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Translated by M. J. Stevenson
40

K-Meson Charge Exchange in Hydrogen and Deuterium

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(Submitted to JETP editor October 20, 1955)
J. Exper. Theoret. Phys. USSR **30**, 218-219 (January, 1956)

COMPARISON of cross sections for charge exchange of K-mesons in hydrogen and deuterium can give valuable information about their spins and parities. Theoretical investigation can be carried out similarly to the charge exchange of π-mesons in hydrogen and deuterium[1]. At the present time, apparently, the existence of at most two different K-mesons has been established: θ and τ. θ-meson decays into two π-mesons and consequently should have even parity with even spin and odd parity with odd spin. Analysis carried out by Dali [2] indicates that τ-meson apparently has odd parity and even spin. We shall consider the charge exchange of mesons with spins 0 and 1.

In a general case the amplitude of charge exchange of a meson with a proton is equal to $u_p = a + \mathbf{b}\vec{\sigma}$. Here a and $\mathbf{b}$ are functions of momenta and spins of meson before and after the charge exchange; $\vec{\sigma}$ is the spin operator. The amplitude of charge exchange with deuteron is expressed by u_p:

$$u_d = \sqrt{2}\int \psi^*(\mathbf{r})\, e^{i\vec{\varkappa}\mathbf{r}}\, u_p \psi_d(\mathbf{r})\, d\mathbf{r}.$$

Here ψ_d is the wave function of the deuteron, $\psi(\mathbf{r})$ is the wave function of two neutrons appearing as a result of the collision, $\vec{\varkappa} = (\mathbf{k} - \mathbf{k}')/2$ and $\mathbf{k}$ and $\mathbf{k}'$ are the momenta of the meson before and after the collision ($\hbar = c = 1$).

The cross section for the charge exchange with a proton in terms of the amplitude is $\sigma_p = \sigma_a + \sigma_b$; $\sigma_a = \overline{a^2}$, $\sigma_b = \overline{b^2}$. The cross section of charge exchange with deuteron, summed over states of the two neutrons after collisions*

$$\sigma_d = (\sigma_a + {}^2/_3\,\sigma_b)\,F_- + {}^1/_3\,\sigma_b F_+,$$
$$F_\pm = 1 \pm (\alpha/\varkappa)\,\mathrm{arc\,tg}\,(\varkappa/\alpha).$$

For $\varkappa = 0$: $F_+ = 2$, $F_- = 0$. Here $\epsilon = \alpha^2/M$ is the binding energy of the deuteron and the bars denote averaging and summations over the spin states of the meson (if it has spin).

We shall consider charge exchange with scattering at small angles. In this case $\varkappa \ll k$ and it may be assumed that $\mathbf{k}$ and $\mathbf{k}'$ have the same direction. We shall now consider several cases in more detail:

1. Charge exchange of K-meson with spin 0 without a change in parity. In this case a is a scalar, $\mathbf{b}$ is a pseudovector. However, since there is only one vector in the problem, $\mathbf{k}$, and for the construction of a pseudovector at least two vectors are necessary, then $\mathbf{b} = 0$. We obtain $\sigma_p = \sigma_a$, $\sigma_d = \sigma_a F_-$.

For $\varkappa = 0$: $\sigma_d/\sigma_p = 0$.

2. Charge exchange of K-meson with spin 1 without a change in parity. Beside the vector $\mathbf{k}$ there are two other vectors (pseudovectors): $\mathbf{j}$ and $\mathbf{j}'$, determining the direction of the meson spin before and after the charge exchange. In this case $\mathbf{b} \sim [\mathbf{j}\mathbf{j}']$

$$\sigma_p = \sigma_a + \sigma_b, \qquad \sigma_d = (\sigma_a + {}^2/_3\,\sigma_b)\,F_- + {}^1/_3\,\sigma_o F_+.$$

For $\varkappa = 0$: $\sigma_d/\sigma_p = 2\sigma_b/3(\sigma_a + \sigma_b)$.

3. Charge exchange of K-meson with spin 1 into K-meson with spin 0 without a change in parity. In this case $a = 0$, $\mathbf{b} \sim \mathbf{j}$,

$$\sigma_p = \sigma_b, \qquad \sigma_d = {}^2/_3\,\sigma_b F_- + {}^1/_3\,\sigma_b F_+.$$

For $\varkappa = 0$: $\sigma_d/\sigma_p = {}^2/_3$.

4. Charge exchange of K-meson with spin 0 with a change in parity. In this case $a = 0$, $\mathbf{b}$ is a vector ($\mathbf{b} \sim \mathbf{k}$) and

$$\sigma_p = \sigma_b, \quad \sigma_d = {}^2/_3\,\sigma_b F_- + {}^1/_3\,\sigma_b F_+.$$

For $\varkappa = 0$: $\sigma_d/\sigma_p = {}^2/_3$.

5. Charge exchange of K-mesons with spin 1 with a change in parity. In this case $\mathbf{b} \sim \mathbf{k} \times [\mathbf{j}\mathbf{j}']$,

$$\sigma_p = \sigma_a + \sigma_b, \quad \sigma_d = (\sigma_a + {}^2/_3\,\sigma_b)\,F_- + {}^1/_3\,\sigma_b F_+.$$

For $\varkappa = 0$: $\sigma_d/\sigma_p = 2\sigma_b/3(\sigma_a + \sigma_b)$.

6. Charge exchange of K-meson with spin 1 into K-meson with spin 0 with a change in parity. In this case $\mathbf{b} \sim [\mathbf{j}\mathbf{k}]$,

$$\sigma_p = \sigma_a + \sigma_b, \quad \sigma_d = (\sigma_a + {}^2/_3\,\sigma_b)\,F_- + {}^1/_3\,\sigma_b F_+.$$

For $\varkappa = 0$: $\sigma_d/\sigma_p = 2\sigma_b/3(\sigma_a + \sigma_b)$.

