On the Decay Process of Positive and Negative Mesons

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SOME years ago Tomonaga and Araki[1] pointed out that on account of the electrostatic interaction with nuclei, the capture probability should be for negative mesons in dense material much greater than the decay probability; while for positive mesons the decay probability should prevail on the capture probability.

In 1941 in a direct measurement of the mean-life of mesons stopped in Al-absorber, Rasetti[2] obtained for the ratio η between decay-processes and stopped mesons the value $\eta=0.42\pm0.15$. Successively Auger, Maze, and Chaminade[3] found no essential lack from unity for η. Further experiments by Rossi and Nereson[4] (Al absorber), and by ourselves[5] (Fe absorber) gave, respectively, $\eta=0.4$ and $\eta=0.49\pm0.07$.

From the above mentioned works it seems reasonable to conclude that η is about 0.5. However, some doubt can be raised against the precision of such a value of η, considering that it is deduced from the comparison between its evaluated value and the rate of the actually registered decay-electrons, which represent only a small fraction of all the decay-processes occurring in the absorber.

Among other sources of error affecting the evaluation of η, one ought to consider the determination of the minimum delay of the registered electrons which depends on the size and shape of the counter-pulses. In order to avoid such a difficulty, in our previous work[5] we counted the delayed coincidences with little and slightly different delays and obtained from the plotted results the point "zero" of the time-scale. In order to obtain an independent determination of η and to check at the same time whether, according to Tomanaga and Araki prediction, negative mesons do not undergo the decay-process in dense materials, we performed an experiment based on the possibility of concentrating positive and negative mesons by means of magnetized iron cores.

The registering set—whose circuit has been already described in a previous paper[6]—consisted of three-fold (III) delayed-coincidences and of an anticoincidences unit. (This unit was really a four-fold (IV) coincidences unit.) It registered the decay-electrons, due to mesons stopped in a Fe absorber 3 cm thick. By means of convenient magnetized iron cores we could concentrate on this absorber alternatively positive or negative mesons. The energy of such mesons was well defined as that corresponding to the range interval between 20 cm of iron (magnetized iron cores) and 20+3 cm (absorber). We took care that the value of the magnetic induction B inside the magnetized iron cores was high enough ($B\approx 15{,}000$ gauss) to concentrate on or bend away from the absorber all mesons of such an energy.

With a fixed delay we found the following results:

Concentrating positive mesons:

$$(\text{III–IV})_+ = 58/177^h\,16' = 0.33\pm0.04,$$

Concentrating negative mesons:

$$(\text{III–IV})_- = 13/168^h\,06' = 0.077\pm0.02.$$

Regarding the actual result only as a qualitative one, we have not taken into account the small lack of efficiency of the four-fold coincidences.

These results point out the greatly different behavior of negative and positive mesons, so that the prediction of Tomonaga and Araki seems to be confirmed experimentally. We have not yet checked whether the small rate $(\text{III–IV})_-$ is caused by some instrumental effect, or not. Further experiments are now in progress.

[1] S. Tomonaga and G. Araki, Phys. Rev. **58**, 90 (1940).
[2] F. Rasetti, Phys. Rev. **60**, 198 (1941).
[3] Auger, Maze, and Chaminade, Comptes rendus **213**, 381 (1941).
[4] B. Rossi and N. Nereson, Phys. Rev. **62**, 417 (1942).
[5] M. Conversi and O. Piccioni, Nuovo Cimento II, 71 (1944); Phys. Rev. (submitted for publication).
[6] M. Conversi and O. Piccioni, Nuovo Cimento II, 40 (1944).

On a Type of Kinematical "Red-Shift"

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THE work of Page and Milne on the introduction of accelerated coordinate systems in relativity theory has recently been put on a more definite basis by the explicit reduction of the transformations involved to the 4-dimensional conformal group.[1] One of the important points thus introduced is the necessary use of a 15-parameter group of transformations, whereas the corresponding classical group requires but thirteen. The purpose of this note is to indicate an interpretation of one of these new parameters which leads to a type of "red-shift" phenomenon. We use the notation of reference 1 and leave aside transformations based on X_{15}, since these do not lead directly to velocity changes. If we consider an observer situated at the origin of coordinates, but having neither velocity nor acceleration, we can still modify his coordinate system by the 1-parameter subgroup of transformations based on X_{14}. To first orders this yields the equations

$$\mathbf{r}'=(1-\alpha_{14}t)\mathbf{r},\quad t'=t-\alpha_{14}\cdot\tfrac{1}{2}(t^2+r^2/c^2),$$

which, in turn, lead to the velocity formula

$$\begin{aligned}\mathbf{v}'&=\mathbf{v}-\alpha_{14}[\mathbf{r}-\mathbf{v}(\mathbf{r}\cdot\mathbf{v})/c^2]\\&=\mathbf{v}-\alpha_{14}\mathbf{r},\ \text{to terms in } v^2/c^2.\end{aligned}$$

To this order of approximation the added term is a simple radial velocity with magnitude proportional to the distance from the observer. The sign of the velocity may be either positive or negative, and to obtain formal agreement with the observed red-shift we take $\alpha_{14}=-1.8\times10^{-17}$ sec.$^{-1}$. At very great distances, at which the radial velocity approaches that of light, the term in v^2/c^2 acts to limit the speed, but its effect is too small to be observable at present, since it amounts to only about 0.01 km/sec. at a distance of 2×10^6 parsec., at which the red-shift gives a radial speed of around 1000 km/sec. In any event the first-order approximation which has been used here would become invalid, and the calculation would need to be carried out more exactly.

