# THE CENTURY'S PROGRESS IN PHYSICS.

BY HENRY SMITH WILLIAMS, M D.

## PART I.—THE "IMPONDERABLES."

### I.

THERE were giants abroad in the world of science in the early days of our century. Herschel, Lagrange, and Laplace; Cuvier, Brongniart, and Lamarck; Humboldt, Goethe, Priestley—what need to extend the list?—the names crowd upon us. But among them all there was no taller intellectual figure than that of a young Quaker who came to settle in London and practise the profession of medicine in the year 1801. The name of this young aspirant to medical honors and emoluments was Thomas Young. He came fresh from professional studies at Edinburgh and on the Continent, and he had the theory of medicine at his tongue's end; yet his medical knowledge, compared with the mental treasures of his capacious intellect as a whole, was but as a drop of water in the ocean.

Incidentally the young physician was prevailed upon to occupy the interims of early practice by fulfilling the duties of the chair of Natural Philosophy at the Royal Institution, which Count Rumford had founded, and of which Davy was then Professor of Chemistry—the institution whose glories have been perpetuated by such names as Faraday and Tyndall, and which the Briton of to-day speaks of as the "Pantheon of Science."

As early as 1793, when he was only twenty, Young had begun to communicate papers to the Royal Society of London, which were adjudged worthy to be printed in full in the Philosophical Transactions; so it is not strange that he should have been asked to deliver the Bakerian lecture before that learned body the very first year after he came to London. The lecture was delivered November 12, 1801. Its subject was "The Theory of Light and Colors," and its reading marks an epoch in physical science; for here for the first time was brought forward convincing proof of that undulatory theory of light with which every student of modern physics is familiar—the theory which holds that light is not a corporeal entity, but a mere pulsation in the substance of an all-pervading ether, just as sound is a pulsation in the air, or in liquids or solids.

Young had, indeed, advocated this theory at an earlier date, but it was not until 1801 that he hit upon the idea which enabled him to bring it to anything approaching a demonstration. It was while pondering over the familiar but puzzling phenomena of colored rings into which white light is broken when reflected from thin films—Newton's rings, so called—that an explanation occurred to him which at once put the entire undulatory theory on a new footing. With that sagacity of insight which we call genius, he saw of a sudden that the phenomena could be explained by supposing that when rays of light fall on a thin glass, part of the rays being reflected from the upper surface, other rays, reflected from the lower surface, might be so retarded in their course through the glass that the two sets would interfere with one another, the forward pulsation of one ray corresponding to the backward pulsation of another, thus quite neutralizing the effect. Some of the component pulsations of the light being thus effaced by mutual interference, the remaining rays would no longer give the optical effect of white light; hence the puzzling colors.

By following up this clew with mathematical precision, measuring the exact thickness of the plate and the space between the different rings of color, Young was able to show mathematically what must be the length of pulsation for each of the different colors of the spectrum. He estimated that the undulations of red light, at the extreme lower end of the visible spectrum, must number about 37,640 to the inch, and pass any given spot at a rate of 463 millions of millions of undulations in a second, while the extreme violet numbers 59,750 undulations to the inch, or 735 millions of millions to the second.

Young similarly examined the colors that are produced by scratches on a smooth surface, in particular testing the light from "Mr. Coventry's exquisite micrometers," which consist of lines scratched on glass at measured intervals. These microscopic tests brought the same results as the other experiments. The colors were produced at certain definite and measurable angles, and the theory of interference of undulations explained them perfectly, while, as Young affirmed with confidence, no other theory hitherto advanced could explain them at all. Taking all the evidence together, Young declared that he considered the argument he had set forth in favor of the undulatory theory of light to be "sufficient and decisive."

This doctrine of interference of undulations was the absolutely novel part of Young's theory. The all-compassing genius of Robert Hooke had, indeed, very nearly apprehended it more than a century before, as Young himself points out, but no one else had so much as vaguely conceived it; and even with the sagacious Hooke it was only a happy guess, never distinctly outlined in his own mind, and utterly ignored by all others. Young did not know of Hooke's guess until he himself had fully formulated the theory, but he hastened then to give his predecessor all the credit that could possibly be adjudged his due by the most disinterested observer. To Hooke's contemporary, Huyghens, who was the originator of the general doctrine of undulation as the explanation of light, Young renders full justice also. For himself he claims only the merit of having demonstrated the theory which these and a few others of his predecessors had advocated without full proof.

