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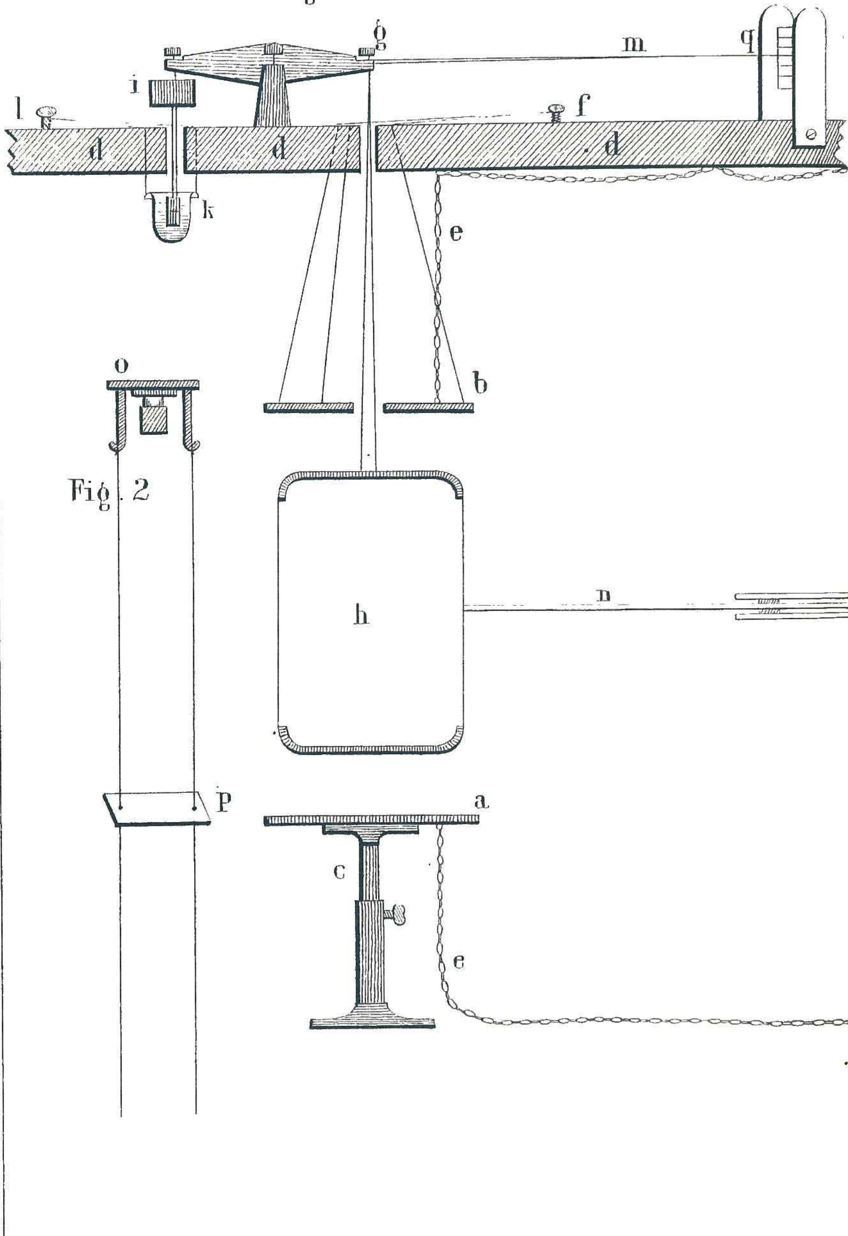

MATTER AND FORCE,

AN ANALYTICAL AND SYNTHETICAL

ESSAY

ON

PHYSICAL CAUSATION,

IN WHICH

THE PRINCIPAL PHÆNOMENA AND
LAWS OF CHEMISTRY, ELECTRICITY AND HEAT,
ARE DERIVED MATHEMATICALLY,

FROM AN UNIFORM VOLITION,

AND

THE PRESERVATION OF THE UNIVERSE DEMONSTRATED
TO BE CONTINGENT ON THE INCESSANT EXERCISE
OF
A MORAL POWER.

By RICHARD LAMING.

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THIS WORK

IS DEDICATED TO THE MEMORY

OF

SIR GEORGE LEMAN TUTHILL, M.D., F.R.S.

&c. &c. &c.,

TO WHOSE PREDICTION OF A SUCCESSFUL RESULT

TO HIS ANALYTICAL RESEARCHES

THE AUTHOR

ATTRIBUTES HIS PERSEVERANCE

DURING A

QUARTER OF A CENTURY.

MATTER AND FORCE,

ETC. ETC.

INTRODUCTORY ARGUMENT,

SHOWING THAT THE SEARCH AFTER PHYSICAL CAUSATION HAS BEEN UNDERTAKEN WITH A RATIONAL HOPE OF SUCCESS, AND EXPOSING SOME OF THE MEANS ADOPTED FOR AVOIDING A REPETITION OF FAILURE.

IN all preceding theories of physical causation force has been assumed to have the same nature as the things put in motion by it; and, in consequence, to be subject, in common with them, to the axioms of mechanical philosophy; the present theory differs from its predecessors in ascribing the motion of material things, immediately, to a moral cause. The dispensing with physical force will not be a difficulty to those who believe in a Creation; for it is quite as easy to imagine the Creator to have acted by his will on matter, as to have interposed a physical agent previously called by him into existence for that purpose. But the present work goes further; it professes to establish such a relation between the motions of material things and the Creative will, as is susceptible of being reduced to laws, and to render Creation indisputable.

To deduce laws of motion from a force of any kind, presupposes the force to be measurable; and it may be urged that Volition, as we understand and exercise it, is not proved by its consequences to be a force of an exact and measurable nature; but, however well that objection may apply to ourselves, it is altogether inapplicable to a moral power whose attributes cannot be suspected of imperfection; such as that Mind must be which formed the universe and approved the end of his plan from the beginning. The will of the Creator with respect to physical things cannot be objected to as a basis for a mathematical superstructure.

But although the will of the Almighty Architect acts in such a manner as to make its consequences mathematically certain and uniform, as we must conceive to be necessary for establishing the order we find around us, His will is still a moral agency, and as such not necessarily subject to axioms which are only known to apply to cases in which nothing but material things are concerned. We arrive at the same conclusion also in another and a practical way; if the impulse upon matter be derived immediately from a moral, and not a physical force, we should be informed of the circumstance, if, in certain cases, we were to find that its results do not conform themselves to it consistently with those laws of proportion which are always observed between causes and their effects when both are physical, and which are expressed by the mechanical axioms. Now such an observation as this has actually been made, and it was by examining it in conjunction with other equally new inferences from experiment that the present view of moral causation was indicated.

Some of the most successful cultivators of Baconian induction do not hesitate to express a doubt whether man will ever be able to raise the veil which seems to hang around the works of creation, and it is perhaps very generally believed that, with our present stock of observations to gain it from, the discovery of causation is impossible. To these opinions we owe deference; but we may err, nevertheless, in attaching to them an undue importance. While we admit they may be true, we are sure they cannot be known to be so; and therefore it is at least possible they may be false. We express ourselves dissatisfied with theories of causation only because we have found them destitute of the internal evidences by which the true theory would be characterized; but has it ever been ascertained that theories are never to differ in their internal evidences? The past might serve as an infallible type of the future if all the circumstances of the two periods could be precisely the same; because the like causes must invariably produce like results, but it has never yet been shown that all human minds are identical, both in their powers, and in their acquirements also; and it is evident that a mind devoted to the search after causation need only to differ from other minds, in some mere accident of education, to become thereby fitted for the perception of a new truth; and we can also understand that it is possible for a new truth to be a leading one, and all that is needed to initiate man into the mysteries of causation. If then it be not in the nature of things to inform us that the knowledge which we covet is unattainable, ought we to permit ourselves to be deterred from what may prove a successful search by pre-ordaining that it must needs be a vain one? Would it not be more philosophical to encourage a fear lest by thus succumbing to difficulty we may become in some measure blinded to the light of truth, if ever it be laid open before us?

Not only has the discovery of causation never been shown to be impossible, but, as we shall find if we properly consider the subject, it is consistent with all we know of its author, and of his dealings with us, to anticipate that, in furtherance of his own glory and in good will towards man, He has placed it within reach of our industry. We are called upon to exercise faith in God's promises; in order to do so, we must first have an assurance of his existence. To assure us, He has laid open the book of nature, wherein, if we be learned in the language in which it is written, we may find the truth plainly inscribed; but we must be capable of reading what is written. The utmost that men ordinarily attain to by this help is belief; but we should vastly improve our moral condition, if, for faith in the existence of our Creator, we could substitute absolute knowledge. Man sometimes refuses to give credence to revelation because it reaches him through the testimony of his fellow-man, whom he suspects to be no more unerring than himself; but scepticism would be dumb before a mathematical, and therefore unmistakeable, demonstration of the Creator's existence, such as He could display by granting to our industry a knowledge of the way in which He willed the universe into being. In the ignorance of the world's scientific infancy, inspiration recorded an assurance of his existence; but all good, so far as man is concerned, is progressive, and we may rationally imagine, that for the world's judgement, matured by the successive rewards of intellectual toil, He has written down in nature a perfect witness of himself which will not be questioned. We have something analogous to this in our physical experience; in earliest infancy we were each impelled for self-preservation to act upon knowledge which we could not then obtain for ourselves, seeing we had no previous experience of the physical things to which the knowledge related; we call that particular kind of knowledge instinct, and it was given to us in anticipation of the time when we should have become capable of learning it from observation. In our riper age we have had opportunity of observing facts, and obtaining from them inductive truths; and now the necessity for receiving instincts to occupy their place is superseded. May we not likewise expect that in the full fruition of physical science, achieved by the labour prescribed by our Maker, man's intellect will inevitably perceive for itself the existence, power and goodness of the Creator which he in times of our incapacity intimated without our co-operation?

If, as the author believes, science has been commissioned by the Deity to display his existence to his intelligent creatures in a manner that shall be indisputable, how could it do so otherwise than by showing that the cause from which it mathematically derived physical phænomena has the attributes of intellect? and how could it present the attributes of intellect better than by demonstrating mathematically that the cause of the axioms of mechanical science is itself not observant of them? We can conceive it possible for an Almighty Being to have first observed those axioms as a means for establishing them, but the same attribute of unlimited power removes the necessity for His doing so, and we reject the idea as incompatible with wisdom, for had it been adopted the Creator would have chosen to leave his works unimpressed with an unanswerable testimony of his own existence, while He reveals himself to us as a Being jealous of his glory.

If we attain to a knowledge of causation, it will inevitably place at our disposal new and almost boundless resources for improving our physical condition, to say nothing of the high influence it may be expected to exert on our moral faculties. We should then really be able to do what Descartes vainly assayed to accomplish, namely, to discover effects by synthetical argument; for the analytical method will then have answered its purpose, and put us into a condition to descend step by step from the origin of all things to ultimate and unknown facts, and with the certainty which always marks a syllogism when it is founded in true premises. This consideration should encourage us to devote much time and energy to the search after causation, if the probability of finding it were slight; much more should it stimulate us to persevere if we knew that the probability cannot be estimated, and may be great. We may take courage by reflecting that it is a peculiarity of the analytical method of reasoning to bring us suddenly upon new truths, without informing us of their vicinity, and to put them into our possession before we are familiar with the road by which they are approached.

Whether causation be hidden beneath a complication of physical phænomena or lay comparatively exposed on the surface of only a few of them, one thing at least is certain, namely, that the doctrines taught in the schools are incompetent to lead us to it, or they would have done so long ago. Our systems have something radically wrong in their very elements, for we are hardly set out in our attempts to apply them deductively before we become conscious of their deficiency; whereas we cannot help believing that the system of nature would, on the contrary, multiply its evidences at every successive step, that, setting out with simplicity from a single point of truth, it would immediately radiate in every possible direction until it had satisfactorily comprised within its sphere the phænomena generally of all the physical sciences. It is unnecessary to say we have no such system as this; nor can we hope to obtain one unless we change our way of proceeding,—unless we become much more independent in our reasoning about phænomena than we yet are, while at the same time we are more strict in arranging our argument,—unless we cease to confound together the probabilities of theory and the certainties of truths as we still do,—and whether we be advancing by the one or the other, unless we accept the inference which directly presents itself, without shaping it down to make it square with previous doctrines. If the inference in certain cases be not new it must be worthless; if it be new it may be wrong; but it is also possible it may happen to be right, in which case it will lead us forward; and it cannot be our good fortune to go forward if we remain obsequious to bad precedents. Had Kepler and Newton hesitated to substitute for the doctrines which prevailed in their times what were then strange inferences, they would never have subverted old errors and established new truths; and when we see that by an independent manner of reasoning upon facts certain laws of force have been discovered, we are encouraged by the circumstance to seek in the same way for the cause of force, which the science of the present day avowedly cannot make known to us; at all events, if we find it not in this way it will probably escape us for ever.

The philosophy of bygone times laid itself open to deserved reproach for allowing inferences to outstrip facts to an unwarrantable extent; the reaction in the present age is marked by a zeal for the multiplication of facts, on the supposition that they have not yet been accumulated in sufficient number and diversity to afford an inference that can indicate the theory of nature. We need only remark, that if so unreasonable a conclusion be once admitted, there will be no cause why it should not be adhered to up to the very moment that the true theory becomes known to us, and consequently after the facts which made it known had been observed. In such a case it would of course be untrue; it ought therefore now to be rejected.

Our want of success, so far from depending on a paucity of materials to reason upon, may be more justly ascribed to a vicious habit in experimentalists of confounding together in their arguments truth and probability, though in their writings may be found passages which declaim against the practice. That this evil is more general than is supposed might be proved by many examples, of which however we shall cite only one or two. It is known that bodies tend to gravitate towards one another, and the term body is used to imply a thing which exclusively occupies space. Now we find in works on experimental philosophy a coupling together of that word body with the fact of gravitation, which leads tacitly to the implication that all things which exclusively occupy space gravitate, or have weight; and with this assumption mistaken for truth, we attempt to go forward with exactitude in our analysis. Philosophy demands that the word body shall not be assumed to mean every kind of thing which occupies space; because for aught we have yet observed, or know to the contrary, there may be things in bodies which have volume without being heavy. However well the doctrine of universal gravitation may apply to bodies of sensible magnitude, and even down to the unseen atoms of chemistry, we have no evidence that it applies to all matter, that is to say to all things which occupy space ; and therefore our indiscriminate application of the doctrine may perhaps hinder the progress of our knowledge towards causation. A multitude of instances of the confounding together of truth and probability present themselves in consequence of our disposition to universalize laws which are only general ; it will suffice however to cite an example of another kind, taken from what is known and taught respecting electricity. In experimenting electrically with ordinary bodies, we can cause them mutually to approach and recede from one another. When we simply describe these motions, we narrate facts without admixture of probability. The observation of bodies in motion makes known, by our perception of its necessity, the existence of a cause for that motion, to which we give the name of force; and thus the existence of force, as well as motion, becomes a truth. But if we proceed one step further, and imagine the force to act in the direction of the motion, which we imply by the terms attraction and repulsion, we do so without the guidance either of observation or infallible necessity, and thereby add to what is true something else which may be false, and which at most can be only probable. We may philosophically entertain the fictions of attraction and repulsion as hypotheses so long as they are the best means we have for systemizing our scattered collection of facts, but we cannot assume the existence of forces which act from and towards centres and invest the assumption with the character of truth, without committing a fault which may entail its evil consequences upon us for ever.

The imperfection of language, or rather the loose way in which we employ it for scientific purposes, is another prolific source of hindrances to our progress towards causation. If we really did not know a distinction between the things which we call Theory and Fact, and could not point out a difference between Fact and Truth, the confounding together of these words would be of no importance; but each of the three things possesses a nature which is common to neither of the others, and therefore we ought to distinguish them by applying to each a different name and assigning to it an exact definition.

By carefully attempting to avoid the sources of error which have been pointed out, as well as others of an equally insidious and prejudicial kind, the author of this essay has been brought to believe that more satisfactory inferences respecting causation than the doctrines in our possession may logically be obtained from the physical phænomena we are already familiar with. He has been enabled to construct a series of analytical arguments in which facts and laws take their places with a generality hitherto unprecedented, and which have finally initiated him into the perception of an universal system of causation, which, if it be not the system of nature, is only therefore the more remarkable, for it descends mathematically from a common centre, whence causation branches out in every direction towards ultimate facts in each of the physical sciences with an exactitude which can hardly be attributed to accident. Whether true or artificial, the new theory has the advantage of being more simple in its elements, more comprehensive in its plan, and more satisfactory in its details than those which have preceded it; and it stops not short of showing by number and measure, in what manner the universe may have been called into existence by the exercise of an orderly and Almighty Will on mere space—how, in fact, the Creator made all things out of nothing and still sustains them, they being, when considered abstractedly from the will, still nothing.

The idea of bodies being composed of mathematical centres of force instead of the solid particles which Newton conceived to exist, is a doctrine which has not passed away with the generation which gave it birth; and it has a consequence which is worthy of being remarked. If, with Boscovich, we reject the existence of solid particles, how can we, as he did, entertain the idea of centres of physical force? If the expression 'physical force' have any meaning other than to signify a moral agent capable of producing physical phænomena, it must be held to imply that the force is itself an attribute or quality inherent in something physical, the existence of which we begin by denying; for we cannot imagine a mathematical centre or point in space, which physically is nothing, to have an inherent physical quality. It would accord with the simple machinery involved in the new theory, to adopt the doctrine of mathematical centres in preference to that of solid particles, for thus, in addition to dispensing with the intervention of a created force between the Divine Will and physical phænomena, we should at the same time comprehend the nature of all the materials employed in creating the universe, which in the opposite case we should be left entirely ignorant of.