The Doppler shift of the light emitted from a distant point may be attributed in a conventional manner to the alteration in the emission time of a signal with the coordinate system, since

$$\Delta t' = (1 - \alpha_{14} t)\Delta t,$$

where $t = r/c$ is now the travel time of the signal from the source to the observer.

The structure of the conformal group shows that this type of transformation is introduced as soon as one expands the Lorentz group by adjoining to it the transformations to accelerated axes, owing to the non-commutativity of the velocity and acceleration transformations. This procedure in turn rests on the hypothesis that the invariance of the Maxwell field equations is a fundamental physical requirement.

While a more complete analysis of the physical interpretation of the full group of transformations will be required before all of its implications can be appreciated, the simple treatment given here does seem to strengthen Milne's idea of an approach to the red-shift phenomenon without an explicit appeal to the relativistic theory of gravitation.

[1] E. L. Hill, Phys. Rev. **67**, 360 (1945).

The Pair Production of Light Mesons by Electrons

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IN a recent series of seminars given at the Massachusetts Institute of Technology, M. Schein discussed certain experiments in cosmic rays which seemed to indicate the existence of mesons of low mass of about 20 electron masses. The development of the betatron has made available a source of electrons of sufficiently great energy to make the laboratory production of these mesons feasible.

The mesons may originate either in the meson field or in the electric field associated with a nucleus. In this note we shall compute the second effect only, inasmuch as the only unknown constant involved is the meson mass whereas the first effect would also involve the unknown interaction between nucleons and light mesons. The method of virtual quanta, as given for example by E. J. Williams,[1] is used. In this procedure an electron of energy E may be replaced by a photon field such that the number of photons with an energy between ϵ and $\epsilon + d\epsilon$ is:

$$N(\epsilon)d\epsilon = \frac{2\alpha}{\pi}\left(\ln\frac{E}{\epsilon}\right)\frac{d\epsilon}{\epsilon}, \tag{1}$$

$$\alpha = e^2/\hbar c.$$

These photons will under the influence of the Coulomb field of a nucleus produce meson pairs. The cross section for this process for "scalar" particles[2] of spin 0 and for particles[3] of spin $\hbar/2$ is

$$Q(\epsilon) = Z^2\alpha\left(\frac{e^2}{\mu c^2}\right)^2\left[A\ \ln\frac{2\epsilon}{\mu c^2} - B\right], \tag{2}$$

where Z is the charge of the nucleus, μ = meson mass, $A = 16/9$, $B = 104/27$ for spin 0, and $A = 28/9$, $B = 218/27$ for spin $\hbar/2$. The cross section for the total process, the pair production of mesons by electrons becomes:

$$\sigma = \int^E N(\epsilon)Q(\epsilon)d\epsilon \sim \frac{A}{3\pi}(\alpha Z)^2\left(\frac{e^2}{\mu c^2}\right)^2\left(\ln\frac{E}{\mu c^2}\right)^3. \tag{3}$$

A similar formula has been derived[4] for the case of the production of an electron-positron pair by an electron. It differs from (3) with $A = 28/9$ only in the replacement of the meson mass by the electron mass. Formula (3) is valid only when both the energy of the incident electrons and the emitted mesons is high compared to their rest mass. Moreover the energy lost by the electron should be small compared to its initial energy.

When the incident electron energy is 100 Mev, the meson mass is 20 electron masses, and the nucleus $Pb(Z=82)$ then for scalar mesons, $\sigma \sim 2\times 10^{-28}$ cm^2 while for spin $\hbar/2$ mesons $\sigma \sim 3\times 10^{-28}$ cm^2.

It should be emphasized that formula (3) underestimates the total cross section since only one of the possible processes in which mesons can be produced is calculated. In addition, if the mesons were of the vector type, i.e., of spin $\hbar$, one would judge by analogy with the known meson bremstrahlung formulae[5] that the cross section for the pair production of vector mesons is greater than that given by (3).

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[2] W. Pauli and V. Weisskopf, Helv. Phys. Acta. **7**, 709 (1934).
[3] W. Heitler, *Quantum Theory of Radiation* (Oxford University Press, Oxford, 1936), p. 200.
[4] See reference 3, p. 203.
[5] R. F. Christy and S. Kusaka, Phys. Rev. **59**, 405 (1941).

Method of Increasing Betatron Energy

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CONVENTIONAL betatrons used to date have followed the conservative designs similar to those described previously.[1,2] In these betatrons the flux density at the orbit of the electron is limited to a value less than half of the flux density which can be used in the center of the orbit. These betatrons have customarily been operated with approximately 4000 gauss at the orbit and 11,000 or 12,000 gauss in the iron within the orbit. This distribution of flux was necessary to have an equilibrium orbit at radius, r, since the flux, ϕ, within the orbit must satisfy $\phi - \phi_0 = 2\pi r^2 H$. ϕ_0 is the flux linking the orbit when the field at the orbit is zero. With the conventional machine, ϕ_0 is zero.

The purpose of this letter is to point out that the flux, ϕ_0, need not be zero when the electrons are injected; it can be biased reversely so that the flux through the center of the orbit has a large negative value initially and changes to a large positive value during the acceleration process. Thus, since the maximum flux density in the center of the orbit can be made to change by twice the conventional amount, the field at the orbit and hence the final energy