

Letters to the Editor.

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The Law of Dispersion and Bohr's Theory of Spectra.

It is well known that a consistent description of the phenomena of dispersion, reflection, and scattering of electromagnetic waves by material media can be given on the fundamental assumption that an atom, when exposed to radiation, becomes a source of secondary spherical wavelets, which are coherent with the incident waves. If we imagine that the incident radiation consists of a train of polarised harmonic waves of frequency ν , the electric vector of which at the point in space where the atom is situated at rest can be represented by

$$\mathbf{E} = E\nu \cos 2\pi\nu t, \quad \dots \quad (1)$$

where E is the amplitude and ν is a unit vector; the secondary wavelets can be described as originating from a varying electrical doublet, the strength of which is given by

$$\mathbf{P} = Pw \cos (2\pi\nu t - \phi), \quad \dots \quad (2)$$

where P is the amplitude and w also a unit vector, while ϕ represents the phase difference between the secondary and primary waves. The quantities P , w , and ϕ depend on ν , and on the peculiarities of the atom; moreover, the amplitude P will be proportional to the amplitude E of the incident waves.

If we consider an atom containing an electron of charge $-e$ and mass m , which is isotropically bound to a position of equilibrium, we find on the classical theory that the vectors ν and w will coincide and the following expression for P is found to hold for frequencies which differ sensibly from the natural frequency ν_1 of the electron.

$$P = E \frac{e^3}{m} \frac{1}{4\pi^2(\nu_1^2 - \nu^2)}. \quad \dots \quad (3)$$

In the region where this formula holds the phase difference ϕ is very small and of such a magnitude as to ensure energy-balance. For substances exhibiting absorption lines at the frequencies $\nu_1, \nu_2, \dots, \nu_i$, a formula of the type

$$P = E \sum_i f_i \frac{e^2}{m} \frac{1}{4\pi^2(\nu_i^2 - \nu^2)}, \quad \dots \quad (4)$$

where the quantities f_i are constants, has actually been found to represent the results of experiment with considerable accuracy. Especially the experiments of Wood and Bevan on the dispersion of light in monoatomic vapours of alkali metals have confirmed formula (4) and allowed a determination of the constants f_i which are conjugated to the different absorption lines of the vapour.

In Bohr's theory of spectra, the picture of electrons which are elastically bound inside the atom is abandoned, and for it is substituted a picture according to which an atom exhibiting an absorption line of frequency ν is capable of performing under the influence of the illumination a transition from the state under consideration to a stationary state the energy content of which is $h\nu$ greater. On Bohr's principle of correspondence, the possibility for such transitions is considered as being directly connected with the periodicity properties of the motion of the atom, in such a way that every possible transition between two

stationary states is conjugated with a certain harmonic oscillating component in the motion.

In a paper by Bohr, Slater, and the writer, which gives a more detailed discussion of an idea briefly described by Dr. Slater in a recent letter to NATURE (March 1, p. 307), and is to appear shortly in the *Philosophical Magazine*, it will be shown that, with the correspondence principle as a guide, it seems possible to arrive at an adequate description of the activity of the atoms regarding their interaction with radiation. On this theory the picture described above of the mechanism underlying dispersion and scattering phenomena is essentially preserved, and the important question arises concerning the quantitative laws connecting the quantities P , w , and ϕ appearing in (2), which characterise the reaction of an atom in a given state against external radiation, with the peculiarities of the transitions which the atom may perform to other stationary states. The present state of the quantum theory does not allow a rigorous deduction of these laws. It is, however, possible to establish a very simple expression for P , which fulfils the condition, claimed by the correspondence principle, that, in the region where successive stationary states of an atom differ only comparatively little from each other, the interaction between the atom and the field of radiation tends to coincide with the interaction to be expected on the classical theory of electrons.