The following year Dr. Young detailed before the Royal Society other experiments, which threw additional light on the doctrine of interference; and in 1803 he cited still others, which, he affirmed, brought the doctrine to complete demonstration. In applying this demonstration to the general theory of light, he made the striking suggestion that "the luminiferous ether pervades the substance of all material bodies with little or no resistance, as freely, perhaps, as the wind passes through a grove of trees." He asserted his belief also that the chemical rays which Ritter had discovered beyond the violet end of the visible spectrum are but still more rapid undulations of the same character as those which produce light. In his earlier lecture he had affirmed a like affinity between the light rays and the rays of radiant heat which Herschel detected below the red end of the spectrum, suggesting that "light differs from heat only in the frequency of its undulations or vibrations—those undulations which are within certain limits with respect to frequency affecting the optic nerve and constituting light, and those which are slower and probably stronger constituting heat only." From the very outset he had recognized the affinity between sound and light; indeed, it had been this affinity that led him on to an appreciation of the undulatory theory of light.

But while all these affinities seemed so clear to the great co-ordinating brain of Young, they made no such impression on the minds of his contemporaries. The immateriality of light had been substantially demonstrated, but practically no one save its author accepted the demonstration. Newton's doctrine of the emission of corpuscles was too firmly rooted to be readily dislodged, and Dr. Young had too many other interests to continue the assault unceasingly. He occasionally wrote something touching on his theory, mostly papers contributed to the *Quarterly Review* and similar periodicals, anonymously or under a pseudonym, for he had conceived the notion that too great conspicuousness in fields outside of medicine would injure his practice as a physician. His views regarding light (including the original papers from the Philosophical Transactions of the Royal Society) were again given publicity in full in his celebrated volume on natural philosophy, consisting in part of his lectures before the Royal Institution, published in 1807; but even then they failed to bring conviction to the philosophic world. Indeed, they did not even arouse a controversial spirit, as his first papers had done.

So it chanced that when, in 1815, a young French military engineer, named Augustin Jean Fresnel, returning from the Napoleonic wars, became interested in the phenomena of light, and made some experiments concerning diffraction, which seemed to him to controvert the accepted notions of the materiality of light, he was quite unaware that his experiments had been anticipated by a philosopher across the Channel. He communicated his experiments and results to the French Institute, supposing them to be absolutely novel. That body referred them to a committee, of which, as good fortune would have it, the dominating member was Dominique François Arago, a man as versatile as Young himself, and hardly less profound, if perhaps not quite so original. Arago at once recognized the merit of Fresnel's work, and soon became a convert to the theory. He told Fresnel that Young had anticipated him as regards the general theory, but that much remained to be done, and he offered to associate himself with Fresnel in prosecuting the investigation. Fresnel was not a little dashed to learn that his original ideas had been worked out by another while he was a lad, but he bowed gracefully to the situation, and went ahead with unabated zeal.

The championship of Arago insured the undulatory theory a hearing before the French Institute, but by no means sufficed to bring about its general acceptance. On the contrary, a bitter feud ensued, in which Arago was opposed by the "Jupiter Olympius of the Academy," Laplace, by the only less famous Poisson, and by the younger but hardly less able Biot. So bitterly raged the feud that a life-long friendship between Arago and Biot was ruptured forever. The opposition managed to delay the publication of Fresnel's papers, but Arago continued to fight with his customary enthusiasm and pertinacity, and at last, in 1823, the Academy yielded, and voted Fresnel into its ranks, thus implicitly admitting the value of his work.

After Fresnel's admission to the Institute in 1823 the opposition weakened, and gradually the philosophers came to realize the merits of a theory which Young had vainly called to their attention a full quarter-century before.

## II.

The full importance of Young's studies of light might perhaps have gained earlier recognition had it not chanced that, at the time when they were made, the attention of the philosophic world was turned upon another field, which for a time brooked no rival. How could the old familiar phenomenon, light, interest any one when the new agent, galvanism, was in view?

The question of the hour was whether in galvanism the world had to do with a new force, or whether it is identical with electricity, masking under a new form. Very early in the century the profound, if rather captious, Dr. Wollaston made experiments which seemed to show that the two are identical; and by 1807 Dr. Young could write in his published lectures, "The identity of the general causes of electrical and of galvanic effects is now doubted by few." To be entirely accurate he should have added, "by few of the leaders of scientific thought," for the lesser lights were by no means so fully agreed as the sentence cited might seem to imply.

But meantime an even more striking affinity had been found for the new agent galvanism. From the first it had been the chemists rather than the natural philosophers—the word physicist was not then in vogue—who had chiefly experimented with Volta's battery; and the acute mind of Humphry Davy at once recognized the close relationship between chemical decomposition and the appearance of the new "imponderable." The great Swedish chemist Berzelius also had an inkling of the same thing. But it was Davy who first gave the thought full expression, in a Bakerian lecture before the Royal Society in 1806—the lecture which gained him not only the plaudits of his own countrymen, but the Napoleonic prize of the French Academy at a time when the political bodies of the two countries were in the midst of a sanguinary war.

