THE QUANTUM THEORY

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BY

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INTRODUCTION

THE old saying that small causes give rise to great effects has been confirmed more than once in the history of physics. For, very frequently, inconspicuous differences between theory and experiment (which did not, however, escape the vigilant eye of the investigator) have become starting-points of new and important researches.

Out of the well-known *Michelson-Morley* experiment, which, in spite of the application of the most powerful methods of exact optical measurement, failed to show an influence of the earth's movement on the propagation of light as was predicted by classical theory, there arose the great structure of *Einstein's* Theory of Relativity. In the same way the trifling difference between the measured and calculated values of black-body radiation gave rise to the Quantum Theory which, formulated by *Max Planck*, was destined to revolutionise in the course of time almost all departments of physics.

The quantum theory is yet comparatively young. It is therefore not surprising that we are confronted with an unfinished theory still in process of development which, changing constantly in many directions, must often destroy what it has built up a short time before. But under such circumstances as these, in which the theory is continually deriving new nourishment from a fresh stream of ideas and suggestions, there is a peculiar fascination in attempting to review the life-history of the quantum theory to the present time and in disclosing the kernel which will certainly outlast changes of form.

CHAPTER I

The Origin of the Quantum Hypothesis

§ 1. Black-Body Radiation and its Realisation in Practice

THE Quantum Theory first saw light in 1900. When, in the years immediately preceding (1897-1899), *Lummer* and *Pringsheim* made their fundamental measurements [1] of black-body radiation at the *Reichsanstalt*, they could have had no premonition that their careful experiments would become the starting-point of a revolution such as has seldom occurred in physics.

In the field of heat radiation chief interest at that time was centred in the radiation of a black body (briefly called "black-body" radiation), that is, of a body which absorbs completely all radiation which falls on it and which thus reflects, transmits, and scatters [2] none. We may shortly call to mind the following facts. It is known that any body at a given temperature sends out energy in the form of radiation into the surrounding space. This radiation is not energy in a single simple form but is made up of a number of single radiations of different colours, i.e. of different wave-lengths λ or of different frequencies [3] ν. In other words, it forms in general a spectrum in which radiations of all frequencies between $\nu = 0$ and $\nu = \infty$ are represented. Further, these radiations are present in varying "intensities." We define this term thus. Consider the radiation emitted from unit surface of the body per second in a certain direction; break it up spectrally and cut out of the spectrum a small frequency interval $d\nu$ such that it contains all frequencies between ν and $\nu + d\nu$. The energy of radiation E_ν thus sliced out (namely, *the emissivity of the body for the frequency* ν) may be defined in the following terms: [4]

$$E_\nu = 2\pi \mathbf{K}_\nu d\nu \quad . \quad . \quad . \quad (1)$$

provided that—as we shall assume for the sake of simplicity—the surface of the body emits uniform and unpolarised radiation in all directions.

The magnitude $\mathbf{K}_\nu$ thus defined is called the intensity of radiation of the body for the frequency ν. It is in general a more or less complicated function of the frequency ν, of the absolute temperature of the body T, and of the inherent properties of the body. The black body alone is unique in this respect. For its radiation and therefore its $\mathbf{K}_\nu$ is, as *G. Kirchhoff*[5] was the first to point out, dependent only on the frequency ν and the absolute temperature T, that is, mathematically,

$$\mathbf{K}_\nu = f(\nu, T) \quad . \quad . \quad . \quad . \quad (2)$$

This formula which gives the relation between the intensity of radiation from a black body, the temperature, and the "colour" is called the radiation formula or the law of radiation of a black body.

To calculate this relationship on the one hand and to measure it on the other were unsolved problems at that time. Unimpeachable measurements were of course possible only if one could succeed in constructing a black body which approached sufficiently near the theoretical ideal. This important step, the realisation of the black body, was taken by *O. Lummer* and *W. Wien*[6] on the basis of *Kirchhoff's*[7] Law of Cavity Radiation, which states: *In an enclosure or a cavity which is enclosed on all sides by reflecting walls, externally protected from exchanging heat with its surroundings, and evacuated, the condition of "black radiation" is automatically set up if all the emitting and absorbing bodies at the walls or in the enclosure are at the same temperature.* In a space, therefore, which is hermetically surrounded by bodies at the same temperature T and which is prevented from exchanging heat with its surroundings, every beam of radiation is identical in quality and intensity with that which would be emitted by a black body at the temperature T.

Lummer and *Wien*, therefore, had only to construct a uniformly heated enclosure with blackened walls having a small opening. The radiation emitted from this opening was then "black" to an approximation which was the closer