment, be a defence and shield for his property and person in the days of turbulence and wars.

CHAPTER VI.

ON THE COMPLEX SCIENCES.

Complex Sciences (496).—Astronomy (497).—Geology (498). —Other Complex Sciences (499).—Sciences of Organised Beings (500).—Vitality (501).

(496.) We have heretofore considered what may be called the simple sciences, in which a certain number of material conditions or actions are considered together, for the purposes of arrangement, and the convenience of study: these, collectively, form physical science, but, separately, they are called, improperly, the physical sciences. As a whole, physical science comprises all material actions and conditions, and therefore all physical knowledge may be referred to the respective parts or sciences of which physical science is made up. But there are various studies which comprise several of these sciences, and therefore, although they fall within physical science, may be called, from their comprising several portions of physical science, the complex sciences.

(497.) Almost all our more comprehensive sciences are complex, taking in several departments of the physical science of the universe. Astronomy, one of the most exalted sciences, is of this nature. It has for its object the study of the matter of all the worlds that stud the firmament, consequently it depends partly upon the fundamental sciences; it comprises the study of their form, size, position, and consequently contains the sciences of matter under attraction; it treats of their motion and their force, the subjects of which are classed with the sciences of the disturbance of attractions; it also registers their events, and examines into their heat and light, the sciences of which are studied with other sciences arising from the resistance to the disturbance of attractions. In a few words, astronomy is a complex science, as it cannot be pursued without the most thorough knowledge of every simple division of physical science.

(498.) The science of the structure of the earth is not so comprehensive in the extent of the matter examined, though but little inferior in the range of sciences it takes in. Geology comprehends the fundamental sciences, the sciences of attracted matter, of the disturbance of attractions, and the sciences of resistance to the destruction of attractions. Although a complex science like astronomy, there is no principle or new property of matter which is superadded to those treated in the simple sciences; all facts comprised within its study falling within the range of several portions of physical science.

(499.) It is useless particularly to call attention to the numerous complex sciences which exist, for their number might be increased to a very great extent; and, in fact, we may state that all material sciences, not treated of in the first four chapters, may be regarded complex. Even many of the sciences discussed in the former parts of this work are complex, because, as generally handled by authors, they infringe on the path of several others. Thus chemistry, which should properly be confined to the study of the union of dissimilar elements, also comprises their analysis, the action of light and of heat upon bodies so united. It is customary for authors of chemical works to make them almost treatises on physical science.

(500.) Besides these complex sciences, we have yet other studies which would naturally engross our attention as soon as we have sufficiently considered the purely material sciences. Those studies, to which I particularly allude, are those of plants and organised beings. It is very difficult to treat of the divisions of physical science without infringing on the properties of man himself, who unquestionably is the masterpiece of creation, by having greater power to use upon matter than any other created being.

(501.) This work, as I have already stated, is but an introduction to the study of the higher departments of human inquiry, for it is the especial intention of this work to investigate the nature of matter and its properties, that we may be enabled, in a subsequent treatise, to trace the material actions that take place in the material organs of our bodies. By following on the inquiry of this nature we shall be led gradually to inquire into the nature of vitality, and finally to contemplate the existence of that which gives to human beings their immortality. A variety of complex sciences of the utmost importance to mankind require consideration in connexion with these subjects; for after the study of physiology has sufficiently engrossed attention, the sciences of pathology, medicine, surgery, are of this character. They are pre-eminently complex sciences, for not only do they take in the entire range of physical science, but they depend also on the science of physiology in addition.

CHAPTER VII.

ON THE RELATION OF THE MATERIAL TO THE IMMATERIAL.

Cause of Attraction (502).—No Imponderable attached to Matter (503).—Commencement of Attraction (504).—First Attraction (505).—Why Matter first Attracted (506).—Cause derived from some Immaterial Power (507).—Immaterial Power, Author or Governor of Material Actions (508).—Creator of the Universe (509).—Attributes of the Creator (510—516).—Properties of Matter not to be confounded with the Attributes of God (517).—The Deity from being Omnipresent is inferred to be Omniscient (519).—From absolute control over Matter, Omnipotent (520).—Attributes of God Incomprehensible (521).