Here it was that Davy explicitly stated his belief that "chemical and electrical attraction are produced by the same cause, acting in one case on particles, in the other on masses," and that "the same property under different modifications is the cause of all the phenomena exhibited by different voltaic combinations." The phenomena of galvanism were thus linked with chemical action on the one hand, and with frictional electricity on the other, in the first decade of the century. But there the matter rested for another decade. Davy, whose penetrative genius must have carried him further had it not been diverted, became more and more absorbed in the chemical side of the problem. For a time no master-generalizer came to take the place of these men in their study of the "imponderables" as such, and the phenomena of electricity occupied an isolated corner in the realm of science, linked, as has been said, rather to chemistry than to the field we now term physics.

But in the year 1819 there flashed before the philosophic world, like lightning from a clear sky, the report that Hans Christian Oersted, the Danish philosopher, had discovered that the magnetic needle may be deflected by the passage near it of a current of electricity. The experiment was repeated everywhere. Its validity was beyond question, its importance beyond estimate. Many men had vaguely dreamed that there might be some connection between electricity and magnetism—chiefly because each shows phenomena of seeming attraction and repulsion—but here was the first experimental evidence that any such connection actually exists. The wandering eye of science was recalled to electricity as suddenly and as irresistibly as it had been in 1800 by the discovery of the voltaic pile. But now it was the physical rather than the chemical side of the subject that chiefly demanded attention.

At once André Marie Ampère, whom the French love to call the Newton of electricity, appreciated the far-reaching importance of the newly disclosed relationship, and combining mathematical and experimental studies, showed how close is the link between electricity and magnetism, and suggested the possibility of signalling at a distance by means of electric wires associated with magnetic needles. Gauss, the great mathematician, and Weber, the physicist, put this idea to a practical test by communicating with one another at a distance of several roods, in Göttingen, long before "practical" telegraphy grew out of Oersted's discovery.

A new impetus thus being given to the investigators, an epoch of electrical discovery naturally followed. For a time interest centred on the French investigators, in particular upon the experiments of the ever-receptive Arago, who discovered in 1825 that magnets may be produced at will by electrical induction. But about 1830 the scene shifted to London; for then the protégé of Davy, and his successor in the Royal Institution, Michael Faraday, the "man who added to the powers of his intellect all the graces of the human heart," began that series of electrical experiments at the Royal Institution which were destined to attract the dazed attention of the philosophic world, and stamp their originator as "the greatest experimental philosopher the world has ever seen." Nor does the rank of prince of experimenters do Faraday full justice, for he was far more than a mere experimenter.

In 1831 Faraday opened up the field of magneto-electricity. Reversing the experiments of his predecessors, who had found that electric currents may generate magnetism, he showed that magnets have power under certain circumstances to generate electricity; he proved, indeed, the interconvertibility of electricity and magnetism. Then he showed that all bodies are more or less subject to the influence of magnetism, and that even light may be affected by magnetism as to its phenomena of polarization. He satisfied himself completely of the true identity of all the various forms of electricity, and of the convertibility of electricity and chemical action. Thus he linked together light, chemical affinity, magnetism, and electricity. And, moreover, he knew full well that no one of these can be produced in indefinite supply from another. Nowhere, he says, "is there a pure creation or production of power without a corresponding exhaustion of something to supply it."

When Faraday wrote those words in 1840 he was treading on the very heels of a greater generalization than any he actually formulated. He saw a great truth without fully realizing its import; it was left for others, approaching the same truth along another path, to point out its full significance.

## III.

The great generalization which Faraday so narrowly missed is the truth which since then has become familiar as the doctrine of the conservation of energy—the law that in transforming energy from one condition to another we can never secure more than an equivalent quantity; that, in short, "to create or annihilate energy is as impossible as to create or annihilate matter; that all the phenomena of the material universe consist in transformations of energy alone."

A vast generalization such as this is never a mushroom growth, nor does it usually spring full grown from the mind of any single man. Always a number of minds are very near a truth before any one mind fully grasps it. Pre-eminently true is this of the doctrine of conservation of energy. Not Faraday alone, but half a dozen different men had an inkling of it before it gained full expression; indeed, every man who advocated the undulatory theory of light and heat was verging toward the goal. The doctrine of Young and Fresnel was as a highway leading surely on to the wide plain of conservation. The phenomena of electromagnetism furnished another such highway. But there was yet another road which led just as surely, and even more readily, to the same goal. This was the road furnished by the phenomena of heat, and the men who travelled it were destined to outstrip their fellow-workers. Just at the close of the last century Count Rumford and Humphry Davy independently showed that labor may be transformed into heat, and correctly interpreted this fact as meaning the transformation of molar into molecular motion. We can hardly doubt that each of these men of genius realized, vaguely, at any rate, that there must be a close correspondence between the amount of the molar and the molecular motions; hence that each of them was in sight of the law of the mechanical equivalent of heat. In 1824, a French philosopher, Sadi Carnot, caught step with the great Englishmen, and took a long leap ahead by explicitly stating his belief that a definite quantity of work could be transformed into a definite quantity of heat, no more, no less. His conclusions made no impression whatever upon his contemporaries. Carnot's work in this line was an isolated phenomenon of historical interest; it did not enter into the scheme of the completed narrative in any such way as did the work of Rumford and Davy.

