THE

CORRELATION AND CONSERVATION

OF

FORCES:

A Series of Expositions,

BY

PROF. GROVE, PROF. HELMHOLTZ, DR. MAYER, DR. FARADAY, PROF. LIEBIG AND DR. CARPENTER.

WITH AN

INTRODUCTION AND BRIEF BIOGRAPHICAL NOTICES OF THE CHIEF PROMOTERS OF THE NEW VIEWS.

BY

EDWARD L. YOUMANS, M. D.

"—The highest law in physical science which our faculties permit us to perceive—the Conservation of Force."—DR. FARADAY.

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TO

JOHN WILLIAM DRAPER, M.D., LL.D.

PROFESSOR OF CHEMISTRY AND PHYSIOLOGY IN THE UNIVERSITY OF NEW YORK.

DEAR SIR :—

IT seems peculiarly appropriate that this volume should be dedicated to you. Knowing the eminent esteem in which you are held in the circles of European science, I cannot doubt that the distinguished authors of the following essays would cordially approve this connection of your name with their introduction to the American public.

There is, besides, a further reason for this in that large coincidence of purpose which is manifest in their labors and your own. For while the pervading design of the present collection is to widen the range of thought by unfolding a broader philosophy of the energies of nature, your own comprehensive course of research—beginning with an extended series of experimental investigations in chemical physics and physiology, and rising to the consideration of that splendid problem, the bearing of science upon the History of the Intellectual Development of Europe—has powerfully contributed to the same noble end; that of elevating the aim and enlarging the scope of scientific inquiry.

I gladly avail myself of this occasion to say how greatly I am indebted to your writings, in which accurate and profound instruction is so often and happily blended with the charms of poetic eloquence. That you may live long to enjoy your well-won honors, and to contribute still further to the triumphant advance of scientific truth, is the heartfelt wish of

Yours truly,

E. L. Y.

PREFACE.

In his address before the British Association for the Advancement of Science last year, the President remarked that the new views of the Correlation and Conservation of Forces constitute the most important discovery of the present century. The remark is probably just, prolific as has been this period in grand scientific results. No one can glance through the current scientific publications without perceiving that these views are attracting the profound attention of the most thoughtful minds. The lively controversy that has been carried on for the last two or three years respecting the share that different men of different countries have had in their establishment, still further attests the estimate placed upon them in the scientific world.

But little, however, has been published in this country upon the subject; no complete work, I believe, except the admirable volume of Prof. Tyndall on "Heat as a Mode of Motion," in which the new philosophy is adopted, and applied to the explanation of thermal phenomena in a very clear and forcible manner. I have, therefore, thought it would be a useful service to the public to reissue some of the ablest presentations of these views which have appeared in Europe, in a compact and convenient form. The selection of these discussions has been determined by a desire to combine clearness of exposition with authority of statement. In the first of these respects the essays will speak for themselves; in regard to the last I may remark that all the authors quoted stand high as founders of the new theory of forces. Although I am not aware that Prof. Liebig has made any claims in this direction, yet it can scarcely be doubted that his original researches in Animal Chemistry tended strongly toward the promotion of the science of vital dynamics.

The work of Professor Grove, which is here reprinted in full, has a high European reputation, having passed to the fourth edition in England, and been translated into several continental languages. It is hardly to the credit of science in our country, that this is the first American edition. The eloquent and interesting paper of Helmholtz, though delivered as a popular lecture, was translated for the Philosophical Magazine, and has been very highly appreciated in scientific circles. The three articles of Mayer, which were also translated for the Philosophical Magazine, will have interest not only because of the great ability with which the subjects are treated, but as emanating from a man who stands perhaps preëminent among the explorers in this new tract of inquiry. The researches of Faraday in this field have been conspicuous and important, and his argument is marked by the depth and clearness which characterize, in an eminent degree, the writings of this extraordinary man. The essay of Liebig forms a chapter in the last edition of his invaluable 'Familiar Letters on Chemistry,' which has not been republished here; and, as it touches the relation of the subject to organic processes, it forms a fit introduction to the final article of the series by Dr. Carpenter, on the "Correlation of the Physical and Vital Forces." The eminent English physiologist has worked out this branch of the subject independently, and the paper quoted gives evidence of being prepared with his usual care and ability. A certain amount of repetition is of course unavoidable in such a collection, yet the reader will find much less of this than he might be inclined to look for, as each writer, in elaborating the subject, has stamped it with his own originality.

In the introduction I have attempted to bring forward certain facts in the history of these discoveries, in which we as Americans have a special interest, and also to indicate several applications of the new principles which are not treated in the volume. It seemed best to confine the general discussion to those aspects of the subject upon which most thought had been expended, and which may be regarded as settled among advanced scientific men. But there are other applications of the doctrine, of the highest interest, which though incomplete are yet certain, and these will be found briefly noticed in the introductory observations—too briefly, I fear, to be satisfactory. Those, however, who desire to pursue still further this branch of the inquiry—the correlation of the vital, mental, and social forces—are referred to the last edition of Carpenter's "Principles of Human Physiology;" Morell's "Outlines of Mental Philosophy;" Laycock's "Correlations of Consciousness and Organization;" Sir J. K. Shuttleworth's address before the Social Science Congress of 1860, on the "Correlation of the Moral and Physical Forces;" Hinton's "Life in Nature," and "First Principles" of Herbert Spencer's new system of Philosophy. The first and last of these works are the only ones, it is believed, that have appeared in an American form, and the last is much the ablest of all; I was chiefly indebted to it in preparing the latter part of the introduction. The biographical notices, brief and imperfect as they are, it is hoped may enhance the reader's interest in the volume.

I have been specially incited to procure the publication of a work of this kind, by the same motive that has impelled me to write upon the subject elsewhere; a conviction of our educational needs in this direction. The treatment of a vast subject like this in ordinary school text-books, is at best quite too limited for the requirements of the active-minded teacher; to such, a volume like the present may prove invaluable.

But a more serious difficulty is that, until compelled by the demands of intelligent teachers, the compilers of school-books will pass new views entirely by, or give them a mere hasty and careless notice, while continuing to inculcate the old erroneous doctrines. And thus it is that from inveterate habit, or intellectual sluggishness, or a shrewd calculation of the indifference of teachers, outworn and effete ideas continue to drag through school-books for half a century after they have been exploded in the world of living science. He who continues to teach the hypothesis of *caloric*, falsifies the present truth of science as absolutely as he would do in teaching the hypothesis of *phlogiston;* in fact, the reasons offered for persisting in the erroneous notions of the materiality of heat—convenience of teaching, unsettledness of the new vocabulary, &c., are precisely those that were offered for clinging to phlogiston, and rejecting the Lavoiserian chemistry of combustion. Both conceptions have no doubt been of service, but both were transitional, and having done their work they become hindrances instead of helps. We can now see that when the true chemistry of combustion was once reached, the notion of phlogiston was of no further use, and if retained could only produce confusion and prevent the reception of correct ideas. So with caloric, and those false conceptions of the materiality of forces, which it implies: not only are they errors, but the ideas they involve are radically incompatible with the higher truths to which science has advanced so that while the errors are retained the truths cannot be received.

Nor will it answer merely to mention the new views while adopting the old, on the plea that the facts are the same in both cases. The facts are very far from being the same in both cases. It is precisely because the old ideas are out of harmony with the facts, and can no longer correctly explain and express them, that new ideas are sought. Was not phlogiston abandoned because it no longer agreed with the facts? So with the conception of the materiality of the forces; it contradicts the facts, and therefore, for scientific purposes, can no longer represent them. In the workshop it may perhaps be very well to magnify facts, and depreciate their theoretical explanations, but not in the school-room; the business is here not working, but thinking. It is the aim of art to *use* facts, but of science to *understand* them. And it is simply because science goes beyond the fact to its explanation, and is ever striving after the highest truth, that it is fitted to discipline the thinking and reasoning faculties, and therefore has imperative educational claims.

In therefore bringing forward these able and authoritative expositions in a form readily accessible to teachers, I trust I am not only doing them a helpful service, but that they will be led to require of the preparers of school-books a more conscientious performance of their tasks, and that the interests of sound education will be thereby promoted.

NEW YORK, *Oct.* 1, 1864.

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INTRODUCTION.

THERE are many who deplore what they regard as the materializing tendencies of modern science. They maintain that this profound and increasing engrossment of the mind with material objects is fatal to all refining and spiritualizing influence. The correctness of this conclusion is open to serious question: indeed, the history of scientific thought not only fails to justify it, but proves the reverse to be true. It shows that the tendency of this kind of inquiry is ever *from* the material, *toward* the abstract, the ideal, the spiritual.

We may appeal to the oldest and most developed of the sciences for confirmation of this statement. The earliest explanations of the celestial movements were thoroughly and grossly material, and all astronomic progress has been toward more refined and ideal views. The heavenly bodies were at first thought to be supported and carried round in their courses by solid revolving crystalline spheres to which they were attached. This notion was afterward replaced by the more complex and mobile mechanism of epicycles. To this succeeded the hypothesis of Des Cartes', who rejected the clumsy mechanical explanation of revolving wheelwork, and proposed the more subtile conception of ethereal currents, which constantly whirled around in vortices, and bore along the heavenly bodies. At length the labors of astronomers, terminating with

Newton, struck away these crude devices, and substituted the action of a universal immaterial force. The course of astronomic science has thus been on a vast scale to withdraw attention from the material and sensible, and to fix it upon the invisible and supersensuous. It has shown that a pure principle forms the immaterial foundation of the universe. From the baldest materiality we rise at last to a truth of the spiritual world, of so exalted an order that it has been said 'to connect the mind of man with the Spirit of God.'

The tendency thus illustrated by astronomy is characteristic in a marked degree of all modern science. Scientific inquiries are becoming less and less questions of matter, and more and more questions of force; material ideas are giving place to dynamical ideas. While the great agencies of change with which it is the business of science to deal—heat, light, electricity, magnetism, and affinity, have been formerly regarded as kinds of matter 'imponderable elements,' in distinction from other material elements, these notions must now be regarded as outgrown and abandoned, and in their place we have an order of purely immaterial forces.

Toward the close of the last century the human mind reached the great principle of the indestructiblity of matter. What the intellectual activity of ages had failed to establish by all the resources of reasoning and philosophy, was accomplished by the invention of a mechanical implement, the balance of Lavoisier. When nature was tested in the chemist's scale-pan, it was first found that never an atom is created or destroyed; that though matter changes form with protean facility, traversing a thousand cycles of change, vanishing and reappearing incessantly, yet it never wears out or lapses into nothing.

The present age will be memorable in the history of science for having demonstrated that the same great principle applies also to forces, and for the establishment of a new philosophy concerning their nature and relations. Heat, light, electricity, and magnetism are now no longer regarded as substantive and independent existences—subtile fluids with peculiar properties, but simply as modes of motion in ordinary matter; forms of energy which are capable of mutual conversion. Heat is a mode of energy manifested by certain effects. It may be transformed into electricity, which is another form of force producing different effects. Or the process may be reversed; the electricity disappearing and the heat reappearing. Again, mechanical motion, which is a motion of masses, may be transformed into heat or electricity, which is held to be a motion of the atoms of matter, while, by a reverse process, the motion of atoms, that is, heat or electricity, may be turned back again into mechanical motion. Thus a portion of the heat generated in a locomotive is converted into the motion of the train, while by the application of the brakes the motion of the train is changed back again into the heat of friction.

