PRODUCTION OF TWO TEMPERATURES IN AN IONIZED GAS IN A MAGNETIC FIELD

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WE consider an ionized gas in which the ionic temperature is assumed given. The energy radiated by the electrons per unit time by virtue of cyclotron radiation is:

$$(dE_e/dt)_c = -\frac{E_{e\perp}}{t_c} = -(4e^4H^2/3c^5m_e^3)\,E_{e\perp}. \qquad (1)$$

Here e is the charge of the electron, H is the magnetic field, m_e is the mass of the electron and $E_{e\perp}$ is the electron energy due to motion in the transverse magnetic field. In order-of-magnitude terms, the energy radiated in a time t_c is equal to the energy of the electrons. The frequency of the cyclotron motion is $\nu \sim eH/m_e$; in what follows it will be assumed that the gas is transparent in this frequency region. This condition is rather stringent; given characteristic dimensions, we assume either a highly rarified gas or high values of the magnetic field and ionic temperature.

If the electrons radiate a significant part of their energy in a time short compared to the relaxation time t_{eq} of the electronic and ionic components of the gas, i.e., if $t_{eq} > t_c$, it can be shown that the electronic temperature will differ considerably from the ionic temperature.

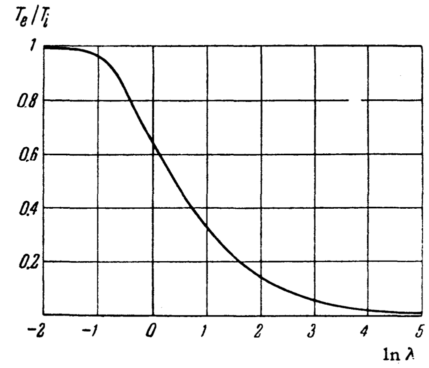
The relaxation time for the electronic component is[1]

$$t_r = m_e^{1/2}(3kT_e)^{3/2}/8\cdot 0.714\,\pi n_e e^4 \ln\Lambda. \qquad (2)$$

Here T_e is the kinetic temperature of the electrons, n_e the number of electrons per unit volume and $\ln\Lambda$ is the Coulomb logarithm. It will be assumed that $t_c \gg t_r$ so that the electron gas is characterized by a Maxwellian distribution. Thus, the Spitzer formula[1] can be used in analyzing the exchange of energy between the electron gas and the ion gas:

$$\left[\frac{dE_e}{dt}\right]_i = \frac{E_i - E_e}{\alpha t_{eq}}$$
$$= (E_i - E_e)\Big[\Big(\frac{3\alpha m_e m_i k^{3/2}}{8\pi^{1/2} n_i Z^2 e^4 \ln\Lambda}\Big(\frac{T_e}{m_e} + \frac{T_i}{m_i}\Big)^{3/2}\Big]^{-1} \qquad (3)$$

Here m_i is the ion mass, Z is the charge of the ion and n_i is the number of ions per unit volume.



The factor α takes account of the retardation of the relaxation process because of the magnetic field, $\alpha \sim 3$.

In the quasi-stationary state we can equate (1) and (3). Whence the following expression is obtained for the ratio $T_e/T_i = \theta$:

$$\lambda^2 = \frac{(1/\theta - 1)}{\theta^3(1 + m_e/m_i\theta)}, \quad \lambda = \frac{\alpha k^{2/3} m_i}{3(2\pi)^{1/2} c^5 m_e^{7/2} Z^2 \ln\Lambda}\,\frac{T_i^{2/3} H^2}{n_i} \qquad (4)$$

The condition $t_c \gg t_r$ is equivalent to the inequality $\lambda \ll 10^6$ in which case $m_e/\theta m_i \ll 1$, so that Eq. (4) can be simplified: $\lambda = \theta^{-5/2}(1-\theta)$. The function $\theta = \theta(\lambda)$ is given in the figure. At large values of λ it is apparent that $\theta = \lambda^{-2/5}$. Thus, the difference in temperatures for the ionic component and the electronic component can become very large.

[1] Spitzer. Physics of Fully Ionized Gases, Interscience, New York (1955).

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INVESTIGATION OF K_{e3}-DECAY WITH THE EMISSION OF A GAMMA PHOTON

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THE spectra of π mesons and electrons produced in K_{e3} decay have been investigated by a number of authors.[1-3] An important contribution to these spectra is due to the K_{e3} decay with the emission of a hard γ photon. Hence we investigate this process in this paper:

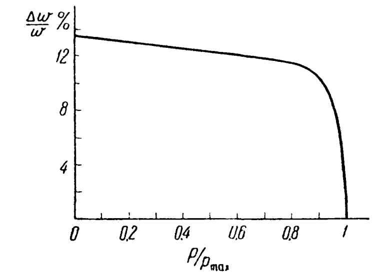
$$K^0 \rightarrow \pi^\pm + e^\pm + \nu + \gamma. \qquad (1)$$