The man who really took up the broken thread where Rumford and Davy had dropped it, and wove it into a completed texture, was James Prescott Joule, who came upon the scene in 1840. His home was in Manchester, England, his occupation that of a manufacturer. Joule's work it was, done in the fifth decade of our century, which demonstrated beyond all cavil that there is a precise and absolute equivalence between mechanical work and heat; that whatever the form of manifestation of molar motion, it can generate a definite and measurable amount of heat, and no more. Joule found, for example, that at the sea-level in Manchester a pound weight falling through 772 feet could generate enough heat to raise the temperature of a pound of water one degree Fahrenheit. There was nothing haphazard, nothing accidental, about this; it bore the stamp of unalterable law. And Joule himself saw, what others in time were made to see, that this truth is merely a particular case within a more general law. If heat cannot be in any sense created, but only made manifest as a transformation of another kind of motion, then must not the same thing be true of all those other forms of "force"—light, electricity, magnetism—which had been shown to be so closely associated, so mutually convertible, with heat? The law of the mechanical equivalent of heat then became the main corner-stone of the greater law of the conservation of energy. Colding, a philosopher of Copenhagen, had hit upon the same idea, and carried it far toward a demonstration. In Germany three other men were independently on the track of the same truth, and two of them, it must be admitted, reached it earlier than either Joule or Colding. The names of these three Germans are Mohr, Mayer, and Helmholtz.

As to Karl Friedrich Mohr, it may be said that his statement of the doctrine preceded that of any of his fellows, yet that otherwise it was perhaps least important. In 1837 this thoughtful German had grasped the main truth, and given it expression in an article published in the *Zeitschrift für Physik*, etc. Five years later, in 1842, Dr. Julius Robert Mayer, practising physician in the little German town of Heilbronn, published a paper in Liebig's *Annalen* on "The Forces of Inorganic Nature," in which not merely the mechanical theory of heat but the entire doctrine of the conservation of energy was explicitly if briefly stated. Two years earlier Dr. Mayer, while surgeon to a Dutch India vessel cruising in the tropics, had observed that the venous blood of a patient seemed redder than venous blood usually is observed to be in temperate climates. He pondered over this seemingly insignificant fact, and at last reached the conclusion that the cause must be the lesser amount of oxidation required to keep up the body temperature in the tropics. Led by this reflection to consider the body as a machine dependent on outside forces for its capacity to act, he passed on into a novel realm of thought, which brought him at last to independent discovery of the mechanical theory of heat, and to the first full and comprehensive appreciation of the great law of conservation. The great principle he had discovered became the dominating thought of his life, and filled all his leisure hours. He applied it to all the phenomena of the inorganic and organic worlds. It taught him that both vegetables and animals are machines, bound by the same laws that hold sway over inorganic matter, transforming energy, but creating nothing. Then his mind reached out into space and met a universe made up of questions. Each star that blinked down at him as he rode in answer to a night call seemed an interrogation point asking, How do I exist? Why have I not long since burned out, if your theory of conservation be true? No one hitherto had even tried to answer that question; few had so much as realized that it demanded an answer. But the Heilbronn physician understood the question and found an answer. His meteoric hypothesis, published in 1848, gave for the first time a tenable explanation of the persistent light and heat of our sun and the myriad other suns.

Yet for a long time his work attracted no attention whatever. In 1847, when another German physician, Hermann von Helmholtz, one of the most massive and towering intellects of any age, had been independently led to comprehension of the doctrine of conservation of energy, and published his treatise on the subject, he had hardly heard of his countryman Mayer. When he did hear of him, however, he hastened to renounce all claim to the doctrine of conservation, though the world at large gives him credit of independent even though subsequent discovery.

Meantime in England Joule was going on from one experimental demonstration to another, oblivious of his German competitor, and almost as little noticed by his own countrymen. He read his first paper before the chemical section of the British Association for the Advancement of Science in 1843, and no one heeded it in the least. Two years later he wished to read another paper, but the chairman hinted that time was limited, and asked him to confine himself to a brief verbal synopsis of the results of his experiments. Had the chairman but known it, he was curtailing a paper vastly more important than all the other papers of the meeting put together. However, the synopsis was given, and one man was there to hear it who had the genius to appreciate its importance. This was William Thomson, the present Lord Kelvin, now known to all the world as among the greatest of natural philosophers, but then only a novitiate in science. He came to Joule's aid, started rolling the ball of controversy, and subsequently associated himself with the Manchester experimenter in pursuing his investigations.