In constructing his analysis, the author has not adhered to the order of succession by which he was himself led forward; for he can now look back and indicate a shorter road by which a number of inferences are avoided, about which there would inevitably be formed a diversity of opinions, and the inquirer consequently brought more promptly to the synthetical part of the work, where the true inferences may be more surely obtained as demonstrations.

A preliminary part of the essay consists of particular views which the author has been accustomed to take of the philosophy of science, and which, although they have progressively improved with his other inferences, have mainly contributed to his success: they will be found to differ considerably from what has already been published on the same subject; and although more concisely given than he could have wished, they will, he hopes, be sufficiently intelligible for the present purpose.

Although many years have passed since this work was commenced, it is at last submitted to the public more hastily and in a much more crude state than the author intended; no time would have sufficed to make it in his hands as presentable as it ought to be; but as he has had abundant opportunities, though with long intervals between, to satisfy himself of the usefulness of his theory, he does not feel justified in withholding it any longer from mathematicians who are fully competent to explore the field of investigation which it lays open, and to do it justice. He is conscious that it abounds in unscholastic imperfections; but he has no care on that account, for if it be founded in eternal truth it must survive them, and if it be not true they cannot make it the more worthless. He is only anxious for it to be judged of as a whole; for even truth may hardly bear to have its parts isolated from one another and then made, in its disjointed state, amenable to doctrines which it denounces as errors. The truth of each inference can be fairly tested only by its adaptation to all the rest, and by the perfection of the whole system of which it is a part.

The new theory is ushered to the world under unfavourable auspices, without even the sanction of a well-known name; for its author has preferred obscurity rather than to rise among the lovers of science to a station approaching mediocrity perhaps, by adopting for the starting-point of his labours the doctrines which were then and still remain current, and in which he had no confidence.

In concluding this Argument, he ventures to allude to the spirit in which he thinks the investigation of his labours should be undertaken. The age in which we live is pre-eminently the age of facts ; men of science are almost exclusively engaged in recording physical occurrences, and inferring from them laws of phænomena with an absolute contempt for fanciful speculations about their causes, into which they justly complain that our forefathers illogically and fruitlessly entered. The commercial part of the community is taxing its ingenuity to apply the facts and laws of physics to the purposes of social life, and with such success that the practical inventions of the present greatly exceed those of any former epoch. Now, if we be faithful to this matter-of-fact way of proceeding, if the homage we profess to pay to experience be not a delusion, we shall be prepared to sacrifice at the shrine of observation any doctrine that may be found in direct opposition to it.

ON THE PHILOSOPHY OF PHYSICAL SCIENCE,

EXPOSING CERTAIN VIEWS OF TRUTH NECESSARY TO BE PERCEIVED BEFORE A PROMISING ANALYSIS OF PHYSICAL FACTS CAN BE ENTERED UPON.

1. THE object of science is to discover Truths and Probabilities; to distinguish one of these two kinds of things from the other; and to estimate their relative amounts of importance in each individual case. Science consists therefore of Knowledge and Belief. Belief is not implied by the term science, etymologically considered, but it is included in the thing meant, namely, the pursuit of knowledge.

2. Truth and probability are merely ideas, having no existence out of the mind. We prove this by remarking that one and the same inference from physical phænomena may be both true and probable, which cannot be said of any physical phænomenon. Thus an inference drawn from a fact observed in physics, may be to one of three observers who best understands its relations, a truth; to a second, less well-informed, a probability; and to a third, comparatively unacquainted with the subject, error. It is evident, therefore, that neither truth, nor probability in any of its degrees, is the absolute nature or quality of an inference, but relatively so to the particular mind in which the inference has been conceived.

3. One and the same mind, as it becomes progressively better informed, may view a particular inference drawn from physical phænomena, first as improbable, then as probable, and ultimately as true; or the qualities of an inference may follow each other in an inverse order, in either case confirming the conclusion, namely, that the nature of an inference from fact is not absolute, but relative.

4. When a given mind has perceived an inference of any kind to be true, it has perceived it to be indubitable, and perceiving it to be indubitable, it has recognised its necessity. Hence all truths are necessary truths, because it is the perception of their necessity which makes them truths. To other minds which have not yet recognised their necessity, they have not become truths at all.

5. If a particular mind perceive not the truth of an inference, known by other minds to be true, it is because it is ignorant of one or more of the circumstances which conspire to make it necessary.

6. Although probability is convertible into truth, the conversion cannot take place in any mind conscious of the possibility of a rival doctrine equally probable, because in such a case there can be no perception of necessity to make either probability true.

7. When any two inferences used as premises to a syllogism are perceived by a particular mind to be both true, they may be so used with certainty that the conclusion logically deduced from them will, relatively to the mind in question, be true also.

8. If either of the premises of a syllogism be only probable, the conclusion cannot convey a truth to

the mind ; no conclusion can be more probable than the least certain of its premises. But as different minds may be differently impressed concerning the nature of a premiss, so in like manner may they differ as to the nature of the conclusion.

9. Truth embraces the knowledge, and probability the belief, which relate to all things that ever have existed.

10. Not anything can exist without duration; and duration is time. Everything which exists has a locality ; and locality is space. All things therefore exist in time and space.

11. Time and space exist without the possibility of a beginning or an end, in precisely the same sense that we may imagine that nothing would have existed in the eternal absence of the Creator and the creation. Space and time are voids in which the Creator exists and the universe has been created. For the existence of a void, no act of creation is necessary ; void must have been, had there been no Creator.

12. Externally to the mind, time and space are non-entities ; within the mind they have a positive existence as ideas, the proof of which is simply its consciousness of their presence. Time is an idea of the duration of something ; space is the idea that things have locality.

13. A difference between two non-entities is impossible, and therefore, beyond the precincts of the mind, there is no difference between time and space ; within the mind they have a distinction, because the idea of duration is distinct from the idea of locality.

14. The ideas of duration and locality enable us to take the first great step in experimental philosophy. We find by observation that certain created things are susceptible of being brought into contact with one another, from which circumstance we infer that each of those things needs a place to exist in, and which it appropriates exclusively to itself; for it is evident that if two or more of them could at the same time enter into the same place, they would not come into contact. On the other hand, we are conscious of the existence of things which we cannot bring into contact, from which we conclude that none of those things needs a locality exclusively to itself.

15. We are taught by this induction how to separate into two classes all the things about which we desire to obtain knowledge; those which exclusively occupy any part of space being put into one class, and all those capable of existing at one and the same time in any given locality being assembled into the other class.

16. Having made this distribution of the things known in nature into two classes, we call the former class material things, and the latter immaterial.

17. The duration of the existence of anything without exception, is said to be the measure of a part of time; the volume of an impenetrable or material thing we call the measure of a part of space. Space is thus measurable in three directions, namely, length, breadth, and thickness; and time is measurable in one direction, namely, length. But these expressions, though convenient in practice, require

to be mentally qualified, or they will be calculated to mislead. As time and space are merely ideas, they can be neither measurable nor divisible into parts; wherefore, in speaking of the measure of a part of space, we must be held to mean the measure of the volume of some material thing; and by the measure of a part of time the measure of an existence or duration.

18. Immaterial and material things cannot act on one another by mutual contact, because immaterial things are unsusceptible of contact, not only with one another, but with those also which are material.

19. In order that immaterial and material things may act upon one another, a medium of communication of some kind becomes requisite. We cannot conceive any kind of medium that would answer that purpose; but without knowing its nature, we are sure that such a medium of communication does exist, and that it produces the phænomena of animal life, which is all that it is necessary for us to know for prosecuting our investigations of physical science. The phænomena of animal life teach us also, that by its means different immaterial things hold intercourse with one another.

20. As man, the most intellectual of animal beings, has to become acquainted with both material and immaterial things, he combines in his person the two dissimiliar natures; his impenetrable parts enable him to make the discovery of external material things by admitting of his contact with them, whilst his immaterial parts perceive the con-

sequences of that contact, and acquire from it, as well as from other sources of a different kind, the knowledge of truths and probabilities.

21. Man discovers the presence of external material things only through the organs of sense, in which they produce sensations; what the nature is of his sensations we have now to inquire.

22. Isomerism teaches in a very unequivocal manner that the natures or qualities of bodies become changed by an alteration in the arrangement of their constituent parts; it is quite reasonable to conclude from this, that if we alter the condition or arrangement of the parts of a material organ of sense, its nature or quality as a material thing will be thereby changed also. The question therefore is, Does the condition of an organ of sense become altered by its contact with material things? In reply, we know that it is impossible to place bodies in general in contact without establishing an action between them, particularly if by solution or fluidity we give their parts free liberty to move and intermingle with one another; and as we have these conditions established more or less perfectly whenever we apply material things to the organs of sense, we are prepared to find at such times a disposition in those organs to change their condition. We know also that different kinds of matter, by contact with the organs of sense, produce different sensations. Soda and hydrochloric acid, for example, produce on the organs of taste sensations which are distinguishable from one another; and we ascribe the difference in the sensations to a dif-

ference in the qualities of the two bodies. If we combine the bodies together before applying them to the organs of taste, the contact of the compound which they form produces a third sensation, as different from the other two as they were from each other, and this new difference we ascribe to the difference of the quality. Now the cause of this new quality is unavoidably perceived to be nothing else than a new arrangement of the particles of sodium, chlorine and water in the compound body, and it supplies a key to the action of bodies on our organs of sense. As all known bodies change the qualities of other bodies by combining with them, either superficially or in the mass, and as this change must be attended by motion to some greater or lesser extent, we are free to believe that the organs of sense do not form an exception to the general rule merely because they communicate in an unknown manner with the immaterial mind, but that their parts are made to move to some extent or another whenever foreign bodies are brought into contact with them.

23. It is this movement in the constituent parts of an organ of sense, perceived by the mind and nicely distinguished by it from other movements of an analogous kind, that we understand to be a particular sensation. Thus we have an external physical contact for the cause of sensation, a motion in the parts of an organ of sense for its nature, and an act of the mind for its perception.

24. If an organ of sense be tardy in returning to its normal condition on the cessation of the contact

which produced the sensation, then that contact may be immediately repeated with the production of a less acute sensation; because the same cause in such a case can excite only a lesser amount of motion.

25. The mind can perceive the condition of no material thing excepting that of an organ of sense; because the mysterious medium of communication which is established between the organs of sense and the mind is extended to nothing external to man's organization. To conceive otherwise is to suppose the organs of sense unnecessary.

26. Of the organs of sense in man, those of taste, hearing and feeling, are obviously acted upon by material things in contact with them; contact in the other two cases is not so evident, but still we can understand that it may be always directly or indirectly established. The organs of smell detect the presence of certain material things at a distance, but in the interval there is intervening matter; and odour, for anything known to the contrary, may be conveyed from a distance by polarization of the particles of that matter established by the physical condition of the odoriferous body. In the case of sight we can adopt a similar explanation; and although we should perhaps thereby need to require solar light to overleap empty space, we may find that its doing so would be a necessary consequence of the prevailing theory, if modified by the substitution of polarization for undulation.

27. Man's material organs of sense differ from each other either in the nature or the arrangement of

their constituent parts ; were it not so, any external material thing could produce in two or more of them the same sensation.

28. Material things external to man's organization differ from one another in the nature or arrangement of their component parts; were it otherwise, any organ of sense would receive from two or more of them the same sensation, in which case we should have to conceive different material things to be identical.

29. We have said that the mind can perceive the physical condition of no material thing except an organ of sense; by the term organ of sense, we mean to include all its parts, however distant they may be from the place where the external contact is received, and among others the brain with its nerves of sensation. We imagine that the change of place of the constituent parts of an external organ, causes a corresponding change of place in the constituent parts along the whole line, and eventually in those of the brain itself; and that it is this movement of parts which constitutes the sensation. The mind then perceives the condition of the brain, and that perception is an idea which exactly corresponds with the external impact on the organ of sense by which it was caused. When we reflect that when once momentum is communicated to matter it never becomes expended though it may be infinitely distributed,—that large and small are only relative terms as applied to material things,—and that in nature nothing is too minute to be perfect,—we are prepared to understand, not only that the relative positions of the smallest parts

of an aged brain may have resulted from numberless sensations, but that the impulses those parts have received during years of observation have caused motions which are still undulating and reciprocally modifying one another. The perception by the mind of such a mass of motions would be the perception of the consequences of facts, many of them long since passed away; or, in a word, memory.

30. Among the ideas or conceptions of the mind of man are truths and probabilities. Truths are of five kinds; by which is to be understood only that they arrive in the mind by five different means. They are:—

1st, PERCEPTIONS, or truths derived by the mind irrespectively of argument, and perceived simultaneously with the observation by the senses of facts or phænomena.

2nd, INDUCTIONS, or truths not derived immediately from the observation of facts, but by comparing or contrasting perceptions with one another.

3rd, DEDUCTIONS, or truths conceived in the mind as the conclusions of arguments and irrespectively of observation by the senses.

4th, INSTINCTS, or truths acquired by the mind irrespectively of argument and observation by the senses; but having the nature of perceptions in all other respects.

5th, INSPIRATIONS, or truths acquired by the mind without either an effort of reason or an observation by the senses; and not having the nature of perceptions.

31. PERCEPTIONS.—Truth and Fact are not synonymous terms; for the former is a mental possession, and the latter is external to the mind. A fact is a motion of some material thing; truth is its history. That truth and fact cannot be philosophically confounded together appears further in this: whenever two bodies separate, the separation is the fact; and it exists whether observed or not; the knowledge of the separation is the corresponding truth, which does not exist unless the fact have been observed.

32. Whenever a fact is observed by the senses, the observation is simultaneous with the perception of a truth by the mind by which that particular fact is exactly represented; that truth, from the manner in which it is acquired, may be appropriately and conveniently distinguished from truths derived from other sources by the noun *perception*.

33. Facts afford perceptions by the power of the mind to become cognizant of motions in the organs of sense, and not as conclusions to an argument.

34. Facts may occur in our presence without enriching our minds with perceptions, because the motions may be too minute to be observed by our organs of sense.

35. A perception, like every other kind of truth, is always necessarily true. On the other hand, we need not always attach the same necessity to a fact; for example, if we observe a flower of a par-

ticular form and colour, we can imagine, without doing violence to our understanding, that it might have been in either of those respects different; but, whatever it might have been, it is not possible for our minds to suppose it different from what it is. The reason why facts are not always characterized by necessity is, because in our ignorance of their causes we cannot recognize their necessity as effects; an explanation that is supported by the necessity of certain other facts of which the causes are known: thus, when a ball is observed to be moving in a certain direction, the necessity for the fact is recognized immediately the ball is known to be in contact with and in advance of some other material thing impelled in that direction, because if it did not so move the two material things would both occupy the same part of space, which is impossible.

36. A fact impresses the knowledge of a truth, or a perception on the mind of him whose senses have observed it; but it conveys only belief of a truth, or probability to the minds of others who receive its narration on testimony.

37. Inductions.—The authority of even so great a name as that of the father of the modern art of philosophizing, will not justify us in retaining such a use of words as tends to perpetuate confusion in science, if those words can be used more precisely. Nor can Bacon be cited with propriety for such a purpose, for the whole tenor of that great man's efforts proves that he himself would have been the first to introduce the pruning-knife into his own vineyard, if anything he had planted were found in

the course of time to be grown so out of order as to impede the improvement he had at heart, and for which he so successfully laboured. It is on this consideration that the writer, who now aspires to follow him at a humble distance, takes courage to suggest that a more restricted meaning be impressed on the term *induction* than it was introduced with, and which has more or less attached to it down to the present time. In doing so he does not pretend to indicate a more etymological application of the word; he has only the plea of expediency, and urges that, as we can make a broad distinction between *induction* and *inference*, the interests of science will be forwarded by our doing so. He hopes his motive will be accepted as an apology for an act which would else be charged to him as presumption.

38. In the following pages, the expression *induction* will be restricted to truth only, and to that particular kind of truth which is not derived immediately from observations made by the organs of sense, but which results from an act of the judgement, while the mind is contemplating truths obtained from observations. Inductive truth will thus, on the one hand, resemble perception, inasmuch as, like it, it is contingent on observation; and it will, on the other hand, differ from perception, in being not a simple narrative of observation.

39. Inference differs from induction in being drawn from considerations which are only probable, and consequently in not itself possessing the

necessity of truth. These two things resemble one another in flowing from considerations placed in juxtaposition by the arrangement of materials peculiar to the process of analytical argument.

40. All laws of phænomena are inductive truths ; but in order that they may be inductions, and not mere inferences, they need to be restrained within proper limits ; that is to say, never extended to cases not comprised in the observation. We commit this error whenever we assume a general law to be universal in its applicability, and even when we regard it as being so general as to include a single phænomenon which it has not acquired by experiment. Let us suppose, for example, two bodies to be placed at different times at different distances apart, and that their tendencies to approach one another have been estimated by the weights they were respectively able to overcome. Each motion of the balance will have been a fact, and the language which expresses it will exactly correspond to the perception of a truth caused by it in the mind of the observer. So far he will have had nothing to do with induction ; but if he then proceed to compare together the several tendencies with the several distances, such a comparison will involve an act of the judgement, by which he will perhaps find that the former vary in an arithmetical or geometrical ratio with the latter. The mind of an observer will have thus been inducted into the knowledge of a new truth, namely the law of the tendencies, which is no part of the observations, though derived from them. If he now represent that, because the two bodies with which

he experimented gave him the law, all other bodies examined in the same way will also establish it; or that all the possible parts of the two bodies which gave the law, are individually subject to it; he will in either case depart from induction, and introduce an inference, about which, although it may have the extreme of probability, he really knows nothing.