If it is assumed that the π meson, electron, and neutrino are created at one point on the Feynman diagram for the process and that the spin of K^0 meson is zero, the most general form of the interaction Lagrangian for the K_{e3} decay in the x representation is:

$$L_{e3} = \Big\{ g_S' (\bar{\psi}_e (1 + \alpha_S' \gamma_5) \psi_\nu) \varphi_\pi^* \varphi_K + \frac{g_S''}{M^2} (\bar{\psi}_e (1 + \alpha_S'' \gamma_\nu) \psi_\nu) \frac{\partial \varphi_\pi^*}{\partial x_\mu} \frac{\partial \varphi_K}{\partial x_\mu} + \frac{g_V'}{M} (\bar{\psi}_e (1 + \alpha_V' \gamma_5) \gamma_\mu \psi_\nu) \varphi_\pi^* \frac{\partial \varphi_K}{\partial x_\mu} + \frac{g_T'}{M^2} (\bar{\psi}_e (1 + \alpha_T' \gamma_5) \gamma_{\mu\rho} \psi_\nu) \frac{\partial \varphi_\pi^*}{\partial x_\mu} \frac{\partial \varphi_K}{\partial x_\rho} \Big\} \frac{1}{M}, \qquad (2)$$

$$\gamma_{\mu\rho} = {}^1/_2 (\gamma_\mu \gamma_\rho - \gamma_\rho \gamma_\mu); \quad \gamma_\mu^+ = \gamma_\mu; \quad \hbar = c = 1.$$

Here ψ_e, ψ_ν, φ_π, and φ_K are the wave functions for the electron, neutrino, π meson and K meson respectively while M is the mass of the K meson. The mass of the electron is neglected in comparison with the momenta which are of importance in this decay.



In considering the process in (1), it is necessary to replace $\partial\varphi_\pi^*/\partial x_\mu$ in (2) by $\partial_\mu \varphi_\pi^* = (\partial/\partial x_\mu - ieA_\mu)\varphi_\pi^*$. In this case we already have $\psi_e(\partial/\partial x_\mu + ieA_\mu)\gamma_\mu = 0$.

The complete matrix element for the decay (1) in the rest system of the K^0 meson is of the form (in Heaviside units):

$$M_{i\rightarrow f} = e \frac{(2\pi)^4}{(2M)^{3/2}(E\omega)^{1/2}} \bar{\psi}_e \times \sum_{i=S,V,T} g_i (1 + \alpha_i \gamma_5) \Phi_i \psi_\nu \delta(P - p - p_e - k - k_\nu). \qquad (3)$$

We use the notation:

$$\Phi_S = \frac{\hat{\varepsilon}\hat{k}}{2(kp_e)} + \delta_0; \quad \Phi_V = \Big(\frac{\hat{\varepsilon}\hat{k}}{2(kp_e)} + \delta_0\Big)\gamma_4;$$

$$\Phi_T = \frac{i}{M}\Big[\Big(\frac{\hat{\varepsilon}\hat{k}}{2(kp_e)} + \delta_0\Big)\gamma_4 \gamma \mathbf{p} + \gamma_4\Big(\hat{\varepsilon} - \frac{(\varepsilon p)}{(kp)}\gamma \mathbf{k}\Big)\Big];$$

$$\delta_0 = \frac{(\varepsilon p_e)}{(kp_e)} - \frac{(\varepsilon p)}{(kp)}; \quad \hat{a} = \gamma_\mu a_\mu = \gamma \mathbf{a} + \gamma_4 a_4;$$

$$(ab) = \sum_{\mu=1}^{4} a_\mu b_\mu, \quad a_4^* = -a_4.$$

P is the four-momentum of the K meson and ϵ is the polarization vector of the photon. **p**, E; $\mathbf{p}_e$, $\epsilon_0 \approx |\mathbf{p}_e|$; **k**, ω; $\mathbf{k}_\nu$, k_ν are respectively the momenta and energies of the π meson, the electron, the γ photon and the neutrino.

In the limiting case (emission of soft protons) we have:

$$M_{i\rightarrow f} = (e / \sqrt{2\omega})\, \delta_0 M_{i\rightarrow f}^{(0)}, \qquad (4)$$

where $M_{i\rightarrow f}^{(0)}$ is the matrix element for the K_{e3} decay. This means that in the present case the ratio $\Delta w/w$ the probability of the decay in (1) to the probability for K_{e3} decay is a quantity which is independent of the particular interaction.

If the emission of the π meson is neglected, we have for a scalar interaction:

$$\Delta w / w = (e^2 / 2(2\pi)^2) A_S, \qquad (5)$$

where

$$A_S = \Big(z \ln\frac{z+1}{z-1} - 2\Big)\Big(\ln\frac{2}{\delta} + 4\Big) + 2\Big(\ln\frac{2}{\delta} - 2\Big)\Big(\ln\frac{p(z+1)}{2\omega_{min}} - \frac{1}{2}\ln\frac{z+1}{z-1} - 1\Big) - \ln^2\frac{z+1}{z-1} + \frac{1}{2}\Big(\ln\frac{2}{\delta} - z\ln\frac{z+1}{z-1} + \frac{5}{2}\Big) + \frac{\pi^2}{3} + 2. \qquad (6)$$

Here $z = (M - E)/p \leq 1$ while ω_{min} is the minimum frequency of the photon. In the integration over electron emission angles we take account of the electron mass, writing $1/v_e = 1 + \delta$; if this is not done, an expression which diverges logarithmically is obtained. Assuming that on the average the energy going to the electron, photon, and neutrino is distributed uniformly between these, we find $\delta = {}^9/_2 (m/pz)^2$. It is easy to show that an error in the estimate of δ cannot change these results by more than 10%. Equation (6) applies when $z - 1 \gg \delta$. Assuming $\omega_{min} = m \approx 0.5$ Mev, we obtain the dependence of $\Delta w/w$ on π-meson energy shown in the figure.