But meantime the acknowledged leaders of British science viewed the new doctrine askance. Faraday, Brewster, Herschel—those were the great names in physics at that day, and no one of them could quite accept the new views regarding energy. For several years no older physicist, speaking with recognized authority, came forward in support of the doctrine of conservation. This culminating thought of our first half-century came silently into the world, unheralded and unopposed. The fifth decade of the century had seen it elaborated and substantially demonstrated in at least three different countries, yet even the leaders of thought did not so much as know of its existence. In 1853 Whewell, the historian of the inductive sciences, published a second edition of his history, and, as Huxley has pointed out, he did not so much as refer to the revolutionizing thought which even then was a full decade old.

## IV.

The gradual permeation of the field by the great doctrine of conservation simply repeated the history of the introduction of every novel and revolutionary thought. Necessarily the elder generation, to whom all forms of energy were imponderable fluids, must pass away before the new conception could claim the field. Even the word energy, though Young had introduced it in 1807, did not come into general use till some time after the middle of the century. To the generality of philosophers (the word physicist was even less in favor at this time) the various forms of energy were still subtle fluids, and never was idea relinquished with greater unwillingness than this. The experiments of Young and Fresnel had convinced a large number of philosophers that light is a vibration and not a substance; but so great an authority as Biot clung to the old emission idea to the end of his life, in 1862, and held a following.

Meantime, however, the company of brilliant young men who had just served their apprenticeship when the doctrine of conservation came upon the scene had grown into authoritative positions, and were battling actively for the new ideas. Confirmatory evidence that energy is a molecular motion and not an "imponderable" form of matter accumulated day by day. The experiments of two Frenchmen, Hippolyte L. Fizeau and Léon Foucault, served finally to convince the last lingering sceptics that light is an undulation; and by implication brought heat into the same category, since James David Forbes, the Scotch physicist, had shown in 1837 that radiant heat conforms to the same laws of polarization and double refraction that govern light. But, for that matter, the experiments that had established the mechanical equivalent of heat hardly left room for doubt as to the immateriality of this "imponderable." Doubters had, indeed, expressed scepticism as to the validity of Joule's experiments, but the further researches, experimental and mathematical, of such workers as William Thomson (Lord Kelvin), Rankine, and John Tyndall in Great Britain, of Helmholtz and Clausius in Germany, and of Regnault in France, dealing with various manifestations of heat, placed the evidence beyond the reach of criticism.

Out of these studies, just at the middle of the century, to which the experiments of Mayer and Joule had led, grew the new science of thermo-dynamics. Out of them also grew, in the mind of one of the investigators, a new generalization, only second in importance to the doctrine of conservation itself. Professor William Thomson (Lord Kelvin) in his studies in thermo-dynamics was early impressed with the fact that whereas all the molar motion developed through labor or gravity could be converted into heat, the process is not fully reversible. Heat can, indeed, be converted into molar motion or work, but in the process a certain amount of the heat is radiated into space and lost. The same thing happens whenever any other form of energy is converted into molar motion. Indeed, every transmutation of energy, of whatever character, seems complicated by a tendency to develop heat, part of which is lost. This observation led Professor Thomson to his doctrine of the dissipation of energy, which he formulated before the Royal Society of Edinburgh in 1852, and published also in the *Philosophical Magazine* the same year, the title borne being, "On a Universal Tendency in Nature to the Dissipation of Mechanical Energy."

From the principle here expressed Professor Thomson drew the startling conclusion that, "since any restoration of this mechanical energy without more than an equivalent dissipation is impossible," the universe, as known to us, must be in the condition of a machine gradually running down; and in particular that the world we live on has been within a finite time unfit for human habitation, and must again become so within a finite future. This thought seems such a commonplace to-day that it is difficult to realize how startling it appeared half a century ago. A generation trained, as ours has been, in the doctrines of conservation and dissipation of energy as the very alphabet of physical science can but ill appreciate the mental attitude of a generation which for the most part had not even thought it problematical whether the sun could continue to give out heat and light forever. But those advanced thinkers who had grasped the import of the doctrine of conservation could at once appreciate the force of Thomson's doctrine of dissipation, and realize the complementary character of the two conceptions.

Here and there a thinker like Rankine did, indeed, attempt to fancy conditions under which the energy lost through dissipation might be restored to availability, but no such effort has met with success, and in time Professor Thomson's generalization, and his conclusions as to the consequences of the law involved, came to be universally accepted.

