in absorption in Mg vapor.[11] The fact that in the ^2P states of HgH one electron interacts with the H electron, while in the Mg($^3P_1$)H(^2S) state of MgH the two Mg electrons interact with each other and not with the H electron, may be correlated with the fact that Hg shows chemical valences of both one and two, while Mg shows only the valence two; similar differences also exist in the spectroscopic behavior of the two atoms. A more complete discussion will be given in later papers.

[1] R. S. Mulliken, these PROCEEDINGS, March, 1926.

[2] W. Pauli, Jr., *Zeit. Physik*, **31**, 765 (1925). W. Heisenberg, *Ibid.*, **32**, 841 (1925). F. Hund, *Ibid.*, **33**, 345 (1925).

[3] R. Mecke, *Naturwissenschaften*, Sept. 4, 1925.

[4] E. E. Witmer, these PROCEEDINGS, April, 1926.

[5] J. C. Slater, these PROCEEDINGS, Dec., 1925.

[6] W. Lenz, *Verhandl. D. Phys. Ges.*, **21**, 632 (1919).

[7] L. Nordheim, *Zeit. Physik*, **19**, 69 (1923); cf. also L. Mensing, *Zeit. Physik*, **34**, 602 (1925).

[8] A. Sommerfeld, *Atombau und Spektrallinien*, 4th edition, p. 203–6.

[9] R. T. Birge, *Nature*, Feb. 13 and Feb. 27, 1926.

[10] Cf. H. Sponer and J. J. Hopfield, *Physic. Rev.*, May (?), 1926 (Abstract).

[11] S. Barratt, *Proc. Roy. Soc.*, **109A**, 194 (1925).

ON THE NATURE OF LIGHT

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In a recent article in these PROCEEDINGS[1] Professor G. N. Lewis has suggested that the conflict between the quantum theory of light and the known facts of interference might be resolved by assuming that an atom never emits a quantum of light except to another atom, the possibility of transmission of the quantum being determined by the nature of the paths connecting the two atoms in such a manner that the transmission will not occur if forbidden by the known laws of interference. The idea is made more plausible by describing such transmissions with the help of Minkowski's four-dimensional geometry of relativity. In the language of this geometry the path of the quantum passing between the two atoms would lie along a singular line, and since intervals along such singular lines have zero length in the geometry used, the atoms may be regarded as in virtual contact, thus making it less surprising that the emitting atom should "know" the existence of a receiving atom in such a condition and location as to permit a transfer. The apparent contradiction to our usual ideas as to the sequence of cause and effect also becomes less serious when viewed from the point of view of this four-dimensional geometry. To common sense it seems absurd that the emission of light from a distant star should be determined by the condition, thousands of years later, of a chloryphyll molecule on the earth which had not even been synthesized at the time of emission. Nevertheless by a proper choice of space-time axes in the four-dimensional geometry, both the distance between the source and recipient and the time of transmission may be made as small as desired.

Views, in some ways similar to those of Lewis, have previously been presented by other authors.[2] Thus as early as 1921–22 Schottky discussed in considerable detail the difficulties encountered by the quantum theory as to the sequence of cause and effect, and indeed speaks as follows: ". . . .die gegenseitige Bedingtheit von Emission und Absorption nicht verständlich wäre, wenn man die Emission in normaler Weise als die zeitlich vorangehende Ursache der Absorption ansahe; vielmehr müsse die Wechselbeziehung zwischen Emission und Absorption so aufgefasst werden, dass beide Vorgänge sich in völlig symmetrischer Weise gegenseitig bedingen." In addition Smekal in 1922 formulated the general thesis that absorbing and emitting systems must be regarded as fundamentally coupled together. While Wentzel in 1924, accepting the idea of such coupling, presented a fairly complete quantum theory of interference containing rules by which not only the possibility, but also the probability of the passage of a quantum along any given path connecting the emitting and absorbing bodies is governed by the configuration of the total system, his inclusion of an expression for probability of transmission permitting him to obtain the correspondence principle as well as to account for interference.

