XXIX. *The History of the Doctrine of Radiant Energy.*By Lord RAYLEIGH, *Sec. R.S.**

IN his interesting Address† to the American Association for the Advancement of Science, Prof. Langley sketches the development of the modern doctrine of Radiant Energy, and deduces important lessons to be laid to heart by all concerned in physical investigation. This is a most useful undertaking; but in the course of it there occur one or two statements which, in the interest of scientific history, ought not to be allowed to pass without a protest.

After quoting Melloni's very unequivocal conclusion of 1843, that "Light is merely a series of calorific indications sensible to the organs of sight; or, *vice versâ*, the radiations of obscure heat are veritable invisible radiations of light," Prof. Langley goes on to say, "So far as I know, no physicist of eminence reasserted Melloni's principle with equal emphasis till J. W. Draper, in 1872. Only sixteen years ago, or in 1872, it was almost universally believed that there were three different entities in the spectrum, represented by actinic, luminous, and thermal rays."

These words struck me strangely as I first read them. My own scientific ideas were formed between 1860 and 1866, and I certainly never believed in the three entities. Having on a former occasion referred to this question‡ as an illustration of the difference of opinion which is sometimes to be found between the theoretical and experimental schools of workers, I was sufficiently interested in the matter to look up a few references, with results which are, I think, difficult to reconcile with Prof. Langley's view.

In Young's Lectures§ we read:—"Dr. Herschel's experiments have shown that radiant heat consists of various parts which are differently refrangible, and that, in general, invisible heat is less refrangible than light. This discovery must be allowed to be one of the greatest that have been made since the days of Newton

"It was first observed in Germany by Ritter, and soon afterwards in England by Dr. Wollaston, that the muriate of silver is blackened by invisible rays, which extend beyond the prismatic spectrum, on the violet side. It is therefore probable that these black or invisible rays, the violet, blue, green, perhaps

* Communicated by the Author.

† Amer. Journ. Sci. Jan. 1889.

‡ Address to Section A, Brit. Assoc. Report, 1882.

§ Vol. i. p. 638 (1807).

the yellow, and the red rays of light, and the rays of invisible heat, constitute seven different degrees of the same scale, distinguished from each other into this limited number, not by natural divisions, but by their effects on our senses: and we may also conclude that there is some similar relation between heated and luminous bodies of different kinds."

And, again, on p. 654: "If heat is not a substance, it must be a quality; and this quality can only be motion. It was Newton's opinion that heat consists in a minute vibratory motion of the particles of bodies, and that this motion is communicated through an apparent vacuum by the undulations of an elastic medium, which is also concerned in the phenomena of light. If the arguments which have been lately advanced in favour of the undulatory theory of light be deemed valid, there will be still stronger reasons for admitting this doctrine respecting heat; and it will only be necessary to suppose the vibrations and undulations principally constituting it to be larger and stronger than those of light, while at the same time the smaller vibrations of light, and even the blackening rays, derived from still more minute vibrations, may perhaps, when sufficiently condensed, concur in producing the effects of heat. These effects, beginning from the blackening rays, which are invisible, are a little more perceptible in the violet, which still possess but a faint power of illumination; the yellow-green afford the most light; the red gives less light, but much more heat; while the still larger and less frequent vibrations, which have no effect upon the sense of sight, may be supposed to give rise to the least refrangible rays, and to constitute invisible heat."

It is doubtless true that Young's views did not at the time of the publication of these lectures* command the authority which now attaches to them. But when the undulatory theory gained acceptance, there was no room left for the distinct entities.

J. B. Reade, one of the pioneers of photography, in a letter to R. Hunt†, of date Feb. 1854, thus speaks of Young:—"Dr. Young's propositions are, that radiant light consists in undulations of the luminiferous æther, that light differs from heat only in the frequency of its undulations, that undulations less frequent than those of light produce heat, and that undulations more frequent than those of light produce chemical and photographic action,—all proved by experiments."

* I may remark, in passing, that Brougham knew a little of experimenting, as of everything else, except law!

† Hunt's 'Researches on Light,' Longmans, 1854, p. 374. Hunt himself, not being an undulationist, was upon the other side.