The introduction of the new views regarding the nature of energy followed, as I have said, the course of every other growth of new ideas. Young and imaginative men could accept the new point of view; older philosophers, their minds channelled by preconceptions, could not get into the new groove. So strikingly true is this in the particular case now before us that it is worth while to note the ages at the time of the revolutionary experiments of the men whose work has been

THOMAS YOUNG.

From Peacock's *Life of Young*, by permission of John Murray, publisher, London.

mentioned as entering into the scheme of evolution of the idea that energy is merely a manifestation of matter in motion. Such a list will tell the story better than a volume of commentary.

Observe, then, that Davy made his epochal experiment of melting ice by friction when he was a youth of twenty. Young was no older when he made his first communication to the Royal Society, and was in his twenty-seventh year when he first actively espoused the undulatory theory. Fresnel was twenty-six when he made his first important discoveries in the same field; and Arago, who at once became his champion, was then but two years his senior, though for a decade he had been so famous that one involuntarily thinks of him as belonging to an elder generation.

Forbes was under thirty when he discovered the polarization of heat, which pointed the way to Mohr, then thirty-one, to the mechanical equivalent. Joule was twenty-two in 1840, when his great work was begun; and Mayer, whose discoveries date from the same year, was then twenty-six, which was also the age of Helmholtz when he published his independent discovery of the same law. William Thomson was a youth just past his majority when he came to the aid of Joule before the British Society, and but seven years older when he formulated his own doctrine of dissipation of energy. And Clausius and Rankine, who are usually mentioned with Thomson as the great developers of thermo-dynamics, were both far advanced with their novel studies before they were thirty. We may well agree with the father of inductive science that "the man who is young in years may be old in hours."

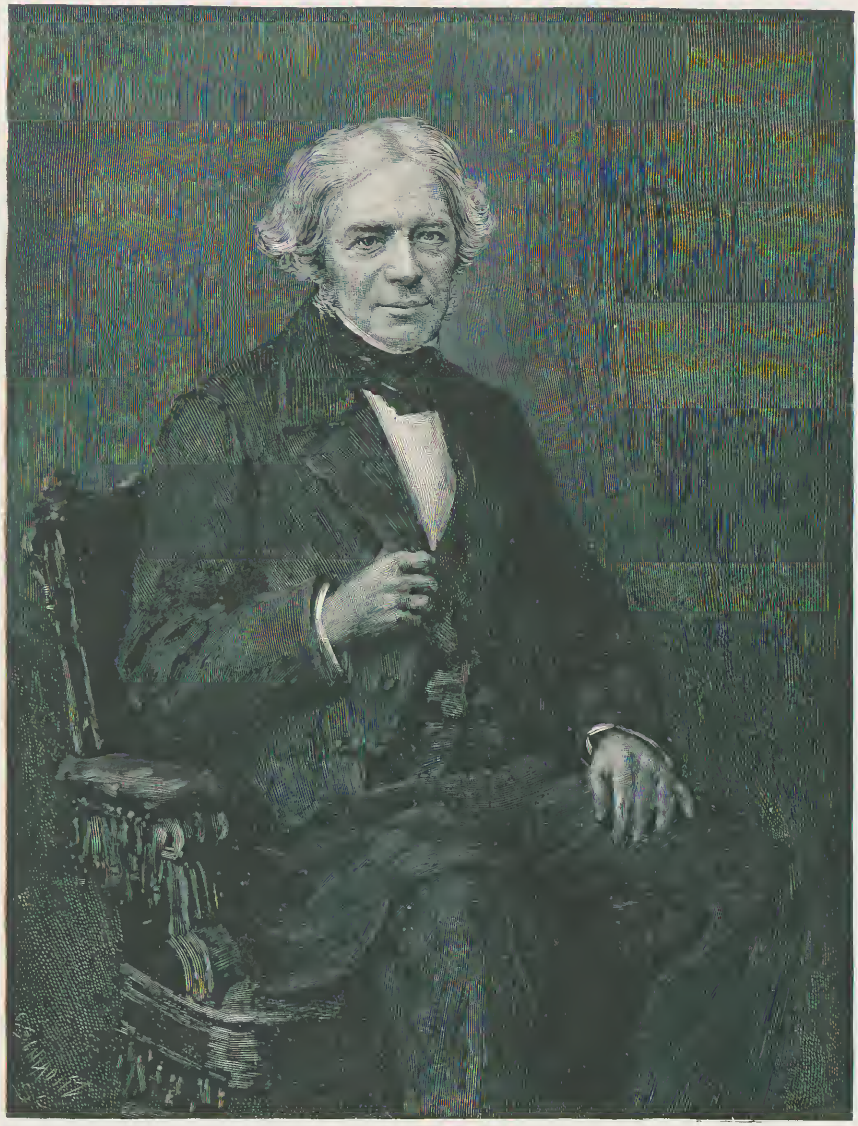
Yet we must not forget that the shield has a reverse side. For was not the greatest of observing astronomers, Herschel, past thirty-five before he ever saw a telescope, and past fifty before he discovered the heat rays of the spectrum? And had not Faraday reached middle life before he turned his attention especially to electricity? Clearly, then, to make his phrase complete, Bacon must have added that "the man who is old in years may be young in imagination." Here, however, even more appropriate than in the other case—more's the pity—would have been the application of his qualifying clause: "but that happeneth rarely."

