VI. On the thermodynamical theory of radiation

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corresponding formulæ in Prof. J. J. Thomson's 'Recent Researches,' Articles 367 and 364 respectively. It will be noticed that the great difference between his results and those obtained here is that the complex constant B is evaluated in 'Recent Researches,' but is left unevaluated in the present discussion. As a matter of fact, the evaluation of B is not required for the important inferences usually drawn from these results, such as the mode of dependence of the intensity of the scattered wave on the wave-length and on the diameter of the wire, the determination of the direction in which the scattered wave nearly vanishes, and the greater proportional scattering when the electric intensity in the incident wave is parallel to the wire than when it is perpendicular. For a full discussion of the interpretation of formulæ (26) and (32) the student naturally turns to 'Recent Researches.'

8. It need hardly be pointed out that the discussions of Articles 3 to 7 of the present paper are fundamentally the same as those given by Prof. Thomson. The functions used are, at most, different only by constant factors. The sole advantage, but that an important one, claimed for the present formulation is that it assumes no knowledge of Bessel's functions on the part of the reader and makes no appeal to formulæ, but obtains from first principles all the approximations required. The work is thus greatly shortened and simplified, and ought to be easily understood by many students to whom the standard formulation presents difficulty.

30th March, 1906.

VI. *On the Thermodynamical Theory of Radiation.* By
J. H. JEANS, M.A., F.R.S., Professor of Applied Mathematics in the University of Princeton*.

1. **T**HERE are two entirely distinct ways of attacking the problem of determining the intensity and partition of radiation from a body at a given temperature.

One method is based on what is commonly termed the "Thermodynamics of Radiation." Its fundamental conception is that of a hot body surrounded by æther, in which the partition of energy is such that the energy absorbed by the matter from the æther in any time is exactly equal to that yielded up by matter to æther. From the condition that equilibrium of this kind shall exist, it has been shown by Bartoli, Boltzmann, and Wien, that the law of partition of

* Communicated by the Author.

radiant energy must be of the form

$$\lambda^{-4} T f(\lambda T) d\lambda, \dots \dots \dots (1)$$

and that the total energy of radiation per unit volume must be of the form

$$\sigma T^4. \dots \dots \dots (2)$$

This method, it is seen, arises essentially from the contemplation of a conservative dynamical system.

2. The second method consists in regarding the radiator and the æther surrounding it as a non-conservative system. This method is not concerned with the equilibrium between matter and æther, but with the rate of transfer of energy from the former to the latter. Assuming the source of radiation to be the motion of electric charges in the radiator, it can be shown by this second method also that the radiation must be given by formulæ of the type (1) and (2)*.

3. In the opinion of the present writer neither method has so far led to a valid determination of the form of the function f of formula (1). The two theories can, however, be differentiated by their treatment of the constant σ of formula (2).

4. In the second theory the quantity σ enters as a physical entity, dependent on the magnitude of the electric charges only (as soon as the temperature scale has been determined). From the observed value of σ it is found that the electric charges producing the radiation must, if the theory is valid, be of the order of magnitude of 1.8×10^{-10} C.G.S. electrostatic units†—a circumstance which points very clearly to electrons as the source of radiation.

5. In the first theory, on the other hand, the quantity σ enters mathematically as a constant of integration, and the theory itself does not supply the means of evaluating it. Since, however, σT^4 is to be the amount of energy per unit volume, the physical dimensions of σ are known.

The thermodynamical argument by which, in this first theory, the formula σT^4 is reached, is concerned only with phenomena taking place in the æther. Thus we should naturally expect that it would be possible to evaluate σ in terms of quantities which measure the properties of the æther. The properties of the æther, as contemplated by the argument which leads to the formula σT^4 , are, however, all contained in the one constant which measures the velocity of wave-propagation, and obviously a quantity of the physical dimensions appropriate for σ cannot be constructed from this alone. Even if we attribute a further property, *e.g.* material density

* "On the Laws of Radiation," Roy. Soc. Proc. vol. 76 A. p. 545.

† *L. c. ante*, § 9.

([mass] $\div$ [length]³) to the æther, it remains impossible to construct σ out of æther-constants.

The evaluation of σ can, however, proceed by taking advantage of the circumstance that there are physical constants associated with matter, which are common to all kinds of matter—in particular, the charge of the electron, e . If we make σ depend on the charge of the electron, the evaluation of σ may be borrowed from the second theory. We then find that σ is proportional to e^{-6} , and the numerical value of e deduced from the observed value of σ supplies strong confirmation that this is the right way of evaluating σ .

6. Thus if we agree to extend the first (thermodynamical) theory in the way here suggested, we may say that both theories lead to the formula σT^4 , that both lead to the same numerical evaluation of σ , and that this evaluation is in agreement with experiment.

7. Next let us imagine an enclosure with perfectly reflecting walls, containing matter at temperature T . Let us refer to this piece of matter as R , and let us suppose that the matter is real matter in which each electron has the customary charge e . Let us suppose that we have also a mass of “ideal” matter I , in which each electron has a charge $\frac{1}{2}e$ only.

If we put R inside the enclosure we obtain, according to the thermodynamical argument, a state of equilibrium in which the æther has a volume density of energy σT^4 .

Remembering that the constant σ has been found to be proportional to e^{-6} , it appears that if we take R out of the enclosure and insert I , we obtain equilibrium with a volume density of energy $64\sigma T^4$.

Now let us put R and I in the enclosure together. The thermodynamical argument might, I think, very fairly be used at this juncture to establish the equation $1=64$. Without pressing it thus far, however, we may say that it shows that the ideal matter I will give out more energy than it receives, while the opposite will be true of the real matter R . Thus the two bodies, originally at *equal* temperatures, will tend to assume *different* temperatures. This might or might not happen in nature if we had ideal matter to experiment with. What is of more importance is that the thermodynamical argument has led to a result which is opposed to the fundamental principles of thermodynamics. Or, to state the situation in another way, the thermodynamical argument first supposes the second law to be of such wide applicability that it may be applied to the æther, and then proves that it may not legitimately be applied even to different kinds of matter.

8. The difficulty may be illustrated by a second imaginary experiment, suggested to the writer in a conversation with

Prof. Lorentz. Let us join a piece of real and a piece of ideal matter, so as to form a closed circuit. Let one of the junctions, A, be a perfect conductor of heat devoid of radiating power, while each face of the other junction B is a perfect radiator, devoid of conducting power. Let all the rest of the surfaces of both R and I be supposed impervious to energy.

If junction A is thrown out of action the bodies R, I will as before assume different temperatures. If junction B is thrown out of action the temperatures will equalise by conduction of heat across A. If both junctions are in operation at once, we shall get a continuous flow of energy round the circuit in the direction I A R B, and a continuous rise of temperature as we pass through I from B to A, or through R from A to B.

These difficulties do not cast suspicion on the validity of the second form of the theory of radiation, which begins by presupposing a flow, rather than equilibrium, of energy, but to the present writer they seem fatal to the thermodynamical theory.

Princeton, N.J.,
April 24.

VII. *The H-Theorem and the Dynamical Theory of Gases.*
By J. H. JEANS, M.A., F.R.S., Professor of Applied
Mathematics in Princeton University*.

IN the Phil. Mag. for April (pp. 455-465), Mr. Burbury again discusses my work on the Theory of Gases. While grateful for parts of his discussion which seem to be sympathetic and appreciative, I recognize that on the main question at issue Mr. Burbury is still inclined to disagree *in toto* with my views.

* Communicated by the Author.