between energy, momentum, wave-length and velocity for both. But this does not justify the confusion of the two principles. The 'microscope experiment' illustrates uncertainty I, and neither the 'experiment' nor the principle offers any evidence relevant to uncertainty II. I mention these facts in the hope of contributing to the eventual removal of uncertainty I from its present misleading position in text-books.

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April 9.

[1] Cowley, W. L., *Nature*, **163**, 492 (1949).

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H. V. STOPES-ROE agrees with my criticism that the application of the resolution-power formula to the uncertainty principle is irrelevant. His letter conveys the impression, however, that I have concerned myself with out-of-date matter and that the position is quite satisfactory in the new wave-particle theory. I wish to make it clear that my criticism was levelled at an application which is generally accepted throughout the science as sound, and which frequently appears in text-books side by side with analysis similar to that sketched out by Mr. Stopes-Roe. Although the new theory has gone from strength to strength since its introduction by de Broglie and others, I find it impossible to accept, and I am sure many must share my difficulties. The wave-particle duality is disturbing enough; but even more so is the incomprehensible duality of quantum theory logic.

The representation of a particle by a group of waves in a limited region as mentioned by Mr. Stopes-Roe is adversely criticized in "Wave Mechanics of Free Electrons" by G. P. Thomson. It is shown in this book that because the component waves have different speeds, the group will continually change its form or characteristics as it travels along. Apparently the view now held by the orthodox is that two de Broglie waves of very nearly the same frequency and speed $V$ greater than light produce beats of speed $U$ less than light such that $UV = C^2$, where $C$ is the speed of light. This simple formula, by the way, and this is very important, would not hold for a Fourier group. The beat wave is not identified with the particle, therefore, in the manner of Mr. Stopes-Roe. The particle is assumed to be carried by the wave, the latter being identified with the motion or velocity of the particle. Nevertheless, the view that the particle *is* a bunch of waves is not abandoned. Arguments based upon this conception are allowed to pass unchallenged.

Probably the most startling duality in the theory is that which concerns the fact that de Broglie waves have speeds greater than light, although they are evolved theoretically from the theory of relativity which postulates that speeds cannot exceed light. The arguments justifying the position are so crude as to be valueless. The following is typical and was taken from a popular book meant for the novice, "The Restless Universe" by Max Born: "Simple harmonic waves cannot carry a signal. They are as smooth as oil and each wave crest is exactly like every other, and they go on monotonously for ever. Hence they may well travel faster than light, for the theory of relativity would only be contradicted *if they could be used to send distinguishing signals for the comparison of clocks*" (p. 164). Yet the reader must know that clocks are controlled by a continuous electric wave in his supply main, the signal being a constant frequency. Later the reader learns from the uncertainty theory itself that no measurement can be made or action taken without affecting the motion of the particle concerned. The motion of the particle determines the velocity of the de Broglie wave. Therefore, de Broglie waves cannot go on monotonously for ever, for they change every time an action occurs. Whatever may be the answer to this problem it is not contained in the statement quoted, and to a novice this statement cannot convey anything more than false conceptions.

Beginners are even expected to appreciate the following logic, which is quite typical and is taken from "Wave Mechanics—an Introductory Sketch", by H. F. Biggs. "That this velocity exceeds that of light need, of course, cause us no misgiving from the relativity point of view, since it is the velocity of propagation, not of any mass or energy, but merely of the phase of a hitherto unspecified quantity $\psi$" (p. 17). The reader has to wait until p. 35 for the specification, if indeed it is such.

There is even duality as to what actually is the uncertainty principle. One aspect is what may be termed inadequate representation, and the other is chance, uncontrolled by Nature, in the actions of fundamental particles. Inadequate representation means that although a point may represent a body under certain conditions it will not do so under others. We need not go to the quantum theory to establish this or to obtain the order of magnitude of the error. A reasonable person would accept that when studying galaxies of stars the errors would be measurable in light years; when in the tool room or macroscope laboratory errors are of the order of a thousandth part of a millimetre; and in the measurement of fundamental particles the error would have to be very small if the measurement is to mean anything. This error may as well be associated with Planck's constant $h$ as with anything else.

The second aspect of the principle involves chance, and my reading leaves me with the view that this has featured in the uncertainty principle since its inception and that it still holds ground.

Modern theory has made the position more nebulous if anything, as many writers of advanced books do not discuss the chance aspect explicitly, whereas others do by still retaining all the older views. The former seem to degenerate into the principle of 'inadequate representation'.

Whether or not the uncertainty principle of chance can be proved is a moot point. I think it can never be more than a faith. Observation for the purpose of proof can only show whether or not something happens which our theories predicted should happen. Non-occurrence of the event revealed by a test may, on one hand, arise because of an uncertainty in Nature; but, on the other hand, we may be in error because of our inability to deal with all the factors of the problem. By accepting the uncertainty principle we imply either blind faith, or that we are satisfied that orthodox authority can adequately deal with any problem, however complex, and deal with it regardless of the number of factors involved. This position is rendered untenable when the first error or irregularity is found in the orthodox.

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