These mutations are rigidly subject to the laws of quantity. A given amount of one force produces a definite quantity of another; so that power or energy, like matter, can neither be created nor destroyed: though ever changing form, its total quantity in the universe remains constant and unalterable. Every manifestation of force must have come from a preëxisting equivalent force, and must give rise to a subsequent and equal amount of some other force. When, therefore, a force or effect appears, we are not at liberty to assume that it was self-originated, or came from nothing; when it disappears we are forbidden to conclude that it is annihilated: we must search and find whence it came and whither it has gone; that is, what produced it and what effect it has itself produced. These relations among the modes of energy are currently known by the phrases *Correlation* and *Conservation* of Force.

The present condition of the philosophy of forces is perfectly paralleled by that of the philosophy of matter toward the close of the last century. So long as it was admitted that matter in its various changes may be created or destroyed, chemical progress was impossible. If, in his processes, a portion of the material disappeared, the chemist had a ready explanation—the matter was *destroyed;* his analysis was therefore worthless. But when he started with the axiom that matter is indestructible, all disappearance of material during his operations was chargeable to their imperfection. He was therefore compelled to improve them—to account in his result for every thousandth of a grain with which he commenced; and as a consequence of this inexorable condition, analytical chemistry advanced to a high perfection, and its consequences to the world are incalculable. Precisely so with the analysis of forces. So long as they are considered capable of being created and destroyed, the quest for them will be careless and the results valueless. But the moment they are determined to be indestructible, the investigator becomes bound to account for them; all problems of power are at once affected, and the science of dynamics enters upon a new era.

The views here briefly stated will be found fully and variously elucidated in the essays of the present volume; in these introductory remarks I propose to offer some observations on their history and the extended scope of their application.

I have spoken of the principles of Correlation and Conservation of Forces as established; it may be well to state the sense in which this is to be taken. They have been accepted by the leading scientific minds of all nations with remarkable unanimity; their discussion forms a leading element in scientific literature, while they occupy the thoughts and guide the investigations of the most philosophical inquirers. But while science holds securely her new possession as a fundamental principle, its various phases are by no means completely worked out. Not only has there been too little time for this, even if the views were far less important, but the questions started lie at the foundation of all branches of science, and can only be fully elucidated as these advance in their development. The new doctrine of forces is now in much the same condition as was the new astronomy of Copernicus. It is not without its difficulties, which time alone must be trusted to remove; but it simplifies so many problems, clears up so many obscurities opens so extended a range of new investigations, and contrasts so strongly with the complexities and incongruities of the older doctrines, as to leave little liberty of choice between the opposing theories. Not only does the reception of these views mark a signal epoch in the progress of science, but from their comprehensive bearings and the luminous glimpses which they open into the most elevated regions of speculative inquiry, they have a profound interest for many thinkers who give little attention to the specialties of exact science.

In the history of human affairs there is a growing conception of the action of general causes in the production of events, and a corresponding conviction that the part played by individuals has been much exaggerated, and is far less controlling and permanent than has been hitherto supposed. So also in the history of science it is now acknowledged that the progress of discovery is much more independent of the labors of particular persons than has been formerly admitted. Great discoveries belong not so much to individuals as to humanity; they are less inspirations of genius than births of eras. As there has been a definite intellectual progress, thought has necessarily been limited to the subjects successively reached. Many minds have been thus occupied at the same time with similar ideas, and hence the simultaneous discoveries of independent inquirers, of which the history of science is so full. Thus at the close of the sixteenth century, philosophers had entered upon the investigation of the laws of motion, and accordingly we find Galileo, Benediti, and Piccolomini proving independently that all bodies fall to the earth with equal velocity, whatever their size or weight. A century after, when science had advanced to the systematic application of the higher mathematics to general physics, Newton and Leibnitz discovered independently the differential calculus. A hundred years later questions of molecular physics and chemistry were reached, and oxygen was discovered simultaneously by Priestley and Scheele, and the composition of water by Cavendish and Watt. These discoveries were made because the periods were ripe for them, and we cannot doubt that if those who made them had never lived, the labors of others would have speedily attained the same results. The discoverer is, therefore, in a great degree, but the mouthpiece of his time. Some discern clearly what is dimly shadowed forth to many; some work out the results more completely than others, and some seize the coming thought so long before it is developed in the general consciousness, that their announcements are unappreciated and unheeded. This view by no means robs the discoverer of his honors, but it enables us to place upon them a juster estimate, and to pass a more enlightened judgment upon the rival claims which are constantly arising in the history of science.

Probably the most important event in the general progress of science was the transition from the speculative to the experimental period. The ancients were prevented from creating science by a false intellectual procedure. They believed they could solve all the problems of the universe by thought alone. The moderns have found that for this purpose meditation is futile unless accompanied by observation and experiment. Modern science, therefore, took its rise in a change of method, and the adoption of the principle that the discovery of physical truth consists not in its mere logical but in its experimental establishment. It is now an axiom that not he who *guesses*, though he guess aright, is to be adjudged the true discoverer, but he who *demonstrates* the new truth, and thus compels its acceptance into the body of valid knowledge.

Now the later doctrines of the constancy and relations of forces, and that heat is a kind of motion among the minuter parts of matter, have had their twofold phases of history, corresponding to the two methods of inquiry. They had an early and vague recognition among many philosophers, and may be traced in the writings of Galileo, Bacon, Newton, Locke, Leibnitz, Des Cartes, Bernoulli, Laplace, and others; but they were held by these thinkers as unverified and fruitless speculations, and the subject awaited the genius that could deal with it according to the more effective methods of modern science.

It was this country, widely reproached for being over-practical, which produced just that kind of working ability that was suited to translate this profound question from the barren to the fruitful field of inquiry. It is a matter of just national pride that the two men who first demonstrated the capital propositions of pure science, that lightning is but a case of common electricity, and that heat is but a mode of motion—who first converted these propositions from conjectures of fancy to facts of science, were not only Americans by birth and education, but men eminently representative of the peculiarities of American character—Benjamin Franklin and Benjamin Thompson, afterwards known as Count Rumford. The latter philosopher is less known than the former, though his services to science and society were probably quite as great. The prominence which his name now occupies in connection with the new views of heat, and the relations of forces, make it desirable to glance briefly at his career.

BENJAMIN THOMPSON was born at Woburn, Mass., in 1753. He received the rudiments of a common school education; became a merchant's apprentice at twelve, and subsequently taught school. Having a strong taste for mechanical and chemical studies, he cultivated them assiduously during his leisure time. At seventeen he took charge of an academy in the village of Rumford (now Concord), N. H., and in 1772 married a wealthy widow, by whom he had one daughter. At the outbreak of revolutionary hostilities he applied for a commission in the American service, was charged with toryism, left the country in disgust, and went to England. His talents were there appreciated, and he took a responsible position under the government, which he held for some years.

After receiving the honor of knighthood he left England and entered the service of the elector of Bavaria. He settled in Munich in 1784, and was appointed aide-de-camp and chamberlain to the Prince. The labors which he now undertook were of the most extensive and laborious character, and could never have been accomplished but for the rigorous habits of order which he carried into all his pursuits. He reorganized the entire military establishment of Bavaria, introduced not only a simpler code of tactics, and a new system of order, discipline, and economy among the troops and industrial schools for the soldiers' children, but greatly improved the construction and modes of manufacture of arms and ordnance. He suppressed the system of beggary which had grown into a recognized profession in Bavaria, and become an enormous public evil—one of the most remarkable social reforms on record. He also devoted himself to various ameliorations, such as improving the construction and arrangement of the dwellings of the working classes, providing for them a better education, organizing houses of industry, introducing superior breeds of horses and cattle, and promoting landscape-gardening, which he did by converting an old abandoned hunting-ground near Munich into a park, where, after his departure, the inhabitants erected a monument to his honor. For these services Sir Benjamin Thompson received many distinctions, and among others was made Count of the holy Roman Empire. On receiving this dignity he chose a title in remembrance of the country of his nativity, and was thenceforth known as Count of Rumford.

His health failing from excessive labor and what he considered the unfavorable climate, he came back to England in 1798, and had serious thoughts of returning to the United States. Having received from the American government the compliment of a formal invitation to revisit his native land, he wrote to an old friend requesting him to look out for a "little quiet retreat" for himself and daughter in the vicinity of Boston. This intention, however, failed, as he shortly after became involved in the enterprise of founding the Royal Institution of England.

There was in Rumford's character a happy combination of philanthropic impulses, executive power in carrying out great projects, and versatility of talent in physical research. His scientific investigations were largely guided and determined by his philanthropic plans and public duties. His interest in the more needy classes led him to the assiduous study of the physical wants of mankind, and the best methods of relieving them; the laws and domestic management of heat accordingly engaged a large share of his attention. He determined the amount of heat arising from the combustion of different kinds of fuel, by means of a calorimeter of his own invention. He reconstructed the fireplace, and so improved the methods of heating apartments and cooking food as to produce a saving in the precious element, varying from one-half to seven-eighths of the fuel previously consumed. He improved the construction of stoves, cooking ranges, coal grates, and chimneys; showed that the non-conducting power of cloth is due to the air enclosed among its fibres, and first pointed out that mode of action of heat called *convection;* indeed he was the first clearly to discriminate between the three modes of propagation of heat—radiation, conduction, and convection. He determined the almost perfect non-conducting properties of liquids, investigated the production of light, and invented a mode of measuring it. He was the first to apply steam generally to the warming of fluids and the culinary art; he experimented upon the use of gunpowder, the strength of materials, and the maximum density of water, and made many valuable and original observations upon an extensive range of subjects.

Prof. James D. Forbes, in his able Dissertation on the recent Progress of the Mathematical and Physical Sciences, in the last edition of the Encyclopedia Britannica, gives a full account of Rumford's contributions to science, and remarks:

"All Rumford's experiments were made with admirable precision, and recorded with elaborate fidelity, and in the plainest language. Every thing with him was reduced to weight and measure, and no pains were spared to attain the best results.

"Rumford's name will be ever connected with the progress of science in England by two circumstances: first, by the foundation of a perpetual medal and prize in the gift of the council of the

Royal Society of London, for the reward of discoveries connected with heat and light; and secondly, by the establishment in 1800 of the Royal Institution in London, destined, primarily, for the promotion of original discovery, and, secondarily, for the diffusion of a taste for science among the educated classes. The plan was conceived with the sagacity which characterized Rumford, and its success has been greater than could have been anticipated. Davy was there brought into notice by Rumford himself, and furnished with the means of prosecuting his admirable experiments. He and Mr. Faraday have given to that institution its just celebrity with little intermission for half a century."

Leaving England, Rumford took up his residence in France, and the estimation in which he was held may be judged of by the fact that he was elected one of the eight foreign associates of the Academy of Sciences.

Count Rumford bequeathed to Harvard University the funds for endowing its professorship of the Application of Science to the Art of Living, and instituted a prize to be awarded by the American Academy of Sciences, for the most important discoveries and improvements relating to heat and light. In 1804 he married the widow of the celebrated chemist Lavoisier, and with her retired to the villa of Auteuil, the residence of her former husband, where he died in 1814.

Having thus glanced briefly at his career, I now pass to the discovery upon which Count Rumford's fame in the future will chiefly rest. It is described in a paper published in the transactions of the Royal Society for 1798.

He was led to it while superintending the operations of the Munich arsenal, by observing the large amount of heat generated in boring brass cannon. Reflecting upon this, he proposed to himself the following questions: "Whence comes the heat produced in the mechanical operations above mentioned?" "Is it furnished by the metallic chips which are separated from the metal?"