(502.) Having now traced the manner in which the material universe is composed of atoms, or ultimate particles, to which we give the name, matter, and that the term matter is given to whatever attracts, the mind of man is naturally led to consider how and from what cause matter attracts, and by that attraction produces all the varied phenomena observed in the physical world.

(503.) The first question that naturally suggests itself to the mind that attempts this investigation, is the probability which is given to the attachment of some imponderable or essence to matter, by virtue of which attachment, the power to attract is bestowed on material particles. Such a question appears to be answered without much depth or profundity of reasoning, for if matter exerted attraction by virtue of some principle, essence, or imponderable attached to it, then would that principle exert attraction without matter, or at least we cannot perceive why it should not exert that property.

(504.) From the general views that are forced upon us by our present mode of studying physical phenomena, we must assume that attraction was first exerted before new attractions could produce the effects of electricity, galvanism, heat, light, sound, &c. As attraction must have preceded the greater number of physical phenomena, we may also presume, or, in fact, we must admit, that attraction itself had a commencement. And time itself we have already shewn is derived from an old attraction resisting a new one acting upon it. Each event, consequently, must have a commencement and a termination. To increase the number of these events will not assist us, for, how far soever we carry back the events, still their character is immutable; there must have been one event which was prior to all others, and that first event must have had a beginning.

(505.) The beginning of the first event affecting matter was the primary attraction, which the subsequent attraction sought to disturb; and the great question which the human mind desires to speculate upon, is the cause of this first exertion of attraction.

(506.) The first exertion of attraction, probably, does not arise from any principle attached to matter; but still, even if it owed its power of attraction to an imponderable, the cause of the imponderable attaching itself to matter would be the obscure point on which the human mind delights to contemplate; for the first exertion of attraction, however arising, would alone give to matter its material properties, or, in fact, there would not have been matter (according as we define matter) without the capacity of its particles to set up attraction.

(507.) This power of matter to generate attraction in the first instance could never have arisen from any thing inherent, we, therefore, are compelled to admit that from something extraneous it derived its power. If we look at the means necessary to endow matter with the property of attraction we are instantly astonished at the unbounded magnitude, magnipotence, and magnipresence of that power; for we have evidence to shew that that power was evinced over enormous masses of matter, separated by hundreds of thousands of millions of miles. If that power is continually being exerted the author necessarily appears as the governor of material phenomena; but if the government of the world is continually being affected, we discover that no variation has taken place in the general properties evinced by matter since the world began; the earth still continues to run its daily and yearly course; matter continues to be hot, illuminated, and capable of causing sound when acted on in a peculiar manner; and, as far as we can learn, not the slightest alteration has occurred since the earliest human event was recorded.

(508.) Whether that power was in the first instance implanted for once and for ever, or, whether by a continuance of the exertion of that power, matter continues to attract, are subjects for contemplation far beyond the capacity of human intellect to deduce from physical phenomena. We can only admit that the same power which first caused matter to attract, may also cause, at any given moment, that phenomenon to cease.

(509.) To the source of that immensity of power, which we see either has been exerted once, or which continues to be exerted, we attach the name of the Creator, or Almighty.

(510.) The attributes of the Creator of all material particles naturally form a subject of the most sublime contemplation for all beings endowed with reason sufficient for that purpose. But here again we must refer to our incapacity to enter into a subject so much beyond human understanding, for man can only appreciate things which are material, and which, by virtue of their properties, communicate impressions through material organs to the human mind. We find that we cannot determine the absolute attributes of the Deity from physical science, but only infer certain attributes by not attributing to His divinity the properties of matter, which solely derives its properties through the exertion of His power. In fact, nothing is more erroneous than the comparison of perfections in God with natural qualities in man. Out of this have arisen incalculable mistakes.

