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Radiation Laboratory
Berkeley, California

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REGENERATION OF θ^0_1 MESONS BY A MAGNETIC FIELD

Myron L. Good

October 12, 1956

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This letter is to point out a surprising phenomenon that should occur if the θ^0 particle has a spin and a magnetic moment. The sequence of events is shown schematically, thus:

$$\begin{aligned}
 \begin{array}{c} \uparrow \\ \theta^0 \end{array} &= \frac{\begin{array}{c} \uparrow \\ \theta_1 \end{array} + i \begin{array}{c} \uparrow \\ \theta_2 \end{array}}{\sqrt{2}} \xrightarrow{\text{decay}} \begin{array}{c} \uparrow \\ \theta_2 \end{array} \\
 &= \frac{\begin{array}{c} \uparrow \\ \theta_0 \end{array} - \begin{array}{c} \uparrow \\ \bar{\theta}_0 \end{array}}{i\sqrt{2}} \xrightarrow{\text{mag. field}} \frac{\begin{array}{c} \theta_0 + \bar{\theta}_0 \end{array}}{i\sqrt{2}} \\
 &= -i \theta_1 \xrightarrow{\text{decay}} 2\pi
 \end{aligned}$$

A θ^0 meson is made, in associated production with a hyperon, and let us say the spin (solid arrow) is up. After $\sim 10^{-10}$ sec, θ_1 decay has left only the θ_2 component of the original wave.¹ This also has spin up. The θ_2 is part θ^0 , part $\bar{\theta}^0$, each of which has, of course, spin up. But the magnetic moment (dotted arrow) of the $\bar{\theta}^0$ will be oppositely directed from that of the θ^0 , since it is the antiparticle of the θ^0 . Therefore, if the θ_2 beam, in vacuum, encounters a uniform vertical magnetic field, there will be an energy difference

$$\Delta\epsilon = 2\mu H \text{ between the } \theta^0, \bar{\theta}^0,$$

and a difference $\Delta\epsilon/\hbar$ in their De Broglie frequencies. The $\theta^0, \bar{\theta}^0$ components will therefore, in time, get out of phase. Once they are out of phase, the particle is no longer entirely a θ_2 , but has a θ_1 component. The θ_1 component then quickly decays into two π mesons.

A long-lived θ_2 beam can therefore be "quenched" by a magnetic field, if the θ^0 has a magnetic moment.

¹ M. Gell-Mann and A. Pais, Phys. Rev. 97, 1387 (1955).

For a moment $\mu = \frac{e\hbar}{m_k c}$, the fields and times required are about like

those needed to rotate a nuclear spin by ~ 1 radian, or on the order of 10^4 or 10^5 gauss-feet. The effect could therefore be observed experimentally.

The equation for the regenerated θ_1 amplitude can be derived in a manner entirely similar to that of Case.² A plot of $|a_1|^2$ vs distance into the magnetic field (a_1 is the amplitude of θ_1) is given in Fig. 1. The values of the parameters used are:

$$\tau_1 = 10^{-10} \text{ sec}, \quad \tau_2 = \infty (\tau_{1,2} = \theta_{1,2} \text{ lifetime}),$$

$$\gamma = \frac{1}{\sqrt{1 - \beta^2}} = 6,$$

$$\omega_2 - \omega_1 = (\text{mass difference frequency}) = \frac{1}{2\tau_1}, \quad \text{and}$$

$$\frac{2\mu H}{\hbar} = \frac{1}{2\tau_1} \quad (\text{for } \mu = \frac{e\hbar}{m_k c}, \text{ this corresponds to}$$

a field of 22.7 kilogauss).