41. The existence of place and duration are truths of induction. The mind, by contemplating the perceptions which have been derived from physical facts generally, conceives a necessity for place and duration, and this necessity makes their existence an inductive truth in the mind. Space and time, apart from the ideas of locality and duration of things, are negative existences—as such they are unsusceptible of being observed by the organs of sense—and being unobserved by the organs of sense they convey to the mind no perceptions.

42. Inductions comprise, also, analogies and dissimilarities, made known to the mind by its comparing or contrasting two or more truths resulting from facts with one another.

43. Induction, though possessing equally with deduction all the necessity of truth, differs from deduction in not being the conclusion of a syllogistic argument either expressed or understood. The premises of an inductive argument are not necessarily confined to two or any other definite number; nor can either of the premises be considered with propriety as minor to any of the others.

44. Induction, in the mind of an observer of the facts from which it is derived, is a truth; in all other minds to which it may be communicated by testimony, it becomes only a probability.

45. Deductions.—The conclusions of all syllogistic arguments based upon premises either expressed or understood, both of which are true, are themselves true also. Hence all the conclusions of geometry and arithmetic logically obtained are deductive truths.

46. Deduction, like Induction, results from the comparison or contrast of truths with one another; and therefore, like it, deduction must be preceded in the mind by certain other truths on which it is immediately consequent. We have seen, too, that one and the same doctrine may be an induction from perceived truths to one mind, and a mere inference from probabilities to the mind of another person; so in like manner is it with deduction, for it cannot enter as such into any mind which has not already received each of the subordinate and elementary truths which the argument involves. Hence deductions also are relative, and not absolute.

47. Deductions and Inductions contrast most forcibly in this, namely, that while the latter are essentially requisite to enable us to advance towards the knowledge of physical causation, it is by the former that we must ascertain the value of the theoretical views we attain to on that subject. This is paradoxical, inasmuch as inductions and deductions are equally true, but the explanation is evident. If we could acquire the knowledge of causation by

inductions, either alone or in conjunction with other truths, every subsequent step of our analytical argument would be as satisfactory as the preceding, and the final result indisputable; in which case the proof for which we appeal to deduction would be superfluous; but in order to proceed by analysis in this manner, we need to be better furnished than we really are with inductions, both to begin with and to introduce at each step as we proceed. For want of them we supply their places with mere inferences; from whence arises uncertainty in the end, and the usefulness of deduction to enable us to estimate how much improbability we have mixed up with truth during our progress.

48. Whenever we succeed in banishing error from every preceding step of our argument, both Induction and Deduction are equally certain in their results. We can only debase induction by changing it into inference; and with regard to Deduction, we can only vitiate it by introducing a false premiss.

49. INSTINCT.—Were there no other kinds of truth than the three we have described, mankind would soon become extinct, or rather as a race they could never have existed; and the same is true of the animal creation generally. We owe our preservation to Instinct. We know that the newly-born infant must soon be nourished or die, and before he can be nourished he must be furnished with the knowledge of the mechanical efforts necessary to be made for that purpose. This knowledge he cannot acquire for himself; he is not in a

condition to comprehend the mental process of induction, and deduction would not answer the purpose if he could employ it. Perception is equally unavailable, for it must be founded on a physical observation of which, as yet, he has had no experience. Appetite is incompetent to supply the lack of knowledge, for appetite is a condition of certain parts of the material organization, or a fact, of which a mind may perceive the existence while it remains ignorant of its cause, its consequence, and its remedy. In this predicament instinct comes to the child's assistance, with precisely the kind and amount of knowledge necessary for his preservation, and in so doing proclaims its own origin. Instinct is a gift of the Creator to the mind of his creature, and temporarily supplies him with the knowledge he is shortly to acquire for himself. Instinct is a form of truth, and considering the source from whence it immediately flows into the mind, it ought to be regarded as a truth of the highest dignity.

50. Instinct may become confounded with induction, so soon as the corresponding perceptions exist in the mind. Sometimes instinct may remain in the mind throughout the creature's whole existence, as a permanent substitute for induction, as is probably the case in animals destined by their Maker to practise arts for which it is difficult to conceive they have been given an adequate amount of intellect.

51. The higher kinds of instinct have been withheld from man, probably because it is part of the

design of his Creator that he should become diligent in the exercise of his superior intellect for acquiring a knowledge of truth, and which he might be tempted to neglect if he possessed in instinct a satisfactory substitute.

52. Instincts relate only to material things, because they take the place, either temporarily or permanently, of perceptions and inductions which have reference to nothing but things of sense.

53. INSPIRATION.—Inspiration resembles instinct by arriving in the mind without the aid of observation or of reason ; and it differs from instinct in not essentially relating to material things. Its object is to impress our minds with such truths as are calculated to affect our moral condition, and the knowledge of which we are incapable of gaining by scientific research. By instructing the intellect of man, inspiration influences his affections ; instinct by the same means conduces to his physical well-being. The mind acquires the truths of inspiration by the simple exercise of desire for their possession ; the truths of instinct are not attainable by any mental effort.

54. The moral qualities become known to us only by inspiration. Left to his own intellect, man could never have discovered even that the destruction of his own species is a moral evil. To know moral perfection, he must first desire to know it ; and if the desire actuate the affections of his mind, the knowledge will be communicated to his intellect by inspiration. Intellectually considered, therefore, the qualities of good and evil are not absolute, but

relative. But man as a whole is responsible for errors he may commit respecting them, because he is responsible for the state of his affections by which his intellect may be enlightened.

55. There is a truth which relates to physical science, and which has been inspired into the minds of the whole human race; when strictly examined, it has however an application which partakes as much of a moral as of a physical character; indeed if we respect the superiority of the one class of things over the other, its application will be considered more moral than physical;—we mean the necessity for universal causation. The existence of such a necessity is admitted by all, although philosophers are not agreed as to the avenue by which it enters the mind. We think it inspiration for the following reasons:—1st. The necessity for causation is not a mental perception acquired through observation by the senses, because a perception, if put into language, would merely narrate the facts from which it was obtained, and there are no facts which, by being narrated, would convey such a perception to the mind. 2nd. It cannot be an induction, because it may not be derived from a comparison or a contrast of facts, as all inductions are derived. 3rd. It is not a deduction; for there are no truths known to man on which a syllogism competent to afford such a conclusion can be founded. 4th. And it has not the character of an instinct; for instinct only performs the offices of perception and induction, which we have already seen to be incompetent to prove the necessity for causation. If,

therefore, our classification of truths be founded upon natural principles, it only remains for us to regard the necessity for causation as having been inspired into our minds by the Deity ; and if that be true, then our thirst after physical knowledge which emanates from it is intended for our moral rather than our physical good, because such is the object of all Inspiration, of which the necessity for causation is an instance.

56. Taking, then, this view of the nature of its necessity, it leads us directly to the origin of other axioms which relate to causation. When we say that "causes are measured by their effects," we thereby mean that the relation between them is always uniform ; now as the necessity for such an uniformity has not the character of an instinct, and is not presented to our mind either through the observation of facts or its own powers of reasoning, we can only ascribe the necessity of the axiom, that causes are measured by their effects, to the same source as in the former case ; thus regarding it as an inspired truth put into our minds, but an immediate act of the Deity. Ar d the same explanation may be applied to the third axiom on the same subject, which represents "action and reaction" to be equal ; for it is a mere repetition of the preceding one, and only asserts that causation, which is the action, increases in amount with the work it has to do, that is, with the reaction opposed to its efficiency.

57. With regard to causation itself, it must be our business in searching after its nature to multi-

ply inductions by using the truths we are in possession of, whatever be their origin, so far as they promise to be useful for such a purpose, in the hope that among the new truths that may thus be arrived at we may make the desired discovery. If we could conduct an analytical argument in this unobjectionable manner to an unlimited extent, we should inevitably arrive at last at causation; for by following a chain, every link of which is necessarily connected with a former one, we must eventually arrive at its beginning. Or to use another figure, somewhat more complex and much more appropriate, if we could without once losing sight of our track carry the eye from any one of the extreme twigs of an animal artery through the small branch to which it is annexed, thence to a larger branch from which it is given off, afterward along the main trunk of the artery towards the heart, there is no possible doubt of our arriving at the heart at last; we should indeed have to pass a multitude of bifurcations as we passed along, but while we took no heed of them and steadily continued our course, the way would in reality be no more difficult to a steady perseverance than in the case of the simple unbifurcated chain we have previously imagined. The only difficulty would then consist in keeping the eye on truth; but unfortunately it is not in our power to go forward with such precision; it is too much to expect that in progressing towards causation we shall always have at command precisely the very truths we require for constructing the proper succession of arguments, and that we shall not be compelled occasionally to support our argument on probabilities in place of knowledge. One such occurrence must be fatal to certainty; for at the place where it happens theory will be grafted on to the stem of truth, and the fruit must in consequence degenerate into hypothesis.

58. Were we perfect in knowledge, we should have no probabilities in our minds; as we are not perfect, we must be content to regard them, as well as truths, as the materials by which alone we can hope to advance in the physical sciences.

59. There are two sources of probability. In one way we obtain it in the form of simple inferences, from the ideas which exist in our minds respecting facts observed either by ourselves or others; and secondly, we acquire probabilities by extending inductions beyond their legitimate limits. Whatever be the origin of a probability, its importance varies with its amount of usefulness, with the simplicity of the machinery which it involves, and with the imperfection of the doctrines which it is possible to substitute for it.

AN ANALYTICAL ESSAY IN SEARCH OF THE TRUE THEORY OF CAUSATION.

1. Matter is impenetrable, because it exclusively occupies a part of space (Philosophy, 14, 15, 16).

2. All things that are wholly composed of matter are impenetrable, because matter is so (1).

3. Bodies of sensible magnitude contain matter, because they occupy more or less space into which certain other bodies cannot penetrate.

4. Bodies of sensible magnitude contain space, because they are not wholly impenetrable by other matter.

5. Matter is not divisible, because it is impenetrable (1.). Impenetrability implies indivisibility; thus, let impenetrable matter be divisible; to divide it we must separate it into parts, and if we separate it into parts, we shall admit spaces between them. In those spaces matter has existed, and therefore may penetrate again; in which case matter would be both penetrable and impenetrable. The impenetrability of matter therefore implies that it is also indivisible.

6. Bodies of sensible magnitude can be divided only in the direction of their spaces, because their material parts are indivisible (5.).

7. The distribution of the spaces in bodies has a limit. To prove this, imagine a body to be intersected by spaces without limit, and let it be divided in the direction of those spaces into equal parts an infinite number of times. By each successive division the parts will become smaller, but the thickness of the spaces through which the section is made will remain always the same. This is obvious, because the spaces selected for making the divisions might have followed an inverted, or any other order of succession. After a sufficient number of sections each of the parts of the divided body will have become no larger in magnitude than the thickness of a dividing space; and if, when that stage of the process is reached, the part still contains one space more, the whole matter of the body is annihilated. It follows therefore that the divisibility of bodies has a limit; that is to say, matter is composed of atoms.

8. The unknown force by which atoms are associated together acts where matter is not; or in other words, matter acts where it is not. This paradox will be clearly explained by criticising the language in which it is conveyed. There can of course be no agency without an agent, and therefore when matter is the agent there can be no action originated if there be no matter. But when matter has originated an action, we may conceive it possible for the sphere of that action to extend beyond the matter into space; and if it do so, then matter will be acting where it is not. Now we know that the sphere of action is so extended by the

circumstance of atoms acting upon one another, although separated by their interstitial spaces.

9. The direction in which force acts can only be discovered by observing its effects ; and these effects consist in the position which each atom in the universe has assumed with relation to all the other atoms, and in the movements of the atoms whenever an existing relation is disturbed. In consequence of the minute volumes of atoms, their relative positions and individual movements elude the observation of our organs of sense. If we attempt to make our organs of sense suffice for discovering the effects of force upon atoms by observing the effects of force as displayed upon masses of atoms, we shall be in danger of implicating all the atoms of a body in a conclusion which may possibly apply only to certain of them, because we are not sure, even in the case of a chemically simple molecule, that it is not composed of atoms of different physical natures.

10. If we could experiment upon a mass of matter which we knew to be physically homogeneous, the result would be satisfactory, because the effect of force observed in it would be due to each of its constituent atoms.

11. We cannot assume the simple bodies of chemistry to be physically simple, without assuming also that the causes of the phænomena of electricity and heat, which simple bodies exhibit, are not material things, which would not be readily granted. And if electricity and caloric be material, they will have better claim to be regarded as physically

simple bodies than any of those things in which they are both to be found.

12. Electricity contains something which is material, because there are particular bodies of sensible magnitude which are impervious to it. The spaces of those bodies have nothing in their nature to enable them to resist its entrance ; and if its entrance be resisted by the material atoms of the bodies, then it must itself, at least in part, be material.

13. It is no indication of the immateriality of electricity that certain other bodies may be penetrated by it ; for all bodies of sensible magnitude are pervaded by interstitial spaces into which material atoms of any kind, and therefore atoms of electricity, may enter, provided only that their volumes be sufficiently minute.

14. Electricity is further seen to contain something which is material, because it impinges on material organs of sense, namely those of touch, of smell and of vision.

15. We can conceive of no material thing being contained in electricity except it be caloric ; but if we assume the materiality of caloric, it will not supersede the necessity which exists for electricity being considered as material also, because electricity will not pass through spaces which observation teaches us to be large enough for the passage of caloric.

16. We infer from these circumstances that electricity itself is material, and composed, like the other kinds of matter, of atoms.

17. Either caloric is material, or it does not occupy space ; but caloric, by combining with masses of atoms, increases their volumes, the most simple inference from which is, that it occupies space, and consequently is material.

18. Caloric is capable of impinging physically on an organ of sense, to do which it must come into contact with its material parts (Philosophy, 20 *et seq.*) ; and it cannot be brought into mechanical contact unless it be itself material.

19. It is no evidence of the immateriality of caloric, that all bodies of sensible magnitude are permeable to it, even those which resist the entrance of electricity. This fact only indicates, either that atoms of caloric are smaller than those of electricity, or that the latter are sometimes prevented from entering into spaces large enough to receive them, in consequence of having atoms of caloric inseparably connected with them. And it may be that both these inferences are true.

20. From the preceding considerations, we arrive at a conclusion that caloric is composed of material atoms.

21. We have no conception of the quantity of caloric combined with other kinds of matter ; but the phænomena of heat teach us that no kind of what is usually called common matter is ever without caloric in larger or smaller proportion ; we may assume that the electrical matter is not an exception to the rule. If this be true, any force we may discover in action among the parts of a mass of elec-

tricity may be attributable either to that particular kind of matter, or to the caloric combined with it.

22. Although it is probable that we cannot experiment with electricity without having caloric present, we know we can experiment with caloric without danger of confounding the results with those of electricity. This consideration opens up a hope of finding the way out of our difficulty. The force we are in search of will either impel the atoms of matter towards one another, in which case we should call it attraction, or it will tend to separate the atoms of matter, when it would be called repulsion. The sciences of electricity and heat both abound with phænomena which are ascribed to a repulsive force; but while it is possible to account for electrical repulsion on the principle of attraction, we are without a single evidence in favour of calorific attraction. If, then, in experimenting with a mass of electricity we detect the results of an idio-attractive force, we may rationally assume that it is the atoms of electricity, rather than those of the caloric in combination with it, that attract one another.

23. We know from observation that when a considerable mass of electricity is directed by suitable arrangements, which are too well known to need description, through the minute space which exists between the flat surfaces of two pieces of plate glass pressed firmly together, one or both pieces usually are broken, although when the mass of electricity is less considerable it will pass without causing a

fracture. In analysing this fact, we ought to strip the electric fluid of all its imputed mysterious qualities, and simply regard it as we should do any other kind of matter whose atoms were free to move over each other, and which was being impelled by any adequate means between the contiguous surfaces of the glass. It is obvious that the transverse sectional area of the space through which the electricity had to pass would be greater as the space was wider; and therefore, that if a given unit of width was insufficient for its free passage, an adequate amount of resistance by the glass would cause the electricity to accommodate its form to two or more units of width. Now what would be an adequate amount of resistance by the glass? The answer manifestly is, exactly that amount of force with which the passing electricity resisted being spread out to the required width; and electricity would rather tend to spread itself out, than to resist being so spread, if its atoms were idio-repulsive. The simple inference from the fact under consideration therefore is, that the atoms of electricity attracted one another during their passage between the two flat surfaces with a force greater than that of the cohesion of the glass.

24. Again: whenever a mass of matter whose atoms are free to move upon one another is surrounded by a gaseous medium, they tend to place themselves at the shortest distance possible from their common centre; and this fact is ascribed to an attraction of the atoms for one another. Electricity in like circumstances exhibits a like tendency;

if the like tendency have a like cause, then we may legitimately apply idio-attraction to the atoms of electricity.