The ideas adopted by Professor Lewis have much to recommend them, and the present writers feel very sympathetic towards his point of view and in particular appreciate the use of four-dimensional geometry in making the ideas clearer and more plausible. The purpose of the present note, however, is to point out in the first place that Professor Lewis's proposed crucial experiment might not necessarily give the result that he states, even if his point of view is correct, and in the second place to present a somewhat different although not conflicting statement of the relation between wave theory and light quantum theory which seems to be temporarily adequate to describe the facts.

The proposed crucial experiment is illustrated by figure 1 in which the relative dimensions are approximately the same as in Professor Lewis's figure 4. S is a source of light, AA' and BB' mirrors so adjusted as to produce an interference pattern on the screen CD, C being the center of a dark band and D of a light band. The mirror AA' is suspended from its center in such a way as to permit a detection of any tendency to rotate in the plane of the diagram, and is narrow enough so that all light quanta reaching D would be reflected from one half of the mirror, while if light quanta could travel to C they would be reflected from the other half of the mirror. Since C is the center of a dark band Professor Lewis concludes that no quanta travel over the path $SA'C$ and hence the quanta travelling over the path SAD would produce an unbalanced torque on the mirror which could be detected from the tendency of the mirror to rotate, a tendency which would not exist on other theories of light.

The present writers, however, cannot agree with Professor Lewis's assumption that no light quanta can pass over the path $SA'C$ merely because there is no evidence of light at C. It is certain if light quanta travel in straight lines that they are able to pass through positions where the laws of interference forbid them to produce any effect. For example, if we arrange to detect the presence of light by a layer of sensitized gelatine of appreciable thickness, it is found that light acts only at those depths in the film where the laws of the wave theory predict a reinforcement and no action occurs at intermediate points through which the light quanta must

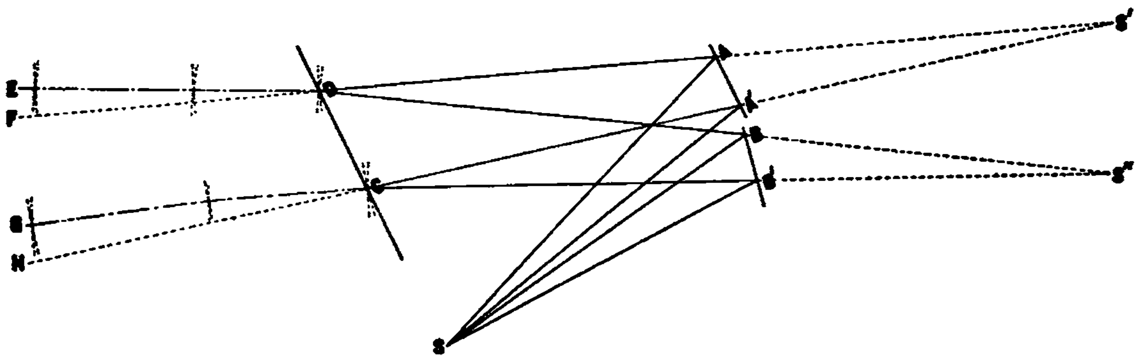

FIGURE 1

have passed but where the wave theory predicts an interference. As is well known this phenomenon is made use of in the Lippmann process of color photography in which the standing waves produced inside a film of gelatine by oncoming and reflected light are used to deposit the silver in thin laminae at the depths predicted by the wave theory as the positions of the loops of the standing waves.[3]

In view of this fact it seems unreasonable to assume that no light quanta pass over the path $SA'C$ merely because C is a dark band. Rather we should believe that light quanta do pass over the path $SA'C$ and that on arriving at C, then in accordance with the transmissive and reflective properties of the material of the screen, some of the quanta penetrate to depths where the laws of the wave theory permit them to be absorbed, while other quanta are reflected from the screen and are also finally absorbed at positions on the surrounding walls where the wave theory permits. If this be the correct view it is possible that no torque on the mirror AA' would be observed in Professor Lewis's proposed experiment.

In order to make the condition of affairs clearer, figure 1 has been drawn to include the positions S' and S'' of the mirror images of the source S, and the points back of the surface of the screen where reinforcement and interference could take place. The dot and dash line DE gives the location of points equidistant from S' and S'' and the slightly curved dot and dash line CG gives the location of points such that the distance from S' is half a wave-length greater than the distance S''.

