CHAPTER VIII

The Doppler effect in molecular scattering

75. In the discussion of fundamental principles contained in our first chapter, we have already had occasion to refer to the Doppler effect arising from the uncoordinated movements of the molecules and found that it has no influence on the proportion of energy laterally scattered. We may now briefly consider the question whether it has any effect on the refractivity of the medium. The light scattered by a stationary molecule has the same wavelength in all directions as the incident radiation; and if we leave out of account the question of polarisation, there is no direction specially favoured as regards intensity as well. But in the case of a moving molecule, the wavelength of the scattered light is smaller in the direction of motion than in the opposite direction or intermediate directions. Since the molecule receives the incident radiation with an altered frequency, its motion must, according to the Rayleigh law of scattering, alter the *intensity* of the scattering, the latter being increased when the molecule moves against the advancing waves and decreased when it moves with the advancing waves. The velocity of the scattered waves is however independent of the movements of the molecules, and hence the phase-relation between the advancing primary and secondary waves remains unaffected. The coherence of the primary and the scattered waves in the direction of propagation of the former on which the refractivity of the medium depends continues therefore to subsist. Any alteration in the scattering power of a molecule must produce a corresponding alteration in its contribution to the refractivity of the medium. If we assume that the movements of the molecules occur in random directions, the increased scattering and refractivity due to the molecules moving up towards the incident light is completely set off by the decreased scattering and refractivity due to the molecules moving in the opposite direction, and hence the refractivity of the medium considered as a whole remains unaffected. If however all the molecules have a common direction of movement relative to the advancing primary waves, the case is entirely different. If the molecules move against the direction of propagation of the primary waves, the scattering by all of them is increased and hence also the refractivity of the medium. If the molecules move with the waves, the scattering is diminished and therefore also the refractivity. In other words, the velocity of light through the medium is increased or decreased by a certain

Fresnel's principle of the convection of light in a moving medium, and in a paper appearing in the *Philosophical Magazine*, Dr Nihal Karan Sethi and the present writer have shown that the convection of light (Fizeau effect) in moving gases can be explained in this way, and we obtain (at least in the case of gases where the molecules can be regarded as independent centres of secondary radiation) a convection co-efficient agreeing with the values given by Fresnel's well-known expression and by the Theory of Relativity. The extension of the same argument to the case of liquids and solids will probably not present insuperable difficulties.

Experimental observations of Doppler effect

76. As is well known, the Doppler effect in the light reflected from a system of moving mirrors was demonstrated experimentally by Belopolsky and later by Prince Galitzin and Stark's work on the Kanalstrahlen has also established the effect in the light emitted by electrically luminescent moving molecules. Recently Fabry and Buisson* have greatly simplified the laboratory demonstration of the Doppler effect by using a rapidly-revolving paper disk, the edge of which is illuminated by a mercury lamp and observed through an etalon. It appears to the author that it would be interesting and quite practicable to make an experimental study of the Doppler effect in light *scattered* by moving molecules. The experimental arrangements most suitable would probably be very similar to those adopted in Fabry and Buisson's experiments. A flat revolving steel vessel containing compressed carbon dioxide or some suitable liquid may be provided with glass windows through which monochromatic light is admitted into it, the scattered light being observed laterally. By photographing the scattered light through an etalon and reversing the direction of rotation, the alteration of wavelength should be capable of observation. Simpler still would be to experiment with the light internally scattered within a rapidly revolving disk of glass. It would also be interesting to find in such cases whether there is any difference in the behaviour of molecularly scattered light and of fluorescent radiation.

77. The widening of the lines in the spectrum of a luminous gas due to the Doppler effect arising from the thermal movements of the molecules in it has been discussed by several writers, notably by the late Lord Rayleigh, and has been established by laboratory experiments. It would appear worthwhile to examine experimentally the similar effect which may be expected to arise in the light *scattered* by a gas at high temperature. Light from a source at low temperature may be passed through a compressed gas or a liquid at a high temperature and the width of the lines in the spectrum of the scattered light determined by

photographing it through an etalon or echelon spectroscope. The magnitude of the effect that may be expected has been discussed theoretically at the suggestion of the author in a paper by Mr Panchanan Das.* The astrophysical importance of the Doppler effect in molecular scattering in such cases as for instance, the light of the sun's corona is fairly obvious, and has already been emphasised by Fabry.†

Planck's law and molecular scattering

78. The Doppler effect in molecular diffraction is also of theoretical importance from another standpoint. Consider a space bounded by completely reflecting walls and containing enclosed within it radiant energy corresponding to some known temperature distributed amongst the different wavelengths according to Planck's law of radiation. We may assume further that the enclosed space contains a few molecules of a gas at the same temperature, and for simplicity also assume that the molecules do not either absorb or emit light but merely scatter the radiations incident on them in accordance with the Rayleigh law of scattering. Owing to the movement of the molecules, the scattered energy will not always have the same wavelength as the incident waves, and hence the postulated conditions provide a mechanism for the interchange of energy between different wavelengths. If, further, we assume that the molecules scatter the waves incident on them continuously, the mechanism provided for the interchange of energy would operate according to the classical laws of electrodynamics, and the final distribution of energy in the enclosure would not be that given by Planck's law but would necessarily be that consistent with the principle of the equipartition of energy‡ viz

$$f(\lambda)\mathrm{d}\lambda = 8\pi RT\lambda^{-4}\mathrm{d}\lambda.$$

In other words, the distribution of energy in the enclosure which was postulated in the first instance would be altered, and the thermodynamic equilibrium of the system would be upset. As the system was assumed to be initially at the same temperature throughout, such a conclusion is *primâ facie* inacceptable, and we must therefore draw the inference either that the Rayleigh law of scattering is not valid or that the molecules do not scatter the radiations incident on them continuously. Since the Rayleigh law of scattering is supported by experiment, at least over a considerable range of wavelengths, it seems more reasonable to accept the latter conclusion, and to infer that molecular *scattering of light* cannot

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* *Bull. Calcutta Math. Soc.*, 1921, pp. 6–10.

† *J. Phys.*, 7, 1919, pp. 89–102.

‡ *Cf.* Jeans; *Report on Quantum Theory*, § 10.

take place in a continuous manner as contemplated by the classical electrodynamics. It seems to be difficult, however, to reconcile this with the hypothesis that light is propagated through space in the form of continuous waves, and we are apparently forced to consider the idea that light itself may consist of highly concentrated bundles or quanta of energy travelling through space. This will be further discussed in the following chapter.