25. It is customary to imagine the pressure of the atmosphere to exercise some influence on electricity, by which it is confined to the surfaces of bodies, and also made to assume the globular form which it exhibits when passing from one place to another in the atmosphere. The nature of such an influence of atmospheric pressure has never been described, nor does it seem possible to conceive it; it is moreover quite unnecessary for establishing many of the electrical phænomena said to be dependent on it. Nothing is more easy, for example, than to cause electricity to assume the form of the spark in highly rarefied air; one means of doing this is to pass an electrical discharge between two balls placed in a large exhausted receiver, and separated from each other only by a thin piece of mica about an inch in diameter; in passing round the edge of the interposed non-conductor, in its way from one conductor to the other, the atoms of electricity appear as a spherical mass. In this experiment the plate of mica may be dispensed with if the receiving ball be well uninsulated, and if the distance of the balls from the sides of the glass receiver be great compared with the space between them.

26. In some experiments made many years ago with the balance-electrometer and unit-jar of Sir William Snow Harris, and which were at the time communicated to that electrician, it was observed that when a disc of gilded wood suspended to the

arm of a balance was made positively electrical, it overcame a given amount of weight attached as a resistance to the opposite arm with a fewer number of discharges from the unit-jar than when the charge of the gilded disc was made negative. As in these experiments the charged disc had to descend, the results indicated an idio-attractive force among the electrical atoms; a conclusion I had previously arrived at in another way, and which I sought either to confirm or repudiate by an appeal to new observations.

27. The experiments with Harris's balance, to which I have just alluded, suggested to me another arrangement of apparatus, which promised to be quite conclusive in its indications; and to my mind it immediately proved so. It is evident that if atoms of electricity act upon each other, either by attraction or repulsion, every electrical atom attached to the arm of a balance must be acted upon by every electrical atom in the mass of the earth, and tend, in consequence of that action, to approach or recede from the earth, as the case may be. This is precisely the way in which we are accustomed to ascertain, not the kind of force only, but also its amount, with which bodies of limited magnitude near the earth's surface tend to approach its centre by virtue of a force which we call gravity. If, then, we suspend to one of the arms of a balance some additional atoms of electricity, they will cause that arm either to approach or recede from the earth; because, under such circumstances, electrical idio-attraction would add something to the force of that

arm's gravity, and electrical idio-repulsion would to a certain extent counteract its gravity. The only difficulty in such an experiment is to prevent the interference of common electrical attraction, as of course the atoms of electricity added to or subtracted from the arm of the balance, would invest it with a plus or negative charge, and thereby cause it to tend towards the earth, or any other conducting body sufficiently near; this difficulty, however, is not insuperable, and I have succeeded in overcoming it. The experiment about to be described demands a nice adjustment of apparatus, and a favourable state of the weather; but with a proper attention to details, which every practical electrician will understand, it is more easy to do than would perhaps be anticipated, and its indications are quite palpable and uniform.

28. A circular plate of brass, *a*, fig. 1, twelve inches in diameter, was raised by an uninsulating stand about ten inches from the floor; a second similar plate, *b*, was suspended by three threads from a firm wooden frame, over and about twenty-six inches distant from *a*. The wooden frame was well secured from vibrating by cords attached to the opposite walls of the apartment. By means of a chain, *e e*, a conducting communication was established between *a* and *b*, at the same time that both were put in uninsulated connexion with the floor. A cylinder, *h*, about eighteen inches long and eleven inches in diameter, made of paper, and closed with ends made of the wood of the lime-tree, and turned as thin as possible and free from edges, was covered

with tin-foil, and suspended by two thoroughly dry and well-varnished silk threads to one of the arms of a balance, in such a manner as to hang about midway between the two uninsulated plates *a* and *b*. The manner of arranging these two silk threads, so as to prevent the gyration of the cylinder, is shown by fig. 2. A box, *i*, suspended from the opposite arm of the balance, carried the counterpoising weights, part of which consisted of a wire projecting downward from the bottom of the box, and supporting a small wooden cylinder, which, by plunging to its middle in water contained in the cup *k*, served to arrest the oscillations of the balance. A screw, *l*, afforded a means of bringing the long straw index, *m*, of the balance to the horizontal position. This position was denoted by a mark on the scale-board *q*. A brass wire, *n*, insulated by passing along the axis of a long glass tube, firmly fixed to the wooden standard of the apparatus, and presenting its extremity horizontally and without friction against the paper cylinder, could be charged either positively or negatively at pleasure, by aid of an ordinary electrical machine. In this state of things, whenever the cylinder was electrified, either positively or negatively, it was, in obedience to the well-known law of electrical attraction, put in motion towards that one of the two plates which was at the time at the least distance from it.

29. To prepare the apparatus for experiment, the distance of the plate *b* was so nicely adjusted by means of the screw *f*, while the cylinder contained a positive charge, as to make it impossible to say in which

direction it most tended to move. The charge being then withdrawn, and a negative one substituted in its place, the cylinder ascended, and continued uniformly to do so whenever the negative charge was repeated.

I explain this experiment in the following manner:—When the positively charged cylinder *h* was equally tending in both directions, it was nearer to the upper than to the lower plate, and therefore electrically attracted more forcibly in the upward direction, being kept from ascending by a new tendency downward which it had acquired by the attraction of its plus electricity by the electricity of the earth. This tendency downward was removed and reversed by afterwards charging the cylinder negatively, and consequently the equilibrium which had been established in the first instance was destroyed.

30. The screw *f* was next turned a little so as to allow the plate *b* to descend, until under a negative charge the cylinder equally tended in both directions. In this condition of the distances, whenever a positive charge of the cylinder was substituted for the negative one, the cylinder invariably descended.

The explanation of this experiment is as follows:—When the negatively charged cylinder *h* tended equally to move in the two directions, it was nearer to, and therefore most forcibly attracted by, the lower plate; just enough so to counterbalance a tendency upwards, caused by the loss of electricity sustained by the cylinder. When the positive charge became afterwards established in the cylinder, the electrical atoms which entered it destroyed the previously existing equilibrium, by virtue of their tendency towards the electricity of the earth.

31. In neither of the two foregoing experiments was the cylinder supposed to be midway between the plates; if we place it there, we shall be able, by alternating the positive and negative charges, to make it fall and rise alternately, because, when equidistant from the two plates, the cylinder under the mere influence of electrical attraction will equally tend in both directions, and therefore exhibit only the tendency of such atoms of electricity in it which are not counterpoised. This midway position between the plates may be practically found exactly enough for the purpose by first adjusting the distance of the upper plate as for the first experiment (29.), and then lowering it a very little by means of its screw; or we may proceed in the opposite order, and adjust the apparatus for the second experiment (30.), increasing the distance between the cylinder and the upper plate by raising the latter a very little. By these means I have frequently adjusted the apparatus for the double experiment; and the result uniformly has been, that a positively electrical charge made the cylinder to fall, and a negatively electrical charge has as constantly caused it to ascend*.

* The attraction of electricity for common matter is so comparatively great, that it is only when it preponderates but slightly in either direction that the tendency of the atoms of electricity towards one another can be made appreciable by the means I have described. Care must be

32. It has been conjectured that the results observed in the foregoing experiments may possibly be due to ordinary electrical attraction, and that a negatively electrical state of the earth would be competent to originate such an electrical attraction; the most cursory examination of the apparatus employed would however promptly dispel such an illusion, for it would show us that the earth was virtually as much above the cylinder as below it, so far as ordinary electrical attraction is concerned. It seems almost superfluous to say, that however much we may imagine the earth to have been at the time of the experiment negatively electrical, its electrical condition must have been equally participated in by the two plates *a* and *b*, for the same reason that they

taken in repeating the above experiments that the plates be well uninsulated, that they occupy planes as horizontal as possible, that the coated paper cylinder be suspended by silk threads so perfectly dry and well-varnished as not to become electrical, and that the cylinder itself neither gyrate nor oscillate; the atmosphere should be dry and preserved from sensible agitation; the wire for communicating the charge to the cylinder should be presented at right angles to its axis, and be terminated by a smooth blunt end, barely allowed to touch the cylinder, lest its return to a proper position be impeded. The electrical machine should be placed at a considerable distance, and the experimentalist be careful not to approach the suspended cylinder.

I intended to repeat these experiments before the Physical Section of the British Association for the Advancement of Science, at the meeting held at Southampton in 1846, but I was deterred from making the attempt by the unfavourable state of the 'Long Rooms' in which the Section assembled. I may, however, take this opportunity to remark that they were witnessed in Paris, in the year 1839, by M. Becquerel, and other members of the Institut, and reported to be successful at a subsequent meeting of that body, by a member on the authority of the philosopher I have named. I believe that MM. Pouillet and Savart, who were appointed by the Academy to examine and report upon my experiments, still acknowledge their perfect success, as they did to me at the time, though they have never made an official report of what they saw.

would have participated in the electrical state of a Leyden jar, or anything else negatively charged, and in conducting communication with both of them. The plates were contrived and used for the sole purpose of balancing the ordinary electrical attractions in the opposite directions; and every electrician will understand that it was only by the two plates completely performing their office that the weaker force was enabled to become apparent.

33. Hoping to remove all discussion and doubt as to the nature of the electrical force in question, I had my apparatus altered in a manner to prove that that force did not observe, with relation to quantity, the law of ordinary electrical attractions, but, on the contrary, that of gravitation; the new apparatus was never put into requisition, because, before it was completed, I had recollected that it is part of the task I have undertaken to show that the two forces in question observe different laws. The modified experiment would have consisted in causing the counterpoised arm of the balance to be kept at rest on a fixed point of support by weights in excess differing in amount, and then ascertaining, by means of the unit-jar, what ratio those weights in excess would observe with regard to the counteracting quantities of electricity in the cylinder, suspended from the opposite arm of the balance, and hanging midway between the plates.

34. Another arrangement may also be adopted to prove the idio-attractive force of electricity. In the construction of the pendulum of a time-keeper, we might introduce a column of circular plates of

glass, coated with tin-foil in the centre of one of their sides, and so put together that every two plates may have tin-foil between them; the lowermost plate should be coated on both sides, and its under coating put in conducting communication with the bob of the pendulum. The whole column might be maintained in an electrically-charged state by causing the bob of the pendulum to perform the office of a middle plate to an electrical doubler, as suggested for another purpose by Mr. Ronalds*. If we made the lower surface of any one of the glasses plus, the lower surfaces of all the glasses would be plus; and if, on the contrary, one of the lower surfaces were made minus, all the lower surfaces would be minus likewise. We could thus lower or raise the centre of the mass of electricity in a pendulum at pleasure; and since we know that by lowering the centre of gravity in a pendulum we retard its velocity, so by charging any given surface in our Leyden series alternately plus and minus, we should have the means of ascertaining whether the centre of the mass of electricity and the centre of gravity have the same or opposite properties; or in other words, whether the electricity in the pendulum was attracted or repelled by the terrestrial electricity.

35. It is seldom that isolated phænomena, when they contain many subjects for contemplation, bring minds of different capacities and acquirements to the same uniform inference; in all complex cases the intellect hungers for a mass of evidences, and will not give up its early impressions in

* Descriptions of an Electrical Telegraph, &c., p. 53.

exchange for anything less extensive. I have never expected much aid from individual facts, and I consequently neglected to try the experiment just suggested until it has become, in my own estimation at least, quite superfluous.

36. Whether the evidences which I have adduced be deemed conclusive or not of the idio-attractive nature of the electrical force, they will, at all events, justify me in assuming the existence of that force as an hypothesis to be verified hereafter by the parallel I shall be able to show between the consequences deduced from it, and the physical phænomena that must necessarily depend upon it for their explanation.

37. Science hitherto has represented gravity to be the universal attribute of what we have been accustomed to designate common matter, and it has denied ponderability to electricity. We are now under the necessity of reversing these ideas; for in the first place, if gravity and ponderability mean the force by which atoms of matter of like kind tend to approach one another, then we are to consider electricity as ponderable; and as electricity seems, so far as observation has extended, to be connected with bodies of sensible magnitude universally, simplicity demands that we regard their tendency to gravitate as conferred upon them by the idio-attractive force of the electricity they respectively contain.

38. In proceeding to investigate the immediate consequences of these inferences, in order to test their validity, I shall speak of the combining quan-

tity, or equivalent of the chemist, as a molecule of matter rather than as a simple atom; because I assume it to be composed of, at least, three different kinds of atoms or centres of force, which I propose to distinguish throughout this essay as Basic, Electrical, and Calorific.

39. Assuming then the idio-attractive force of electricity to be the sole cause of gravitation, and that all electrical atoms attract each other equally at equal distances, it follows that the relative numbers of electrical atoms naturally present in molecules of matter of different kinds, may be exactly indicated by numbers which express their equivalent weights or combining ratios.

40. And on the same assumption, it must be true, also, that as any particular molecule has an unvarying weight, its basic atom can never attract either more or less electricity at one time than at another; from which it follows, that if, from any cause not yet explained, a basic atom acquire more electricity than it attracts, it must be positively electrical; and if, on the contrary, it become possessed of less electricity than it attracts, it will be negatively electrical.

41. It will be readily admitted that we have abundant evidence of an attractive force tending to unite electricity and common matter; this attraction, to which Coulomb, under the teaching of his experiments, applied the law of the inverse square of the distance, we may appropriately speak of as the *major* electrical force, and we may regard it as reciprocal between the electrical and basic

atoms. The idio-attractive force of electricity of this theory will, of course, have assigned to it Newton's law of the simple direct ratio of the quantity, and the inverse square of the distance, and it may be distinguished as the *minor* electrical force.

42. To try the efficacy of our inferences, let us imagine the nucleus of a simple chemical molecule, or as I have called it a *basic atom*, to be surrounded by an assemblage of atoms of electricity in considerable numbers; as these, in conformity to Coulomb's law, will tend to place themselves at the shortest possible distances from the common centre, they will, if free to move, arrange themselves around the basic atom in concentric spherical strata.

43. The relative number of electrical atoms around a basic atom is determined by the particular equivalent weight of the chemical molecule of which the basic atom is the centre; and the number of concentric spherical strata is determined by the number of electrical atoms of which they are to be formed. Hence the heavier a chemical molecule is, the greater will be its radius, and consequently the more distant will be some of its electrical atoms from the common centre of attraction, and therefore the more feebly will it resist the abstraction of those most distant electrical atoms by external agency.

44. The number of electrical atoms belonging to any particular basic atom may be such as to leave its external stratum of electrical atoms imperfect to any greater or lesser extent; that stratum may contain any small number of electrical atoms, each

one of which, so far as the major electrical attraction is concerned, having free liberty to move on the surface of the next inner and perfect stratum, because while so moving it will not change its distance from the common centre of major force.

45. Next imagine, for sake of simplicity, each of two chemical molecules of unequal radii to have a single electrical atom on its most distant perfect stratum of electrical atoms ; and let the two molecules be so placed together that the two most distant atoms of electricity shall be in a line between them, and crossing their common axis at right angles, fig. 3. Each basic atom will now attract only the nearest hemisphere of its own most distant electrical atom, making up its equivalent quantity of electricity by attracting, also, a hemisphere of the electrical atom belonging to its associate ; because two hemispheres are equal to a sphere, and in this case two half atoms are nearer to the centre of attraction on either side, than is the whole of either of the two electrical atoms.

46. A mechanical separation of the two chemical molecules, fig. 4, will cause one to become electrically plus, and the other minus ; because,—1st, atoms are indivisible ; and, 2ndly, the two electrical atoms are more forcibly retained in the direction of the shorter distance. The plus basic atom, therefore, is combined with more electricity than it attracts, and the minus basic atom with less than it attracts ; the disposing cause in both cases being the fact, that matter is not infinitely divisible, but, on the contrary, composed of atoms.

Fig 7.

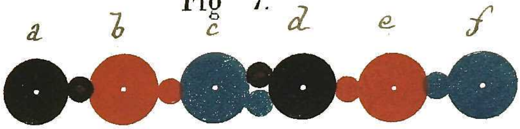


Fig . 3.

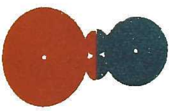


Fig 4 .

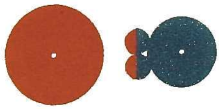


Fig 6.

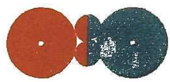


Fig . 9.

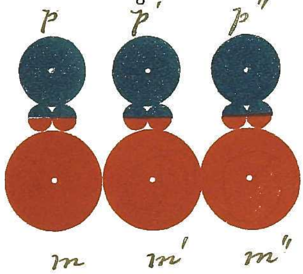


Fig 10.

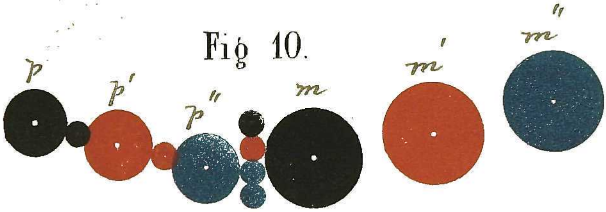


Fig . 11.

47. According to this view of electrical excitation, plus and minus charges must always be simultaneous and equal as to quantity ; so that whenever any mass of basic atoms possesses more electricity than they naturally attract, the excess or plus charge has its basic atoms in other places; and every mass of basic atoms which has been deprived of part of its natural quantity of electricity has the deficiency attached as a plus charge to other basic atoms.

48. The two molecules (45.) before their separation will cohere together with a force greater than that of gravitation acting at an equally short distance, because they are combined by the major electrical attraction as well as by the minor. It is evident also, that so long as the two molecules were separated from each other by a distance greater than twice the diameter of an electrical atom, measured between their external perfect strata, the minor electrical force only would be in action to unite them.

