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# Doppler effect in light-scattering

It is a problem of great interest to consider the changes in spectral character of monochromatic radiation resulting from the thermal agitation of a medium in which it is scattered. If we regard the subject classically the result to be expected is obvious: there should be a Doppler broadening of the incident spectral line, varying with the angle of observation, and determined by the Maxwellian distribution of velocities of the molecules which scatter the light. It can readily be shown that, except in respect of the total intensity of scattered light, it would make no difference to the argument by which this result is deduced whether the molecules are loosely distributed as in a gas or are closely packed together as in a dense vapour or liquid.

It is very remarkable, however, that a wholly different result was deduced by L Brillouin,[1] following the idea that the medium which scatters the radiation can be treated as a continuum filled with moving sound-waves of various wavelengths which reflect the light-waves much in the same way that a moving crystal would give Bragg's reflection of X-rays. Brillouin's theory indicates that in the spectrum of the scattered rays the single line which represents the incident light should be replaced by a close doublet, the frequency shifts of which are given by the formula $\Delta\nu/\nu = \pm 2a/c \sin\frac{1}{2}\theta$, where $a$ and $c$ are the velocities of sound and light respectively, and $\theta$ is the angle of observation; the incident line itself would be missing in the scattered light. Brillouin's deduction of this formula has outwardly the appearance of being based on classical ideas. Actually, however, the argument ignores the existence of discrete molecules in the medium, and the results to which it leads cannot be reconciled with classical point of view, according to which the incident line should persist in the scattered light in the same position with no change except a Doppler broadening.

The paradox presented above is resolved if we adopt the following view of the matter based on quantum principles. In a medium scattering light we are dealing with an assemblage of photons having energy $h\nu$ and momentum $h\nu/c$, material particles having translatory energy $\frac{1}{2}Mv^2$ and linear momentum $Mv$ and also associated with the latter, quanta of sound, having energy $h\nu_s$ and linear momentum $h\nu_{s/a}$. The result of an individual encounter must satisfy the equations

[1] *Ann. Phys.*, 1922 **17**, p. 88.

of the Compton type:

$$\tfrac{1}{2}Mv^2 + h\nu_s + h\nu_l = \tfrac{1}{2}Mv'^2 + h\nu'_s + h\nu_l$$

$$\overrightarrow{Mv} + \overrightarrow{h\nu_{s/a}} + \overrightarrow{h\nu_{l/c}} = \overrightarrow{Mv'} + \overrightarrow{h\nu'_{s/a}} + \overrightarrow{h\nu'_{l/c}}.$$

The first is a scalar and the second is a vector equation. We obtain Brillouin's result immediately, if the energy and momenta of the material particles are ignored, and the equations are solved. If, on the other hand, the energy and momenta of the sound quanta are ignored, and the equations are solved, the classical Doppler broadening results. These are, however, two extreme cases, and in general both types of phenomena may be expected to be present and to influence each other.

It must here suffice to remark very briefly that the considerations set out above enable us readily to offer a satisfactory interpretation of the experimental results recently reported by Gross[2] on the modification of the fine structure of spectral lines produced by scattering in liquids and solids.

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[2] *Nature*, 1930 **126**, pp. 201, 400, 603; and *Zeit. für Physik*. 1930 **63**, p. 685.