EFFECT OF A STRONGLY MAGNETIZED PLASMA ON THE RESONANT PHOTON SCATTERING PROCESS

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Introduction

It is the established fact that the presence of a magnetic field in a wide class of astrophysical objects is a typical situation for the observable universe. The scale of the magnetic induction can vary over a very wide range: from large-scale (~ 100 kpc) intergalactic magnetic field $\sim 10^{-21}$ Гс [1], to the fields that are realized in the scenario of a rotational supernova explosion $\sim 10^{17}$ Гс. In this case, objects with a fields scale of the so-called critical value are of particular interest $B_e = m^2/e \approx 4.41 \cdot 10^{13}$ G (The work uses a natural system of units, where $c = h = k_B = 1$, m – electron mass, m_f – fermion mass, e_f – fermion charge, $e > 0$ – elementary charge). These include, in particular, isolated neutron stars, which include radio pulsars and the so-called magnetars, which have magnetic fields with induction from $B \sim 10^{12}$ G (radio pulsars) до $B \sim 4 \cdot 10^{14}$ G (magnetars).

An analysis of the emission spectra of radio pulsars and magnetars also indicates the presence of an electron-positron plasma in their magnetospheres with a concentration of the order of the Goldreich-Julian concentration [2]:

$$n_{GJ} \approx 3 \cdot 10^{13}\text{см}^{-3}\frac{B}{100B_e}\frac{10c}{P}\,, \qquad (1)$$

where P – the rotation period of the neutron star.

It is of interest under such conditions to consider the reaction of Compton scattering, taking into account the possible resonance on a virtual electron, taking into account the change in the polarization and dispersion properties of the photon.

Photon absorption rate in the strong magnetic field

In a magnetized plasma, in the general case, a photon will have elliptical polarization and 3 polarization states.

In the limit $B \gtrsim B_e$ and charge symmetric plasma ($\mu = 0$) polarization vectors will be the same as in a pure magnetic field

$$\varepsilon_\mu^{(1)} = \frac{(\varphi q)_\mu}{\sqrt{q_\perp^2}},\quad \varepsilon_\mu^{(2)} = \frac{(\tilde\varphi q)_\mu}{\sqrt{q_{\shortparallel}^2}},$$

where q^μ и q'^μ – momenta of the initial and final photons.

In this case, 4 partial photon scattering channels possible

$e\gamma^{(1)} \to e\gamma^{(1)}$, $e\gamma^{(2)} \to e\gamma^{(2)}$, $e\gamma^{(2)} \to e\gamma^{(1)}$, $e\gamma^{(1)} \to e\gamma^{(2)}$.

The following designations were used in this work: $(ab)_\perp = a_x b_x + a_y b_y$, $(ab)_{\shortparallel} = a_0 b_0 - a_z b_z$, $(a\varphi b) = a_y b_x - a_x b_y$. $\varphi_{\alpha\beta} = F_{\alpha\beta}/B$ and $\tilde\varphi_{\alpha\beta} = \frac{1}{2}\varepsilon_{\alpha\beta\mu\nu}\varphi_{\mu\nu}$ – dimensionless field tensor and dual tensor, respectively.

Symbols 1 and 2 correspond to $\parallel$ and $\perp$ polarizations at work (Adler 1971), X - and O - mods at work (Mushtukov et al. 2016), and E - and O - mods at work (Thompson et al. 1995).

Photon mod 2 on the area $q_{\shortparallel}^2 \geqslant 4m^2$ is instability – damping $\gamma^{(2)} \to e^+e^-$.

Mod 1 photon decays into e^+e^- pair on the area

$$q_{\shortparallel}^2 \geqslant (m + \sqrt{2eB + m^2})^2$$

The scale of photon energy 1 at which resonance is possible

$$q_{\shortparallel}^2 \gtrsim (\sqrt{m^2 + 2eB} - m)^2\,,$$

Therefore, to study the resonance, it is sufficient to consider the channels $e\gamma^{(1)} \to e\gamma^{(1)}$ and $e\gamma^{(1)} \to e\gamma^{(2)}$.

- Amplitude taking into account the finite width of electron absorption given by

$$\mathcal{M}_{\lambda\to\lambda'} = -4\pi\alpha\exp\left[-\frac{q_\perp^2 + q_\perp'^2 - 2i(q\varphi q')}{4eB}\right]\times$$
$$\times\sum_{n=0}^{\infty}\frac{\varepsilon_\alpha^{*(\lambda')}(q')\varepsilon_\beta^{(\lambda)}(q)T^n_{\alpha\beta}}{q_{\shortparallel}^2 + 2(pq)_{\shortparallel} - 2eBn + i(E+\omega)\Gamma_n} +$$
$$+ (q \leftrightarrow -q')$$

Γ_n – total electron absorption width [3], $T^n_{\alpha\beta}$ – regular value, p^μ and p'^μ – momenta of the initial and final electron.

- In the case of a narrow resonance peak, the denominator of the electron propagator can be interpolated by the δ-function:

$$|\mathcal{M}_{\lambda'\lambda}|^2 \simeq \sum_{n=0}^{\infty}\times\frac{\pi}{(\omega + E_n)\,\Gamma_n}$$
$$\times\delta(q_{\shortparallel}^2 + 2(pq)_{\shortparallel} - 2eBn - M_n^2)\times$$
$$\times|...|^2\,.$$

In this case, the absorption rate [4]:

$$W_{\lambda e \to \lambda' e} = W_{\lambda e\to e}$$

О δ-approximations can be found in more detail in the literature [4].