(511.) If we review the properties of matter we find that its first property is number, that the juxtaposition of units forms addition and multiplication, and the mass of matter so formed is susceptible of diminution and division. The material character of number forbids us to attach that property to the attributes of the Almighty, for His attributes are clearly immaterial, having no connection with the properties which His mighty power caused matter to evince. Natural philosophy, therefore, teaches us that the Almighty has no relation to number; that, consequently, He is indivisible, and incapable of addition. For ages the greatest disputes have arisen, and schisms and heresies sprung up throughout Christian communities, by attributing the properties of number to the Deity, and conferring material virtues on the Almighty. It is equally incorrect to attach unity as plurality to His indivisibility, for unity infers a possibility of plurality, and therefore, a possibility of being amenable to number, which property matter solely derives from the will of the Creator.

(512.) As we must discard the very idea of number as being an attribute of God, so must we also deny the possibility of any attribute arising from attracted number. We cannot, therefore, give to His majesty form or size, for these are properties of his created matter. His presence, moreover, cannot be limited to one spot, for position is a material effect. He must extend over space, and consequently omnipresence must be a characteristic attribute of his greatness.

(513.) His omnipresence cannot be interfered with by the presence, in certain positions, of created matter. Impenetrability is a property of matter, perhaps by virtue of attraction, and therefore cannot interfere with the Immaterial. The omnipresence of the Deity will not be prevented by attracted matter; but He must be present in the structure of the hardest stones, the most massy rocks; in fact, throughout the matter of this great globe, and even throughout the matter existing over the universe.

(514.) The phenomena of electricity, of galvanism, of motion, are in similar manner material actions, which alone have their existence by virtue of attraction. The immaterial character of the Almighty forbids these phenomena to be attached to His attributes; indeed, we scarcely imagine how the Deity, whose attribute is omnipresence, can have the property of motion.

(515.) As the material character of the preceding properties forbids their assumption as an attribute of the Creator, so are we compelled to deny the possibility of time, with its dependencies, to be a phenomenon to which the Author of that time should be amenable. The Almighty consequently could have no beginning, no end. Eternity is His distinguishing attribute; and time can have none, no, not even the feeblest quality of eternity. Time, however exaggeratedly it may be increased, never becomes eternity; for time is made up of a series of events, each having a beginning and an end. Eternity is not made up of events, and has, therefore, no beginning, no end.

(516.) The actions called heat, light, and sound, are similarly material, appertaining to particles of matter alone. The Maker of all things cannot, therefore, be supposed to be subject to phenomena which exist by His Almighty fiat.

(517.) We have thus seen, that whilst all the properties of matter are strictly material, so the attributes of the immaterial are purely immaterial. Science, therefore, directs us to attach materiality to the material, immateriality to the immaterial; and by no means at any time, under any circumstance, to confound the properties of matter with the attributes of the immaterial, or the attributes of the immaterial with the properties of matter.

(518.) It is, then, the property of matter to attract, and by virtue of that attraction to yield number, size, form, duration. It is the attribute of the immaterial not to yield number, to be omnipresent and eternal. Matter attracts by virtue of power conferred upon it by the immaterial. Matter is matter by the volition of the Creator.

(519.) The power which conferred attraction on matter is present not only where matter is, but even where matter is not, inasmuch as position is a material phenomenon. In consequence of that omnipresence, we may infer that He is cognizant of every alteration of each respective particle of matter, which omnicognizance is called the omniscience of the Deity. Our material bodies allow certain expressions to be carried to the mind through certain material organs called the senses, and therefore we only appreciate those impressions which act upon those senses; His omnipresence must know every single change, without respect to any material conditions. His omniscience cannot be interfered with by darkness, quiescence, or temperature. Darkness is no darkness with Him; the stillness of an action cannot cause it to be hid from His observation. His omniscience is derived from omnipresence, not from the properties of matter from which man derives his knowledge.