The common hypothesis affirmed that the heat produced had been latent in the metal, and had been forced out by *condensation* of the chips. But if this were the case the capacity for heat of the parts of metal so reduced to chips ought not only to be changed, but the change undergone by them should be sufficiently great to account for *all* the heat produced. With a fine saw Rumford then cut away slices of the unheated metal, and found that they had *exactly the same capacity for heat as the metallic chips.* No change in this respect had occurred, and it was thus conclusively proved that the heat generated could not have been held latent in the chips. Having settled this preliminary point, Rumford proceeds to his principal experiments.

With the intuition of the true investigator, he remarks that "very interesting philosophical experiments may often be made, almost without trouble or expense, by means of machinery contrived for mere mechanical purposes of the arts and manufactures." Accordingly, he mounted a metallic cylinder weighing 113.13 pounds avoirdupois, in a horizontal position. At one end there was a cavity three and a half inches in diameter, and into this was introduced a borer, a flat piece of hardened steel, four inches long, 0.63 inches thick, and nearly as wide as the cavity, the area of contact of the borer with the cylinder being two and a half inches. To measure the heat developed, a small round hole was bored in the cylinder near the bottom of the cavity, for the insertion of a small mercurial thermometer. The borer was pressed against the base of the cavity with a force of 10,000 pounds, and the cylinder made to revolve by horse-power at the rate of thirty-two times per minute. At the beginning of the experiment the temperature of the air in the shade and also in the cylinder was 60°F. at the end of thirty minutes, and after the cylinder had made 960 revolutions the temperature was found to be 130°F.

Having taken away the borer, he found that 839 grains of metallic dust had been cut away. "Is it possible," he exclaims, "that the very considerable quantity of heat produced in this experiment

—a quantity which actually raised the temperature of upward of 113 pounds of gun metal at least 70°, could have been furnished by so inconsiderable a quantity of metallic dust, and this merely in consequence of a change in the capacity for heat?"

To measure more precisely the heat produced, he next surrounded his cylinder by an oblong wooden box in such a manner that it could turn water-tight in the centre of the box, while the borer was pressed against the bottom. The box was filled with water until the entire cylinder was covered, and the apparatus was set in action. The temperature of the water on commencing was 60°. He remarks, "The result of this beautiful experiment was very striking, and the pleasure it afforded amply repaid me for all the trouble I had taken in contriving and arranging the complicated machinery used in making it. The cylinder had been in motion but a short time when I perceived, by putting my hand into the water and touching the outside of the cylinder, that heat was generated."

As the work continued the temperature gradually rose; at two hours and twenty minutes from the beginning of the operation, the water was at 200°, and in ten minutes more it actually boiled! Upon this result Rumford observes, "It would be difficult to describe the surprise and astonishment expressed in the countenances of the bystanders, on seeing so large a quantity of water heated and actually made to boil without any fire. Though there was nothing that could be considered very surprising in this matter, yet I acknowledge fairly that it afforded me a degree of childish pleasure which, were I ambitious of the reputation of a grave philosopher, I ought most certainly rather to hide than to discover."

Rumford estimated the total heat generated as sufficient to raise 26.58 pounds of ice-cold water 180°, or to its boiling point; and he adds, "from the results of these computations, it appears that the quantity of heat produced equally or in a continuous stream, if I may use the expression, by the friction of the blunt steel borer against the bottom of the hollow metallic cylinder, was *greater* than that produced in the combustion of nine wax candles, each three-quarters of an inch in diameter, all burning together with clear bright flames."

"One horse would have been equal to the work performed, though two were actually employed. Heat may thus be produced merely by the strength of a horse, and in a case of necessity this might be used in cooking victuals. But no circumstances could be imagined in which this method of producing heat could be advantageous, for more heat might be obtained by using the fodder necessary for the support of the horse, as fuel.

"By meditating on the results of all these experiments, we are naturally brought to that great question which has so often been the subject of speculation among philosophers, namely, What is heat? Is there such a thing as an igneous fluid? Is there any thing that with propriety can be called caloric?

"We have seen that a very considerable quantity of heat may be excited by the friction of two metallic surfaces, and given off in a constant stream or flux *in all directions*, without interruption or intermission, and without any signs of *diminution* or *exhaustion*. In reasoning on this subject we must not forget *that most remarkable circumstance*, that the source of the heat generated by friction in these experiments appeared evidently to be *inexhaustible*. (The italics are Rumford's.) It is hardly necessary to add, that any thing which any *insulated* body or system of bodies can continue to furnish *without limitation*, cannot possibly be a *material substance;* and it appears to me to be extremely difficult, if not quite impossible, to form any distinct idea of any thing capable of being excited and communicated in those experiments, except it be MOTION."

No one can read the remarkably able and lucid paper from which these extracts are taken, without being struck with the perfect distinctness with which the problem to be solved was presented, and the systematic and conclusive method of its treatment. Rumford kept strictly within the limits of legitimate inquiry, which no man can define better than he did. "I am very far from pretending to know how, or by what means or mechanical contrivances, that particular kind of motion in bodies, which has been supposed to constitute heat, is exerted, continued, and propagated; and I shall not presume to trouble the Society with new conjectures. But although the mechanism of heat should in part be one one of those mysteries of nature, which are beyond the reach of human intelligence, this ought by no means to discourage us, or even lessen our ardor in our attempts to investigate the laws of its operations. How far can we advance in any of the paths which science has opened to us, before we find ourselves enveloped in those thick mists, which on every side bound the horizon of the human intellect."

Rumford's experiments completely annihilated the material hypothesis of heat, while the modern doctrine was stated in explicit terms. He moreover advanced the question to its quantitative and highest stage, proposing to find the numerical relation between mechanical power and heat, and obtained a result remarkably near to that finally established. The English unit of force is the foot-pound, that is, one pound falling through one foot of space; the unit of heat is one pound of water heated 1° F. Just fifty years subsequently to the experiment of Rumford, Dr. J. P. Joule,* of Manchester, England, after a most delicate and elaborate series of experiments, determined that 772 units of force produce one unit of heat; that is, 772 pounds falling through one foot produces sufficient heat to raise one pound of water 1° F. This law is known as the mechanical equivalent of heat. Now, when we throw Rumford's results into these terms, we find that about 940 units of force produced a unit of heat, and that, therefore, on a large scale, and at the very first trial, he came within twenty per cent. of the true

* JAMES PRESCOTT JOULE, born December 24th, 1818, at Salford, near Manchester, England, where he pursued the occupation of a brewer. Long and deeply devoted to scientific investigation, he became a member of the Manchester Philosophical Society in 1842, and of the Royal Society of London in 1850.

statement. No account was taken of the heat lost by radiation, which, considering the high temperature produced, and the duration of the experiment, must have been considerable; so that as Rumford himself noticed, this value must be too high. The earliest numerical results in science are rarely more than rough approximations, yet they may guide to the establishment of great principles. Certainly no one could question Dalton's claim to the discovery of the law of definite proportions, because of the inaccuracy of the numbers upon which he first rested it.

We are called further to note that Rumford's ideas upon the general subject of forces were far in advance of his age. He saw the relation of all friction to heat, and suggested that of fluids, by churning processes, as a means of producing it—precisely the method finally employed by Joule in establishing the mechanical equivalent of heat. He furthermore regarded animals *dynamically*, considering their force as the derivative of their food, and therefore as not created. That Rumford held these views in the comprehensive and matured sense in which they are now entertained is, of course, not asserted. The advance from his day to ours has been prodigious. Whole sciences have been created, which afford the most beautiful exemplifications of the new doctrines. Those doctrines have received their subsequent development in various directions by many minds, but we may be allowed to question if the contributions of any of their promoters will surpass, if indeed they will equal, the value and importance which we must assign to the first great experimental step in the new direction.

The claims of Rumford may be summarized as follows:

I. He was the man who first took the question of the nature of heat out of the domain of metaphysics, where it had been speculated upon since the time of Aristotle, and placed it upon the true basis of physical experiment.

II. He first proved the insufficiency of the current explanations of the sources of heat, and demonstrated the falsity of the prevailing view of its materiality.

III. He first estimated the quantitative relation between the heat produced by friction and that by combustion.

IV. He first showed the quantity of heat produced by a definite amount of mechanical work, and arrived at a result remarkably near the finally established law.

V. He pointed out other methods to be employed in determining the amount of heat produced by the expenditure of mechanical power, instancing particularly the agitation of water, or other liquids, as in churning.

VI. He regarded the power of animals as due to their food, there fore as having a definite source and not created, and thus applied his views of force to the organic world.

VII. Rumford was the first to demonstrate the quantitative convertibility of force in an important case, and the first to reach, experimentally, the fundamental conclusion that heat is but a mode of motion.

In his late work upon heat, Prof. Tyndall, after quoting copiously from Rumford's paper, remarks: "When the history of the dynamical theory of heat is written, the man who in opposition to the scientific belief of his time could experiment, and reason upon experiment, as did Rumford in the investigation here referred to, cannot be lightly passed over." Had other English writers been equally just, there would have been less necessity for the foregoing exposition of Rumford's labors and claims; but there has been a manifest disposition in various quarters to obscure and depreciate them. Dr. Whewell, in his history of the Inductive Sciences, treats the subject of thermotics without mentioning him. An eminent Edinburgh professor, writing recently in the Philosophical Magazine, under the confessed influence of 'patriotism,' under-takes to make the dynamical theory of heat an English monopoly, due to Sir Isaac Newton, Sir Humphry Davy, and Dr. J. P Joule; while an able writer in a late number of the North British Review, in sketching the historic progress of the new views, puts Davy forward as their founder, and assigns to Rumford a minor and subsequent place.

Sir Humphry Davy, it is well known, early rejected the caloric hypothesis. In 1799, at the age of twenty-one, he published a tract at Bristol, describing some ingenious experiments upon the subject. It was the publication of this pamphlet which brought him to Rumford's notice, and resulted in his subsequent connection with the Royal Institution. But Davy's ideas upon the question were far from clear, and will bear no comparison with those of Rumford, published the year before. Indeed his eulogist remarks: "It is certain that even Davy himself was led astray in his argument by using the hypothesis of change of capacity as the basis of his reasoning, and that he might have been met successfully by any able calorist, who, though maintaining the materiality of heat, might have been willing to throw overboard one or two of the less essential tenets of his school of philosophy." It was not till 1812 that Davy wrote in his Chemical Philosophy, "The immediate cause of the phenomena of heat then is motion, and the laws of its communication are precisely the same as those of the communication of motion." When, therefore, we remember that Davy's first publication was subsequent to that of Rumford's, that he confined himself to the narrowest point of the subject, the simple question of the existence of caloric; and that he nowhere gives evidence of having the slightest notion of the quantitative relation between mechanical force and heat, the futility of the claim which would make him the experimental founder of the dynamical theory, is abundantly apparent.

The inquiries opened by Rumford and Davy were not formally pursued by the succeeding generation. Even the powerful adhesion of Dr. Thomas Young—perhaps the greatest mind in science since Newton—failed to give currency to the new views. But the salient and impregnable demonstration of Rumford, and the ingenious experiments of Davy, facts which could neither be evaded nor harmonized with the prevailing errors, were not without influence. That there was a general, though unconscious tendency toward a new philosophy of forces, in the early inquiries of the present century, is shown by the fact that various scientific men of different nations, and with no knowledge of each other's labors, gave expression to the same views at about the same time. Grove and Joule of England, Mayer of Germany, and Colding of Denmark, announced the general doctrine of the mutual relations of the forces, with more or less explication, about 1842, and Seguin of France, it is claimed, a little earlier. From this time the subject was closely pursued, and the names of Helmholtz, Holtzman, Clausius,* Faraday, Thompson, Rankine,† Tyndall, Carpenter, and others are intimately associated with its advancement. In this country Professors Henry ‡ and Leconte § have contributed to illustrate the organic phase of the doctrine.

