Letters to the Editor.

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The Conservation of Photons.

WHATEVER view is held regarding the nature of light, it must now be admitted that the process whereby an atom loses radiant energy, and another near or distant atom receives the same energy, is characterised by a remarkable abruptness and singleness. We are reminded of the process in which a molecule loses or gains a whole atom or a whole electron but never a fraction of one or the other. When the genius of Planck brought him to the first formulation of the quantum theory, a new kind of atomicity was suggested, and thus Einstein was led to the idea of light quanta which has proved so fertile. Indeed, we now have ample evidence that radiant energy (at least in the case of high frequencies) may be regarded as travelling in discrete units, each of which passes over a definite path in accordance with mechanical laws.

Had there not seemed to be insuperable objections, one might have been tempted to adopt the hypothesis that we are dealing here with a new type of atom, an identifiable entity, uncreatable and indestructible, which acts as the carrier of radiant energy and, after absorption, persists as an essential constituent of the absorbing atom until it is later sent out again bearing a new amount of energy. If I now advance this hypothesis of a new kind of atom, I do not claim that it can yet be proved, but only that a consideration of the several objections that might be adduced shows that there is not one of them that can not be overcome.

It would seem inappropriate to speak of one of these hypothetical entities as a particle of light, a corpuscle of light, a light quantum, or a light quant, if we are to assume that it spends only a minute fraction of its existence as a carrier of radiant energy, while the rest of the time it remains as an important structural element within the atom. It would also cause confusion to call it merely a quantum, for later it will be necessary to distinguish between the number of these entities present in an atom and the so-called quantum number. I therefore take the liberty of proposing for this hypothetical new atom, which is not light but plays an essential part in every process of radiation, the name *photon*.

Let us postulate for the photon the following properties: (1) In any isolated system the total number of photons is constant. (2) All radiant energy is carried by photons, the only difference between the radiation from a wireless station and from an X-ray tube being that the former emits a vastly greater number of photons, each carrying a very much smaller amount of energy. (3) All photons are intrinsically identical. As the molecules of hydrogen differ from one another in direction and energy of translation, and in direction and amount of rotation, so two photons, as seen by a single observer, differ in direction of motion, in energy, and in polarisation. If we were moving with rapid acceleration toward a wireless station, its photons would appear to possess increasing amounts of energy, and would pass over the whole spectral scale through the visible and into the ultraviolet. At a certain instant, for example, they would be indistinguishable from the photons emitted by excited sodium atoms. (4) The energy of an isolated photon, divided by the Planck constant, gives the frequency of the photon, which is therefore by definition strictly monochromatic; although two photons coming even from similar atoms would never have precisely the same frequency. (5) All photons are alike in one property which has the dimensions of action or of angular momentum, and is invariant to a relativity transformation. (6) The condition that the frequency of a photon emitted by a certain system be equal to some physical frequency existing within that system, is not in general fulfilled, but comes nearer to fulfilment the lower the frequency is.

The serious objections to the idea of the conservation of photons are met in a consideration of the thermodynamics of radiation and of the laws of spectroscopy. According to the classical thermodynamics of radiation, the energy of a *hohlraum* at a given temperature is determined solely by the volume. If we define the number of photons in a small spectral interval by the amount of energy in that interval divided by $h\nu$, then, by Wien's displacement law, the number of photons remains constant in any reversible adiabatic process. Also, in the irreversible adiabatic process of free expansion from a given volume to a larger volume (both with perfectly reflecting walls) the number of photons remains constant, for neither the energies nor the frequencies are changed. If the original radiation, corresponding to a definite temperature, freely expands, let us say, to sixteen times the first volume, then, according to the thermodynamics of Wien and Planck, it may be brought to a new temperature equilibrium by introducing an infinitesimal black body. Calculating from their equations, we find that in this process the number of photons is doubled. If this is so, there obviously can be no conservation law for photons. However, if we analyse carefully the thermodynamics of radiation, we find that Wien and Planck have tacitly employed a postulate which is supported by no experimental facts; namely, if an infinitesimal black body is introduced into a *hohlraum*, the radiation will come to a certain temperature, and then *no further change will ensue* when a large black body of the same temperature is introduced.

Dispensing with this postulate, and adding a new variable, the number of photons, to the variables which have previously been deemed sufficient to define the state of a system, we obtain a greatly enlarged science of thermodynamics. In this new thermodynamics, which includes as true and stable equilibria such states of equilibrium as those to which Einstein has applied the terms " aussergewöhnlich " and " improprement dit " (*Ann. Phys.*, 38, 881, 1912; *Jour. de Phys.*, 3, 277, 1913), the familiar laws of radiation and of physical and chemical equilibrium become special cases, true only for an unlimited supply of photons. Even so fundamental a process as the flow of heat must involve two factors, the amount of energy and the number of photons transferred. A fuller account of this new thermodynamics will shortly be published.

Turning to spectroscopy, we find that the principle of the conservation of photons is in obvious conflict with existing notions of the radiation process. We must assume that in an elementary process of radiation one, and only one, photon is lost by the emitting atom. Suppose that an atom which is in the 4-2 state drops to the 3-3, then to the 2-2, then to the 1-1. It thus loses three photons, but the same atom dropping directly from the 4-2 state to the 1-1 loses only one photon. If, therefore, we are to admit the conservation of photons, we must say that the atom does not pass from precisely the same initial to the same final state by the two paths, but rather that either the 4-2 or the

1-1 states must be multiple. Even if the inner quantum number is given, as well as the total and the azimuthal quantum numbers, the atomic states must still be regarded as not completely specified. Indeed, numerous examples have been found (see the review by Ruark and Chenault, *Phil. Mag.*, **50**, 937, 1925) of a superfine structure which is not yet accounted for.