Consider an atom in a stationary state which by absorption of radiation of frequencies ν_1^a, ν_2^a, \dots may perform transitions to states of higher energy, and by emission of radiation of frequencies ν_1^e, ν_2^e, \dots may perform spontaneous transitions to states of lower energy. We will, following Einstein, denote the probability of the isolated atom performing in unit time one of the latter transitions by A_1^e, A_2^e, \dots whereas the analogous probability coefficients for the spontaneous transitions of which the state under consideration represents the final state are denoted by A_1^a, A_2^a, \dots . For the sake of simplicity we will further assume that the statistical weights of all the states involved are the same, and that the atom is so oriented in space that the electrical vector in the spontaneous radiation conjugated with the different transitions under consideration is always parallel to the electrical vector of the incident waves. The expression for P alluded to above takes, then, the following form:

$$P = E \sum_i A_i^a \tau_i^a \frac{e^2}{m} \frac{1}{4\pi^2(\nu_i^{a2} - \nu^2)} - E \sum_j A_j^e \tau_j^e \frac{e^2}{m} \frac{1}{4\pi^2(\nu_j^{e2} - \nu^2)}, \quad (5)$$

where $\tau_i^a = \frac{3mc^3}{8\pi^2 e^2 \nu_i^{a2}}$ and $\tau_j^e = \frac{3mc^3}{8\pi^2 e^2 \nu_j^{e2}}$ represent the

time in which on the classical theory the energy of a particle of charge e and mass m performing linear harmonic oscillations of frequency ν is reduced to $1/\epsilon$ of its original value, where ϵ is the base of the natural logarithms. In analogy with the region of applicability of formula (3), this formula only applies in the regions for ν which lie outside the absorption and the emission lines, where the phase angle ϕ is negligibly small.

The reaction of the atom against the incident radiation can thus formally be compared with the action of a set of virtual harmonic oscillators inside the atom, conjugated with the different possible transitions to other stationary states. These oscillators might be thought of as electrical particles with such charge e^* and mass m^* that the classical formula (3) would give the right result directly, but if we do so, we meet with the remarkable circumstance that, while for the

"absorption oscillators" $\frac{e^{*2}}{m^*} = A_j^a \tau_j^a \frac{e^2}{m}$ is a positive

quantity, the corresponding expression for the "emission oscillators" $\frac{e^{*2}}{m^*} = -A_i e^{\tau_i} \frac{e^2}{m}$ becomes negative. Denoting the quantity $A\tau$ which thus can be conjugated with a given transition and has the dimensions of a number, by f , one might introduce the following terminology: in the final state of the transition the atom acts as a "positive virtual oscillator" of relative strength $+f$; in the initial state it acts as a negative virtual oscillator of strength $-f$. However unfamiliar this "negative dispersion" might appear from the point of view of the classical theory, it may be noted that it exhibits a close analogy with the "negative absorption" which was introduced by Einstein, in order to account for the law of temperature radiation on the basis of the quantum theory.

Led by considerations of the close connexion between dispersion and selective absorption, Ladenburg has proposed a formula equivalent to ours if the second term on the right side is omitted. In the case where the dispersing atoms are present in the normal states and only positive oscillators come into play, his formula is thus equivalent to ours. In the general case of a stationary state where the atom can perform spontaneous transitions to states with lower energy, negative virtual oscillators also come into play, corresponding to the second term in our formula.

As shown by Ladenburg, there is considerable experimental evidence in favour of the connexion between selective absorption and dispersion as indicated by the formula when applied to atoms in their normal state. The experiments at hand scarcely allow testing the complete formula in a more general case. It may be remembered, however, that the presence of the second term in (5) is necessary if the classical theory can be applied in the limiting region where the motions in successive stationary states differ only by small amounts from each other. H. A. KRAMERS.

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Copenhagen, March 25.

Sunshine and Health in Different Lands.

MAY I ask the courtesy of your columns to make the following remarks in connexion with the letter on the above subject by Mr. L. C. W. Bonacina which appeared in NATURE of April 5?