49. When we reflect to what extent simple chemical molecules differ from each other in weight, and consequently in their radii, and how varied may be the numbers of electrical atoms on the surfaces of their external spherical strata, we shall be prepared to understand how molecules may unite together with all the degrees of force which are presented to us in the phænomena of cohesion and chemical affinity.

50. As physical action and reaction are in all cases equal, it follows that basic atoms attract elec-

tricity as forcibly as the latter attracts basic atoms. To apply the axiom in the case we have imagined (46.), we say that the minus basic atom of one molecule attracts the plus electricity of the other molecule, just as much as and no more than the plus electricity attracts the minus basic atom. Why then do not electrical discharges take place through as great distances as electrical attractions? We have the paradox explained by the doctrine that matter is not infinitely divisible. In the case before us, the hemispheres of the two atoms of electricity which constitute the plus charge of one of the basic atoms cannot quit it because atoms are indivisible; and neither of the two whole atoms of electricity can quit the plus basic atom without placing part of its equivalent, namely an hemisphere of one electrical atom, at an increased distance; and these circumstances, under the law of the inverse square of the distance, restrain the discharge. On the other hand, there is not the same impediment to the reciprocal approach of the plus and minus molecules, and therefore the phænomena of electrical attractions usually become established through greater distances than electrical discharges. I say usually, because there are exceptions to the rule, but they confirm the general conclusion; by opposing inertia, for example, we may obstruct the mutual approach of oppositely electrified bodies, and so approximate the sphere of sensible attraction to that of electrical discharge.

51. If we repeat the preceding case of electrical excitation (45.), with this difference, namely, that

each chemical molecule has two instead of a single electrical atom on its most distant perfect stratum, then, on the mechanical separation of the molecules (46.), we shall have one of them plus and the other minus to double the former amount, so far as regards the quantity of the electrical charge. The mechanical axiom which represents physical effects to be necessarily proportionate to their physical causes, will lead us to anticipate, that in our modified case the resulting force of electrical attraction will be exactly twice as great as it was in the former instance; but this is not consistent with observation, for all facts combine to prove that electrical attraction varies as the squares of the quantities of electricity, and not in the simple ratio. The inference from these facts is of the utmost importance, and in order to prepare for it an unbiassed reception, I shall first proceed to detail the facts themselves, somewhat at length. In doing so, I shall draw largely from two memoirs published by Sir William Snow Harris in the Philosophical Transactions, and to which I acknowledge myself indebted for many experimental evidences in favour of the new views I have been enabled to take of universal causation.

52. "A quantity of electricity was taken, the attractive force of which operating between two plane surfaces was equivalent to a force of 4·5 grains. When the quantity was doubled the force amounted to exactly 18 grains; three times the quantity balanced a force of 40·5 grains, and so on. When a second and precisely similar surface was

made to divide the charge equally with the first, similar quantities, measured as before, only exhibited one-fourth of the previous forces respectively. With three times the dividing surface, the force was only one-ninth part of the respective forces first observed*."

53. "Three or four perfectly similar and equal conductors of a cylindrical form, being well-insulated, a given quantity of electricity was communicated to one of them, and the attractive force measured by the electrometer. The electrified body being now restored to a neutral state, a second quantity was again communicated to the same conductor as before; after which it was caused to touch one of the others, so as to divide the charge on both. In this case each conductor was observed to be, on transferring it to the electrometer, equally charged; the force, however, after making the requisite correction for distance between the attracting bodies, amounted only to the one-fourth of the previous force. This process, repeated with three and with four similar conductors, reduced the force to one-ninth and one-sixteenth part of the first respectively. The actual results of a series of experiments are given in the following table†."

	Quantities of electricity		Forces at distance constant.
	1	30·	
	$\frac{1}{2}$	7·8—	
	$\frac{1}{3}$	3·27+	
	$\frac{1}{4}$	1·8+	

54. I had the advantage to see similar experiments repeated by their author, and they appeared to

* Phil. Trans. 1834, p. 220, 221. † Ibid. p. 219.

be of so important a character, that I prepared a set of apparatus for diversifying them at my leisure. One of my electrometers was so constructed as to enable me to experiment with it in a receiver nearly exhausted of air, by which means I ascertained that the law of the square of the quantities was not dependent on the pressure of the atmosphere. Some of these experiments were published at the time, but as they confirm my present views I shall reproduce them.

55. In order conveniently to estimate the force of such minute quantities of electricity as are susceptible of being retained by a conductor placed in highly rarefied air, it became necessary to construct an electrometer that should be very delicate, and at the same time occupy but little space. Accordingly, an elliptical beam, $1\frac{3}{4}$ inches in length, made of a thin lamina of mica and gilded, was supported as a balance on two needle points; a circular plate $1\frac{3}{4}$ inches in diameter, of the same material, was suspended by silver threads to one of the arms of the balance, and counterpoised by a weight attached by horizontal sliding straws to the opposite arm. The index, $2\frac{3}{4}$ inches in length, consisted of a needle of glass, carrying at its upper end a small plate of mica, by means of which the scale could be read off without error from parallax; two short straws, one sliding with friction within the other, were so adjusted under the centre of gravity of all the moveable parts, that that centre might be brought to be no more below the points of support than was absolutely necessary, by which means the instru-

ment was made so sensible that a weight of $\frac{1}{80}$th part of a grain moved the index through $4\frac{1}{4}$ divisions of the scale; the $\frac{1}{40}$th part of a grain moved the index through $8\frac{1}{4}$ divisions; $\frac{3}{80}$ths moved it through $12\frac{1}{4}$ divisions, and the $\frac{1}{20}$th through 16 divisions; and as the scale could be read off to quarters of a division, a force equal to $\frac{1}{1280}$th part of a grain was appreciable by its means. When used, this electrometer was suspended with its circular plate of gilded mica over an uninsulated disc of gilded wood, by a wire cemented at about its middle into the axis of a glass tube, the latter being made to slide through an air-tight collar of leathers in the top of an exhausted receiver, about $6\frac{3}{4}$ inches in diameter; while in this position the electrometer was brought into conducting communication with the inner coating of a Leyden jar, exposing about two square feet of coating, and whose electrical charge was estimated by means of Harris's unit-jar. The following results were obtained:—

Comparative quantities.	Forces observed.
1	1
2	4·25
3	9·5

ANOTHER SERIES.

Comparative quantities.	Observed forces.	Same by calculation.
13	1·25	1·35
16	2·	2·
20	3·	3·2
25	5·	5·
30	7·5	7·2
35	10·25	9·8
40	13·	12·8
45	16·75	16·2
50	20·5	20·

56. The remarkable law of the squares of the

quantities first observed by Sir W. S. Harris, was regarded by that philosopher as not indicating the true effects of their cause; because, he remarks, it can only be "consistent with strict philosophical reasoning to assume that every effect is directly proportionate to its cause." In order to reconcile the facts to the axiom, he suggested an hypothesis which assumed that part of the attractive force was "masked by the operation of some peculiar influence," and then imagined that peculiar influence to "consist in an electrical change induced by the redundant electricity in the particles of common matter, by which they exert an attractive force of a greater or lesser extent, and hence neutralize some of the force in respect of the electrometer*."

57. If we admit a necessity for reconciling facts to an axiom, we must seek for another way of doing it in the present instance, than that taken by the author of the experiments, for his hypothesis is quite inadequate; it is itself inconsistent with the very axiom to which it attempts to make facts pay deference. Were we to acknowledge "redundant electricity" as the competent cause of the anomaly, the magnitude of the effect should progress in simple proportion to the quantity of electricity which is redundant, instead of increasing, as it must have done, in a very different ratio. In the words of the author, "taking two terms only, the force evinced by a single quantity (of electricity) amounted to three grains, whilst the addition of a second equal quantity produced a force of nine grains, making

* Phil. Trans. 1834, p. 222.

a total of twelve grains: the mean of this would be six grains; so that if, for the sake of illustration, it is admissible to reason in this way, at least one half of the attractive force of which the first quantity is susceptible has been masked." By carrying on the same mode of reasoning to three terms, the total force would be $3+9+15=27$ grains, the mean of which is 9 grains, thus making the force "masked" to be two-thirds of that of which the first quantity is susceptible, instead of only one-half.

58. It is unnecessary to attempt to reconcile the law of force with the axiom; in chemistry the axiom undoubtedly teaches us, that if one unit of quantity of an acid can saturate a certain quantity of an alkali, two units of quantity of the same acid will be exactly needed to saturate a double quantity of the same alkali. In mechanics the axiom unquestionably teaches, that if a given weight suffice to counterbalance a certain amount of resistance, the latter must be twice as great when it is exactly counterbalanced by two similar weights. And we must believe that the axiom is a truth, in every case of reasoning about effect and causation, where nothing but material things are implicated. But we see no necessity for the applicability of the axiom to physical effects, provided they be immediately caused by the fiat of an immaterial will; if matter have been created and put in order by a supreme intelligence, the material must have been impinged upon by the immaterial at the end of the chain of physical causes, and we can assign no place for the end of the material chain so probable as that where the

atoms of matter are endowed with their respective natures. This would make force immaterial; force and the Divine will respecting matter being one and the same thing; and is it easier to conceive that the Creator and Preserver of the Universe has willed into existence certain physical forces, with which he has enabled atoms to work out an appointed purpose independently of his supervision and direction, than to believe that he acts upon matter without such intervention and at every instant of time by his own enduring and unchanging will? As the case stands at present, the latter is to me the less difficult assumption of the two; but happily for this theory, there are abundant facts to prove that it is the only way of explaining all we really know of the subject.

59. Accepting then the law of the squares of the quantities which we obtain as an induction from facts, to be a law of force, and not merely of phænomena deranged by some inconceivable influence, it has a consequence which is very remarkable, for *it makes an atom of electricity to act through a given distance with variable amounts of force.* Because as the force varies with the squares of the quantities, any given electrical atom must double, treble or quadruple its force, as it may be acting on common matter in concert with one, two, or three other electrical atoms respectively. This variation in the amount of force cannot be attributed to any variation in the relation of an atom of electricity to quantity of common matter, because it attracts the same definite quantity always, while its force of attraction advances from unity to two, three, four,

or more multiples. Of course we cannot ascribe the variation in force to a will and intellect inherent in electricity; and therefore it can only be referred to something external to it, and which has both power and intelligence, or in other words, to the will of the Creator.

60. There is another consequence of regarding the square of the quantity as a law of force, which also identifies the force with moral causation. Imagine the electricity belonging to a given basic atom to be divided into a number of equal parts; experience teaches that if the force of attraction between it and one of the parts, removed to a certain distance, be unity, the force which the basic atom exerts on two parts of its electricity, equally removed, will be 4; on three parts 9, and so on; so that if we suppose it to have only four parts, the total amount of the electrical force of the basic atom may be represented by 16. Now 16—1, for one part removed, makes the force of the basic atom on three remaining parts 15 instead of 9, or the square of 3; 16—4, for two parts removed, makes the force on two remaining parts 12 instead of 4, or the square of two; 16—9, for three parts removed, makes the force on the remaining part 7, instead of the square of 1. Notwithstanding, therefore, that the law of the squares of the quantities is observed practically to apply to the force which basic matter exerts for regaining its own electricity, the applicability of the law can be extended no further than that, but must be restricted to the action of a basic atom on those parts only of its own natural

quantity of electricity which have been removed to an abnormal distance from it.

61. If we compound the two laws of electrical force, namely, that which regards distance and that which relates to quantity, we obtain a third law which may be thus expressed: *The electrical force being constant, the distances and the quantities of electricity vary in a direct simple ratio.*

62. Let us now examine the support which facts give to this compound law of electrical force, and through it to the new elementary law of the squares of the quantities by aid of which it was obtained. We have seen it to be one of the consequences of this theory, that electrical attractions must occur at greater distances than electrical discharges (50.). By the compound law, the electrical force becomes constant at distances which vary in the simple ratio of the quantities of electricity; whereas if the electrical force at a constant distance varied in the simple ratio of the quantities, as the axiom asserts and has hitherto been tacitly assented to, then the electrical force should be constant at distances which vary in the ratio of the square roots of the quantities. It will be easy to find which of these very different ratios is consistent with observation.

63. " A discharging electrometer was so constructed that given distances might be obtained by means of a micrometer-screw. The instrument being affixed to a coated jar, the quantity of electricity requisite to cause a discharge at any given distance was estimated. Under these circumstances it is found that the quantities of electricity vary

exactly with the distances. Similar results ensue in accumulating different quantities on simple conductors, the distances through which a discharge occurs being directly as the quantity*."

64. "Two conductors being separated by a given distance, measured between the nearest points, one of them was withdrawn, so as not to influence the quantity which the opposite conductor could receive. When this last had been charged, then the other conductor was again restored, in an uninsulated state, to its previous position, and the precise distance at which the discharge took place observed by means of a micrometer-screw adjusted for the purpose. This distance being found, the same was repeated when the insulated conductor was charged with only one-half the previous quantity, and so on. In these experiments the distances of discharge varied directly with the respective quantities accumulated. This is not only applicable to discharges produced by different quantities disposed on the same conductor, but it is also true in disposing the same quantity on many conductors precisely similar, so as to double, treble, &c. the extent of similar surface: we have in all cases the distance of discharge, in the simple ratio of the quantity contained on an unit of similar surface. The distance, therefore, through which an electrical accumulation can discharge is an accurate measure of the comparative quantities contained in an unit of space †."

65. "On reviewing the phænomena connected

* Phil. Trans. 1834, p. 225. † Ibid. p. 226.

with the discharge of electricity between conductors, we may trace an interesting and consistent relation. If we call the force exerted between the two conductors at the instant of a discharge unity, and we now suppose them to be placed with the same accumulation at twice the previous distance, then, according to the general law (Coulomb's) of electrical attraction, the force will be reduced to one-fourth, since it varies in an inverse ratio of the squares of the respective distances, at three times the distance it would be one-ninth, and so on: hence the discharge could not occur at those distances with the same quantity. But since double, treble, &c. accumulations develope free quantities or intensities, which are as the squares of the whole quantity accumulated, we have with double, treble, &c. quantities accumulated, attractive forces which exactly compensate the decreased force due to the respective increases of distance; and hence at the instant of the discharge at double, treble, &c. distances, with double, treble, &c. accumulations, the force is precisely the same*."

66. During my experiments on electrical attraction in exhausted receivers, I took occasion to prove also that the withdrawal of the atmosphere did not affect the law of electrical discharges; under such circumstances, just as in the open air, when the distances are correctly taken by counting the revolutions of a fine screw, the quantities come out absolutely exact. In one experiment, when the distances were increased in arithmetical pro-

* Phil. Trans. 1834, p. 227.

gression by unity, the quantities of electricity necessary to effect a discharge were as 35, 70, 106, 140, and 175; and in another experiment as 12, 24, 36, 48, 60, and 71*. In these cases the quantities were estimated by the unit-jar, and passed in discharge between two large brass balls communicating respectively with the opposite coatings of a larger jar, exposing about two square feet of tinfoil. The balls were placed in the axis of a glass receiver about 4½ inches in diameter.

67. Dismissing, as before, the hypothesis which assumes some part of the force of the electrical accumulations to be masked, the foregoing experiments with electrical discharges all confirm the new law, namely, that the major electrical force varies in the ratio of the squares of the quantities. I have already had occasion to remark that I attach very little importance to isolated experiments, seeing how difficult it is to draw from a single complicated observation the true inference, and even having done so to convince others that they ought to adopt the same views as ourselves; but in the case we have been considering we have an inference made, not from one or two phænomena, but from a multitude of observations all implying the same thing, and thus rendering it almost incontestable. We cannot, perhaps, adduce a more palpable instance of the evil which is sure to result from a

* Beyond the above numbers they became inexact; the disturbance always commences when the distance of the discharge approximates to that between the discharging body and the glass receiver, the cause of which will hereafter be made intelligible.

satisfied state of mind with respect to our theoretical knowledge in matters of physical science, or, in other words, from the prejudices of education, and long habit of thinking, than is afforded by the attempt of the very able electrician, whose experiments I have quoted, to vindicate by an inadequate hypothesis a particular theoretical view against an attack made upon it by facts.

68. It may not be useless to show that the axiom in question, which at one time Sir W. S. Harris desired to protect from a seeming refutation, he afterward, in the same memoir, practically disavowed. In some experiments made on air of different densities, he ascertained that "the respective quantities of electricity requisite to pass a given interval varied in a simple ratio of the density of the air. When the density was only one-half as great, the discharge occurred with one-half the quantity. The distance through which a given accumulation could discharge, was found to be in an inverse simple ratio of the density of the air, the intensity or free action being constant. In air of one-half the density, the discharge occurred at twice the distance*." Now, as the pressure of the air varies in the simple ratio of its density, it would follow, if electrical discharges were resisted by atmospheric pressure, as was alleged in explanation, that these experiments deny the axiom; for as the quantities of electricity varied in the simple ratio of the densities of the air, as the forces varied in the ratio of the squares of the quantities of electricity,

* Phil. Trans. 1834, p. 229.

and as the resistances were equal to the forces, the resistances to discharge must have varied as the squares of the densities of the air. As in these cases the electrical discharge and its resistance are both physical in their nature, they are, of course, subject to the mechanical axiom ; and if subject to the axiom, then electrical discharges are not resisted by atmospheric pressure.