## V.

There are only a few great generalizations as yet thought out in any single field of science. Naturally, then, after a great generalization has found definitive expression, there is a period of lull before another forward move. In the case of the doctrines of energy, the lull has lasted half a century. Throughout this period, it is true, a multitude of workers have been delving in the field, and to the casual observer it might seem as if their activity had been boundless, while the practical applications of their ideas—as exemplified, for example, in the telephone, phonograph, electric light, and so on—have been little less than revolutionary. Yet the most competent of living authorities, Lord Kelvin, could assert two years ago that in fifty years he had learned nothing new regarding the nature of energy.

This, however, must not be interpreted as meaning that the world has stood still during these two generations. It means rather that the rank and file have been moving forward along the road the leaders had already travelled. Only a few men in the world had the range of thought regarding the new doctrine of energy that Lord Kelvin had at the middle of the century. The few leaders then saw clearly enough that if one form of energy is in reality merely an undulation or vibration among the particles of "ponderable" matter or of ether, all other manifestations of energy must be of the same nature. But the rank and file were not even within sight of this truth for a long time after they had partly grasped the meaning of the doctrine of conservation. When, late in the fifties, that marvellous young Scotchman, James Clerk Maxwell, formulating in other words an idea of Faraday's, expressed his belief that electricity and magnetism are but manifestations of various conditions of stress and motion in the ethereal medium (electricity a displacement of strain, magnetism a whirl in the ether), the idea met with no immediate popularity. And even less cordial was the reception given the same thinker's theory, put forward in 1863, that the ethereal undulations producing the phenomenon we call light differ in no respect except in their wave-length from the pulsations of electro-magnetism.

At about the same time Helmholtz formulated a somewhat similar electro-magnetic theory of light; but even the weight of this combined authority could not give the doctrine vogue until very recently, when the experiments of Heinrich Hertz, the pupil of Helmholtz, have shown that a condition of electrical strain may be developed into a wave system by recurrent interruptions of the electric state in the generator, and that such waves travel through the ether with the rapidity of light. Since then the electro-magnetic theory of light has been enthusiastically referred to as the greatest generalization of the century; but the sober thinker must see that it is really only what Hertz himself called it—one pier beneath the great arch of conservation. It is an in-



MICHAEL FARADAY.

teresting detail of the architecture, but the part cannot equal the size of the whole.

More than that, this particular pier is as yet by no means a very firm one. It has, indeed, been demonstrated that waves of electro-magnetism pass through space with the speed of light, but as yet no one has developed electric waves even remotely approximating the shortness of the visual rays. The most that can positively be asserted, therefore, is that all the known forms of radiant energy—heat, light, electro-magnetism—travel through space at the same rate of speed, and consist of transverse vibrations—"lateral quivers," as Fresnel said of light—known to differ in length, and not positively known to differ otherwise. It has, indeed, been suggested that the newest form of radiant energy, the famous X ray of Professor Röntgen's discovery, is a longitudinal vibration, but this is a mere surmise. Be that as it may, there is no one now to question that all forms of radiant energy, whatever their exact affinities, consist es-

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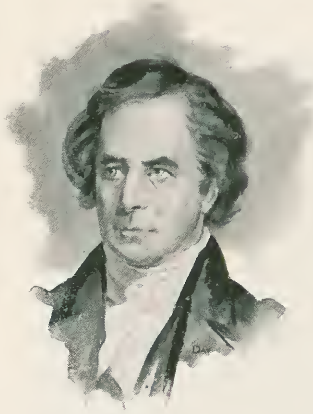
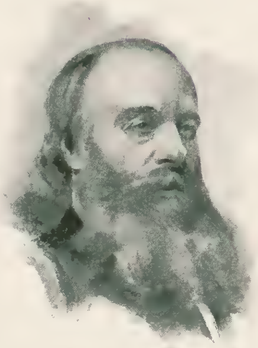


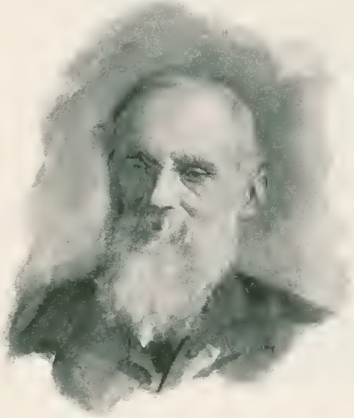
DOMINIQUE FRANÇOIS ARAGO.