Photon absorption rate [5]:

$$W_{\lambda e\to\lambda' e} = \frac{eB}{16(2\pi)^4\omega_\lambda}\int|\mathcal{M}_{\lambda\to\lambda'}|^2 Z_\lambda Z_{\lambda'}\times$$
$$\times f_E(1 - f_{E'})(1 + f_{\omega'})\delta(\omega_\lambda(\mathbf{k}) + E - \omega_{\lambda'}(\mathbf{k}'))\frac{dp_z d^3k'}{EE'\omega_{\lambda'}}.$$

$f_\omega = [\exp(\omega/T) - 1]^{-1}$, $f_E = [\exp(E/T) + 1]^{-1}$.

$Z_\lambda^{-1} = 1 - \frac{\partial\mathcal{P}^\lambda}{\partial\omega^2}$. E и E' the energy of the initial and final electrons, respectively.

$\lambda, \lambda' = 1, 2.$

Numerical analysis

Comparative analysis of the probability of scattering in the case of resonance (solid line), work [5] (dotted line) and interpolation δ-function marked with dots.

for the channel $1 \to 1$

B=200B_e T=1 MэВ

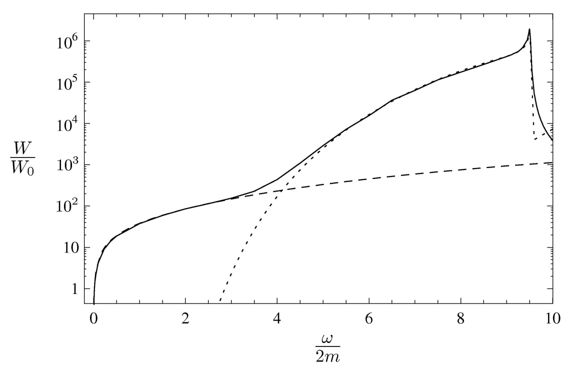

Рис. 1:

B=200B_e T=50 кэВ

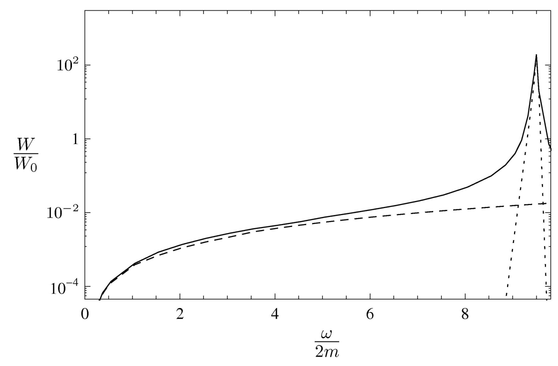

Рис. 2:

Для канала $1 \to 2$

B=200B_e T=1 MэВ

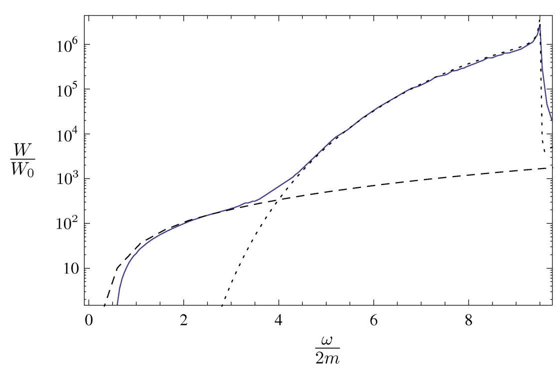

Рис. 3:

B=200B_e T=50 кэВ

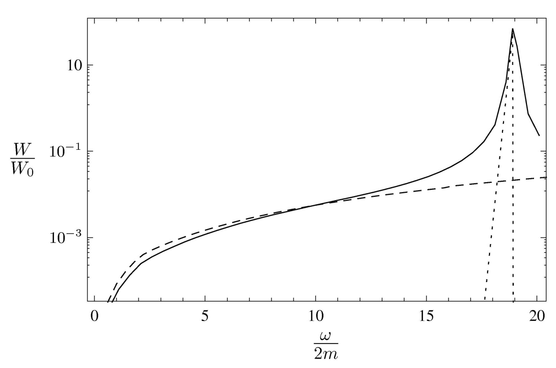

Рис. 4:

Summary

- The cross section is calculated and compared with the results available in the literature. It is shown that in the case of high temperatures $T > m$, when resonance has an effect on the photon absorption coefficient earlier than assumed in the work [5]. In particular for a magnetic field $B = 200B_e$ and temperature $T = 1$ MeV results of work [5] should be limited to photon energies $\omega \sim 4$ MeV.
- It is shown that the use δ-functional approximation of resonance peaks in the resonance region is in good agreement at a temperature $T \sim 1$ MeV with relevant results [6] obtained cumbersome numerical calculations. At a temperature $T \sim 50$ keV δ-functional approximation works worse, since the peak becomes narrower and the resonance effect occurs later.

Literature

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