69. In some subsequent experiments the same author proved that atmospheric pressure did not restrain electrical discharges, by causing the pressure to vary, by communicating to a confined portion of air a range of temperature between 50 degrees and 300 degrees of Fahrenheit, the density and distance remaining always the same. Under such circumstances the discharge invariably occurred with the same quantity of electricity ; so that pressure evidently had nothing to do with the result*. Notwithstanding these facts, and in despite of the axiom, we find the doctrine announced, " that the resistance of the air to the passage of electricity is as the square of the density directly."

70. The facts which I have cited, and the inferences drawn from them, may now be placed in juxtaposition with certain other facts which have been generally observed; and we shall be able to obtain from them, if our analysis hitherto be correct, additional contributions towards the perfect knowledge of causation.

71. The minor electrical attraction, or force of gravitation, tends to bring all the electrical atoms

* Phil. Trans. 1834, p. 241.

which constitute the weight of a chemical molecule into contact with one another; and such a contact, as mathematicians have demonstrated, would, if established, be for ever indissoluble. Under such circumstances, the major electrical force would be incompetent to disturb the natural electrical equilibrium; for not only would the electrical atoms of each molecule be inseparably united to it, but they would also be as inseparably connected to one another. It follows, therefore, that each electrical atom must be enveloped in atoms of some other kind, which they attract, and which have no attraction for each other. Now, as caloric is always present in bodies, and as we have no facts to warrant a supposition that its atoms are idio-attractive, we may be allowed to assume that they exert no influence at all on one another, and that they are attracted by electrical atoms, forming around each of them a number of concentric spherical strata, of which the electric atom is the common centre.

72. As different simple molecules have unequal quantities of electricity naturally attached to them, and as all completely isolated or gaseous simple molecules have equal volumes, it is evident that, in the case of any particular simple molecule, the volume that it wants of electricity must be made up by the presence of some other kind of matter. In conformity to this indication, I assume that the sums of the volumes of electricity and caloric, in all simple gaseous molecules of equal volume, is a constant quantity.

73. As there is no limit to the volumes which

gases may assume, so I infer that the attraction of a basic atom for caloric is unlimited with respect to quantity.

74. All basic atoms attract caloric equally, because all gaseous molecules have equal volumes, which could not be unless the calorific force were in all cases a constant quantity at a given distance.

75. Such are some of the probable inferences which I conceive may be drawn from what we know of the phænomena of physical science; and they are sufficient to enable me to construct the elementary molecule of chemistry, which I shall next proceed to do; and I propose then to apply it synthetically in elucidation of some of the most important phænomena and laws of physics generally.

76. In concluding this analysis I have only to add, that if the theory which it has developed shall presently establish, by the success of its synthetical application, a claim to be considered as the most probable one in our possession, it must banish from our philosophy the idea of physical force; and force will be regarded in future as nothing less than an omnipotent will, ever active for the preservation of the universe, as in the beginning it was for its creation, and that without the intervention of any instrumentality, except mere space, which in reality is nothing. It would not become absolutely necessary to believe that the will of the Divinity acts from points in space, for the theory would be equally effective if it assumed atoms to be solid; but there is no advantage in assuming solid atoms, as they would virtually differ nothing in their

properties from spheres of space, ordained by the great Lawgiver never to intersect one another. Such spheres would be solids to all intents and purposes; and the latter is so much the more simple and the more acceptable idea of the two, because it enables us to conceive how the Creator may have called the whole corpuscular system out of nothing, it being, if considered independently of Him, nothing still, His will being everything. Physical phænomena, in common with the immaterial ideas of which the knowledge and affections of our minds consist, would then be understood to result immediately from the same moral cause; acting in the one case from centres of spheres of space for the establishing and upholding of material worlds, and impinging in the other case upon immaterial minds, which it has pleased Him to endow with capacities for contemplating and admiring His power and purposes.

PRINCIPLES AND SYNTHETICAL APPLICATION OF THE THEORY INFERRED FROM THE PRECEDING ANALYSIS.

THE principles which result from the preceding analysis of physical facts, and to which the experimental evidences of its general accuracy are to conform, may be thus stated :—

1st. A molecule of matter is composed of atoms. These atoms are distinguishable into three kinds, because they differ in their action on one another, and consequently in the positions which they relatively assume. We call the three kinds of atoms Basic, Electrical, and Calorific.

2nd. Basic atoms do not act upon each other ; they all attract calorific atoms with equal force, and in unlimited numbers ; each basic atom attracts a number of electrical atoms which is definite and peculiar to itself ; and it is in this circumstance alone that basic atoms differ in their natures.

3rd. All electrical atoms attract one another equally.

4th. Calorific atoms do not act upon one another.

5th. Electrical atoms attract calorific atoms in numbers which are unlimited.

6th. Force acts at all distances. The forces of the different classes of atoms are such as to assemble the electrical atoms of a molecule around its basic atom in successive concentric spherical strata, the external stratum being sometimes incomplete ; to collect calorific atoms around each electrical atom in numbers varying with the freedom of their supply; and sometimes, when the numbers of calorific atoms are very great, to form them into a sphere of comparatively large volume outside the sphere of electrical atoms, with the basic atom of the molecule as a common centre to the whole.

7th. The idio-electrical force is a feeble one; it varies as the quantities directly, and as the squares of the distances inversely. The force with which basic and electrical atoms attract one another is comparatively great; it varies as the squares of the distances inversely, and directly as the squares of the quantities of electricity removed to an abnormal distance from their basic matter. The calorific force is intermediate to the two electrical forces, and varies in some inverse ratio of the distance.

To facilitate the references we shall have frequently to make to the molecule provided by the above principles, I propose to call the whole volume of the molecule its *calorisphere*; and the unchangeable quantity of electricity attracted by its common centre of force, its *electrical equivalent*. The latter I subdivide by calling the sphere comprised within the outer surface of the most external PERFECT STRATUM of its electrical atoms, including the calorific atoms around and at the time belonging to each of them, its *electrosphere*; and the electrical atoms on the surface of the external stratum of the electrosphere, the *complementary* electrical atoms of the molecule.

The diagram, fig. 5, may serve to illustrate the construction of an isolated or gaseous molecule, the volume comprised within the outer boundary line denoting its calorisphere; the sum of the volumes of the parts coloured blue its electrical equivalent; the larger blue circle its electrosphere, and the smaller blue circle a complementary electrical atom, of which there may be any number not great enough to occupy the whole surface of the electrosphere.

Section I. *Gravitation and Chemistry.*

Proposition 1.—Two molecules of matter tend towards one another with a force which varies as the inverse squares of the distances.

The two electrical equivalents of the molecules tend to approach one another with a force which varies in that ratio (Prin. 7), and the electrical equivalents are united to the basic atoms by the major electrical force, and to the calorific atoms by their particular force; as each of these two forces is superior to the minor electrical force, they cannot, even when acting at an equal distance, be overcome by it; and therefore the tendency of the electrical equivalents is participated in by all the parts of the two molecules.

Prop. 2.—Dissimilar molecules of matter tend towards one another at given distances with unequal forces.

Molecules are dissimilar only because their electrical equivalents possess unequal numbers of electrical atoms (Prin. 2); and the tendencies of masses of electrical atoms at given distances to approach

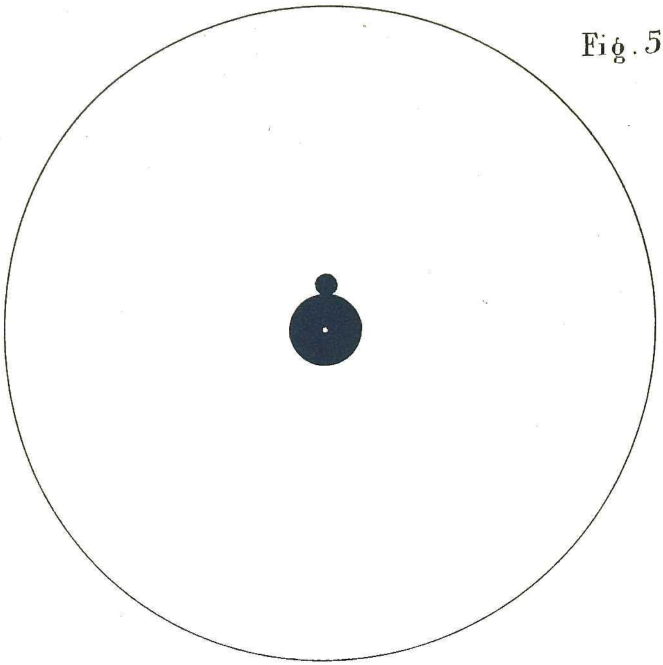


Fig. 5.

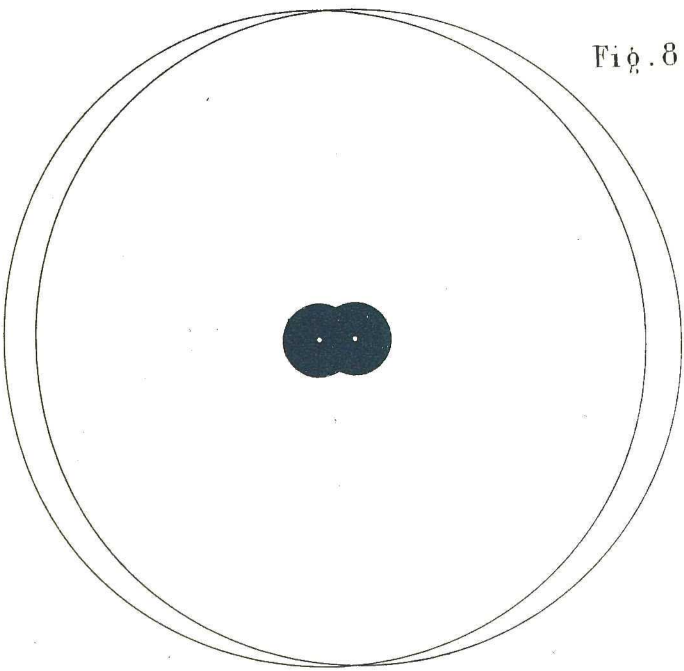


Fig. 8.

one another, vary in the ratio of the numbers of electrical atoms in the respective masses. (Prin. 3.)

Prop. 3.—Any two molecules without complementary atoms on the surfaces of their electrospheres cohere together, if calorific atoms be not freely supplied to them.

Their electrospheres in such a case are in contact (Prin. 6), and the minor electrical force acts at a short distance, and therefore with comparatively great effect.

Prop. 4.—A mass of molecules, like those of the last proposition, are not perfectly free to move over each other's electrospheres.

The electrospheres are bounded by surfaces composed of comparatively minute hemispheres, each hemisphere being the outer surface of an atom ; and therefore the distances from the central basic atom to all parts of the surface of its electrosphere are not equal. The electrospheres tend towards each other by virtue of the minor electrical attraction, which acts at a shorter distance, and therefore with a greater force, as the common centres are less separated ; consequently the convexities on the surface of one electrosphere enter into the concavities on the surfaces of those contiguous to it, and cannot be dislodged except by causing the minor electrical force to act at an increased distance. This elongation of distance impedes the inter-molecular motion.

Scholium.—If the surfaces of the electrospheres were uniform, and the electrospheres were made to revolve about their axes, the inertia of matter would make the motion perpetual.

PROP. 5.—Two equal electrospheres, each with a complementary atom on its surface, will cohere with a comparatively great force, if placed in mutual contact.

The two complementary atoms, under the influence of both the electrical forces, will arrange themselves in a line perpendicular to the common axis of the two molecules; for the major electrical force will tend to place the whole electrical equivalent of each molecule at the least possible distance from its particular basic atom, while the minor electrical force brings the two complementary atoms to the least possible distance from one another. When in the position assigned to them, the complementary atoms will be in contact, and an hemisphere of each will virtually belong to either basic atom, because the radius of a sphere is shorter than its diameter (fig. 6).

PROP. 6.—A mass of molecules, like those of the last proposition, are less free to move over each other's electrospheres than those of Propositions 3 and 4.

In the former case, the impeding pressure of the uneven surfaces of the electrospheres against each other was due chiefly to the minor electrical force; in the present instance the pressure is augmented by a certain addition of major electrical force.

SCHOLIUM.—Props. 3 and 4 represent the case of extreme tenuity in a fluid; Props. 5 and 6 show the commencement of viscidity, leading to plasticity and eventually to solidity, under all its forms of hard, soft, elastic, brittle, and the like. Variety in number of the complementary atoms, with the positions they may assume on the surface of an electrosphere, when surrounded on all sides by other electrospheres of equal or unequal radii, and with like or unlike numbers of complementary atoms, provide for crystallization and for a polarity in molecules to which the facts of magnetism may be attributable.

Prop. 6 *bis*.—Complementary electricity may be put in motion in a mass of molecules by virtue of the minor electrical force.

Let *a b c d e f*, fig. 7, be one of the lines of molecules of which a mass is composed, and let each of them have a single complementary atom on the surface of its electrosphere; while we suppose the line isolated from all external physical influences, the positions of the complementary atoms may be as shown, that is, every two contiguous molecules will have a complementary atom between them, and one pair will have between them two complementary atoms, because these positions make the sum of all their distances from the common centre of gravity the least possible. Things being in this state, let a mass of molecules A approach the extremity *f* of the line; the complementary atom between *e* and *f*, that between *d* and *e*, and one of those between *c* and *d*, may thus be caused to make a semicircular movement, each passing to the other side of its particular electrosphere, and one of them locating itself between *f* and A. These movements of the complementary atoms towards an external mass of molecules will take place whenever the exterior force of gravitation becomes superior to that extended from the middle point of the line, namely, between *c* and *d*, because they can occur without making the major electrical force to act at an increased distance. If we now place molecules in a sufficiently larger mass than A at the end of the line *a*, all the complementary atoms will make half a revolution about their respective centres of major force, and one of them appear on the outer side of *a*.

Prop. 7.—When atoms of caloric are freely supplied to a molecule, the number of its complementary atoms becomes changed; it will acquire them if it had none, and on the other hand it may lose those it has.

The numbers of electrical atoms in the several concentric strata of the electrosphere increase outwards in a slower ratio than their areas, because the major electrical force tends to condense electrical atoms, and by so doing to displace atoms of caloric with greater effect in the strata which are at the least distances from the common centre. When, therefore, the existing equilibrium is deranged by an addition of calorific atoms, these will not distribute themselves equally among all the electrical atoms; the number of electrical atoms necessary to fill the respective strata will be different at different times, and consequently the number of complementary atoms may become anything or nothing.

Cor.—By withdrawing caloric from a molecule, the number of its complementary atoms becomes changed.

Definition.—Degree of temperature varies inversely as the degree of force with which a molecule retains possession of the calorific atoms most distant from its centre.

Prop. 8.—At the moment when, by an accession or loss of caloric, molecules lose their complementary atoms, there will occur a sudden absorption of calorific atoms by the mass, and a sudden increase in volume without a corresponding elevation of temperature.

While two molecules remain connected together by means of complementary atoms, placed between them, and in a line or plane perpendicular to the common axis of the two molecules, the cohesion caused by the major force (Prop. 5) resists the ingress of caloric, which would cause that force to act at a greater distance. On the cessation of that resistance, which occurs suddenly when the complementary atoms of each molecule become numerous enough to fill up a spherical stratum of their own, the calorific force becomes suddenly subject to a diminished amount of antagonism, and can therefore act at a greater distance and still be in equilibrium. To give this greater distance, the molecule must have a greater volume; and that is conferred by the entrance of calorific atoms around and between the separated electrospheres.

Cor.—At equal temperatures the same kind of molecules may have unequal volumes.

Def.—The caloric absorbed by molecules without increase of temperature, and in consequence of the cessation of their mutual cohesion by virtue of the major electrical force, may be called the *latent heat* of their gaseous condition.

Definition.—A gas is an assemblage of molecules not united together by the major electrical force of complementary atoms, but whose electrospheres have been separated from one another by absorbing latent heat perhaps at the moment when all the parts of their electrical equivalents became comprehended in their electrospheres respectively.

Prop. 9.—The volumes of all gaseous molecules are equal when their temperatures are so.

Because when the temperatures are equal the radii of the calorispheres are equal, and the volumes of the calorispheres vary with their radii.

Cor.—All gaseous molecules of equal volumes retain atoms of caloric on the surfaces of their calorispheres with equal forces.

Prop. 10.—In acquiring a given increase in temperature, all gaseous molecules absorb equal quantities of caloric.

When the temperatures increase equally, the radii of the calorispheres increase equally also, and the areas of all the calorispheres bear the same relation to the lengths of their radii.

Def.—The quantities of caloric which molecules can combine with in assuming a given increase in temperature may be called their *specific heats.*

Cor.—The specific heats of all gaseous molecules are equal, and increase with their temperatures or volumes.

Prop. 11.—When a mass of gaseous molecules is subjected to an increase of compression, it gives off caloric without undergoing reduction of temperature, that is to say, its temperature increases.

Compression causes the basic atoms of a mass of gaseous molecules to approach closer to one another, it therefore increases their distance from some of the calorific atoms. All the calorific atoms whose distance is increased may be withdrawn, and still the calorific force act at precisely the same distance as before the increase of compression.

Cor.—If caloric be removed from a mass of gaseous molecules, the mass undergoes reduction in volume without being subjected to increased compression.

Prop. 12.—Reducing the pressure on a mass of gaseous molecules diminishes its temperature.