I cannot here attempt an estimate of the respective shares which these men have had in constructing the new theories; the reader will gather various intimations upon this point from the succeeding essays. The foreign periodicals, both scientific and literary, show that the question is being thoroughly sifted, and materials accumulating for the future history of the subject. The paramount claims are, however, those of Joule, Mayer, and Grove.

* Clausius, Rudolph Julius Immanuel was born at Cöslin, Pommern, January 22, 1822. He became Professor of Philosophy and Physics in the Polytechnic School at Zurich in 1855, and then Professor of the Zurich University (1857). He was afterwards teacher of Physics and Artillery in the School of Berlin, and then private teacher of the University of that place.

† Rankine, William John Macquorn was born at Edinburgh, July 5, 1820. He is a civil engineer in Glasgow, a member of the Philosophical Society at that place, and of the Royal Society of London.

‡ See the article "Meteorology," in the Agricultural Report of the Patent Office, for 1857.

§ See the American Journal of Science for Nov. 1859.

According to the strict rule of science, that in all those cases where experimental proof is possible, he who first supplies it is the true discoverer, Dr. Joule must be assigned the foremost place among the modern investigators of the subject. He dealt with the whole question upon the basis of experiment. He labored with great perseverance and skill to determine the mechanical equivalent of heat—the corner-stone of the edifice; and in accomplishing this result in 1850, he may be said to have matured the work of Rumford, and finally established upon an experimental basis the great law of thermo-dynamics, to remain a demonstration of science forever.

Professor Grove has also worked out the subject in his own independent way. Combining original experimental investigations of great acuteness, with the philosophic employment of the general results of science, he was the first to give complete and systematic expression to the new views. His able work, which opens the present series, is an authoritative exposition, and an acknowledged classic upon the subject.

Again, the claims of Dr. Mayer to an eminent and enviable place among the pioneers of this great scientific movement, are unquestionable. There has evidently been, on the part of some English writers, an unworthy inclination to depreciate his merits, which has given rise to a sharp and searching controversy. The intellectual rights of the German philosopher have, however, been decisively vindicated by the chivalric pen of Prof. Tyndall; and it is to the public interest thus excited, that we are indebted for the translation of Mayer's papers, which appear in this volume. Mayer did not experiment to the extent of Joule and Grove, yet he well knew its importance, and made such investigations as his apparatus and the duties of a laborious profession would allow. Yet his views were not therefore mere ingenious and probable conjectures. Master of the results of modern science, and of the mathematical methods of dealing with them, possessing a broad philosophic grasp, and an extraordinary mental pertinacity, Dr. Mayer entered early upon the inquiry, and not only has he developed many of its prime applications in advance of any other thinker, but he has done his work under circumstances and in a manner which awakens the highest admiration for his genius.*

An eminent authority has remarked 'that these discoveries open a region which promises possessions richer than any hitherto granted to the intellect of man.' Involving as they do a revolution of fundamental ideas, their consequences must be as comprehensive as the range of human thought. A principle has been developed of all-pervading application, which brings the diverse and distant branches of knowledge into more intimate and harmonious alliance, and affords a profounder insight into the universal order. Not only is science itself deeply affected by the presentation of its questions, in new and suggestive lights, but its method is at once made universal. There is a crude notion in many minds, that it is the business of science to occupy itself merely with the study of matter. When, hitherto, it has pressed its inquiries into the higher

* Prof. Tyndall remarks: "Mayer probably had not the means of making experiments himself, but he ransacked the records of experimental science for his data, and thus conferred upon his writings a strength which mere speculation can never possess. From the extracts which I have given, the reader may infer his strong desire for quantitative accuracy, the clearness of his insight, and the firmness of his grasp. Regarding the recognition which will be ultimately accorded to Dr. Mayer, a shade of trouble or doubt has never crossed my mind. Individuals may seek to pull him down, but their efforts will be unavailing as long as such evidence of his genius exists, and as long as the general mind of humanity is influenced by considerations of justice and truth.

"The paucity of facts in Mayer's time has been urged as if it were a reproach to him; but it ought to be remembered that the quantity of fact necessary to a generalization is different for different minds. 'A word to the wise is sufficient for them,' and a single fact in some minds bears fruit that a hundred cannot produce in others. Mayer's data were comparatively scanty, but his genius went far to supply the lack of experiment, by enabling him to see clearly the bearing of such facts as he possessed. They enabled him to think out the law of conservation, and his conclusions received the stamp of certainty from the subsequent experimental labors of Mr. Joule. In reference to their comparative merits, I would say that as Seer and Generalizer, Mayer in my opinion, stands first—*as experimental philosopher, Joule.*"

region of life, mind, society, history, and education, the traditional custodians of these subjects have bidden it keep within its limits and stick to *matter*. But science is not to be hampered by this narrow conception; its office is nothing less than to investigate the laws and universal relations of force, and its domain is therefore coextensive with the display of power. Indeed, as we know nothing of matter, except through its manifestation of forces, it is obvious that the study of matter itself is at last resolved into the study of forces. The establishment of a new philosophy of forces, therefore, by its vast extension of the scope and methods of science, constitutes a momentous event of intellectual progress.

The discussions of the present volume will make fully apparent the importance of the new doctrines in relation to physical science, but their higher implications are but partially unfolded. In the concluding article Dr. Carpenter has shown the applicability of the principle of correlation to vital phenomena. His argument is of interest, not only because of the facts and principles established, but as opening an inquiry which must lead to still larger results: for, if the principle be found operative in fundamental organic processes, it will undoubtedly be traced in those which are higher; if in the lower sphere of life, then throughout that sphere. If the forces are correlated in organic growth and nutrition, they must be in organic action; and thus human activity, in all its forms, is brought within the operation of the law. As a creature of organic nutrition, borrowing matter and force from the outward world; as a being of feeling and sensibility, of intellectual power and multiform activities, man must be regarded as amenable to the great law that forces are convertible and indestructible; and as psychology and sociology—the science of mind and the science of society—have to deal constantly with different phases and forms of human energy, the new principle must be of the profoundest import in relation to these great subjects.

The forces manifested in the living system are of the most varied and unlike character, mechanical, thermal, luminous, electric, chemical, nervous, sensory, emotional, and intellectual. That these forces are perfectly coördinated—that there is some definite relation among them which explains the marvellous dynamic unity of the living organism, does not admit of question. That this relation is of the same nature as that which is found to exist among the purely physical forces, and which is expressed by the term 'Correlation,' seems also abundantly evident. From the great complexity of the conditions, the same exactness will not, of course, be expected here as in the inorganic field, but this is one of the necessary limitations of all physiological and psychological inquiry; thus qualified the proofs of the correlation of the nervous and mental forces with the physical, are as clear and decisive as those for the physical forces alone.

If a current of electricity is passed through a small wire it produces heat, while if heat is applied to a certain combination of metals, it reproduces a current of electricity; these forces are, therefore, correlated. A current of electricity passed through a small portion of a motor or sensory nerve will excite the nerve force in the remainder, while, on the other hand, as is shown in the case of the torpedo, the nerve-force may generate electricity. Nerve-force may produce heat, light, electricity, and, as we constantly experience, mechanical power, and these in their turn may also excite nerve-force. This form of energy is therefore clearly entitled to a place in the order of correlated agencies.

Again, if we take the highest form of mental action, viz.: will-power, we find that while it commands the movements of the system, it does not act directly upon the muscles, but upon the cerebral hemispheres of the brain. There is a dynamic chain of which voluntary power is but one link. The will is a power which excites nerve-force in the brain, which again excites mechanical power in the muscles. Will-power is therefore correlated with nerve-power in the same manner as the latter is with muscular power. Dr. Carpenter well observes: "It is difficult to see that the dynamical agency which we term will is more removed from nerve-force on the one hand than nerve-force is removed from motor force on the other. Each, in giving origin to the next, is itself expended or ceases to exist *as such*, and each bears, in its own intensity, a precise relation to that of its antecedent and its consequent." We have here only space briefly to trace the principle in its application to sensations, motions, and intellectual operations.

The physical agencies acting upon inanimate objects in the external world, change their form and state, and we regard these changes as transformed manifestations of the forces in action. A body is heated by hammering; the heat is but transmuted mechanical force; or a body is put in motion by heat, a certain quantity being transformed into mechanical effect, or motion of the mass. And so it is held that no force can arise except by the expenditure of a preëxisting force. Now, the living system is acted upon by the same agencies and under the same law. Impressions made upon the organs of sense give rise to sensations, and we have the same warrant in this, as in the former case, for regarding the effects as transformations of the forces in action. If the change of molecular state in a melted body represents the heat transformed in fusing it, so the sensation of warmth in a living body must represent the heat transformed in producing it. The impression on the retina, as well as that on the photographic tablet, results from the transmuted impulses of light. And thus impressions made from moment to moment on all our organs of sense, are directly correlated with external physical forces. This correlation, furthermore, is quantitative as well as qualitative. Not only does the light-force produce its peculiar sensations, but the intensity of these sensations corresponds with the intensity of the force; not only is atmospheric vibration transmuted into the sense of sound, but the energy of the vibration determines its loudness. And so in all other cases; the quantity of sensation depends upon the quantity of the force acting to produce it.

Moreover, sensations do not terminate in themselves, or come to nothing; they produce certain correlated and equivalent effects.

The feelings of light, heat, sound, odor, taste, pressure, are immediately followed by physiological effects, as secretion, muscular action, &c. Sensations increase the contractions of the heart, and it has been lately maintained that every sensation contracts the muscular fibres throughout the whole vascular system. The respiratory muscles also respond to sensations; the rate of breathing being increased by both pleasurable and painful nerve-impressions. The quantity of sensation, moreover, controls the quantity of emotion. Loud sounds produce violent starts, disagreeable tastes cause wry faces, and sharp pains give rise to violent struggles. Even when groans and cries are suppressed, the clenched hands and set teeth show that the muscular excitement is only taking another direction.

Between the emotions and bodily actions the correlation and equivalence are also equally clear. Moderate actions, like moderate sensations, excite the heart, the vascular system, and the glandular organs. As the emotions rise in strength, however, the various systems of muscles are thrown into action; and when they reach a certain pitch of intensity, violent convulsive movements ensue. Anger frowns and stamps; grief wrings its hands; joy dances and leaps—the amount of sensation determining the quantity of correlative movement.

Dr. Carpenter, in his Physiology, has brought forward numerous exemplifications of this principle of the conversion of emotion into movement, as seen in the common workings of human nature. Most persons have experienced the difficulty of sitting still under high excitement of the feelings, and also the relief afforded by walking or active exercise; while, on the other hand, repression of the movements protracts the emotional excitement. Many irascible persons get relief from their irritated feelings by a hearty explosion of oaths, others by a violent slamming of the door, or a prolonged fit of grumbling. Demonstrative persons habitually expend their feelings in action, while those who manifest them less retain them longer: hence the former are more weak and transient in their attachments than the latter, whose unexpended emotions become permanent elements of character. For the same reason, those who are loud and vehement in their lamentations seldom die of grief; while the deep-seated emotions of sorrow which others cannot work off in violent demonstrations, depress the organic functions, and often wear out the life.