(520.) We, therefore, are compelled to admit and believe, that matter owes its properties to a power conferred upon it by the omnipresent, omnipotent, omniscient, eternal Creator, who first by His Almighty fiat commanded matter to attract, and who, by the same Almighty fiat, may at any instant will attraction to cease, when worlds would end, when time would be no more. As far as regards all material properties, He must have absolute power. At any moment He may dissolve the earth, the sun, the moon, the stars, and as instantaneously summon their particles to assume new shapes, to occupy new positions. This infinite power or omnipotence, is totally of a different character from our power, which is derived from the properties of matter. Man's boasted power is derived from availing himself of attraction. The Deity can control that property, and from that we infer the attribute of omnipotence.

(521.) It is useless to conceal that these great and glorious perfections are quite incomprehensible to our senses; we can only appreciate material impressions; all else is quite incomprehensible to our mind. To say that God has no relation to number is as unintelligible as His omnipresence, His omniscience, or His eternity. We cannot conceive the nature of such attributes, though we are compelled to believe them because we cannot conceive that such attributes should not exist.

(522.) What other attributes belong to the Almighty we are incapable of ascertaining by physical science; and even the contemplation of these, we must admit, will suffice to fill our minds with an amazement, productive of reverence, submission, and humility.

CONCLUSION.

We have now taken a brief sketch of the fountain springs or sources from whence all physical sciences take their origin: we have found that all have their origin in matter, which is capable, by the will of a Supreme Being, of setting up attraction. The subject which we have been investigating, or rather, in some cases, to speak more correctly, contemplating, is one of the very highest that can possibly engage human intellect. Surely, it is of immense interest to know by what force the round world retains its form? Surely, the most degraded of human beings must, at some moment, think from whence and what is light? Can even the ploughman return from his daily labours, and not occasionally meditate upon such most curious matters? Can even the poacher, who prowls in darkness, escape from an occasional thought as to the cause of the feeble light which enables him to pursue his crimes with but little risk of detection?

If, however, to those who cultivate their bodily strength, and seek to live by mere physical powers, such subjects are interesting, how much more must inquiries into the foundations of physical science be to those who pride themselves on the cultivation of their intellectual faculties !

The position of a man in relation to his employment cannot detract from the importance of the subject we have chosen for our contemplation. Who does not use daily, heat ? — who does not require light ?—who is not acted upon by the concord of sweet sounds ? and yet how obscure are the material relations of these various actions to the generality of mankind.

We live in a material world, and can only converse with matter ; everything we treat of is material. We can only use material properties to effect material phenomena ; and our very existence here depends upon a series of material events taking place in our own bodies, for if these events do not take place, other actions ensue which end in decomposition. An event of definite energy we call an unit of time, and the total of events, taking place in our bodies in our present condition, we term the period of life. Time itself, therefore, is a material phenomenon, depending solely on material properties.

But whilst man can only clearly understand material phenomena, and use matter to give rise to material effects, and thus conduct his affairs, yet he has the power, by virtue of an immateriality in his own constitution, to perceive indistinctly through a veil the existence of an immaterial to whom matter and all material phenomena owe existence. The attributes of the Creator of matter are, indeed, in this world quite beyond the comprehension of man's faculties; and the attributes which man is compelled to attach to the Almighty are but positive expressions for the absence of the properties of matter which are solely derived from His Almighty will.

Having completed our inquiries into the sources of physical science, we have found that man has no conception of matter without the existence of a Supreme Being, who endowed it with properties, *i. e.* caused it to be matter. We have seen that no imponderable attached to matter gives it its properties, but that they are evolved simply from the will of the Almighty. That which gives to matter properties, is the will of God, and we have before mentioned that man can have no conception of matter without that to which it owes its property.

As we can form no idea of matter apart from its Creator, so in our present state, living in a material world, and being ourselves partly immaterial, partly matter, we cannot form any clear conception of the Almighty totally apart from his works. From natural science, man only knows God as being the Creator and Maker of all material things; but hereafter, when man shall rise again, and assume a higher condition, he shall understand these glorious mysteries apart from all created matter.