The calorific force when in equilibrium in a mass of gaseous molecules, is in antagonism with the minor electrical force and the compressing force. By diminishing the latter, the calorific force is made to predominate, and consequently the molecules are capable of combining with caloric at a greater distance, that is, they have a diminished temperature.

Prop. 13.—Two or more gases may enter into a single volume, nearly.

The number of calorific atoms combined with basic atoms, and also with electrical atoms, owing to the indefinite nature of the calorific force with respect to quantity (Prins. 2 and 5), is only determined by the distances within which the several sorts of atoms may be presented to one another. Hence if two basic atoms could occupy exactly the same place, and their electrospheres also, they would have around them only one calorisphere instead of two of equal radii, as in their separate condition. The same reasoning applies also to the caloric surrounding each electrical atom of the electrospheres. But no two atoms can occupy the same place; and the major electrical force, being superior to all the other forces, prevents the basic atoms from ever approaching each other nearer than is represented by the radius of their electrospheres, because before they can approach nearer to one another, some of their electrical atoms must temporarily place themselves at an increased distance from their respective centres of force, which is prevented by the law of distance. But the electrospheres may intersect one another (fig. 8) so far as to place the contiguous basic atoms on their surfaces, provided the electrical atoms are left far enough apart, by emitting caloric, to enter among one another. In this position the basic atoms will be nearly contiguous, and the volumes of the two comparatively large calorispheres reduced nearly to a single volume common to them both.

Scholium.—The resulting volume will approach nearer to a sub-multiple, as each molecule of the gas has a greater calorisphere; and that the calorispheres of gases are always great, compared to the volumes of molecules in a fluid or solid state, is made evident by the great increase in volume which solid and fluid bodies acquire in passing to the gaseous condition.

Prop. 14.—All molecules in contact tend to equalize their temperatures.

Whether the mixed molecules be in the solid, fluid, or gaseous state, or in all of those conditions, their atoms of caloric seek to distribute themselves in such a way that all the forces may be in equilibrium; and when the calorific force in each molecule is in equilibrium with all the other forces which antagonise with it, the temperatures of all the molecules are equal.

Prop. 15.—Two electrospheres of unequal sizes, each with a complementary atom on its surface, and placed in mutual contact, combine together by virtue partly of the major electrical force of either basic atom on part of an electrical atom normally belonging to the other basic atom.

This has been proved with respect to two electrospheres of equal sizes in Proposition 5, and the same demonstration applies equally to electrospheres of unequal radii (fig. 3).

Def.—When molecules, united together by complementary atoms, have unequal radii, the union by the major electrical force may be called *chemical affinity*.

Prop. 16.—Things being as in the last proposition, let the number of complementary atoms belonging to each electrosphere be equally increased, the force of the resulting chemical affinity will be as the squares of the numbers of complementary atoms.

The complementary atoms will arrange themselves in a plane, at right angles to the common axis of the two electrospheres (Props. 5 and 15). In this position, one hemisphere of each of the complementary atoms will be attracted towards the basic atom on either side, with a force which varies as the squares of the quantities (Prin. 7) of electricity, that is, as the squares of the numbers of complementary atoms.

Prop. 17.—Any given electrospheres with complementary atoms may combine with other unequal electrospheres, also with complementary atoms, with either a great or a small amount of affinity.

The force of affinity varies as the squares of the quantities of electricity belonging to one basic atom, and attracted by another basic atom, varies; and these quantities vary as the complementary atoms of one basic atom attracted by the other are more numerous, and as the fractional parts of each complementary atom are greater. Now the fractional parts of a complementary atom attracted in the opposite directions may be very unequal, because the two electrospheres may have very unequal numbers of complementary atoms belonging to them. And the numbers of complementary atoms on either electrosphere may be such as exactly to fill in the vacant places provided for them on the contiguous electrosphere; or they may be too few in number to do so, or too numerous to find places on it.

Prop. 18.—Affinity changes with temperature.

Affinity changes with the number of complementary atoms on the surfaces of contiguous electrospheres (Prop. 17); and the number of complementary atoms on the surfaces of the electrospheres changes with temperature (Prop. 7).

SECTION II. *Electrical Excitation.*

PROP. 19—Things being as in Proposition 15, let the two unequal electrospheres be separated, the basic atom of the lesser electrosphere will thereby be made plus electrical, and that of the larger electrosphere minus.

During the contact of the unequal electrospheres, the two complementary electrical atoms are attracted in both directions, one hemisphere of each virtually belonging to either basic atom. But the amount of major electrical attraction is not the same in the two directions; both the complementary atoms, by virtue of the law of the inverse square of the distance, tending more forcibly towards the basic atom in the centre of the smaller electrosphere. By reason of this greater tendency, and because atoms are indivisible, the whole of the complementary electricity belonging to the two electrospheres will be found on the surface of the lesser one, on its separation from the other (fig. 4). The basic atom of inferior electrical equivalent will thus have become plus electrical by attaching to itself an atom of electricity more than it attracts; while the basic atom of superior electrical equivalent will have become minus to exactly the same amount, by attracting an electrical atom more than it actually possesses.

PROP. 20.—If we repeat the last proposition, with this only difference, namely, that each electrosphere has two complementary atoms on its surface instead of a single one, the force of the resulting plus and minus charges will be four times as great.

The quantities of the charges, respectively, will be twice as great as in the last proposition; and the forces are as the squares of the quantities (Prin. 7).

Cor.—Two lines or planes of unequal electrospheres, each with the same number of complementary atoms on its surface, will be made, by mutual contact and subsequent separation, oppositely electrical; the lighter molecules will have the plus charge, and the heavier molecules will be minus.

Prop. 21.—The force necessary to remove one and the same atom of electricity from the surface of a given electrosphere is not a constant quantity.

A particular complementary atom may be removed alone, or at the same time with one, two, or more others; as the major electrical attraction varies as the squares of the quantities of electricity, the first complementary atom will be retained by its basic atom, under the different circumstances, with a force which varies as the numbers 1, 2, 3, and so on.

Prop. 22.—The complementary electrical atoms are the only parts of an electrical equivalent susceptible of being removed from its basic atom by any other basic atom possessed of its equivalent.

Because as all the electrical atoms which are not complementary form parts of perfect spherical strata, the basic atom to which they belong is nearer to the whole of each of them, than it can be to any part of any foreign electrical atom.

Prop. 23.—The numbers of complementary atoms belonging to two unequal electrospheres, respectively, may be such as to cause that of longer radius to become plus and the other of shorter radius minus, by separation after mutual contact.

Let there be ten complementary atoms arranged in a plane between and perpendicular to the common axis of two electrospheres of unequal radii; one of the ten appertaining to the basic atom of the smaller electrosphere, and the other nine to the basic atom of the larger electrosphere. All the ten complementary atoms will be attracted in both directions; one-tenth part of each by the basic centre of force at the lesser distance, and nine-tenths of each by the basic centre at the greater distance. On applying to these unequal fractional parts the law of the squares of the quantities, we obtain numbers which just neutralize the effect of the major force acting from the lesser electrosphere, though its radius were only one-ninth part as long as that of its associate.

Section III. *Electrical Intensity and Discharge.*

Definition.—Complementary atoms, or their fractional parts, existing at an abnormal distance from the basic atoms of whose electrical equivalents they at the time make part, may be called the *accessory electricity* of the basic atoms to whose electropheres they are attached, and to which they constitute a plus charge.

PROP. 24.—The intensity of the major force of accessory electricity is constant when its quantity and the distance at which it acts vary in the same ratio.

We obtain this result by compounding the law of the inverse square of the distance with that of the square of the quantity, directly.

PROP. 25.—If accessory electricity be removed to an infinitely great distance from its own basic atoms, its tendency to leave the electrosphere to which it is attached as a plus charge will be infinitely small.

Because it tends to leave by virtue only of the major electrical force, which varies inversely as the square of the distance at which it acts.

SCHOLIUM.—The force by which accessory electricity may be acquired by a basic atom, is competent to retain it on the surface of its electrosphere, whether the distance of its own basic be great or small (fig. 4); but facts teach us that electricity accumulated in a body charged plus may become discharged into another which is minus, even although the two bodies have become oppositely electrical by separation after mutual contact. This paradox is to be explained by aid of the law which makes the major electrical force to vary as the squares of the quantities of electricity.

PROP. 26.—When two lines of unequal electrospheres, each having a complementary atom on its surface, are separated, after mutual contact throughout their entire length, and then placed with only their extremities in contact, electricity will pass from the plus line of electrospheres to that which is minus.

Let m m' m'', fig. 9, be three larger electrospheres in contact with three smaller ones, p p' p''; each of the six having one complementary atom belonging to it. Two complementary atoms will take up their positions between each pair of electrospheres, as in Prop. 15 and fig. 3. On separating the two lines of unequal electrospheres and placing one end of each in mutual contact (fig. 10), all the three accessory atoms of the line p p' p'' will first take up their positions with the complementary atom of p'', at the shortest possible distance from the minus line m m' m'', which is between p'' and m. When there each of these four complementary atoms will be attracted in both directions, one-fourth part of each towards p'' and three-fourths of each towards m; the effective discharging force on the first accessory atom to be discharged will be $3^2-1^2=8$. When three complementary atoms remain between p'' and m, one-third part of each will tend towards the former and two-thirds of each towards m; and the discharging force on the second accessory atom to be discharged will be $2^2-1^2=3$. When only two complementary atoms are left between p'' and m, one hemisphere of each of them will be attracted in both directions, and give rise to the state of things shown in fig. 4, Prop. 19, in the proximate ends of the two lines on their being again separated.

Cor. 1.—When each basic atom in two planes of unequal electrospheres, all with the same number of complementary atoms, is made electrical by separation after mutual contact of the dissimilar planes, they may be nearly discharged by bringing their perimeters or angular projections into mutual contact.

Cor. 2.—The intensity with which a given quantity of accessory electricity will be discharged into minus basic atoms varies inversely as the squares of their numbers.

Cor. 3.—When the number of the minus basic atoms is constant, the intensity of the discharging force varies as the squares of the quantity of accessory electricity.

Section IV. *Electrical Conduction and Insulation.*

Prop. 27.—If a line of electrospheres, each with one complementary atom, or more, on its surface, be interposed between two bodies in opposite electrical states, one of those bodies will discharge electricity into the other.

Let the line consist of electrospheres each with three complementary atoms on its surface (fig. 11), and let one of its ends be placed in contact with the body which is plus electrical. So many of the accessory atoms of the plus body as can find places on the surface of the electrosphere at the near end of the line will place themselves on it, because when there a part of each is at a less distance from the central basic atom of that particular electrosphere than is a certain part of each of its own three complementary atoms. For the same cause electrical atoms will pass from the surface of the first electrosphere on to that of the second in the line; from that to a third, and thus forward from one to the next in succession all along the line. Now let us imagine, that, instead of placing the line of electrospheres with its end in contact with the plus body, we have placed it against the body which is minus, this last will appropriate to itself the three complementary atoms of the electrosphere contiguous to it, to aid in making up its electrical equivalent, because this first electrosphere has three other complementary atoms at no greater distance from its own centre, though normally belonging to the next basic atom. This second basic atom is enabled to attract three complementary atoms on the surface of the third electrosphere, and consequently at no greater distance than those it has resigned; the third electrosphere in like manner appropriates to itself the complementary atoms of the fourth; the fourth of a fifth, and so onward continually to the plus end of the line, without at any time requiring the major electrical force to act at an increased distance. Lastly, let both ends of the line of electrospheres be simultaneously placed in contact with the plus and minus bodies respectively; the action which has been described will be set up at both the ends and be communicated in opposite directions along the line until all the accessory electricity of the plus body has become discharged into that which was minus.

Scholium.—Notwithstanding the discharge may be represented as perfect, the conditions of the bodies which were plus and minus respectively may not be normal; for the contact of the conducting line of electrospheres with them will establish a result analogous to that in Proposition 26, fig. 10.

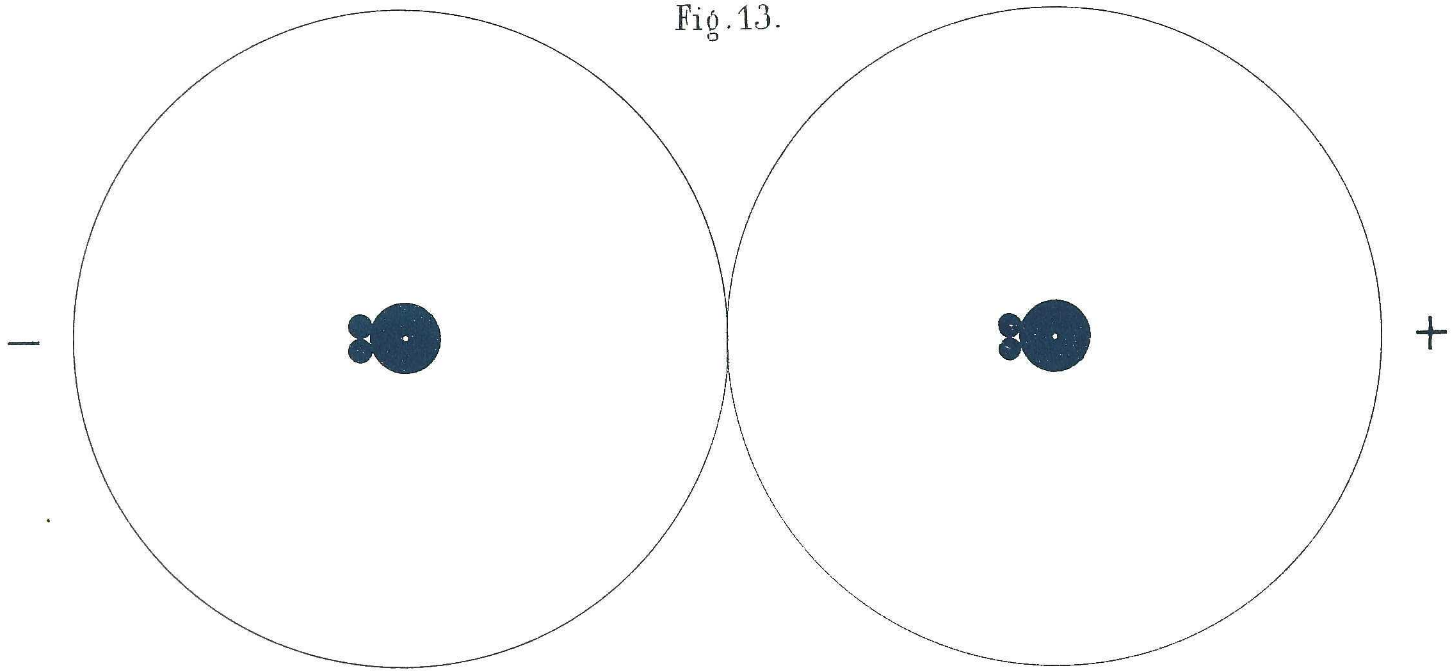
PROP. 28.—A line of molecules whose electrospheres have no complementary atoms on their surfaces may be interposed between and in contact with two oppositely charged bodies, without transmitting accessory electricity from the plus body to the minus one.

All the electrospheres in such a line have unbroken surfaces, and consequently neither of them can receive any foreign electrical atom, as near to its own basic atom, as are the most distant of its own electrical atoms. The accessory electricity of the plus body will therefore remain totally unattracted by the major force of the basic atoms of the interposed line; while, on the other hand, it is being retained by a certain amount of major electrical force by the basic atoms to which they are attached as a plus charge (fig. 12).

PROP. 29.—Two conducting lines of molecules by parallel union may become an electrical insulator.

Two lines of unequal electrospheres, each with complementary atoms, may combine by chemical affinity into a line of compound molecules (Prop. 15); and the complementary atoms on each pair of electrospheres may be in number just enough, when the electrospheres are in mutual contact, to leave no vacant places on their surfaces. Under such circumstances each pair of electrospheres, or each compound molecule, would be in the same

Fig. 13.



position with regard to the major electrical force as those in the last proposition.

Prop. 30.—Conducting and insulating lines of electrospheres may reciprocally change one into the other with change of temperature.

Electrical conduction depends on the presence of complementary atoms on a line of electrospheres (Prop. 27); electrical insulation depends on their absence (Prop. 28); and by Proposition 7 and Cor. complementary atoms appear and disappear on the surfaces of electrospheres with changes in temperature.

Prop. 31.—When electrospheres with complementary atoms are in a line, and each is surrounded by a calorisphere of comparatively large radius, the line of electrospheres will be incapable of conducting accessory electricity from a plus body to another which is minus.

In consequence of the separation of contiguous electrospheres by intervening atoms of caloric, no complementary atom is equidistant from two basic atoms; and therefore no complementary atom can pass from its own to a neighbouring electrosphere without increasing its distance from the centre of major electrical force by which it is attracted (fig. 13).