The intellectual operations are also directly correlated with physical activities. As in the inorganic world we know nothing of forces except as exhibited by matter, so in the higher intellectual realm we know nothing of mind-force except through its material manifestations. Mental operations are dependent upon material changes in the nervous system; and it may now be regarded as a fundamental physiological principle, that "no idea or feeling can arise, save as the result of some physical force expended in producing it." The directness of this dependence is proved by the fact that any disturbance of the train of cerebral transformations disturbs mentality, while their arrest destroys it. And here, also, the correlation is quantitative. Other things being equal there is a relation between the size of the nerve apparatus and the amount of mental action of which it is capable. Again, it is dependent upon the vigor of the circulation; if this is arrested by the cessation of the heart's action, total unconsciousness results; if it is enfeebled, mental action is low; while if it is quickened, mentality rises, even to delirium, when the cerebral activity becomes excessive. Again, the rate of brain activity is dependent upon the special chemical ingredients of the blood, oxygen and carbon. Increase of oxygen augments cerebral action, while increase of carbonic acid depresses it. The degree of mentality is also dependent upon the phosphatic constituents of the nervous system. The proportion of phosphorus in the brain is smallest in infancy, idiocy, and old age, and greatest during the prime of life; while the quantity of alkaline phosphates excreted by the kidneys rises and falls with the variations of mental activity. The equivalence of physical agencies and mental effects is still further seen in the action of various substances, as alcohol, opium, hashish, nitrous oxide, etc., when absorbed into the blood. Within the limits of their peculiar action upon the nervous centres, the effect of each is strictly proportionate to the quantity taken. There is a constant ratio between the antecedents and consequents.

"How this metamorphosis takes place—how a force existing as motion, heat, or light, can become a mode of consciousness—how it is possible for aërial vibrations to generate the sensation we call sound, or for the forces liberated by chemical changes in the brain, to give rise to emotion, these are mysteries which it is impossible to fathom. But they are not profounder mysteries than the transformation of the physical forces into each other. They are not more completely beyond our comprehension than the natures of mind and matter. They have simply the same insolubility as all other ultimate questions. We can learn nothing more than that here is one of the uniformities in the order of phenomena."

The law of correlation being thus applicable to human energy as well as to the powers of nature, it must also apply to society, where we constantly witness the conversion of forces on a comprehensive scale. The powers of nature are transformed into the activities of society; water-power, wind-power, steam-power, and electrical-power are pressed into the social service, reducing human labor, multiplying resources, and carrying on numberless industrial processes: indeed, the conversion of these forces into social activities is one of the chief triumphs of civilization. The universal forces of heat and light are transformed by the vegetable kingdom into the vital energy of organic compounds, and then, as food, are again converted into human beings and human power. The very existence as well as the activity of society are obviously dependent upon the operations of vegetable growth. When that is abundant, population may become dense, and social activities multifarious and complicated, while a scanty vegetation entails sparse population and enfeebled social action. Any universal disturbance of the physical forces, as excessive rains or drouth, by reducing the harvest, is felt throughout the entire social organism. Where this effect is marked, and not counteracted by free communication with more fertile regions, the means of the community become restricted, business declines, manufactures are reduced, trade slackens, travel falls off, luxuries are diminished, education is neglected, marriages are fewer, and a thousand kindred results indicate decline of enterprise and depression of the social energies.

In a dynamical point of view there is a strict analogy between the individual and the social economies—the same law of force governs the development of both. In the case of the individual, the amount of energy which he possesses at any time is limited, and when consumed for one purpose it cannot of course be had for another. An undue demand in one direction involves a corresponding deficiency elsewhere. For example, excessive action of the digestive system exhausts the muscular and cerebral systems, while excessive action of the muscular system is at the expense of the cerebral and digestive organs; and again, excessive action of the brain depresses the digestive and muscular energies. If the fund of power in the growing constitutions of children is overdrawn in any special channel, as is often the case by excessive stimulation of the brain, the undue abstraction of energy from other portions of the system is sure to entail some form of physiological disaster. So with the social organism; its forces being limited, there is but a definite amount of power to be consumed in the various social activities. Its appropriation in one way makes impossible its employment in another, and it can only gain power to perform one function by the loss of it in other directions. This fact, that social force cannot be created by enactment, and that when dealing with the producing, distributing, and commercial activities of the community, legislation can do little more than interfere with their natural courses, deserves to be more thoroughly appreciated by the public.

But the law in question has yet higher bearings. More and more we are perceiving that the condition of humanity and the progress of civilization are direct resultants of the forces by which men are controlled. What we term the moral order of society, implies a strict regularity in the action of these forces. Modern statistics disclose a remarkable constancy in the moral activities manifested in communities of men. Crimes, and even the modes of crime, have been observed to occur with a uniformity which admits of their prediction. Each period may therefore be said to have its definite amount of morality and justice. It has been maintained, for instance, with good reason, that "the degree of liberty a people is capable of in any given age, is a fixed quantity, and that any artificial extension of it in one direction brings about an equivalent limitation in some other direction. French revolutions show scarcely any more respect for individual rights than the despotisms they supplant; and French electors use their freedom to put themselves again in slavery. So in those communities where State restraint is feeble, we may expect to find it supplemented by the sterner restraints of public opinion."

But society like the individual is progressive. Although at each stage of individual growth the forces of the organism, physiological, intellectual, and passional, have each a certain definite amount of strength, yet these ratios are constantly changing, and it is in this change that development essentially consists. So with society; the measured action of its forces gives rise to a fixed amount of morality and liberty in each age, but that amount increases with social evolution. The savage is one in whom certain classes of feelings and emotions predominate, and he becomes civilized just in proportion as these feelings are slowly replaced by others of a higher character. Yet the activities which determine human advancement are various. Not only must we regard the physiological forces, or those which pertain to man's physical organization and capacities, and the psychological, or those resulting from his intellectual and emotional constitution, but the influences of the external world, and those of the social state, are likewise to be considered. Man and society, therefore, as viewed by the eye of science, present a series of vast and complex dynamical problems, which are to be studied in the future in the light of the great law by which, we have reason to believe, all forms and phases of force are governed.

A further aspect of the subject remains still to be noticed. Mr. Herbert Spencer has the honor of crowning this sublime inquiry by showing that the law of the conservation, or as he prefers to term it the 'Persistence of Force,' as it is the underlying principle of all being, is also the fundamental truth of all philosophy. With masterly analytic skill he has shown that this principle of which the human mind has just become fully conscious, is itself the profoundest law of the human mind, the deepest foundation of consciousness. He has demonstrated that the law of the Persistence of Force, of which the most piercing intellects of past times had but partial and unsatisfying glimpses, and which the latest scientific research has disclosed as a great principle of nature, has a yet more transcendent character; is, in fact, an *à priori* truth of the highest order—a truth which is necessarily involved in our mental organization; which is broader than any possible induction, and of higher validity than any other truth whatever. This principle, which is at once the highest result of scientific investigation and metaphysical analysis, Mr. Spencer has made the basis of his new and comprehensive System of Philosophy; and in the first work of the series, entitled "First Principles," he has developed the doctrine in its broadest philosophic aspects. The lucid reasoning by which he reaches his conclusions cannot be presented here; a brief extract or two will, however, serve to indicate the important place assigned to the law by this acute and profound inquirer:

"We might, indeed, be certain, even in the absence of any such analysis as the foregoing, that there must exist some principle which, as being the basis of science, cannot be established by science. All reasoned out conclusions whatever must rest on some postulate. As before shown, we cannot go on merging derivative truths in these wider and wider truths from which they are derived, without reaching at last a widest truth which can be merged in no other, or derived from no other. And whoever contemplates the relation in which it stands to the truths of science in general, will see that this truth, transcending demonstration, is the Persistence of force." * * *

"Such, then, is the foundation of any possible system of positive knowledge. Deeper than demonstration—deeper even than definite cognition—deep as the very nature of mind, is the postulate at which we have arrived. Its authority transcends all others whatever; for not only is it given in the constitution of our own consciousness, but it is impossible to imagine a consciousness so constituted as not to give it. Thought, involving simply the establishment of relations, may be readily conceived to go on while yet these relations have not been organized into the abstracts we call space and time; and so there is a conceivable kind of consciousness which does not contain the truths commonly called *à priori*, involved in the organization of these forms of relations. But thought cannot be conceived to go on without some element between which its relations may be established; and so there is no conceivable kind of consciousness which does not imply continued existence as its datum. Consciousness without this or that particular form is possible; but consciousness without *contents* is impossible.

"The sole truth which transcends experience by underlying it, is thus the Persistence of force. This being the basis of experience, must be the basis of any scientific organization of experiences. To this an ultimate analysis brings us down; and on this a rational synthesis must be built up."

To the question, What then is the value of experimental investigations upon the subject, if the truth sought cannot be established by inductions from them? Mr. Spencer replies: "They are of value as disclosing the many particular implications which the general truth does not specify; they are of value as teaching us how much of one mode of force is the equivalent of so much of another mode; they are of value as determining under what conditions each metamorphosis occurs; and they are of value as leading us to inquire in what shape the remnant of force has escaped, when the apparent results are not equivalent to the cause." And it may be added, that it is to these investigations that we are indebted for the clear and comprehensive establishment of the principle as a law of physical nature; psychological analysis having only shown that it extends much further than it is the business of experimental science to go.

Thus the law characterized by Faraday as the highest in physical science which our faculties permit us to perceive, has a far more extended sway; it might well have been proclaimed the highest law of *all* science—the most far-reaching principle that adventuring reason has discovered in the universe. Its stupendous reach spans all orders of existence. Not only does it govern the movements of the heavenly bodies, but it presides over the genesis of the constellations; not only does it control those radiant floods of power which fill the eternal spaces, bathing, warming, illumining and vivifying our planet, but it rules the actions and relations of men, and regulates the march of terrestrial affairs. Nor is its dominion limited to physical phenomena; it prevails equally in the world of mind, controlling all the faculties and processes of thought and feeling. The star-suns of the remoter galaxies dart their radiations across the universe; and although the distances are so profound that hundreds of centuries may have been required to traverse them, the impulses of force enter the eye, and impressing an atomic change upon the nerve, give origin to the sense of sight. Star and nerve-tissue are parts of the same system—stellar and nervous forces are correlated. Nay more; sensation awakens thought and kindles emotion, so that this wondrous dynamic chain binds into living unity the realms of matter and mind through measureless amplitudes of space and time.

And if these high realities are but faint and fitful glimpses which science has obtained in the dim dawn of discovery, what must be the glories of the coming day? If indeed they are but 'pebbles' gathered from the shores of the great ocean of truth, what are the mysteries still hidden in the bosom of the mighty unexplored? And how far transcending all stretch of thought that Unknown and Infinite Cause of all to which the human spirit turns evermore in solemn and mysterious worship!

It remains only to observe, that so immense a step in the progress of our knowledge of natural agencies as the following pages disclose, cannot be without effect upon the intellectual culture of the age. To the adherents of that scholastic and verbal education which prefers words to things, and ancient to modern thought; which ignores the study of nature, and regards the progress of science with indifference or hostility, it matters little what views of the world are entertained, or what changes these views may undergo. But there is another, and happily an increasing class, who hold that it is the true destiny of mind to comprehend the vast order of existence in the midst of which it is placed, and that the faculties of man are divinely adapted to this sublime task; who see that the laws of nature must be understood before they can be obeyed, and that only through this understanding can man rise to the mastery of its powers, and bring himself into final harmony with his conditions. These will recognize that the discovery of new principles which expand, and elevate, and harmonize our views of the universe—which involve the workings of the mind itself, open a new chapter in philosophy, and touch the very foundations of knowledge, cannot be without a determining influence upon the future course and development of thought, and the spirit and methods of its acquisition.

THE

CORRELATION

OF PHYSICAL FORCES.

By W. R. GROVE, Q.C., M.A., F.R.S.