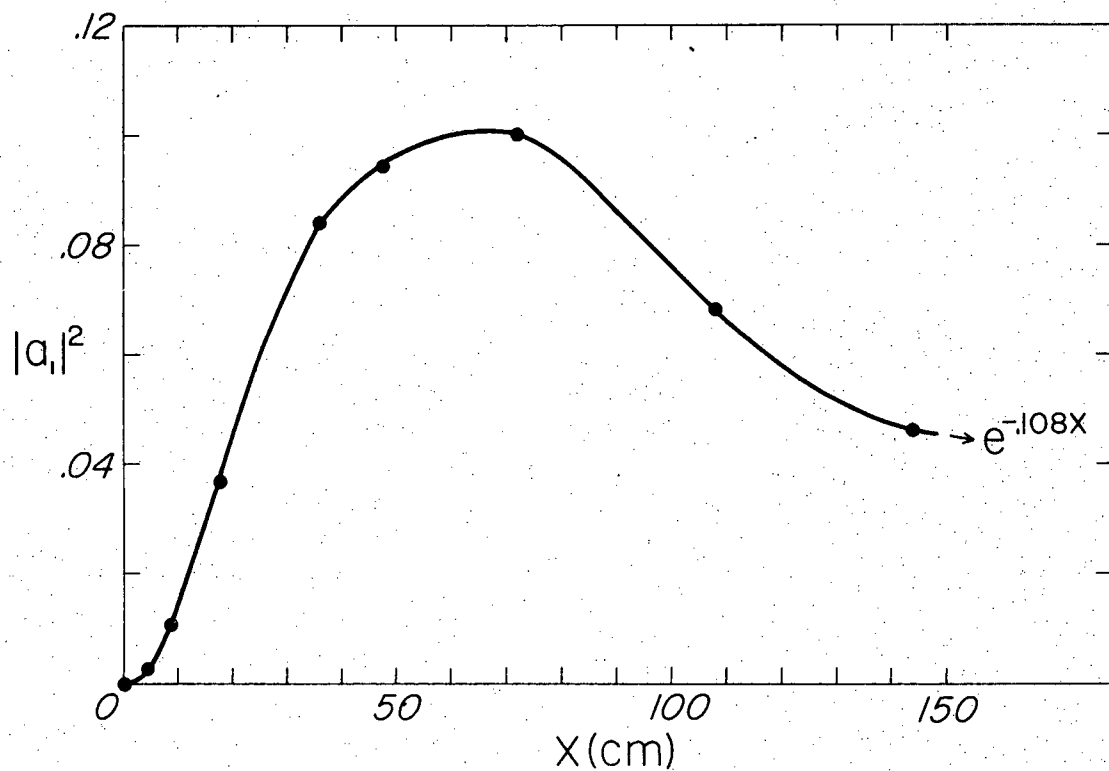
Figure 1 implies that if the magnet is 60 cm long, 10% of the incident θ_2 's would decay just beyond the magnet. However, $|a_1|^2 \left(\frac{1}{\tau\gamma\beta c} = \frac{1}{18 \text{ cm}} \right)$ is the probability, per cm of path,³ for decay in the magnet. Taking this into account, one sees that the reason the curve is falling, for magnet length ≥ 100 cm, is that most of the particles have decayed in the magnet. The effect is therefore quite large.

It is interesting to speculate whether experiments already performed can rule out reasonable values of the magnetic moment. A quick look indicates that probably this is not the case. Experiments where θ^0 's are produced in a magnet cloud chamber do not have much θ_2 path length. On the other hand, in the experiment by Lederman et al.,³ a strong sweeping magnet preceded the cloud chamber. This could have the effect of wiping out all but the $m = 0$ substate (which is unaffected by the field). This substate would then not regenerate in the cloud chamber magnet, since its field was parallel to that of the sweeping magnet. Rather, the typical θ_2 3-body decays would be seen.

This work was done under the auspices of the U.S. Atomic Energy Commission.

² K. Case, Phys. Rev. 103, 1449 (1956).

³ Lande, Booth, Impeduglia, Lederman, Chinowsky, Observation of Long-Lived Neutral V Particles. BNL-2857 [1956].



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Fig. 1. Regeneration of θ 's by magnetic field for

$$\gamma = 6$$

$$\pi = 10^{-10} \text{ sec}$$

$$\omega_2 - \omega_1 = \frac{1}{\tau_1} = \Delta E_{\text{mag}}$$

(corresponds to 22.7 kg if $\mu = \frac{eh}{m_k c}$)