On Pair Annihilation and the Einstein-Podolsky-Rosen Paradox

MENDEL SACHS

Department of Physics, State University of New York,
Buffalo, N.Y.

Abstract

Discussion is given to the experimental facts that are associated with ‘pair annihilation’, as a real example, rather than a gedanken experiment, to illustrate the Einstein-Podolsky-Rosen paradox. It is shown how the paradox disappears in a nonlinear relativistically covariant spinor field theory of this author, which takes the single interaction, rather than many free particles, as the elementary entity. In this theory there is no actual annihilation of matter. Rather, the observed facts that are conventionally interpreted as ‘pair annihilation’ are derived from an exact solution of the nonlinear field equations for the interacting pair in a particular deeply bound state. This solution reveals the observed facts, including the energy separation of 2m from the asymptotic state where the particles can be assumed to be (almost) free, and the prediction of two distinguishable currents whose phases are correlated by a 90° difference and are polarized in a common plane that is perpendicular to the direction of propagation of interaction with a detecting apparatus. The paradox disappears essentially because of the rejection by this theory (in principle and in the exact mathematical formalism) of any physical description in terms of truly uncoupled partial systems.

1. Introduction

In a recent discussion of the development of contemporary physical theory, Dirac (1963) emphasized the fact that in its present state, physics suffers from two kinds of difficulty. The first (which was called ‘Class One difficulty’) is concerned with the logical consistency of the quantum theory. The second (called ‘Class Two difficulty’) is concerned with the mathematical consistency of the necessary extension of quantum mechanics to a relativistic quantum field theory, in order to describe high-energy physics. His comments on these two difficulties were as follows:

'I have disposed of the Class One difficulties by saying that they are really not so important, that if one can make progress with them one can count oneself lucky, and if one cannot, it is nothing to be genuinely disturbed about. The Class Two difficulties are the really
serious ones. They arise primarily from the fact that when we apply our quantum theory to fields in the way we have to if we are to make it agree with special relativity... we have equations that at first look all right. But when one tries to solve them, one finds that they do not have any solutions.'

A major effort of present-day research in theoretical physics is being devoted to investigations of possible resolutions to Dirac’s Class Two difficulties. The current studies of axiomatic field theory† and the $S$-matrix approach (Chew, 1961), as well as Dirac’s own recent studies of quantum field theory (Dirac, 1966), are representative of this effort.

In addition, and in contrast with the recent approaches which attempt to maintain the basic postulates of the quantum theory, this author has been investigating a relativistic theory that is based entirely on the continuous field concept and where quantization plays no role.‡ The aim is to study the outcome of an extension from the Faraday-Einstein conception of field theory and, in particular, to construct a general theory whose formalism is both demonstrably mathematically consistent and contains, in the proper limit (of sufficiently low-energy-momentum transfer within an interacting system) the formal features of nonrelativistic quantum mechanics.

These studies have revealed that, indeed, one can construct a (mathematically consistent) covariant and deterministic formalism that predicts, for example, the correct quantitative spectrum of the hydrogen atom—including the Lamb shift. In addition, an exact solution of the coupled field equations, for a particle–antiparticle pair, has been found that relates to all of the experimental observations that are conventionally interpreted in terms of ‘pair annihilation’. The latter observations can be associated, in turn, with an actual experiment of the type that is discussed by Einstein et al. (1935) in their argumentation against the logical consistency of the quantum theory.§

Dirac’s comments about the Class One difficulties could be interpreted to mean that the argumentation which challenges the logical consistency of the Copenhagen interpretation of the quantum theory is unimportant, so long as quantitative predictions can be made in a


‡ The philosophical aspects of this approach are discussed in Sachs, M. (1964), *British Journal of the Philosophy of Science*, 15, 213; *Synthese*, 17, 29 (1967).

§ The latter will be referred to hereafter as EPR.