I had hoped to be able to derive certain familiar selection principles from the conservation of photons. Here I have not as yet succeeded, and can only state that if we assume the existence of a number of atomic states with nearly the same energy but with different numbers of photons, the new theory is not in conflict with the results of spectroscopy.

The rule that one, and only one, photon is lost in each elementary radiation process, is far more rigorous than any existing selection principle, and forbids the majority of processes which are now supposed to occur. To account for the apparent existence of these processes, it is necessary to assume that atoms are frequently changing their photon number by the exchange of photons of very small energy, corresponding to thermal radiation in the extreme infra-red. The new theory therefore predicts that many atomic processes will be inhibited at very low temperatures, and for this there seems to be some experimental evidence. But the existence of numerous extraneous factors obscures the issue. In order to simplify matters, a molecular stream might be passed through the centre of a tube cooled to a very low temperature, so as to reduce to a minimum the amount of thermal radiation. The theory would predict that in such circumstances certain processes within the stream, such as fluorescence or the emission of light from activated atoms, would be profoundly changed. Experiments in this direction are now in progress.

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The Synthesis and Disintegration of Atoms as Revealed by the Photography of Wilson Cloud Tracks.

IN 1923 Harkins and Ryan developed a simple method (NATURE, **112**, 54; *J. Am. Chem. Soc.*, **45**, 2095) for obtaining a knowledge of what occurs when an atom disintegrates. This consisted of the use of very fast α-rays, such as those of thorium or radium-C, in a modified Wilson (Shimizu) ray track apparatus, and the photography of an extremely large number of tracks. By the use of these fast rays, about 20,000 photographs in air and 21,000 in argon were obtained. Each photograph gave two views at right angles. That Wilson's apparatus had not been applied earlier for this purpose was undoubtedly due to the fact that it had previously seemed almost hopeless to obtain sufficient photographs.

In 1925 Blackett (*Proc. Roy. Soc. A.*, 107, 349), by the use of the method applied earlier by Harkins and Ryan, obtained 22,000 photographs in nitrogen. In these, eight disintegrations of nitrogen atoms to give protons were obtained, and it was found that in rare instances a fast α-particle attaches itself to the nucleus of a nitrogen atom.

The purpose of this letter is to present the results obtained from 34,000 photographs not previously reported. These contained an average of about 14 α-particle tracks each, so that about 270,000 tracks of 8·6 cm. range were obtained.

These have given two cases in which an α-particle attached itself to a nitrogen nucleus. One of the protons was emitted in a forward direction, that is, with a component of velocity in the same direction as that of the α-particle, while in the other case the proton was emitted backward.

Fig. 1 is from a photograph which was presented to the National Academy of Sciences in April 1926.

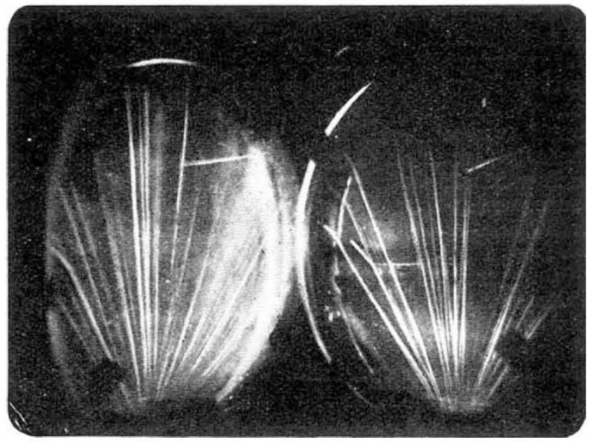

FIG. 1.—Simultaneous views at right angles of Wilson cloud tracks. In the original negative the track of the H^+-particle has about one-tenth the intensity of that of the α-particle or of the oxygen of mass 17. The disintegration is shown at the left side of each of the two views, but is much more distinct in the right-hand view.

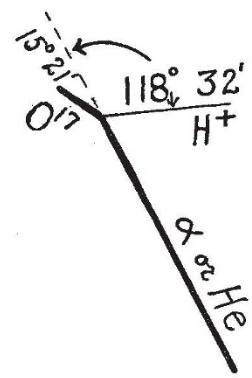

FIG. 2.—The space relations of the synthesis and disintegration exhibited in Fig. 1.

The values obtained in this case (Fig. 2) are θ, 118° 32′; ϕ, 15° 21′; remaining range of α-particle at time of collision, 6·3 cm.; velocity of α-particle at collision, $1{\cdot}86 \times 10^9$ cm. per sec.; initial velocity of proton, $2{\cdot}7 \times 10^9$ cm. per sec.; range of the proton, 19·6 cm., and velocity of heavy nucleus formed, $5{\cdot}3 \times 10^8$ cm. per second.

The kinetic energy after collision is 89 per cent. of that of the α-particle at time of impact, so 11 per cent. of the kinetic energy is stored up in the atom (presumably oxygen of mass 17) which is synthesised.

The hydrogen track of Fig. 1 has, on the original film, only about one-tenth the intensity of the tracks produced by the helium and the oxygen. That this is actually a hydrogen track is also indicated by the fact that the visible range in the original photograph is more than three times the range for an α-particle under the same conditions.

It may be noted that we have obtained only two atomic syntheses and disintegrations in the photography of 265,000 tracks, while with the same number of tracks Blackett obtained eight similar events, which, however, the Cambridge workers consider an abnormally high number. Since we have investigated carefully every bend in the α-ray tracks, it