Materials Physics and Mechanics 45 (2020) 101-103 Received: March 11, 2020

INFLUENCE OF RESONANCE COMPTON SCATTERING IN A MAGNETIC FIELD ON ROTATION OF THE POLARIZATION PLANE OF PHOTONS

Alexey I. Sery

Department of Physics and Mathematics, A. S. Pushkin Brest State University,

Kosmonavtov Boulevard 21, 224016, Brest, Republic of Belarus

e-mail: alexey_sery@mail.ru

Abstract. The solution of the problem of the value of rotation of photon polarization plane in totally spin-polarized electron gas in quantizing magnetic field is obtained. The second order perturbation theory on electromagnetic coupling is considered using modified Gell-Mann–Goldberger–Thirring dispersion relationship and optical theorem. Approximate formula obtained by Fomin and Kholodov for resonance Compton scattering cross-section is used in calculation.

Keywords: Baryshevsky–Luboshits effect, electron gas, quantizing magnetic field, spin polarization of electrons

1. Introduction

Rotation of the polarization plane of photons in matter is possible due to Faraday and Baryshevsky-Luboshits effects; in the second case electron spin polarization being necessary [1, p. 88-89]. In laboratory experiments magnetic field either is absent or its influence on the energy levels of electrons in an atom does not lead to its destruction, i.e. the electron motion remains finite in all three spatial directions. Under such conditions, the above effects are observed in different parts of the spectrum: Faraday effect prevails in the visible range and Baryshevsky-Luboshits effect prevails in the hard X-ray range. In this case Baryshevsky-Luboshits effect appears in the second order of perturbation theory on electromagnetic coupling constant α [1, p. 88-94].

In the magnetic fields which are possible in astrophysical conditions when Landau quantization plays a significant role, the usual structure of substance is broken and the electron motion becomes infinite in the direction of magnetic field lines. In this case the resonance Compton scattering is possible if an intermediate (virtual) electron falls on some Landau level [2, p. 321]. If the photon frequency is far from the resonance, Baryshevsky-Luboshits effect prevails; it appears already in the first order of perturbation theory on α [3, p. 420-422]. If the frequency is close to the resonance, a complicated interaction of the two effects takes place.

2. Problem formulation and calculation algorithm

We need to find the contribution of the second order of perturbation theory on α to the value of the rotation angle of photon polarization plane per unit path $d\varphi/dx$ in a matter with spin-polarized electrons along the direction of electron spin polarization vector. For this purpose the approximation of total spin polarization of electrons in quantizing magnetic field for

http://dx.doi.org/10.18720/MPM.4512020_11

frequencies close to resonance will be used. This case is of interest for the following reasons: 1) Gell-Mann–Goldberger–Thirring dispersion relationship, optical theorem and Gandelman formula for the difference of Compton cross-sections at parallel and anti-parallel spins of electron and photon were used for Compton forward scattering amplitude calculation, a magnetic field being neglected (i.e. the general algorithm is known); 2) in the case of a quantizing magnetic field it's possible to keep the previous structure of the algorithm but to replace the Gandelman formula by the approximate differential Fomin-Kholodov formula for the resonance Compton cross-section [2, p. 324]. The formula can be easy integrated along angles, especially in the limit of total spin polarization of electrons. In the latter case it's necessary to calculate only one cross-section. This is connected with the fact that for the interaction of a photon, moving parallel to magnetic field lines, with any electron there is always the same ratio of photon and electron spin directions. The reason is that there are no electrons on the lowest Landau level with magnetic moments directed oppositely to the magnetic field at total spin polarization.

It should be also noted that Gell-Mann–Goldberger–Thirring dispersion relationship was applied in [1, p. 93] in a modified form to avoid integral divergence. It seems appropriate to do the same in the case of quantizing magnetic field.

3. The results of calculations

It's easy to obtain the following expression for the Compton scattering cross-section near resonance

$$\sigma(\omega, B) = \frac{16\pi r_0^2 b^2}{9\left((\kappa - b)^2 + (4\alpha/3)^2 b^4\right)}. \tag{1}$$

Here r_0 is the electromagnetic electron radius, B_0 is the Schwinger value of magnetic field strength, m is the electron mass,

$$\alpha = \frac{e^2}{\hbar c}, b = \frac{B}{B_0}, \kappa = \frac{\hbar\omega}{mc^2}, B_0 = \frac{m^2 c^3}{e\hbar}, r_0 = \frac{e^2}{mc^2}. \tag{2}$$

We see that the cross-section depends not only on the photon frequency ω but on the magnetic field strength B also. The formula structure is similar to that of Breit-Wigner formula where the resonance width depends on magnetic field strength. Applying the algorithm similar to that used in [1, p. 92-94], one obtains

$$\frac{d\varphi}{dx} = \frac{2\pi n_e r_0^2}{\alpha}(\vec{p}\cdot\vec{n})\left(G_1 + \frac{b}{3\pi}\cdot G_2(b,\kappa)\right), \tag{3}$$

where

$$G_2(b,\kappa) = \frac{\frac{2}{3}\alpha b\left(4b\kappa \ln\kappa + \left(G_3(b) + \kappa^2\right)\ln(G_3(b))\right) + \left(G_3(b) - \kappa^2\right)\left(\frac{\pi}{2} + arctg\left(\frac{3}{4\alpha b}\right)\right)}{\left(b^2 - \kappa^2\right)^2 + b^4\left(\frac{4}{3}\alpha\right)^2\left(b^2 + G_3(b) + 2\kappa^2\right)},$$

$$\vec{p}\cdot\vec{n} = 1, G_1 = \frac{1}{4}\left(\frac{\alpha}{2\pi} - 0{,}328\frac{\alpha^2}{\pi^2}\right)^2, \; G_3(b) = b^2 + \left(\frac{4}{3}\alpha\right)^2 b^4. \tag{4}$$

Here n_e is the electron density, $\vec{p}$ is the average spin polarization vector of electrons, $\vec{n}$ is a unit vector in the direction of photon propagation.

4. Conclusion

The value of rotation of photon polarization plane in totally spin-polarized electron gas in magnetic field has been calculated in the second order perturbation theory on the electromagnetic coupling constant. The values of magnetic field strength at which Landau quantizing is essential have been considered. Modified Gell-Mann–Goldberger–Thirring dispersion relationship, optical theorem and the approximate formula obtained by Fomin and Kholodov for the resonance Compton scattering cross-section have been used in the calculation.

Acknowledgements. *No external funding was received for this study.*

References

[1] Baryshevskii VG. *Nuclear Optics of Polarized Media*. Energoatomizdat, Moscow; 1995. (In Russian)

[2] Fomin PI, Kholodov RI. Resonance Compton scattering in an external magnetic field. *Journal of Experimental and Theoretical Physics*. 2000;90: 281-286.

[3] Sery AI. To the problem of Compton rotation of photons in a strong magnetic field: limit of total spin polarization of electrons. *Nonlinear Phenomena in Complex Systems*. 2014;17(4): 420-422.