Sir John Herschel's presentation of the matter * is not very explicit. "The solar rays, then, possess at least three distinct powers: those of heating, illuminating, and effecting chemical combinations or decompositions; and these powers are distributed among the differently refrangible rays in such a manner as to show their complete independence on each other. Later experiments have gone a certain way to add another power to the list—that of exciting magnetism." Although the marginal index runs "Calorific, luminous, and chemical rays," the choice of words in the text, as well as the reference to magnetism (for surely no one believed in a special magnetizing entity), points to the conclusion that Herschel held the modern view.

For the decade between 1850 and 1860, the citation upon which I most rely as indicative of the view held by the highest authorities, and by those capable of judging where the highest authority was to be found, is from Prof. Stokes's celebrated memoir upon Fluorescence †. On p. 465 we read:—"Now according to the Undulatory Theory, the nature of light is defined by two things, its period of vibration, and its state of polarization. To the former corresponds its refrangibility, and, so far as the eye is a judge of colour, its colour." And in a footnote here appended:—

"It has been maintained by some philosophers of the first eminence that light of definite refrangibility might still be compound; and though no longer decomposable by prismatic refraction may still be so by other means. I am not now speaking of compositions and resolutions dependent upon polarization. It has been suggested by advocates of the undulatory theory, that possibly a difference of properties in lights of the same refrangibility might correspond to a difference in the law of vibration, and that lights of given refrangibility may differ in tint, just as musical notes of given pitch differ in quality. Were it not for the strong conviction I felt that light of definite refrangibility is in the strict sense of the word homogeneous, I should probably have been led to look in this direction for an explanation of the remarkable phenomena presented by a solution of sulphate of quinine. It would lead me too far from the subject of the present paper to explain the grounds of this conviction. I will only observe that I have not overlooked the remarkable effect of absorbing media in causing apparent changes of colour in a pure spectrum; but this I believe to be a subjective phenomenon depending upon contrast."

It can scarcely be necessary to insist that "light" is used here in the wider sense, a large part of the memoir dealing with the transformation of invisible into visible light.

The allusion in the note is, of course, to Brewster. This distinguished discoverer never accepted the wave theory, and was thus insensible to the repugnance with which his

* *Art. Light*, *Enc. Met.* 1830, § 1147.

† "On a Change of Refrangibility of Light." *Phil. Trans.* 1852.

doctrine of three different kinds of luminous radiation was regarded by every undulationist. The matter was not finally set at rest until Helmholtz showed that Brewster's effects depended upon errors of experiment not previously recognized.

The following, from W. Thomson*, is almost equally significant :—

“It is assumed in this communication that the undulatory theory of radiant heat and light, according to which light is merely radiant heat, of which the vibrations are performed in periods between certain limits of duration, is true. ‘The chemical rays’ beyond the violet end of the spectrum consist of undulations of which the full vibrations are executed in periods shorter than those of the extreme visible violet light, or than about the eight hundred million millionth of a second. The periods of the vibrations of visible light lie between this point and another, about double as great, corresponding to the extreme visible red light. The vibrations of the obscure radiant heat beyond the red end are executed in longer periods than this; the longest which has yet been experimentally tested being about the eighty million millionth of a second.”

Again, in Lloyd's ‘Wave Theory of Light’†, we find the following passage :—“It appears, then, that sensibility of the eye is confined within much narrower limits than that of the ear; the ratio of the times of the extreme vibrations which affect the eye being only that of 1·58 to 1, which is less than the ratio of the times of vibration of a fundamental note and its octave. There is no reason for supposing, however, that the vibrations themselves are confined within these limits. In fact, we know that there are *invisible* rays *beyond* the two extremities of the spectrum, whose periods of vibration (and lengths of wave) must fall without the limits now stated to belong to the visible rays.”

I believe that it would be not too much to say that during the decade 1850–1860 nearly all the leading workers in physics, with the exception of Brewster, held the modern view of radiation. It would be quite consistent with this that many chemists, photographers, and workers in other branches of science, who trusted to more or less antiquated text-books for their information, should have clung to a belief in the three entities. After 1860, and the discussions respecting the discoveries of Stewart and Kirchhoff, I should have supposed that there were scarcely two opinions. Stewart's ‘Elementary Treatise on Heat’ was published in

* “On the Mechanical Action of Radiant Heat or Light;” &c. Proc. Roy. Soc. Edinb. Feb. 1852.

