Unstable Particles in an Electric Field.

J. S. Bell and G. Karl (*)
CERN - Geneva

(ricevuto l'1 Giugno 1977)

Summary. --- When a particle decays in an electric field, and parity is violated, the mean angular momentum of the products is tilted with respect to the angular momentum of the parent. It is in this way that the Zel'dovich electric-dipole moment manifests itself; there is no linear Stark effect, and no precession of the spin of undecayed particles, when time reversal is respected.

A stable particle cannot have an electric-dipole moment if time reversibility holds, even if parity is violated (1). It was observed by ZEL'DOVICH (2) that the familiar reasoning does not apply immediately to an unstable particle. The question was further discussed by BELL (3) and by PERELOMOV (4,5). It has come up again (6,7), in the context of the search for parity violation in

(*) On sabbatical leave from the Department of Physics, University of Guelph, Canada, and on leave from the Rutherford Laboratory, Chilton, Didcot, England. Supported in part by the National Research Council of Canada.

atomic physics, in a way that shows that the earlier literature has not been fully digested. This is an attempt to clarify the matter by tracing more explicitly than before the flow of angular momentum when an unstable particle decays in an electric field. We always consider a time-reversible theory, but assume that parity is violated.

It was shown rather generally by Bell (4), and in a particular model by Perelomov (5), that the electric field induces no first-order splitting of the complex energy levels appropriate to the various projections of the spin along the field. Correspondingly there is no precession of the spin of the particle so long as it remains undecayed. As defined by these phenomena the electric-dipole moment of even an unstable particles is zero. But, in the unstable case, as observed by Zel’ dovich, the expectation value of the electric-dipole moment operator is not in general zero. The electric field then exerts a torque on the system. The angular momentum so delivered must go entirely to the decay products (3). We will check explicitly that the mean angular momentum of the decay products is at a fixed angle to the angular momentum of the parent. There is then a change of mean angular momentum, as the decay of an ensemble of unstable particles proceeds, the parent contribution diminishing and the child contribution increasing. It is in this way that the torque exerted by the electric field on the Zel’dovich dipole moment manifests itself.

Consider first a very simple model. Let N and V be spin-½ particles, fixed in position, and let 0 be a spin-zero ° meson °. Consider the S-wave decay

\[ V \rightarrow N 0. \]

Suppose that close in energy to V there be a particle U that can be mixed into V by an electric field. Let the electric field be in the x-direction, and let arrows denote projection of spin in the z-direction. Then the state

\[ (1) \ V^\uparrow, \]

in the absence of the field becomes

\[ (2) \ V^\uparrow + i g E_x |U^\downarrow, \]

to first order in the weak field \( E_x \). The corresponding state of N, generated by the decay, is

\[ (3) \ N^\uparrow + i \alpha g E_x |N^\downarrow, \]

where \( \alpha \) is the ratio of the decay matrix elements from V and U, respectively. In the state (3) the spin is rotated away from the z-direction by a small angle \( 2|\alpha g E_x |E_x \). But in (2) (because V and U are not mixed by \( J \) ) any such deviation is of order \( E_x^2 \). So, the angular momentum of the children (carried entirely