Section V. *Electrical Induction.*

Definition.—As every basic atom has a particular electrical equivalent naturally assigned to it, and as it can attract neither more nor less electricity than is contained in that equivalent, it follows that no instance can occur of any one basic atom becoming plus electrical without a minus charge to the same amount as to quantity being simultaneously established in some other basic atom or atoms; and as the electrical force extends its action to all distances, it is evident that each basic atom will attract its exact equivalent of electricity wherever that equivalent or any of its parts may be located. Again, as the major electrical force acts more powerfully at lesser distances, each particular electrical atom will act upon that basic atom which is nearest to it; if that basic atom be minus, the electrical atom will become part of its electrical equivalent; if, on the contrary, the basic atom have the whole of its electrical equivalent at the normal distances around it, the electrical atom will nevertheless be virtually a part of its equivalent, causing one of the electrical atoms at the normal distance virtually to belong to some other basic atom the nearest to it, and so on *ad infinitum*. Now it is this action of isolated electricity on basic matter, already provided with its equivalent of electricity at a less distance, and the consequent virtual disengagement of a corresponding quantity of that electrical equivalent, that we call *Electrical Induction.*

Prop. 32.—When a basic atom, possessed or not of complementary electrical atoms and in its natural state of equilibrium, is nearer than any other basic atom to a plus charge consisting of a single accessory atom of electricity, it will, however great its distance, sustain an inductive action, and virtually set free one electrical atom of its own equivalent.

Because the accessory electrical atom must attract the basic atom at the least distance from it.

Cor. 1.—A basic atom made plus by induction possesses a certain quantity of electricity which acts by induction on foreign basic matter the most contiguous to it.

Cor. 2.—Complementary atoms on the surfaces of electrospheres, arranged in contact in a line, may transmit inductive action throughout the whole line, however great its length, by each complementary atom travelling through a distance no greater than half the circumference of an electrosphere.

Cor. 3.—Electrical atoms within the surfaces of electrospheres, and constituting parts of the equivalents of insulating molecules, arranged in contact in a line, are competent to transmit electrical induction to any distance, without an electrical atom changing its place.

Scholium.—The last Cor. has an appearance of asserting the efficiency of electrical non-conductors to transmit induction to an indefinite distance under ordinary circumstances; but it does not really assert this, because, as we shall presently understand, the line becomes lost in a surrounding medium of *like nature*.

Prop. 33.—If electricity, supposed to occupy a point in space, be surrounded by an infinite number of non-conducting molecules arranged in successive spherical strata of equal thickness and concentric to the electricity, the inductive action of the common centre will virtually dismiss from each of the strata an equal quantity of electricity.

Because the central electricity will find its equivalent of basic matter in the innermost stratum of insulating molecules, from which it will virtually set free a quantity of electricity equal to itself; the latter attracting its basic matter in the second stratum will liberate from it precisely the same quantity of electricity, to act in like manner on another stratum; and thus from stratum to stratum the inductive action will be extended to an infinite distance.

PROP. 34.—Electrical induction radiating from a centre, as in the last proposition, rapidly reduces electrical intensity.

The induction is distributed among all the basic atoms of the several spherical strata. As the numbers of the basic atoms in the respective strata vary as the squares of their distances from the common centre, so the quantities of electricity, acting on each basic atom, varies inversely in the same ratio; and as the major electrical force acts in all the cases at the same uniform distance, and varies as the squares of the quantities of electricity, so the inductive force on each basic atom varies inversely as the fourth power of its distance from the centre from which it emanates.

Def. — The loss of intensity of an electrical charge, which is ultimately made perfect by the combined influence of the law of the squares of the quantity of the major electrical force, and of the progressively increasing area of a surrounding insulating medium, may be called *artificial electrical equilibrium.*

Prop. 35.—Things being as in the last proposition, let any one of the concentric spherical strata of insulating molecules be withdrawn, and a similar stratum of conducting molecules be substituted in its place; on uninsulating that conducting stratum, the inductive action will cease to be extended beyond it.

The complementary atoms of the conducting molecules being dismissed from their basic atoms by the inductive action of the stratum next within it, will pass on to the earth's surface, where they can establish the artificial equilibrium at a minimum of distance.

Def.—In the preceding state of things, although every stratum of insulating molecules between the outer conducting stratum and the common centre will be sustaining an inductive action, it will be in possession of exactly its natural quantity of electricity: and the minus charge of the conducting stratum will be equal to, and therefore may be said to compensate, the plus electricity from which the induction which it sustains originally emanated. Conductors performing the office of such a conducting stratum may be called *electrical compensators.*

Section VI. *Electrical Charging Capacity.*

Def.—The relative quantities of electricity which bodies can combine with as a plus charge under a given intensity, may be said to denote their relative *charging capacities.* As the major electrical force acts, at a given distance, with an intensity which varies as the squares of the quantities of electricity, the electrical charging capacities of charged bodies vary inversely as the squares of their intensities.

Def.—Conducting molecules *attract* no more electricity than makes up the sum of their respective equivalents; they can, however, combine with additional quantities by virtue of their particular conformation. The susceptibility of conductors to receive accessory electricity may be called the *disposing cause of the electrical charging capacity.*

Def.—Accessory electricity cannot be retained in connection with conductors when the major electrical force acts with more intensity in an opposite direction (Prop. 26), any cause which reduces the discharging force below that with which a particular plus charge is being retained becomes therefore a source of charging capacity. As the artificial equilibrium diminishes the intensity of electrical charges, it may therefore be considered the *immediate cause of the electrical charging capacity.*

Prop. 36.—All the molecules of a simple conducting body, whatever their relative positions in the mass, are equally disposed to receive an electrical charge.

All the molecules of a simple conductor have like electrical equivalents, and therefore equal numbers of complementary electrical atoms; and equal numbers of complementary atoms on the surfaces of electrospheres of equal areas, equally dispose to the charging capacity.

Prop. 37.—The charging capacities, caused in conductors by the artificial equilibrium, are peculiar to the surfaces of the bodies.

The artificial equilibrium is more perfect, as the insulating medium in which it is established is nearer to the plus charge whose intensity it is reducing, and the surface of a conductor is nearer to the insulating medium than any of its other parts.

Prop. 38.—Of all surfaces, that of a mechanical point, or sphere of the smallest magnitude, has the largest charging capacity conferred upon it by the artificial equilibrium, for each unit of surface.

The artificial equilibrium confers charging capacity by spreading the inductive action over successive areas which incessantly increase, the charging capacity being greater as the increase of area is more rapid; and the rapidity is a maximum in the case of successive concentric spherical strata setting out from a point.

Def.—As a point has a maximum of electrical charging capacity, conferred by the artificial equilibrium, in proportion to its surface, the particular ratio with which areas around a point increase with the distance, will serve to denote an *unit of charging capacity*.

Prop. 39.—Upon a given conducting surface, of any form, erect an inverted pyramid, the area of whose base is equal to the square of its height; and then add as many such pyramids, with their apices resting on the conductor, as it admits of, the perimeter of the bases being in contact, but not intersecting one another. The quantity of electricity for which a charging capacity can be conferred upon that particular surface, by the artificial equilibrium, will be represented by the number of pyramids; and the intensity of the charge will increase with their height.

The inverse square of the distance is the ratio in which the areas of concentric spheres increase; and the distance to which the inductive action of the major electrical force extends is greater with the higher intensities.

Prop. 40.—The intensity of the electrical charges being constant, the charging capacities, bestowed by the artificial equilibrium on conductors of different forms, vary as the areas of larger similar forms, inclosing them at a particular distance.

The intensity being given, the height of the inverted pyramids which represent units of capacity is given also, and with the heights the areas of their bases; and the sum of those areas is just equal to the whole of the inclosing surface, measured at that particular distance from the conductors, which is equal to the height of the inverted pyramids.

Prop. 41.—When a plus-charge exists in a series of conducting spheres of unequal sizes, surrounded by an insulating medium, and communicating with one another, all the intensities will be equal; and the quantities of accessory electricity in the several spheres will increase in a slower ratio than their surfaces.

The intensities are equal, or they would not be in equilibrium; the areas of the respective insulating spherical envelopes, measured at a given distance from the charged spheres which they inclose (Prop. 40), increase in a slower ratio than the areas of the spheres themselves ; and the charging capacities which the envelopes confer are in the direct ratio of their areas.

Prop. 42.—A conducting sphere and a conducting circular plate of twice its diameter, consequently of twice its external surface, put into conducting communication with one another, and immersed in an insulating medium, will equally divide an electrical charge between them.

Let the diameter of the sphere be unity, and take the areas of the insulating envelopes (Prop. 40) at ten units of distance; the charging capacity conferred on it by the artificial equilibrium will be $10+10+1=21^2\times 3{\cdot}141$; and for the charging capacity of the plate we have

$$\frac{(10+10+2)+(10+10)}{2}=21^2\times 3{\cdot}141.$$

Prop. 43.—Conducting plane surfaces derive from the artificial equilibrium only a very low charging capacity.

Place upon a plane surface the full number of inverted pyramids (Prop. 39) that it can contain, without their bases intersecting one another. The apices, which represent equal parts of the electrical charge, will be more distant than they would be in the case of a convex surface, however large the sphere from which it is taken. By increasing the height of the pyramids, their bases will diminish in number, and eventually disappear altogether.

PROP. 44.—Concave conducting surfaces have no charging capacities bestowed upon them by the artificial equilibrium, except for very low intensities.

When the apices of the pyramids, which represent units of charging capacity (Prop. 39), are resting on a concave surface, their bases intersect one another at a minimum of height.

COR.—The charging capacities of hollow spheres, conferred by the artificial equilibrium, are proper to their external surfaces, excepting in cases where the intensities are very low compared with their diameters.

PROP. 45.—The charging capacities conferred by the artificial equilibrium on conductors insulated in the atmosphere, vary in the direct ratio of the density of the air.

The efficiency of a given insulating medium in conferring the artificial equilibrium, varies with the numbers of its molecules within a given distance of the electrical charge; and the numbers of molecules of air, within a given distance, vary with its density.

PROP. 46.—The quantity of electricity forming the plus-charge of a cylinder being given, its intensity will be reduced if the extremity of a second insulatedcylindrical conductor be made to approach within such a distance of the charged conductor as is less than the height of the pyramids by which the intensity is represented.

Some of the complementary electrical atoms of the presented conductor are free to move from that end of it which has pierced the bases of the pyramids to the other end, on their being dismissed from their own basic atoms; and they become so dismissed under the inductive action of the plus-charge, because, towards the further end of the presented conductor, they can themselves act by induction on aërial molecules not already occupied in establishing artificial equilibrium. By thus extending the conducting surface upon which the apices of the pyramids (Prop. 39) are to rest, we increase their number, and by so doing place underneath each a diminished quantity of electricity; thus allotting to the pyramids a less height, that is to say, we give to the charge a lower intensity.

Cor.—By uninsulating the presented cylinder, we shall virtually make the earth part of it, and acquire for its charge by induction the establishment of an artificial equilibrium at a minimum of distance.

Prop. 47.—When we accumulate an electrical charge on one conducting surface, and *compensate* it by another similar conducting surface, uninsulated and placed at a minimum of distance, under such circumstances as will prevent a discharge across the interval, we produce a maximum effect in establishing an electrical charge by the artificial equilibrium.

Under such circumstances the number of atoms of electricity which may become accessory to the electrospheres of the charged surface is only limited by the number of complementary atoms existing on the electrospheres of the compensating surface, or *vice versâ*; the minute distance at which the major electrical force acts in establishing induction between those surfaces limits that also at which it acts in establishing the artificial equilibrium; and this latter becomes perfect by having the whole of the earth's surface to act from upon the contiguous atmosphere.

SECTION VII. *Galvanism and Electrolysis.*

PROP. 48.—If $a\ a'\ a''$ and $b\ b'\ b''$ (fig. 14), representing two lines of unequal electrospheres, each with a complementary atom on its surface, be placed in an insulating medium and with one end of each line in mutual contact, a will become electrically plus if the normal condition of b'' be constantly re-established.

By Proposition 15, the two complementary atoms of the contiguous electrospheres a'' and b will be between them; it is manifest that each of the other complementary atoms, in conformity to the law of distance, takes a place between two contiguous electrospheres. Things being in this state, all the complementary atoms of the line $b\ b'\ b''$ tend to pass into the line $a\ a'\ a''$, by virtue of the lesser radius of its electrospheres (Prop. 15), and are prevented from so passing by the attraction of the basic atoms of $b\ b'\ b''$ for those parts of their electrical equivalents. Now that impediment vanishes if electrical atoms be supplied at b''.

PROP. 49.—All other things remaining the same, the aptitude of the lines of smaller electrospheres in the last proposition, to take electricity from the other line, will be greater as the number of com-

Fig. 12.

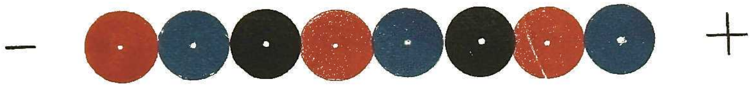


Fig. 14.

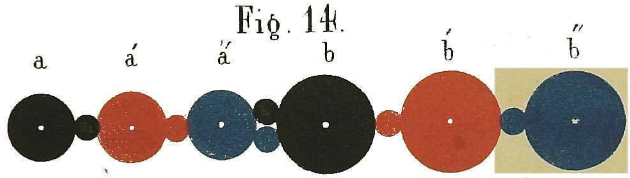
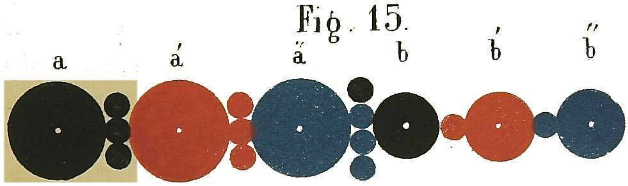


Fig. 15.



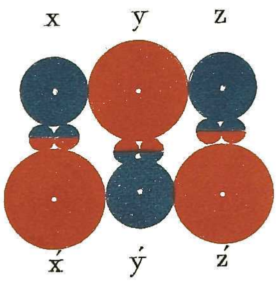


Fig. 16.

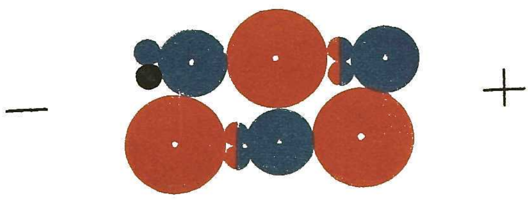


Fig. 17.

plementary atoms, naturally belonging to the electrospheres of larger radius, predominates over the number of those appertaining to the smaller electrospheres.

Let the number of complementary atoms on each larger electrosphere be three, and on each of the smaller only one (fig 15). The tendencies to electromotion will be the same as in the last proposition, with this difference, namely, that now we shall have four complementary atoms between a'' and b, instead of only two. Three-fourths of the complementary atom of b will be attracted in the direction of the larger electrosphere, and one-fourth in the opposite direction, instead of the atom being attracted, a moiety in each direction, as before. Now by the law of major force, with respect to quantity, if the force of the line of smaller electrospheres be represented by the square of unity, that of the line of larger electrospheres will be equal to the square of three, correction being made for difference of distance.

Prop. 50.—When a line of compound molecules, each constructed of a large and a small electrosphere, united by two complementary atoms, one belonging to each, is supplied at one end with atoms of electricity, while they are being removed in equal numbers from the other end of the line, the compound molecules may be decomposed into their elements.

Let x x', y y', and z z' (fig. 16) be the line of compound molecules; x being united to x', y to y', and z to z', each pair of simple molecules, by the two complementary atoms, one belonging to the equivalent of each; and let electricity be withdrawn at the end x x' of the line, and conveyed by any means to the end z z'. The radius of the electrosphere x being shorter than that of x', its basic atom will be attracted the more forcibly of the two by the complementary atoms. Now as one of these is being removed as a plus charge x will escape with it by virtue of the major force which connects them together, unless that force be opposed by another tending to prevent the separation of the two complementary atoms from x'. There is no such opposing force in the case; because, whether x' remain attached to its former associate x, or form a new combination with y', which is precisely similar to x, and at the same distance, makes no difference in the distance at which the forces act. And x' can attach itself to y', because y, in like manner, can unite to z; the latter molecule leaving z' separated and minus its complementary atom, which it replaces by an atom of electricity supplied at that end of the line. This decomposition is shown in fig. 17.

POSTSCRIPT.

There is another consequence of the principles of the theory which is too palpable and too important to be altogether passed over unnoticed, although it is not my intention to enter now into its details; I mean the nature of the body in the centre of our planetary system. If the exactitude with which the theory exposes the operation of accessory electrical atoms, acting by induction on molecules of matter, be not the extreme of all remarkable accidents, then not only is the sun the centre of gravitation, because it is the centre of electricity, but it must possess part at least of its electricity in the state of a plus charge. Were it not so, it ought not to differ, as it does, from the planets in its influence on the earth; nor should the phænomena which it occasions exhibit those analogies with certain others which are observed to be caused by electricity at an abnormal distance from its equivalent of basic matter. And if our great common centre of force contain electricity in excess, that excess must inevitably act by induction on the basic matter of the earth and all the planetary bodies, the consequences of the induction on any one of them being modified by its relative position at the time to all the others. The sun's electrical induction, coupled with the earth's motion around its axis, must produce a diurnal polarization of all those of its electrospheres which possess complementary atoms; and in such a general polarization we may be enabled to discover and comprehend, by aid of the higher mathematics, those relative positions of the molecules, and even of the atoms of matter, on which depend the phænomena of light and magnetism. If light and colour prove to be the results of particular molecular arrangements in matter caused by electrical induction, and recognised by our minds through the instrumentality of corresponding conditions induced in the molecules of our organs of sense, they will probably soon lead us deeper into a knowledge of the minuter mysteries of creation than any other means of research we have hitherto made use of.

ERRATA.

Page 14, line 5 from bottom, *for* were then and, *read* he found and which.
Page 36, line 11 from bottom, *for* but *read* by.

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