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WILLIAM ROBERT GROVE, an English lawyer and physicist, was born at Swansea, July 14, 1811. He graduated at Oxford in 1834, and during the next five years was Professor of Natural Philosophy at the London Institution. Professor Grove is a rare example of the ability which has achieved a distinguished eminence in different fields of effort. While pursuing with marked success the profession of an advocate, he has devoted his leisure to original scientific researches, and obtained a high distinction both as a discoverer and a philosophic writer upon scientific subjects. In 1852 he was made Queen's Counsel, and afterwards Vice-President of the Royal Society. He is the inventor of the powerful galvanic battery known by his name, and his chief researches have been in the field of electricity. Many of his experimental results are referred to in the following pages, which will also attest his high position among the founders of the new philosophy of forces.

PREFACE

THE Phrase 'Correlation of Physical Forces' in the sense in which I have used it, having become recognized by a large number of scientific writers, it would produce confusion were I now to adopt another title. It would, perhaps, have been better if I had in the first instance used the term Co-relation, as the words 'correlate,' 'correlative,' had acquired a peculiar metaphysical sense somewhat differing from that which I attached to the substantive correlation. The passage in the text (p. 183) explains the meaning I have given to the term.

Twenty years having elapsed since I promulgated the views contained in this Essay, which were first advanced in a lecture at the London Institution in January 1842, and subsequently more fully developed in a course of lectures in 1843, I think it advisable to add a little to the Preface with reference to other labourers in the same field.

It has happened with this subject as with many others, that similar ideas have independently presented themselves to different minds about the same period. In May 1842 a paper was published by M. Mayer which I had not read when my last edition was published, and indeed only now know imperfectly by the *vivâ-voce* translation of a friend. It deduces very much the same conclusions to which I had been led, the author starting partly from *à priori* reasoning and partly from an experiment by which water was heated by agitation, and from another, which had, however, previously been made by Davy, viz. that ice can be melted by friction, though kept in a medium which is below the freezing point of water.

In 1843 a paper by Mr. Joule on the mechanical equivalent of heat appeared, which, though not in terms touching on the mutual and necessary dependence of all the Physical Forces, yet bears most importantly upon the doctrine.

While my third edition was going through the press I had the good fortune to make the acquaintance of M. Seguin, who informed me that his uncle, the eminent Montgolfier, had long entertained the idea that force was indestructible, though, with the exception of one sentence, in his paper on the hydraulic ram, and where he is apparently speaking of mechanical force, he has left nothing in print on the subject. Not so, however, M. Seguin himself, who in 1839, in a work on the 'Influence of Railroads,' has distinctly expressed his uncle's and his own views on the identity of heat and mechanical force, and has given a calculation of their equivalent relation, which is not far from the more recent numerical results of Mayer, Joule, and others.

Several of the great mathematicians of a much earlier period advocated the idea of what they termed the Conservation of Force, but although they considered that a body in motion would so continue for ever, unless arrested by the impact of another body, and, indeed, in the latter case, would, if elastic, still continue to move (though deflected from its course) with a force proportionate to its elasticity, yet with inelastic bodies the general, and, as far as I am aware, the universal belief was, that the motion was arrested and the force annihilated. Montgolfier went a step farther, and his hydraulic ram was to him a proof of the truth of his preconceived idea, that the shock or impact of bodies left the mechanical force undestroyed.

Previously, however, to the discoveries of the voltaic battery, electro-magnetism, thermo-electricity, and photography, it was impossible for any mind to perceive what, in the greater number of cases, became of the force which was apparently lost. The phenomena of heat, known from the earliest times, would have been a mode of accounting for the resulting force in many cases where motion was arrested, and we find Bacon announcing a theory that motion was the form, as he quaintly termed it, of heat. Rumford and Davy adopted this view, the former with a fair approximate attempt at numerical calculation, but no one of these philosophers seems to have connected it with the indestructibility of force. A passage in the writings of Dr. Roget, combating the theory that mere contact of dissimilar bodies was the source of voltaic electricity, philosophically supports his argument by the idea of non-creation of force.

As I have introduced into the later editions of my Essay abstracts of the different discoveries which I have found, since my first lectures, to bear upon the subject, I have been regarded by many rather as the historian of the progress made in this branch of thought than as one who has had anything to do with its initiation. Everyone is but a poor judge where he is himself interested, and I therefore write with diffidence, but it would be affecting an indifference which I do not feel if I did not state that I believe myself to have been the first who introduced this subject as a generalised system of philosophy, and continued to enforce it in my lectures and writings for many years, during which it met with the opposition usual and proper to novel ideas.

Avocations necessary to the well-being of others have prevented my following it up experimentally, to the extent that I once hoped; but I trust and believe that this Essay, imperfect though it be, has helped materially to impress on that portion of the public which devotes its attention rather to the philosophy of science than to what is now termed science, the truth of the thesis advocated.

To show that the work of to-day is not substantially different from the thoughts I first published on the subject, at a period when I knew little or nothing of what had been thought before, I venture to give a few extracts from the printed copy of my lecture of 1842:—

Physical Science treats of Matter, and what I shall to-night term its *Affections;* namely, Attraction, Motion, Heat, Light, Electricity, Magnetism, Chemical-Affinity. When these re-act upon matter, they constitute Forces. The present tendency of theory seems to lead to the opinion that all these Affections are resolvable into one, namely, Motion; however, should the theories on these subjects be ultimately so effectually generalised as to become laws, they cannot avoid the necessity for retaining different names for these different Affections; or, as they would then be called, different modes of Motion. . . . .

Œrsted proved that Electricity and Magnetism are two forces which act upon each other; not in straight lines, as all other known forces do, but in a rectangular direction: that is, that bodies invested with electricity, or the conduits of an electric-current, tend to place magnets at right angles to them; and, conversely, that magnets tend to place bodies conducting electricity at right angles to them. . . . .

The discovery of Œrsted, by which electricity was made a source of Magnetism, soon led philosophers to seek the converse effect; that is, to educe Electricity from a permanent magnet:—had these experimentalists succeeded in their expectations of making a stationary magnet a source of electric-currents, they would have realised the ancient dreams of perpetual motion, they would have converted statics into dynamics, they would have produced power without expenditure; in other words, they would have become creators. They failed, and Faraday saw their error; he proved that to obtain Electricity from Magnetism it was necessary to superadd to this latter, motion; that magnets while in motion induced electricity in contiguous conductors; and that the direction of such electric-currents was tangential to the polar direction of the magnet; that as Dynamic-electricity may be made the source of Magnetism and Motion, so Magnetism conjoined with Motion may be made the source of Electricity. Here originates the Science of Magneto-electricity, the true converse of Electro-magnetism; and thus between Electricity and Magnetism is shown to exist a reciprocity of force such that, considering either as the primary agent, the other becomes the re-agent; viewing one in the relation of cause, the other is the effect. . . . .

The Science of Thermo-Electricity connected heat with electricity, and proved these, like all other natural forces, to be capable of mutual reaction. . . . .

Voltaic action is Chemical action taking place at a distance or transferred through a chain of media; and the Daltonian equivalent numbers are the exponents of the amount of voltaic action for corresponding chemical substances. . . .

By regarding the quantity of electrical, as directly proportional to the efficient chemical action, and by experimentally tracing this principle, I have been fortunate enough to increase the power of the Voltaic-pile more than sixteen times, as compared with any combination previously known. . . . .

I am strongly disposed to consider that the facts of Catalysis depend upon voltaic action, to generate which three heterogeneous substances are always necessary. Induced by this belief I made some experiments on the subject, and succeeded in forming a voltaic combination by gaseous-oxygen, gaseous-hydrogen, and platinum; by which a galvanometer was deflected and water decomposed. . . . .

It appears to me that heat and light may be considered as affections; or, according to the Undulatory-theory, vibrations of matter itself, and not of a distinct etherial fluid permeating it: these vibrations would be propagated, just as sound is propagated by vibrations of wood or as waves by water. To my mind, all the consequences of the Undulatory-theory flow as easily from this, as from the hypothesis of a specific ether; to suppose which, namely, to suppose a fluid *sui generis*, and of extreme tenuity penetrating solid bodies, we must assume, first, the existence of the fluid itself; secondly, that bodies are without exception porous; thirdly, that these pores communicate; fourthly, that matter is limited in expansibility. None of these difficulties apply to the modification of this theory which I venture to propose; and no other difficulty applies to it which does not equally apply to the received hypothesis. With regard to the planetary spaces, the diminishing periods of comets is a strong argument for the existence of an universally-diffused matter: this has the function of resistance, and there appears to be no reason to divest it of the functions common to all matter, or superficially to appropriate it to certain affections. Again, the phenomena of transparency and opacity are, to my mind, more easily explicable by the former than by the latter theory; as resulting from a difference in the molecular arrangement of the matter affected. In regard to the effects of double-refraction and polarisation, the molecular gives at once a reason for the effects upon the one theory, while upon the other we must, in addition to previous assumptions, further assume a different elasticity of the ether in different directions within the doubly-refracting medium. The same theory is applicable to Electricity and Magnetism; my own experiments on the influence of the elastic intermedium on the voltaic-arc, and those of Faraday on electrical induction, furnish strong arguments in support of it. My inclination would lead me to detain you on this subject much longer than my judgment deems advisable: I therefore content myself with offering it to your consideration, and, should my avocations permit, I may at a future period more fully develope it. . . . .

Light, Heat, Electricity, Magnetism, Motion, and Chemical-affinity, are all convertible material affections; assuming either as the cause, one of the others will be the effect: thus heat may be said to produce electricity, electricity to produce heat; magnetism to produce electricity, electricity magnetism; and so of the rest. Cause and effect, therefore, in their abstract relation to these forces, are words solely of convenience: we are totally unacquainted with the ultimate generating power of each and all of them, and probably shall ever remain so; we can only ascertain the normæ of their action: we must humbly refer their causation to one omnipresent influence, and content ourselves with studying their effects and developing by experiment their mutual relations.

I have transposed the passages relating to voltaic action and catalysis, but I have not added a word to the above quotation, and, as far as I am now aware, the theory that the so-called imponderables are affections of ordinary matter, that they are resolvable into motion, that they are to be regarded in their action on matter as forces, and not as specific entities, and that they are capable of mutual reaction, thence alternately acting as cause and effect, had not at that time been publicly advanced.

My original Essays being a record of lectures, and being published by the managers of the Institution, I necessarily adhered to the form and matter which I had orally communicated. In preparing subsequent editions I found that, without destroying the identity of the work, I could not alter the style; although it would have been less difficult and more satisfactory to me to have done so, the work would not have been a republication; and I was for obvious reasons anxious to preserve as far as I could the original text, which, though added to, is but little altered.

The form of lectures has necessarily continued the use of the first person, and I would beg my readers not to attribute to me, from the modes of expression used, a dogmatism which is far from my thought. If my opinions are expressed broadly, it is that, if opinions are always hedged in by qualifications, the style becomes embarrassed and the meaning frequently unintelligible.

As a course of lectures can only be useful by inducing the auditor to consult works on the subject he hears treated, so the object of this Essay is more to induce a particular train of thought on the known facts of physical science than to enter with minute criticisms into each separate branch.

In one or two of the reviews of previous editions the general idea of the work was objected to. I believe, however, that will not now be the case; the mathematical labours of Mr. Thompson, Clausius, and others, though not suitable for insertion in an Essay such as this, have awakened an interest for many portions of the subject, which promises much for its future progress.

The short and irregular intervals which my profession permits me to devote to science so prevent the continuity of attention necessary for the proper evolution of a train of thought, that I certainly should not now have courage to publish for the first time such an Essay; and it is only the favour it has received from those whose opinions I highly value, and the, I trust pardonable, wish not to let some favourite thoughts of my youth lose all connection with my name, that have induced me to reprint it.