Mr. Bonacina says: "We are insistently being told that direct sunshine exerts a powerful destructive effect upon germs of disease . . . the fact must be co-ordinated with another fact, namely, that it is precisely in hot sunny climates that many species of pathogenic organism acquire such deadly virulence," etc. But is not this rank exuberance of life due to the high relative humidity associated with the insolation, for the driest regions are the healthiest, at least for Europeans? The chief disadvantage of the large insolation appears to be the liability to heat-stroke.

As regards the insolation of the polar regions, surely the testimony of explorers is that the lack of light in the winter is one of its most trying features.

Excessive insolation may have its disadvantages, and in all probability it is undesirable to take the question of sunlight apart from other climatic features; but surely the results obtained by Sir H. Gauvain and others by the use of sunlight in the treatment of disease prove the advantages thereof. Mr. Bonacina's remarks on light-starvation in cities in winter owing to smoke are true enough; but here, too, this factor of smoke acts, in industrial districts at least, in summer. CICELY M. BOTLEY.

10 Wellington Road, Hastings,
April 16.

I AM indebted to the editor for the opportunity to reply at once to Miss Botley's comments on my letter to NATURE of April 5. It would, indeed, be "undesirable to take the question of sunlight apart from other climatic effects." The whole purpose of my letter was to express a warning against one-sided statements of a many-sided case, and to suggest that if combined efforts were made to discover how different countries compare with an optimum allowance of sunshine, if possible, to be evaluated, the local problems of sunshine therapeutics would be greatly clarified. Apparently there is, or used to be, a belief in India, the Philippines, and other tropical lands, that excessive stimulation by the ultra-violet rays of the sun should be specially guarded against by suitably-coloured clothing, and this in itself would raise the question of an optimum, and of the need of investigating the subject in its geographical relationships, in view of recent pronouncements upon the therapeutic importance of ultra-violet light in temperate latitudes.

Then as to the point raised about tropical humidity, it must be remembered that the constant combination of heat and moisture, denoted by the high wet-bulb thermometer, about 80° F., in regions like the Gold Coast, which is so debilitating, and also particularly favourable to the parasitic enemies of man, is itself a meteorological adjustment to fierce tropical insolation. Although as an adversary of insect life drought is no match for the frost of cold countries, the dry parts of the tropics are certainly more wholesome wherever the temperature is moderate; but these are just the parts where, on account of the scarcity of cloud and rain, the extremes of heat are encountered, as, for example, at Khartoum, where, for at least half the year, the temperature of the air by day soars much above blood-heat, so that the cooling power of the atmosphere upon the body, according to the wet and dry kata thermometer, is very low and sometimes even negative. (See Sutton's "Climate of Khartoum," Cairo, 1923.)

With regard to the comment about an adverse effect of the polar winter darkness, the real point at issue is whether a lengthy periodic darkness under natural climatic conditions, counterbalanced by an equally long seasonal brightness, could be so pernicious to health as the chronic artificial loss and deterioration of sunlight in parts of Lancashire, Yorkshire, Glamorgan, and Staffordshire, which have become excessively industrialised at the high cost of the purity and beauty of climate and soil in so green a land as England. Questions of this kind are rendered extremely complex, because climate acts not only directly, but also indirectly through economic and social factors.

Lastly, concerning Miss Botley's point about loss of summer sunlight in smoky districts, this is scarcely, for various meteorological reasons, comparable with the winter loss, although the Black Country certainly does, even in summer, sometimes suffer days of indescribable gloom. It is known that in London, where there is little factory smoke, domestic smoke is the main cause of many artificially darkened days in winter, a source of atmospheric contamination largely absent in summer. But even if the same amount of smoke were discharged into the atmosphere in June as in December, certain physical and meteorological conditions associated with a high altitude of the sun would not permit so large a proportion of light to be cut off as when the sun is low down at midwinter. On all accounts, therefore, the winter solstice is the period of the year round which the smoke-problem is most serious, though fortunately the frequent stormy weather between November and February prevents very many actual smoke-fogs and hazes. It is also