The spin has been considered a relativistic and pure quantum mechanical property of the electron. Nevertheless, some claims that the spin has nothing to do with relativity and that a classical description is also possible, show that this subject is still controversial and must, therefore, be clarified.

Some statements taken from books suggesting that the spin is a relativistic and/or a quantum property

- L. de Broglie, *L'électron magnétique*, (Paris, 1934) p. 143

  "On voit que les équations de Dirac attribuent automatiquement à l'électron un magnétisme propre au magnéton de Bohr. Nous voyons donc apparaître le magnétisme de l'électron".

- W. Heitler, *Elementary Wave Mechanics*, II ed. (Oxford, 1956). p. 60

  "The spin and all its properties are now understood as a necessary and natural consequence of the theory of relativity combined with wave mechanics. There, the spin appears no longer as an independent addition to wave mechanics but is derived from the principles of these two theories. The value of the magnetic moment follows then also".

- M. Born, *Atomic Physics*, VI ed. (London, 1957) p. 189

  "Dirac has set up a wave equation which satisfies the relativistic postulate of symmetry .... Although we cannot discuss this theory in detail, we have to emphasize particularly that from very general principles, and with no special assumptions about the spin, it deduces all those properties of the electron which we have summarized under the word spin (mechanical and magnetic moment in the correct ratio)".

- H.A. Kramers, *Quantum Mechanics* (Amsterdam, 1958). p. 226

  "According to the Dirac theory of the electron, the spin properties are so closely connected with the relativistic quantum mechanical description of nature, etc.".

- E.U. Condon and G.H. Shortley, *The theory of atomic spectra*, (Cambridge 1959). p. 55

  "Further developments by Dirac have shown the spin to be intimately associated with relativistic effects".

- E.P. Wigner, *Group theory* (New York, 1959). p. 221

  "According to (Dirac's relativistic theory of the electron), the existence of the magnetic moment is entirely a relativistic effect which appears automatically when space and time are treated equivalently".

- H. Weyl, *The theory of groups and Quantum Mechanics*, II ed. (New York, N.Y., 1960). p. 217

  "*The spin appears as a phenomenon necessitated by the theory of relativity*" (underlined by the author).

- B.L. Van der Waerden, in *Theoretical Physics in the Twentieth Century: A memorial volume to Wolfgang Pauli*, M. Fierz and V.F. Weisskopf (eds.) (Interscience, N.Y., 1960) p. 215

  "spin cannot be described by a classical kinematical model, for such a model can never lead to a two-valued representation of the rotation group."

- M.E. Rose, *Relativistic Electron Theory* (New York, 1961) p. 1

  "It is proper to say that, in detail, the spin properties of an electron are a natural consequence of the requirements of relativistic invariance".

- G. Gamow, *Biography of Physics* (New York, N.Y., 1961). p. 263

  "Schrdinger's wave equation considered the electron as a point, and all the attempts to apply it to a spinning electron which possesses the properties of a little magnet were not leading to any satisfactory result.

  In his famous paper published in 1930, Dirac formulated a new equation, now carrying his name, which permits two birds to be killed with one stone. It satisfies all the relativistic requirements... and at the same time it leads automatically to the conclusion that the electron must behave as a little magnetized spinning top".

- D. Bohm, *Quantum Theory*, IX ed. (Eng. Cliffs., N.J. 1961) p. 387

  "Dirac derived a relativistic wave equation for the electron in which the spin and charge were shown to be bound up in a way that can be understood only in connection with the requirements of relativistic invariance".

- P.T. Matthews, *Introduction to Quantum Mechanics* (New York, N.Y., 1963). p. 88

  "The Dirac equation is one of the most remarkable discoveries in physics. It shows that the requirement of Relativity imposed on the quantum theory of the hydrogen atom has the following consequences:

  i) The electron has intrinsic spin $\hbar/2$.

  ii) The magnetic anomaly of the spin (is explained).

  iii) There are "fine structure" corrections to the Bohr formula for the hydrogen levels (...).

  iv) There is a positively charged counterpart, or anti-particle, to the electron– the positron.