My scientific readers will, I hope, excuse the very short notices of certain branches of science which are introduced, as without them the work would be unintelligible to many for whom it is intended. I have endeavoured so to arrange my matter that each division should form an introduction to those which follow, and to assume no more preliminary knowledge to be possessed by my readers than would be expected from persons acquainted with the elements of physical science.

The notes contain references to the original memoirs in which the branches of science alluded to are to be found, as well as to those which bear on the main arguments; where these memoirs are numerous, or not easy of access, I have referred to treatises in which they are collated. To prevent the reader's attention being interrupted, I have in the notes referred to the pages of the text, instead of to interpolated letters.

CORRELATION

OF

PHYSICAL FORCES

I.—INTRODUCTORY REMARKS.

WHEN natural phenomena are for the first time observed, a tendency immediately developes itself to refer them to something previously known—to bring them within the range of acknowledged sequences. The mode of regarding new facts, which is most favourably received by the public, is that which refers them to recognised views—stamps them into the mould in which the mind has been already shaped. The new fact may be far removed from those to which it is referred, and may belong to a different order of analogies, but this cannot then be known, as its co-ordinates are wanting. It may be questionable whether the mind is not so moulded by past events that it is impossible to advance an entirely new view, but admitting such possibility, the new view, necessarily founded on insufficient data, is likely to be more incorrect and prejudicial than even a strained attempt to reconcile the new discovery with known facts.

The theory consequent upon new facts, whether it be a co-ordination of them with known ones, or the more difficult and dangerous attempt at remodelling the public ideas, is generally enunciated by the discoverers themselves of the facts, or by those to whose authority the world at the period of the discovery defers; others are not bold enough, or if they be so, are unheeded. The earliest theories thus enunciated obtain the firmest hold upon the public mind, for at such a time there is no power of testing, by a sufficient range of experience, the truth of the theory; it is accepted solely or mainly upon authority: there being no means of contradiction, its reception is, in the first instance, attended with some degree of doubt. but as the time in which it can fairly be investigated far exceeds that of any lives then in being, and as neither the individual nor the public mind will long tolerate a state of abeyance, a theory shortly becomes, for want of a better, admitted as an established truth: it is handed from father to son, and gradually takes its place in education. Succeeding generations, whose minds are thus formed to an established view, are much less likely to abandon it. They have adopted it in the first instance, upon authority, to them unquestionable, and subsequently to yield up their faith would involve a laborious remodelling of ideas, a task which the public as a body will and can rarely undertake, the frequent occurrence of which is indeed inconsistent with the very existence of man in a social state, as it would induce an anarchy of thought—a perpetuity of mental revolutions.

This necessity has its good; but the prejudicial effect upon the advance of science is, that by this means, theories the most immature frequently become the most permanent; for no theory can be more immature, none is likely to be so incorrect, as that which is formed at the first flush of a new discovery; and though time exalts the authority of those from whom it emanated, time can never give to the illustrious dead the means of analysing and correcting erroneous views which subsequent discoveries confer.

Take for instance the Ptolemaic System, which we may almost literally explain by the expression of Shakspeare: 'He that is giddy thinks the world turns round.' We now see the error of this system, because we have all an immediate opportunity of refuting it; but this identical error was received as a truth for centuries, because, when first promulgated, the means of refuting it were not at hand, and when the means of its refutation became attainable, mankind had been so educated to the supposed truth, that they rejected the proof of its fallacy.

I have premised the above for two reasons: first to obtain a fair hearing, by requesting as far as possible a dismissal from the mind of my readers of preconceived views by and in favour of which all are liable to be prejudiced; and secondly, to defend myself from the charge of undervaluing authority, or treating lightly the opinions of those to whom and to whose memory mankind looks with reverence. Properly to value authority, we should estimate it together with its means of information: if 'a dwarf on the shoulders of a giant can see further than the giant,' he is no less a dwarf in comparison with the giant.

The subject on which I am about to treat—viz., the relation of the affections of matter to each other and to matter—peculiarly demands an unprejudiced regard. The different aspects under which these agencies have been contemplated; the different views which have been taken of matter itself; the metaphysical subtleties to which these views unavoidably lead, if pursued beyond fair inductions from existing experience, present difficulties almost insurmountable.

The extent of claim which my views on this subject may have to originality has been stated in the Preface; they became strongly impressed upon my mind at a period when I was much engaged in experimental research, and were, as I then believed, and still believe, regarding them as a system, new: expressions in the works of different authors, bearing more or less on the subject, have subsequently been pointed out to me, some of which go back to a distant period. An attempt to analyse these in detail, and to trace how far I have been anticipated by others, would probably but little interest the reader, and in the course of it I should constantly have to make distinctions showing wherein I differed, and wherein I agreed with others. I might cite authorities which appear to me to oppose, and others which appear to coincide with certain of the views I have put forth; but this would interrupt the consecutive developement of my own ideas, and might render me liable to the charge of misconstruing those of others; I therefore think it better to avoid such discussion in the text; and in addition to the sketch given in the Preface, to furnish in the notes at the conclusion such references to different authors as bear upon the subjects treated of, which I have discovered, or which have been pointed out to me since the delivery of the lectures of which this essay is a record.

The more extended our research becomes, the more we find that knowledge is a thing of slow progression, that the very notions which appear to ourselves new, have arisen, though perhaps in a very indirect manner, from successive modifications of traditional opinions. Each word we utter, each thought we think, has in it the vestiges, is in itself the impress, of antecedent words and thoughts. As each material form, could we rightly read it, is a book, containing in itself the past history of the world; so, different though our philosophy may now appear to be from that of our progenitors, it is but theirs added to or subtracted from, transmitted drop by drop through the filter of antecedent, as ours will be through that of subsequent, ages.—The relic is to the past as is the germ to the future.

Though many valuable facts, and correct deductions from them, are to be found scattered amongst the voluminous works of the ancient philosophers; yet, giving them the credit which they pre-eminently deserve for having devoted their lives to purely intellectual pursuits, and for having thought, seldom frivolously, often profoundly, nothing can be more difficult than to seize and apprehend the ideas of those who reasoned from abstraction to abstraction—who, although, as we now believe, they must have depended upon observation for their first inductions, afterwards raised upon them such a complex superstructure of syllogistic deductions, that, without following the same paths, and tracing the same sinuosities which led them to their conclusions, such conclusions are to us unintelligible. To think as another thought, we must be placed in the same situation as he was placed: the errors of commentators generally arise from their reasoning upon the arguments of their text, either in blind obedience to its dicta, without considering the circumstances under which they were uttered, or in viewing the images presented to the original writer from a different point to that from which he viewed them. Experimental philosophy keeps in check the errors both of *à priori* reasoning and of commentators, and, at all events, prevents their becoming cumulative; though the theories or explanations of a fact be different, the fact remains the same. It is, moreover, itself the exponent of its discoverer's thought: the observation of known phenomena has led him to elicit from nature the new phenomena: and, though he may be wrong in his deductions from this after its discovery, the reasonings which conducted him to it are them selves valuable, and, having led from known to unknown truths, can seldom be uninstructive.

Very different views existed amongst the ancients as to the aims to be pursued by physical investigation, and as to the objects likely to be attained by it. I do not here mean the moral objects, such as the attainment of the *summum bonum*, &c.—but the acquisitions in knowledge which such investigations were likely to confer. Utility was one object in view, and this was to some extent attained by the progress made in astronomy and mechanics; Archimedes, for instance, seems to have constantly had this end in view; but, while pursuing natural knowledge for the sake of knowledge and the power which it brings with it, the greater number seemed to entertain an expectation of arriving at some ultimate goal, some point of knowledge, which would give them a mastery over the mysteries of nature, and would enable them to ascertain what was the most intimate structure of matter, and the causes of the changes it exhibits. Where they could not discover, they speculated. Leucippus, Democritus, and others, have given us their notions of the ultimate atoms of which matter was formed, and of the *modus agendi* of nature in the various transformations which matter undergoes.

The expectation of arriving at ultimate causes or essences continued long after the speculations of the ancients had been abandoned, and continues even to the present day to be a very general notion of the objects to be ultimately attained by physical science. Francis Bacon, the great remodeller of science, entertained this notion, and thought that, by experimentally testing natural phenomena, we should be enabled to trace them to certain primary essences or causes whence the various phenomena flow. These he speaks of under the scholastic name of 'forms'—a term derived from the ancient philosophy, but differently applied. He appears to have understood by 'form' the essence of quality—that in which, abstracting everything extraneous, a given quality consists, or that which, superinduced on any body, would give it its peculiar quality: thus the form of transparency, is that which constitutes transparency, or that by which, when discovered, transparency could be produced or superinduced. To take a specific example of what I may term the synthetic application of his philosophy:—'In gold there meet together yellowness, gravity, malleability, fixedness in the fire, a determinate way of solution, which are the simple natures in gold; for he who understands form, and the manner of superinducing this yellowness, gravity, ductility, fixedness, faculty of fusion, solution, &c., with their particular degrees and proportions, will consider how to join them together in some body, so that a transmutation into gold shall follow.'

On the other hand, the analytic method, or, 'the enquiry from what origin gold or any other metal or stone is generated from its first fluid matter or rudiments, up to a perfect mineral,' is to be perceived by what Bacon calls the latent process, or a search for 'what in every generation or transformation of bodies, flies off, what remains behind, what is added, what separated, &c.; also, in other alterations and motions, what gives motion, what governs it, and the like.' Bacon appears to have thought that qualities separate from the substances themselves were attainable, and if not capable of physical isolation, were at all events capable of physical transference and superinduction.

Subsequently to Bacon a belief has generally existed, and now to a great extent exists, in what are called secondary causes, or consequential steps, wherein one phenomenon is supposed necessarily to hang on another, until at last we arrive at an essential cause, subject immediately to the First Cause. This notion is generally prevalent both on the Continent and in this country: nothing is more familiar than the expression 'study the effects in order to arrive at the causes.'

Instead of regarding the proper object of physical science as a search after essential causes, I believe it ought to be, and must be, a search after facts and relations—that although the word Cause may be used in a secondary and concrete sense, as meaning antecedent forces, yet in an abstract sense it is totally inapplicable; we cannot predicate of any physical agency that it is abstractedly the cause of another; and if, for the sake of convenience, the language of secondary causation be permissible, it should be only with reference to the special phenomena referred to, as it can never be generalised.

The misuse, or rather varied use, of the term Cause, has been a source of great confusion in physical theories, and philosophers are even now by no means agreed as to their conception of causation. The most generally received view of causation, that of Hume, refers it to invariable antecedence —i. e., we call that a cause which invariably precedes, that an effect which invariably succeeds. Many instances of invariable sequence might however be selected, which do not present the relation of cause and effect: thus as Reed observes, and Brown does not satisfactorily answer, day invariably precedes night and yet day is not the cause of night. The seed, again, precedes the plant, but is not the cause of it; so that when we study physical phenomena it becomes difficult to separate the idea of causation from that of force, and these have been regarded as identical by some philosophers. To take an example which will contrast these two views: if a floodgate be raised, the water flows out; in ordinary parlance, the water is said to flow *because* the floodgate is raised: the sequence is invariable; no floodgate, properly so called, can be raised without the water flowing out, and yet in another, and perhaps more strict, sense, it is the gravitation of the water which *causes* it to flow. But though we may truly say that, in this instance, gravitation causes the water to flow, we cannot in truth abstract the proposition, and say, generally, that gravitation is the cause of water flowing, as water may flow from other causes, gaseous elasticity, for instance, which will cause water to flow from a receiver full of air into one that is exhausted; gravitation may also, under certain circumstances, arrest instead of cause the flow of water.

