Electron Waves -- in What?

Physics

J. W. N. SULLIVAN, in *The Bases of Modern Science* (Doubleday, Doran):

One very important conditioning factor of scientific theories is the contemporary state of scientific instruments. A scientific theory has reference to observations, and these observations are conditioned by the instruments used in making them. But there is no convincing reason to suppose that a given set of observations uniquely determines a scientific theory. We have to allow, also, for the type of mind which, as an historical accident, attained the level of genius at that moment. Nevertheless, although something must be allowed for the subjective factor, we cannot suppose that a given set of observations lend themselves to an indefinite variety of interpretations. It is possible that science can no longer be pursued except in terms of the sort of abstractions that are now being used.

In this connection it is interesting to notice that an alternative theory to Heisenberg's, due chiefly to Schrödinger, and which issues in the same equations, seems, at first, to be more easily picturable. Just as the theory of light as "rays" has to be replaced, for the description of certain phenomena, by the theory of light as "waves," so the conception of "masses" moving in "orbits" is replaced, in Schrödinger's theory, by trains of waves. A hydrogen atom, on this theory, is a region permeated by waves. The waves fall off very rapidly and become inappreciable at a distance from the centre, which is found to be the same as the empirically determined radius of a hydrogen atom. But when we inquire into the physical meaning of the symbol that obeys these wave equations we find that it has no direct physical meaning. The pictorial imagination, which seizes on waves as intelligible, is baffled by the fact that the quantity which is waving has no direct physical significance. We are again in the region of logical constructions which are not picturable.

In spite of the immense degree of co-ordination effected by relativity theory the science of physics, at the present time, is very far from being a unity. The scientific ideal of giving a mathematical description of all natural phenomena in terms of a few simple entities and principles seems farther from realization than it has been at any period since Newton. Our greater knowledge has given us a sight of deeper difficulties and more irreconcilable facts. And yet the impression is strong that we are on the eve of some great illumination, as if the physics of the moment is in the darkness that precedes the dawn. At present special methods are devised for special problems. These special methods are not obviously connected, and yet, if Nature is a unity, we must suppose the problems to be connected. It is possible that these special methods will turn out to be partial aspects of some great generalization, and that the difficulties they now present, their enigmatic quality, are due to their partial character.

It is probable that the most far-reaching changes in our concepts will occur in connection with quantum theory and its relation to the wave theory of light. Two passages, admirably illustrating the disadvantages and advantages of the quantum theory, may be quoted from Dr. Jeans and Dr. Ellis, respectively:

"If, however, radiation is to be compared to rifle bullets, we know both the number and size of these bullets. We know, for instance, how much energy there is in a cubic centimetre of bright sunlight, and if this energy is the aggregate of the energies of individual quanta, we know the energy of each quantum (since we know the frequency of the light) and so can calculate the number of quanta in the cubic centimetre. The number is found to be about ten millions. By a similar calculation it is found that the light from a sixth-magnitude star comprises only about one quantum per cubic metre, and the light from a sixteenth-magnitude star, only about one quantum per ten thousand cubic metres. Thus, if light travels in indivisible quanta like bullets, the quanta from a sixteenth-magnitude star can only enter a terrestrial telescope at comparatively rare intervals, and it will be exceedingly rare for two or more quanta to be inside the telescope at the same time. A telescope of double the aperture ought to trap the quanta four times as frequently, but there should be no other difference. This, as Lorentz pointed out in 1906, is quite at variance with our everyday experience. When the light of a star passes through a telescope and impresses an image on a photographic plate, this image is not confined to a single molecule or to a close cluster of molecules as it would be if individual quanta left their marks like bullets on a target. An elaborate and extensive diffraction pattern is formed: the intensity of the pattern depends on the number of quanta, but its design depends on the diameter and also on the shape of the object glass. Moreover, the design does not bear any resemblance whatever to the 'trial and error' design which is observed on a target battered by bullets. It seems impossible to reconcile this with the hypothesis that quanta travel like bullets directly from one atom of the star to one molecule of the photographic plate."

The wave theory explains the above phenomena perfectly. It does not, however, explain the emission of electrons under the influence of X rays, as is emphasized by the following quotation from Dr. Ellis:

"To take a definite case, suppose X rays are incident on a plate of some material, then it is found that electrons are ejected from the plate with considerable velocities. The number of the electrons depends on the intensity of the X rays and diminishes in the usual way as the plate is moved farther from the source of X rays. The velocity or energy of each electron, however, does not vary, but depends only on the frequency of the X rays. The electrons are found to have the same energy whether the material from which they come is close to the X-ray bulb or whether it is removed away to any distance.

"This is a result which is quite incompatible with the ordinary wave-theory of radiation, because as the distance from the source increases the radiation spreading out on all sides becomes weaker and weaker, the electric forces in the wave-front diminishing as the inverse square of the distance. The experimental result that the photo-electron always picks up the same amount of energy from the radiation could only be accounted for by giving it the power either to collect energy from a large volume or to collect energy for a long time. Both of these assumptions are unworkable, and the only conclusion is that the radiated energy must be localized in small bundles."

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