The authors express their gratitude to Professor I. Ia. Pomeranchuk for the suggestion of this problem and V. V. Sudakov for his valuable advice.

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* The corresponding expression for σ_d in the article of Berestetskii[1] contains several misprints.

[1] V. B. Berestetskii and I. Ia. Pomeranchuk, Dokl. Akad. Nauk SSSR **81**, 1019 (1951).

[2] Rochester conference, 1955.

Translated by M. J. Stevenson
41

On the Theory of Galvanomagnetic Effects in Metals

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(Submitted to JETP editor October 25, 1955)
J. Exper. Theoret. Phys. USSR **30**, 220-222 (January, 1955)

IN this communication we develop the theory of galvanomagnetic effects in metals, without making any special assumptions on the law of dispersion of conduction electrons or on the form of the collision integral.

1. An electron in a metal is here taken to be a quasiparticle carrying a charge e, with energy ϵ and a quasi-momentum p; ϵ is a periodic function of p, with the period of the reciprocal lattice. With an electron moving in a constant magnetic field $\mathbf{H}\,(H_x = H_y = 0;\ H_z = H)$, ϵ and p_z remain unaltered. Thus, in the momentum zone an electron moves along the curve

$$\varepsilon(\mathbf{p}) = \text{const}; \quad p_z = \text{const}. \tag{1}$$

From the equations of motion, $d\mathbf{p}/dt = (e/c)[\mathbf{v}, \mathbf{H}]$ $(\mathbf{v} = \nabla_p \epsilon)$ we obtain:

$$t = -(c/eH)\int dl / v_\perp. \tag{2}$$

Here dl represents an element of arc of curve (1), taken in the direction of motion, while $v_\perp$ represents a projection of velocity vector upon the plane (x, y). The character of an electron's motion along a trajectory within the momentum zone actually depends on whether curve (1) is closed (i.e., whether it consists of a series of closed curves each of which is disposed within the limits of a single space in the reciprocal lattice)*, or whether it is open (i.e., whether it passes uninterruptedly through the entire reciprocal lattice). If curve (1) is closed, then the transition along this curve is

$$T = -\frac{c}{eH}\oint \frac{dl}{v_\perp} = -\frac{2\pi m^* c}{eH}; \quad m^* = \frac{1}{2\pi}\frac{\partial S}{\partial \varepsilon}; \tag{3}$$

where $S = S(\varepsilon, p_z)$ corresponds to the area of intersection of surface $\epsilon(p) = \text{const}$ with plane $p_z = \text{const}$.

The quantity m^* can actually be called the effective mass of an electron in a magnetic field. The sign of this effective mass (and of the period as well) depends on whether the energy within the surface $\epsilon(p) = \epsilon$ is smaller than $\epsilon\,(m^* > 0)$ or larger than $\epsilon\,(m^* < 0)$; this criterion does not hold true for the intersecting curves. It should be noted here that the concept of effective mass cannot be introduced for open trajectories.

2. While describing the state of an electron in a magnetic field it is proper to use variables ϵ, p_z and a dimensionless variable $\tau = t/T_0$, indicating the location of an electron in the trajectory (1) within the momentum zone ($T_0 = 2\pi c m_0/eH$, with m_0 representing the mass of a free electron). T_0 was introduced for the sake of convenience, so as to free τ from its dependence on H. The kinetic equation for the distribution function of f in the variable chosen by us is

$$\frac{\partial f}{\partial \tau}\dot{\tau} + \frac{\partial f}{\partial p_z}\dot{p}_z + \frac{\partial f}{\partial \varepsilon}\dot{\varepsilon} + \left(\frac{\partial f}{\partial t}\right)_{\text{CT}} = 0. \tag{4}$$

(In studying a stationary case, the values of $\dot{\tau}$, $\dot{p}_z$, $\dot{\varepsilon}$ are obtained from the equations of motion). Assuming that $f = f_0 - e t_0 \psi_i E_i$, we align (4) along the electric field E. Noting that $\dot{\varepsilon} = e\mathbf{v}\mathbf{E}$; $\dot{p}_z = eE_z$, $\dot{\tau} = 1/T_0$, we obtain

$$\begin{aligned} &\partial\psi_i/\partial\tau + \gamma \hat{W}\psi_i = \gamma f_0'(\varepsilon)\, v_i; \\ &\hat{W}\psi_i = t_0 (\partial\psi_i/\partial t)_{\text{CT}};\ \gamma = H_0/H; \end{aligned} \tag{5}$$

where f_0 represents the equilibrium Fermi function, t_0 represents the characteristic time of relaxation, and $T_0(H_0) = t_0$. The limiting condition for Eq. (5) is represented, for closed curves, by the condition of periodicty (with a period of T/T_0) of the function ψ_i and, for open trajectories, by the boundedness of the function ψ_i.

As the mean value of Eq. (5) we obtain

$$\overline{\hat{W}\psi_i} = f_0'(\varepsilon)\,\overline{v}_i. \tag{6}$$

The prime in the above equation indicates that the mean value was obtained with respect to τ. For the closed curves, assuming that $2\pi m_0 v_x = -\partial p_y/\partial\tau$, $2\pi m_0 v_y = \partial p_x/\partial\tau$, we obtain $\overline{v}_\alpha = 0$ $(\alpha = x, y)$.

3. We will find the solution for Eq. (5) under conditions (6) for large fields $(\gamma \ll 1)$, in the form of a series* with interval γ. Computations show that for closed curves (1)