  Results i) and ii) were known previously, but had been fed into non-relativistic theory, simply to obtain agreement with experiment. The Dirac equation shows that both effects are required for fundamental reasons".

- D.I. Blokhintsev, *Quantum Mechanics*, (Dordrecht, 1964) p. 196

  "It may be mentioned that the existence of the spin of the electron may now be regarded as a consequence of Dirac's relativistic theory of the electron"

  "Dirac showed that, from the relativistic equation for the motion of an electron, it necessarily follows that the electron must have the magnetic moment $e\hbar/2mc$ and the angular momentum 1/2. This provided a theoretical justification of Uhlenbeck and Goudsmit's hypothesis".

- A. Landé, *New Foundations of Quantum Mechanics* (Cambridge, 1965). p. 2

  "Finally, the spin was *explained* by Dirac through a combination of relativity theory and quantum principles".

- H.A. Bethe and R. Jackiw, *Intermediate Quantum Mechanics* (New York, N.Y. 1968). p. 13

  "The most natural quantum mechanical description of spin is accomplished with the help of relativistic generalizations of Schroedinger's equation".

- P.W. Atkins, *Molecular Quantum Mechanics*, (Oxford, 1970) p. 178

  "Uhlenbeck and Goudsmit's proposal was no more than an hypothesis, but when Dirac wedded quantum mechanics to relativity the existence of particles with half-integral quantum numbers for the angular momentum appeared automatically".

- S. Tomonaga, *The Story of Spin*, (Univ. Chicago Press, 1997) p.. 42

  " Probably you agree with me that nowadays we do not think of self-rotation or rotation when we hear the word *spin* (except in the case of skating)."

- W. Pauli, *The Nobel Lectures on Physics, 1945* p. 30

  "..., since Bohr was able to show on the basis of wave mechanics that the electron spin cannot be measured by classically describable experiments (as, for instance, deflection of molecular beams in external electromagnetic fields) and must therefore be considered as an essentially quantum-mechanical property of the electron."

The spin is not a relativistic property

- R.P. Feynman, *Quantum Electrodynamics* (New York, N.Y., 1961). p. 37

  "This value (of electron's gyromagnetic ratio) did seem to follow naturally from the Dirac equation and it is often stated that only the Dirac equation produces as a consequence the correct value of the electron's magnetic moment. However this is not true, as further work on the Pauli equation showed that the same value follows just as naturally. *i.e.* as the value that produces the greatest simplification. Because spin is present in the Dirac equation, and absent in the Klein-Gordon, and because the Klein-Gordon equation was thought to be invalid, it is often stated that spin is a relativistic requirement. This is incorrect, since the Klein-Gordon equation is a valid relativistic equation for particles without spin".

- M. Jammer, *The Conceptual Development of Quantum Mechanics* (New York, N.Y., 1966). p. 153

  "The so often repeated statement -suggested, probably, by this peculiar historical development- that "the spin is a purely relativistic effect" is a misconception. For it can be shown that a consistent theory of spin 1/2 with the correct value of the intrinsic magnetic moment can be established without *ad hoc* assumptions within the framework of Galileo-invariant, and not necessarily Lorentz-invariant, wave equations, though with the exclusion of spin-orbit interactions and the Darwin term (which thus are truly relativistic effects)".

In the following works

- J.M. Levy-Leblond, *Nonrelativistic Particles and Wave Equations*, Comm. Math. Phys. **6**, 286 (1967).
- V.I. Fushchich, A.G. Nikitin and V.A. Sagolub, *On the non-relativistic motion equations in the Hamiltonian form*, Rep. on Math. Phys. **13**, 175 (1978).

it is shown that $s = 1/2$, $g = 2$, spin-orbit coupling and Darwin's term which are obtained within Dirac's formalism, can also be obtained in a non-relativistic context.

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