Because of the relations in (4) and (6), the value of $\Delta w/w$ in vector or tensor interactions does not differ greatly from this value in the scalar case.

The nonconservation of parity in K_{e3} decay appears in the polarization of the electrons and protons. Using the electron spin-projection operator,[4] it is easy to show that the electrons will be longitudinally polarized and that the degree of polarization for each of the "pure" interactions is given by the expression

$$P_i = (\alpha_i + \alpha_i^*) / (1 + |\alpha_i|^2) \quad (i = S, V, T). \qquad (7)$$

If the two-component neutrino theory is valid, $\alpha_S = \alpha_T = 1$ and $\alpha_V = -1$, that is to say, the polarization can be incomplete only if there is a mixture of vector interaction with scalar or tensor. In this case the direction of polarization can yield information as to the predominance of one or the other of the interactions.

In the case of nonconservation of parity, the photons are circularly polarized. The dependence of the circular polarization on the frequency of the photon for a given π-meson energy and emission angle for the π meson and photon is given by:

$$P_\gamma^i = \frac{\Delta w_R - \Delta w_L}{\Delta w_R + \Delta w_L} = \frac{2x(1-x)}{1+(1-x)^2}\,\frac{\alpha_i + \alpha_i^*}{1+|\alpha_i|^2},$$
$$x = \omega/\omega_m,\quad \omega_m = p(z^2-1)/2(z+\cos\theta). \qquad (8)$$

Here Δw_R and Δw_L are the differential probabilities for decay with the emission of right-polarized or left-polarized radiation respectively; ω_m is the maximum photon frequency for a given π-meson energy and angle of emission. The maximum value of the polarization $P_{\gamma m}^i = 0.41$, for $\alpha = 1$, is achieved with $x = 0.6$.

There is no circular polarization for charge invariance ($\alpha = -\alpha^*$) or if parity is conserved ($\alpha = 0$). It is easy to show that in these cases the radiation will consist of a superposition of unpolarized light and linearly polarized light.

In conclusion we wish to express our gratitude to Professor I. Ia. Pomeranchuk for suggesting this problem and for guiding its execution and to A. F. Grashin for a discussion of the results.

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[4] L. Michel and A. S. Wightman, Phys. Rev. **93**, 354 (1954).

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ON THE HALL EFFECT AT THE CURIE POINT

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THE magnetization of ferromagnets in the low-temperature region[1] is determined, roughly speaking, by an inversion process (the spontaneous-magnetization vector switches from one direction of easy magnetization to another) and a rotation process (the spontaneous-magnetization vector of the domain shifts away from the direction of easy magnetization). Sufficiently far above the Curie point Θ the magnetization is caused by the change in the number of parallel and antiparallel spins when short-range order is absent. We shall call such a process true magnetization, in contradistinction to paraprocesses when short-range order is present and microdomains are formed. A paraprocess causes magnetization by the rotation of microdomains.

Measurements performed by us show that for each of these four processes of magnetization there is a corresponding Hall parameter. As far as the inversion and rotation is concerned, we have obtained the following results. When investigating the Hall effect in iron-aluminum alloys we have observed that the Hall voltage depends in a nonlinear fashion on the magnetization I in the region of technical saturation. However, for an alloy with a zero value of the anisotropy constant (12% Al),[2] we obtained a strictly linear dependence, while the slopes of the straight lines are the same in the regions of inversion and rotation. For alloys with a non-vanishing anisotropy constant we have observed a bending of the curve in the transition region from inversion to rotation. Since this bending is not substantial or very pronounced, it is desirable to perform a direct measurement of the Hall effect on single crystals to bring out the role

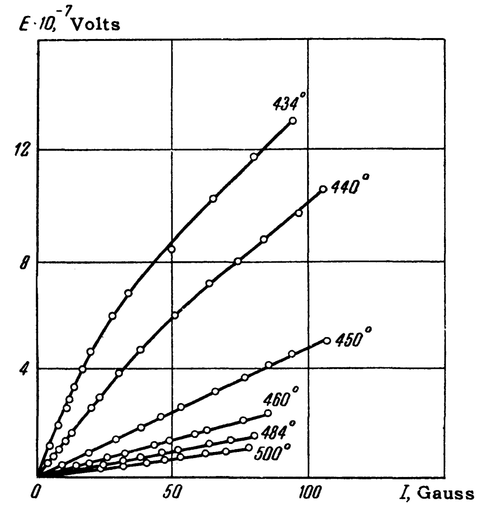

FIG. 1