† Longmans, 1857, p. 16.

1866, and was widely used in schools and colleges. In book II. ch. II., he elaborately discusses the whole question, summing up in favour of the view that "radiant light and heat are only varieties of the same physical agent, and that when once the spectrum of a luminous object has been obtained, the separation of the different rays from one another is physically complete ; so that, if we take any region of the visible spectrum, its illuminating and heating effect are caused by precisely the same rays." What there was further for Draper or any one else to say in 1872 I am at a loss to comprehend*.

To pass on to another point. I have followed the excellent advice to read W. Herschel's original memoirs ; but I must confess that the impression produced upon my mind is different in some respects from that expressed by Prof. Langley. It seems to me that Herschel fully established the diversity of radiant heat. In the first memoir† a paragraph is headed "*Radiant Heat is of different Refrangibility*," the question being fully discussed ; and from the following memoir (p. 291) it is evident that this proposition extends to invisible radiation. "The four last experiments prove that the maximum of the heating power is vested among the invisible rays ; and is probably not less than half an inch beyond the last visible ones, when projected in the manner before mentioned. The same experiments also show that the sun's invisible rays, in their less refrangible state, and considerably beyond the maximum, still exert a heating power fully equal to that of red-coloured light. . . ." Can it then be said of De la Roche that he, in 1811, before anyone else, "derives the just and most important, as well as the then most novel conception, that radiant heat is of different *kinds*" ? It was doubtless a most important step when De la Roche and Melloni exhibited the diversity of radiant heat *by means of selective absorption* ; but I do not see how we can regard them as the discoverers of the fact.

It would take too long to establish by quotations, but it is pretty evident that in his two earlier papers ‡ Herschel leaned to the view that light was not "essentially different from radiant heat." Why then, after laying hands upon the truth, did he let it go, and decide that light and heat are not occasioned by the same rays ?

* I have limited myself to citations from English writers, but I have no reason to think that the course of opinion was different in France and Germany.

† Phil. Trans. 1800, p. 255.

‡ See pp. 272, 291, 292.

"The question,* which we are discussing at present, may therefore at once be reduced to this single point. Is the heat which has the refrangibility of the red rays occasioned by the light of these rays? For, should that be the case, as there will be then only one set of rays, one fate only can attend them, in being either transmitted or stopped, according to the power of the glass applied to them. We are now to appeal to our prismatic experiment upon the subject, which is to decide the question." The issue could not be more plainly stated. The experiment is discussed, and this is the conclusion:—"Here then we have a direct and simple proof, in the case of the red glass, that the rays of light are transmitted, while those of heat are stopped, and that thus they have nothing in common but a certain equal degree of refrangibility. . . ."

I am disposed to think that it was this erroneous conclusion from experiment †, more, perhaps, than preconceived views about caloric, that retarded progress in radiant heat for so many years. We are reminded of Darwin's saying that a bad observation is more mischievous than unsound theory. It would be interesting to inquire upon what grounds we now reject the plain answer which Herschel thought himself to have received from experiment. I do not recall a modern investigation in which the heat and light absorptions are proved to be equal for the various parts of the visible spectrum. Can it be that after all we have nothing but theory to oppose to Herschel's facts?

I hope it will be understood that these criticisms, even if they are sound, do not touch the substance of Prof. Langley's address, which is doubly interesting as coming from one who has done so much himself to enlarge our knowledge of this branch of science.

XXX. *Note on Steel Magnets.* By WILLIAM BROWN, "*Thomson Experimental Scholar*," now *Demonstrator in Physics, Royal College of Science, Dublin* ‡.

NEARLY two years ago I brought before this Society the results of some experiments on the effects of percussion in changing the magnetic moments of steel magnets, which results were subsequently published in the March and May

* Third *Memoir*, p. 520.

† See Whewell's '*History of the Inductive Sciences*,' vol. ii. p. 548 (1847).

‡ Communicated by Sir William Thomson, having been read before the Physical Society of Glasgow University, Oct. 12, 1888.