AUGUSTIN JEAN FRESNEL.

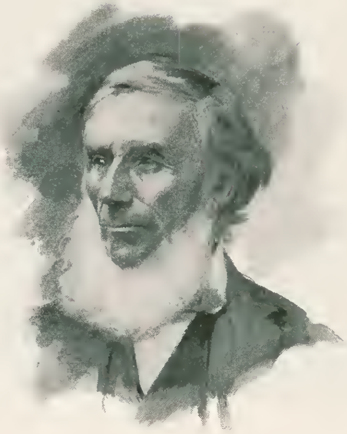
JULIUS ROBERT MAYER.



JAMES PRESCOTT JOULE.

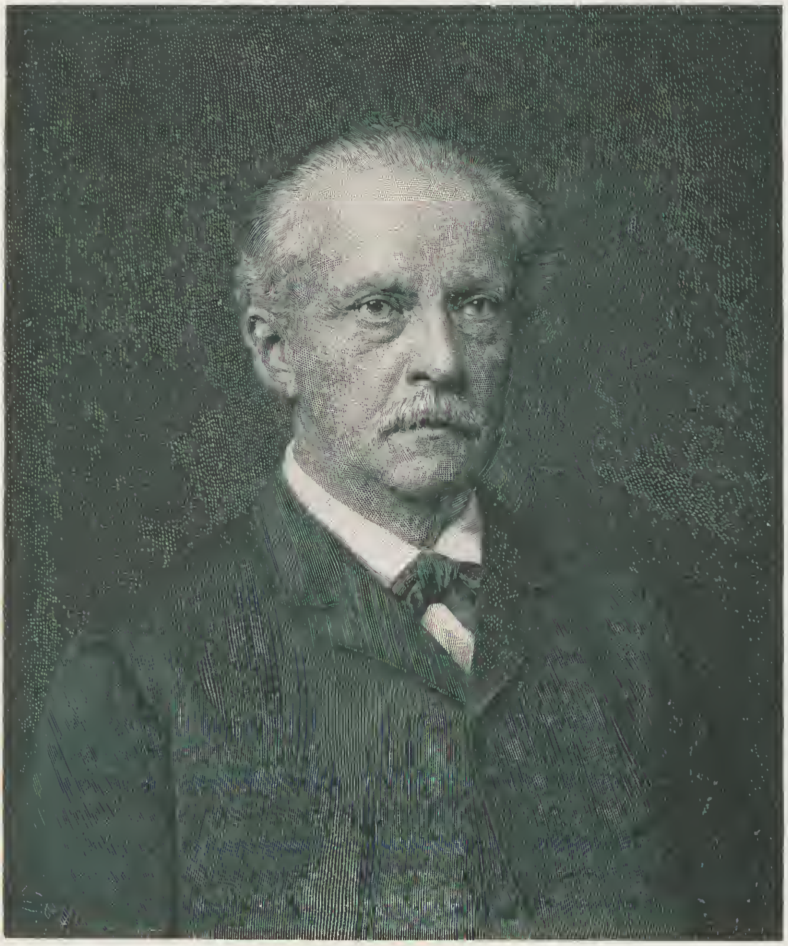


WILLIAM THOMSON (LORD KELVIN).



JOHN TYNDALL.

JAMES CLERK MAXWELL.



HERMANN LUDWIG FERDINAND HELMHOLTZ.
From a photograph by Loescher and Petsch, Berlin.

sentially of undulatory motions of one uniform medium.

A full century of experiment, calculation, and controversy has thus sufficed to correlate the "imponderable fluids" of our forebears, and reduce them all to manifestations of motion among particles of matter. At first glimpse that seems an enormous change of view. And yet, when closely considered, that change in thought is not so radical as the change in phrase might seem to imply. For the nineteenth-century physicist, in displacing the "imponderable fluids" of many kinds—one each for light, heat, electricity, magnetism—has been obliged to substitute for them one all-pervading fluid, whose various quivers, waves, ripples, whirls, or strains produce the manifestations which in popular parlance are termed forms of force. This all-pervading fluid the physicist terms the ether, and he thinks of it as having no weight. In effect, then, the physicist has dispossessed the many imponderables in favor of a single imponderable—though the word imponderable has been banished from his vocabulary. In this view the ether—which, considered as a recognized scientific verity, is essentially a nineteenth-century discovery—is about the most interesting thing in the universe. Something more as to its properties, real or assumed, we shall have occasion to examine as we turn to the obverse side of physics, which demands our attention in the next paper.