Hence if the screen CD consisted of a thick slab of sensitized gelatine (of refractive index unity), there would be a heavy deposition of silver along the line DE corresponding to the reinforcement predicted by the wave theory, and almost no deposition along the line CG corresponding to the almost complete interference predicted by the wave theory. It will be noted, however, from the figure that quanta travelling along the path $A'C$ would continue into the slab of gelatine to points where absorption is permitted in agreement with the idea that the mere absence of effects at C does not prohibit the passage of quanta through that point. It will be noted that quanta coming along the path AD continue into the slab along the path DE to positions where partial interference is predicted and hence are presumably less likely to be absorbed than at D.

If instead of a slab of sensitized gelatine, the screen CD consisted of a plane mirror, the positions of reinforcement and interference would lie in front of the screen, quanta coming along the path $A'C$, however, still entering regions where the wave theory permits adsorption to take place, for example, on the walls of the laboratory.

If the screen consisted of a matt surface of high reflecting power, as Professor Lewis presumably had in mind, the surface could be considered as composed of a large number of little mirrors set at random directions, without, however, introducing any essential change in the considerations.

Finally, if the screen consisted of a highly absorptive material the condition of affairs would be complicated, but not necessarily altered as far as concerns the passage of quanta along the line $A'C$. Of course no quanta would be absorbed at C, since in accordance with the wave theory the amplitude is zero at that point. Quanta coming along the path $A'C$ could, however, continue into the absorptive material, if necessary being deflected on passage through the surface to regions where absorption is permitted by the wave theory.

Hence it does not seem necessary to conclude that no quanta travel along the path $A'C$ merely because no effects are observed at C. Of course the exact relative numbers traveling along different paths would be difficult to determine in the absence of a complete theory. Nevertheless it seems possible that the complete theory might lead to the same or nearly the same forces on the mirror AA' as would be predicted from the wave theory. In any case it is evident that the condition of affairs is more complicated than that indicated by Professor Lewis, and that his proposed crucial experiment might give at best a second-order effect rather than the simple effect which he assumes. The development of a more complete theory might be very interesting.

In conclusion the writers would like to state a possible method of regarding the conflict between the wave theory and the light quantum theory which seems heuristically adequate for describing the present facts. Since both theories contain elements of truth let us regard waves and light quanta as both being present in a radiation field. The energy is carried by the quanta and they move in straight lines except when deflected or absorbed and then they obey at least statistically the laws of the conservation of energy and momentum. The waves carry no appreciable energy but provide the signaling system by which in accordance with the laws of interference the atoms can "know" whether or not they are allowed to interact with an oncoming quantum. On the basis of this point of view the action of light can occur only at those places and those times where *both* the wave theory and the quantum theory would permit such action. The facts of interference show that quanta cannot act unless the wave theory permits, while the experiments of Compton and Simon[4] show that radiation can act only at those *places* where the quantum theory would predict the passage of a light quantum, and the experiments of Bothe and Geiger[5] show that radiation can act only at those *times* when the quantum theory would predict the presence of a light quantum. Each theory thus restricts the predictions of the other.

There is, of course, nothing original in this formulation of the matter, except perhaps the emphasis on the new fact that, even when the wave theory permits, no action of light can occur unless the quantum theory says that a light quantum is present. Furthermore the formulation is obviously only a temporary one, not only because of its theoretical unsatisfactoriness but because it seems probable that further investigations will show its inadequacy even as a statement of the facts.

[1] G. N. Lewis, these PROCEEDINGS, **12,** 22 (1926).

[2] Schottky, *Naturwissenschaften,* **9,** 492, 506 (1921); *Ibid.,* **10,** 982 (1922). Smekal, *Wiener Anzeiger,* No. **10,** 79 (1922). Wentzel, *Zeits. Physik,* **22,** 193 (1924). See also Wentzel, *Ibid.,* **27,** 257 (1924); **29,** 306 (1924), and Herzfeld, *Ibid.,* **23,** 341 (1924). In locating the above references we are indebted to the assistance of Dr. Fritz Zwicky.

[3] For a discussion and microphotograph of such laminae see Wood's *Physical Optics,* Macmillan, 1921, pp. 174–180.

[4] Compton and Simon, *Physic. Rev.,* **26,** 289 (1925).

[5] Bothe and Geiger, *Zeits. Physik,* **32,** 639 (1925).