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Waves and particles

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When in the spring of 1926 Erwin Schrödinger set out the form of the equation for wave propagation and drew important conclusions from it, in some very elegant work which appeared to develop the ideas which I had introduced in 1923–24 (de Broglie 1924), he really profoundly modified the ideas which had guided me two years earlier in my original research. For his idea was that although the ψ wave which he was introducing was still a true physical wave propagated in space and time, it would not have any single area of high field concentration which could be a particle; whereas in my original concept I assumed that the coexistence of waves and particles, perceived by Einstein in 1905 in respect of light in his theory of light quanta, should be extended to all types of particle in the form of the coexistence of a physical wave with a particle *incorporated* in it. Moreover, Schrödinger's ψ wave was soon to lose the nature of a physical wave on the day when Max Born put forward the hypothesis that it was a probability, and for that reason should be normalized, which is equivalent to assigning to it an arbitrary amplitude selected by the theorist. Thus, starting from a synthetic idea of the coexistence in physical space of waves and particles, a theory in which there was no longer any wave or particle was arrived at!

I have recently explained in *Physics Bulletin* (de Broglie 1968) why I reverted some 15 years ago to my original ideas by developing the physical interpretation of wave mechanics by the theory of the double solution which I adumbrated from 1927 onwards (de Broglie 1927) but which I did not then pursue. Without going into this theory in detail here, I wish simply to emphasize one very important point.

In his 1926 work Schrödinger had shown that, in the case of a system made up of an ensemble of particles, it was necessary to construct a configuration space formed by the coordinates of the particles and to imagine that in this abstract space an obviously notional ψ wave was being propagated. This method of research on particle systems has proved extremely fruitful and has led to a large number of predictions which have been verified later with a very high degree of accuracy. It was complemented in the case of systems of particles of the same type by the hypothesis, which has also been very satisfactorily verified, that the function ψ of the configuration space should be made symmetrical when the particles are bosons and should be made antisymmetrical when the particles are fermions.

But as soon as Schrödinger's works were published I was struck by the paradox involved, as indeed I had already emphasized in an article which appeared in 1928 (de Broglie 1928). For since Schrödinger gave up the idea that particles existed in physical space, they no longer have well defined coordinates and it is difficult to imagine how the configuration space can be constructed with nonexistent coordinates. Nevertheless the enormous success of this method leaves no doubt that this corresponds to a physical reality.

It may assist in clarifying this point to recall that in classical mechanics particles are treated as a first approximation as material points which have well defined coordinates in physical space at every moment so that an abstract representation of the configuration space for a system of particles presents no difficulty whatsoever. In such a case the state of a group of particles is represented in the configuration space by a representative point which corresponds to the configuration of the system at the relevant moment. This indeed is the origin of the term 'configuration space'. The displacement in time of the representative point in configuration space traces the development of the configuration of the system. But this representation, clear and logical though it is, loses all its meaning in a theory in which particles have no spatial position as in current quantum mechanics.

Everything becomes clear if the idea that particles always have a position in space through time is brought back, and this is done by the theory of the double solution. According to my current thinking, the particle is always located within a physical wave, the v wave, quite distinct from the usual ψ wave which is only a mental construction based on the v wave by the formula $\psi = Cv$ where C is a normalization factor. The movement of the particle is assumed to be the superposition of a regular movement of alignment imposed upon it by its incorporation within the v wave and of a Brownian movement due to random energy exchanges which take place between the wave and a hidden medium which acts as a subquantum thermostat. The point of prime importance in this model is that at each moment the particle occupies a well defined position in space, and this re-establishes the clear meaning which the configuration space had in classical mechanics.

For some 15 years now I have carefully studied, together with my collaborator Mr Andrade e Silva, the question of the meaning of the use of the configuration space in the double solution theory and of the interpretation of its successes. In his doctoral dissertation Andrade e Silva (1960) published a detailed study of this problem in the case of systems with particles of different types, and I have summarized in one of my books the results so obtained (de Broglie 1963). We have also given much thought to the case of systems of particles of the same type, that is to the symmetrization of the ψ functions of configuration space in the case of bosons and antisymmetrization in the case of fermions. I have just devoted a chapter in a book now being printed to these matters (de Broglie 1971).

To sum up, my conclusion is as follows: the success of the configuration space method, which has enabled so many accurate predictions to be made since Schrödinger did his memorable research can only be fully explained by a theory which brings back the concept of the localization of particles incorporated in a physical wave, and so enables the clear meaning which the representation of the state of a system by a point in the configuration space had in classical mechanics to be restored to it ■

FURTHER READING

Andrade e Silva J L 1960 *Ph D Thesis* (Paris: Gauthier-Villars)

de Broglie L 1924 *Ph D Thesis* (Paris: Masson) reissued 1964

de Broglie L 1927 *J.Phys, Paris* **6** 225

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de Broglie L 1963 *Etude Critique des Bases de la Mécanique Ondulatoire* (Paris: Gauthier-Villars) chap.6. English translation 1964 (Amsterdam: Elsevier)

de Broglie L 1968 *Physics Bulletin* **19** 133

de Broglie L 1971 *La Réinterprétation de la Mécanique Ondulatoire* (Paris: Gauthier-Villars) in the press