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DEPOLARIZATION OF ELECTRONS DUE TO RADIATION IN A MAGNETIC FIELD

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THE change in electron polarization (from initial longitudinal polarization) under rotation in a magnetic field may be utilized for the purpose of measuring the electron anomalous magnetic moment.[1] It is useful here to obtain the magnitude of depolarization due to the side effects of radiation in a magnetic field.

It is convenient, for the purpose of calculating the probability of radiation with spin flip in a uniform magnetic field H, to express the wave functions in the coordinates z, φ and $y = eHr^2/2$:[2]

$$\psi^{(k)} = D_k (2\varepsilon s!\, n!\, 2\pi v^{1/3})^{-1/2} L_s^p y^{p/2} \exp(-y/2 + il\varphi + ip_z z);$$
$$k = 1, 2, 3, 4;$$
$$p = l + 1/2 + (-1)^k/2; \quad D_1 = A\sqrt{n(\varepsilon + m)};$$
$$D_2 = iB\sqrt{\varepsilon + m},$$
$$D_3 = \sqrt{n}(\sqrt{2eHn}\,B + P_z A)/\sqrt{\varepsilon + m};$$
$$D_4 = i(\sqrt{2eHn}\,A - P_z B)/\sqrt{\varepsilon + m};$$
$$\varepsilon = \sqrt{m^2 + P_z^2 + 2eHn}.$$

Here ϵ stands for the total electron energy ($\hbar = c = 1$), $s = n - l - 1$; v is the normalization volume and $L_s^p(y)$ is the associated Laguerre polynomial as defined in reference 3. The constants A and B specify the spin state, $|A|^2 + |B|^2 = 1$.

For the intensity of the transition from n, s = 0, A = 1, 0 to $n' = n - \nu$, $s' = 0$, $A' = 0, 1$ we find ($P_z = 0$ in the initial state):

$$dI_{10}^{\nu} = \frac{1}{2\pi}\left(\frac{\beta^2\nu^2 e^2 H}{4n\varepsilon}\right)^2 \left\{\left(\frac{\varepsilon\beta\sin\theta}{\varepsilon + m} J_\nu - J_{\nu-1}\right)^2 + \cos^2\theta J_{\nu-1}^2\right\}; \quad (1)$$

$$dI_{01}^{\nu} = \frac{1}{2\pi}\left(\frac{\beta^2\nu^2 e^2 H}{4n\varepsilon}\right)^2 \left\{\left(\frac{\varepsilon\beta\sin\theta}{\varepsilon + m} J_\nu - J_{\nu+1}\right)^2 + \cos^2\theta J_{\nu+1}^2\right\}, \quad (2)$$

where $J_n = J_n(n\beta\sin\theta)$ is a Bessel function, $\beta = v/c$, and θ is the angle between the z axis and the direction of the wave vector of the emitted photon. Transitions in which the quantum number s changes do not contribute significantly to the total transition probability for the process n, A = 1, 0 $\to$ $n' = n - \nu$, $A' = 0, 1$. For $\overline{\nu}^2/n \ll 1$ [i.e., up to energies ~ 100 Mev since $\overline{\nu}^2/n \sim R^{-1}(\hbar/mc) \times (\epsilon/mc^2)^5$ where R is the radius of curvature], Eqs. (1) and (2) describe the intensity of emission of photons with frequency $\omega_0\nu = eH\nu/\epsilon$ in the direction θ when the electron spin is flipped. Comparison of these expressions with the classical Schott formula

$$dI^{\nu} = \frac{1}{2\pi}\left(\frac{\nu e^2 H}{\varepsilon}\right)^2 (\cot^2\theta J_\nu^2 + \beta^2 J_\nu'^2)\, do,$$

which describes the intensity of radiation without spin flip, gives

$$dI_{10}^{\nu}/do \sim (\beta\nu/n)^2\, dI^{\nu}/do \ll dI^{\nu}/do,$$

and $dI_{01}^{\nu} \sim \beta^2 dI_{10}^{\nu}$. Consequently, radiation accompanied by spin flip is of order $(\beta\nu/n)^2$ relative to the total radiation. The quantum corrections of order ν/n, calculated by Sokolov and Ternov,[2] refer to radiation without spin flip.

We conclude that electron depolarization due to radiation is exceptionally small. For an electron of energy ϵ the radiation maximum occurs in the region $\overline{\nu} \sim (\epsilon/m)^3$. Making use of the relations $eHR = \beta\epsilon$, $2ec\hbar Hn = \epsilon^2\beta^2$ we find that the emission probability with spin flip during one rotation in the magnetic field is of the order of magnitude

$$dw_{10}/dN \sim \beta^2 (e^2/\hbar c)\, R^{-2} (\hbar/mc)^2 (\varepsilon/mc^2)^5, \quad (3)$$

where R = radius of curvature, N = number of rotations. N must equal 10^4 to 10^5 for the magnetic moment of the electron to be measured with an accuracy sufficient to include the second correction[4] $\Delta\mu^{(2)}/\mu_0 \approx -0.3(e^2/\hbar c)^2$. Clearly, in such an experiment depolarization due to emission of photons is unimportant.

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