Upon neither view, however, can we get at anything like abstract causation. If we regard causation as invariable sequence, we can find no case in which a given antecedent is the only antecedent to a given sequent: thus if water could flow from no other cause than the withdrawal of a floodgate, we might say abstractedly that this was the cause of water flowing. If, again, adopting the view which looks to causation as a force, we could say that water could be caused to flow only by gravitation, we might say abstractedly that gravitation was the cause of water flowing—but this we cannot say; and if we seek and examine any other example, we shall find that causation is only predicable of it in the particular case, and cannot be supported as an abstract proposition; yet this is constantly attempted. Nevertheless, in each *particular* case where we speak of Cause, we habitually refer to some antecedent power or force: we never see motion or any change in matter take effect without regarding it as produced by some previous change; and when we cannot trace it to its antecedent, we mentally refer it to one; but whether this habit be philosophically correct is by no means clear. In other words, it seems questionable, not only whether cause and effect are convertible terms with antecedence and sequence, but whether in fact cause does precede effect, whether force does precede the change in matter of which it is said to be the cause.

The actual priority of cause to effect has been doubted, and their simultaneity argued with much ability. As an instance of this argument it may be said, the attraction which causes iron to approach the magnet is simultaneous with and ever accompanies the movement of the iron; the movement is evidence of the co-existing cause or force, but there is no evidence of any interval in time between the one and the other. On this view time would cease to be a necessary element in causation; the idea of cause, except perhaps as referred to a primeval creation, would cease to exist; and the same arguments which apply to the simultaneity of cause with effect would apply to the simultaneity of Force with Motion. We could not, however, even if we adopted this view, dispense with the element of time in the sequence of phenomena; the effect being thus regarded as ever accompanied simultaneously by its appropriate cause, we should still refer it to some antecedent effect; and our reasoning as applied to the successive production of all natural changes would be the same.

Habit and the identification of thoughts with phenomena so compel the use of recognised terms, that we cannot avoid using the word cause even in the sense to which objection is taken; and if we struck it out of our vocabulary, our language, in speaking of successive changes, would be unintelligible to the present generation. The common error, if I am right in supposing it to be such, consists in the abstraction of cause, and in supposing in each case a general secondary cause—a something which is not the first cause, but which, if we examine it carefully, must have all the attributes of a first cause, and an existence independent of, and dominant over, matter.

The relations of electricity and magnetism afford us a very instructive example of the belief in secondary causation. Subsequent to the discovery by Oersted of electro-magnetism, and prior to that by Faraday of magneto-electricity, electricity and magnetism were believed by the highest authorities to stand in the relation of cause and effect—i. e. electricity was regarded as the cause, and magnetism as the effect; and where magnets existed without any apparent electrical currents to cause their magnetism, hypothetical currents were supposed, for the purpose of carrying out the causative view; but magnetism may now be said with equal truth to be the cause of electricity, and electrical currents may be referred to hypothetical magnetic lines: if therefore electricity cause magnetism, and magnetism cause electricity, why then electricity causes electricity, which becomes, so to speak, a *reductio ad absurdum* of the doctrine.

To take another instance, which may render these positions more intelligible. By heating bars of bismuth and antimony in contact, a current of electricity is produced; and if their extremities be united by a fine wire, the wire is heated. Now here the electricity in the metals is said to be caused by heat, and the heat in the wire to be caused by electricity, and in a concrete sense this is true; but can we thence say abstractedly that heat is the cause of electricity, or that electricity is the cause of heat? Certainly not; for if either be true, both must be so, and the effect then becomes the cause of the cause, or, in other words, a thing causes itself. Any other proposition on this subject will be found to involve similar difficulties, until, at length, the mind will become convinced that abstract secondary causation does not exist, and that a search after essential causes is vain.

The position which I seek to establish in this Essay is, that the various affections of matter which constitute the main objects of experimental physics, viz., heat, light, electricity, magnetism, chemical affinity, and motion, are all correlative, or have a reciprocal dependence; that neither, taken abstractedly, can be said to be the essential cause of the others, but that either may produce or be convertible into, any of the others: thus heat may mediately or immediately produce electricity, electricity may produce heat; and so of the rest, each merging itself as the force it produces becomes developed: and that the same must hold good of other forces, it being an irresistible inference from observed phenomena that a force cannot originate otherwise than by devolution from some pre-existing force or forces.

The term force, although used in very different senses by different authors, in its limited sense may be defined as that which produces or resists motion. Although strongly inclined to believe that the other affections of matter, which I have above named, are, and will ultimately be resolved into, modes of motion, many arguments for which will be given in subsequent parts of this Essay, it would be going too far, at present, to assume their identity with it; I therefore use the term force in reference to them, as meaning that active principle inseparable from matter which is supposed to induce its various changes.

The word force and the idea it aims at expressing might be objected to by the purely physical philosopher on similar grounds to those which apply to the word cause, as it represents a subtle mental conception, and not a sensuous perception or phenomenon. The objection would take something of this form. If the string of a bent bow be cut, the bow will straighten itself; we thence say there is an elastic *force* in the bow which straightens it; but if we applied our expressions to this experiment alone, the use of the term force would be superfluous, and would not add to our knowledge on the subject. All the information which our minds could get would be as sufficiently obtained from the expression, when the string is cut, the bow becomes straight, as from the expression, the bow becomes straight by its elastic force. Do we know more of the phenomena, viewed without reference to other phenomena, by saying it is produced by force? Certainly not. All we know or see is the effect; we do not see force—we see motion or moving matter.

If now we take a piece of caoutchouc and stretch it, when released it returns to its original length. Here, though the subject-matter is very different, we see some analogy in the effect or phenomenon to that of the strung bow. If again we suspend an apple by a string, cut the string, the apple falls. Here, though it is less striking, there is still an analogy to the strung bow and the caoutchouc.

Now when the word force is employed as comprehending these three different phenomena we find some use in the term, not by its explaining or rendering more intelligible the *modus agendi* of matter, but as conveying to the mind something which is alike in the three phenomena, however distinct they may be in other respects: the word becomes an abstract or generalised expression, and regarded in this light is of high utility. Although I have given only three examples, it is obvious that the term would equally apply to 300 or 3,000 examples.

But it will be said, the term force is used not as expressing the effect, but as that which produces the effect. This is true, and in this its ordinary sense I shall use it in these pages. But though the term has a potential meaning, to depart from which would render language unintelligible, we must guard against supposing that we know essentially more of the phe nomena by saying they are produced by something, which something is only a word derived from the constancy and similarity of the phenomena we seek to explain by it. The relations of the phenomena to which the terms force or forces are applied give us real knowledge; these relations may be called relations of forces; our knowledge of them is not thereby lessened, and the convenience of expression is greatly in creased, but the separate phenomena are not more intimately known; no further insight into why the apple falls is acquired by saying it is forced to fall, or it falls by the force of gravita tion; by the latter expression we are enabled to relate it most usefully to other phenomena, but we still know no more of the particular phenomenon than that under certain circumstances the apple does fall.

In the above illustrations, force has been treated as the producer of motion, in which case the evidence of the force is the motion produced; thus we estimate the force used to project a cannon ball in terms of the mass of matter, and the velocity with which it is projected. The evidence of force when the term is applied to resistance to motion is of a somewhat different character; the matter resisting is molecularly affected, and has its structure more or less changed; thus a strip of caoutchouc to which a weight is suspended is elongated, and its molecules are displaced as compared with their position when unaffected by the gravitating force. So a piece of glass bent by an appended weight has its whole structure changed; this internal change is made evident by transmitting through it a beam of polarised light: a relation thus becomes established between the molecular state of bodies and the external forces or motion of masses. Every particle of the caoutchouc or glass must be acting and contributing to resist or arrest the motion of the mass of matter appended to it.

It is difficult, in such cases, not to recognise a reality in force. We need some word to express this state of tension; we know that it produces an effect, though the effect be negative in character: although in this effort of inanimate matter we can no more trace the mode of action to its ultimate elements than we can follow out the connection of our own muscles with the volition which calls them into action, we are experimentally convinced that matter changes its state by the agency of other matter, and this agency we call force.

In placing the weight on the glass, we have moved the former to an extent equivalent to that which it would again describe if the resistance were removed, and this motion of the mass becomes an exponent or measure of the force exerted on the glass; while this is in the state of tension, the force is ever existing, capable of reproducing the original motion, and while in a state of abeyance as to actual motion, it is really acting on the glass. The motion is suspended, but the force is not annihilated.

But it may be objected, if tension or static force be thus motion in abeyance, there is at all times a large amount of dynamical action subtracted from the universe. Every stone upon a hill, every spring that is bent, and has required force to upraise or bend it, has for a time, and possibly for ever, withdrawn this force, and annihilated it. Not so; what takes place when we raise a weight and leave it at the point to which it has been elevated? we have changed the centre of gravity of the earth, and consequently the earth's position with reference to the sun, planets, and stars; the effort we have made pervades and shakes the universe; nor can we present to the mind any exercise of force, which is thus not permanent in its dynamical effects. If, instead of one weight being raised, we raise two weights, each placed at a point diametrically opposite the other, it would be said, here you have compensation, a balance, no change in the centre of gravity of the earth; but we have increased the mean diameter of the earth, and a perturbation of our planet, and of all other celestial bodies necessarily ensues.

The force may be said to be in abeyance with reference to the effect it would have produced, if not arrested, or placed in a state of tension; but in the act of imposing this state, the relations of equilibrium with other bodies have been changed, and these move in their turn, so that motion of the same amount would seem to be ever affecting matter conceived in its totality.

Press the hands violently together; the first notion may be that this is power locked up, and that no change ensues. Not so; the blood courses more quickly, respiration is accelerated, changes which we may not be able to trace, take place in the muscles and nerves, transpiration is increased; we have given off force in various ways, and must, if the effort be prolonged, replenish our sources of power, by fresh chemical action in the stomach.

In books which treat of statics and dynamics, it is common and perhaps necessary to isolate the subjects of consideration; to suppose, for instance, two bodies gravitating, and to ignore the rest of the universe. But no such isolation exists in reality, nor could we predict the result if it did exist. Would two bodies gravitate towards each other in empty space, if space can be empty? the notion that they would is founded on the theory of attraction, which Newton himself repudiated, further than as a convenient means of regarding the subject. For purposes of instruction or argument it may be convenient to assume isolated matter: many conclusions so arrived at may be true, but many will be erroneous.

If, in producing effects of tension or of static force, the effort made pervades the universe, it may be said, when the bent spring is freed, when the raised weight falls, a converse series of motions must be effected, and this theory would lead to a mere reciprocation, which would be equally unproductive of permanent change with the annihilation of force. If raising the weight has changed the centre of gravity of the earth, and thence of the universe, the fall of the weight, it will be said, restores the original centre of gravity, and everything comes back to its original status. In this argument we again, in thought, isolate our experiment; we neglect surrounding circumstances. Between the time of the raising and falling of the weight, be the interval never so small, nay, more, during the rising and during the fall, the earth has been going on revolving round its axis and round the sun, to say nothing of other changes, such as temperature, cosmical magnetism, &c., which we may call accidental, but which, if we knew all, would probably be found to be as necessary and as reducible to law as the motion of the earth. A change having taken place, the fall of the weight does not bring back the *status quo*, but other changes supervene, and so on. Nothing repeats itself, because nothing can be placed again in the same condition: the past is irrevocable.