We have seen that all physical subjects depend on the existence of the Supreme Being, the Creator of matter, from whose will matter is. We have seen that matter is that which attracts; that particles of matter under attraction give to masses of matter their properties; and that this attracted matter, being acted upon by new attractions, produces all physical effects.

Physical science depends on matter, and its property, attraction; and the great problem for man to solve, when he desires to perform his various operations, is comprised in the effect which attraction produces on attracted matter. The object of this volume has been to contribute to the solution of this problem, and to condense the foundations of human knowledge into so small a compass, that the reader from its perusal, by simply having attraction and attracted matter, may be able, at will, to give rise to all physical phenomena.

As a summary of the sources of physical science, I have drawn up the accompanying table to show at one view how physical phenomena may be produced, and how the entire range of physical studies constitutes physical science.

Matter is matter, and solely exists, by the will of God.

Matter is made up of finite particles, or atoms; a series constituting number, and the study of number, arithmetic.

Particles of matter *attracted together* give rise to	Form, Volume, Composition, Cohesion, Adhesion, Position.
Peculiarity in the *direction* of attractions produces	Crystallisation, Polarity, Magnetism.
Attraction *acting on* attracted matter causes	Tension, a tendency for action, Force, a capacity for action.
Force, by *destroying* the attractions of attracted matter, exhibits	Galvanic phenomena, Electric do., Electro-magnetic do., Motion, Disintegration, Decomposition.
The results of force, in consequence of the *resistance* of old, or previously existing attractions, produce the phenomena called	Time, Heat, Light, Sound, Odour (?)
These latter, being the *result* of force, exhibit	The effects of force generally, and, therefore, capacity for the destruction of attractions.

INDEX.

THE END.

London:
Printed by S. & J. Bentley, Wilson, and Fley,
Bangor House, Shoe Lane. W

BY THE SAME AUTHOR.

DEDICATED BY PERMISSION
TO
HIS ROYAL HIGHNESS PRINCE ALBERT.

ELEMENTS OF ELECTRO-METALLURGY,

OR THE

ART OF WORKING IN METALS BY VOLTAIC ELECTRICITY.

SECOND EDITION.

REVISED, CORRECTED, CONSIDERABLY ENLARGED, ILLUSTRATED WITH ELECTRO-TYPES, AND MANY ENGRAVINGS.

"The volume contains many practical observations, and will be read with interest by all engaged in the practice of this very pretty art."—*The Times.*

"Mr. Smee has, in our opinion, carried out this singular process far beyond any other individual, and that he has made it applicable to cases which, judging from published documents, we should scarcely imagine the original discoverer could have foreseen. The treatise before us is short, but it is full of practical information."—*Forbes' Medical Review*, April, 1841.

"As a practical and extensively useful work, comprising everything that is yet known for the guidance of the operator in the new art, we highly commend and recommend the above production."— *Literary Gazette.*

"A practically scientific treatise on the new and beautiful application of Electro-Metallurgy to the mechanical and fine arts ; the matter is condensed and well-arranged ; the style is clear, the directions are explicit.—*Spectator.*

"Mr. Smee's book is not a mere compilation from other men's labours, but it consists principally of the results of his own experiments, by which he has fully developed the laws of metallic precipitation."—*Medical Gazette*, Jan. 1841.

"There is much that is new and valuable in this work, and the author has laid down laws regulating the reduction of the metals ; and has also given instructions for obtaining such metals, either in a state of extreme hardness and brittleness, or with the opposite qualifications of ductility and malleability."
Newton's Journal of Arts and Manufactures, Feb. 1841.

Price, *Ten Shillings and Sixpence.*

LONDON :
LONGMAN & Co., Paternoster Row ; and E. PALMER, Newgate Street.

8


24ColorCard
CameraTrax.com