Resonances in tree-level two-point amplitudes in a magnetized medium

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- Amplitudes of reactions $jf \to j'f'$ in the resonance region
- Resonant Compton scattering
- Conclusion

Introduction

In most astrophysical object the active medium has two components

- Magnetic field
  The scales of the magnetic fields strength are very different
  $B \sim 10^{-21}$ G. – large-scale intergalactic magnetic fields
  (~ 100) kpc
  $B \sim 1$ G. – magnetic fields of the Sun type stars
  $B \sim 10^7 - 10^9$ G. – white dwarfs
  $B \sim 10^{12}$ G. – radio pulsars
  $B \sim 10^{14} - 10^{15}$ G. – magnetars ($\gg B_e = \frac{m^2}{e} \simeq 4.41 \cdot 10^{13}$ G)
- Relatively dense plasma
  The electron number density in the region of closed field lines of radio pulsars and magnetars is estimated as

$$n_{GJ} \simeq 3 \cdot 10^{13}\,\text{sm}^{-3} \left(\frac{B}{100 B_e} \right) \left(\frac{10\,\text{s}}{P} \right) .$$

Introduction

A brief review of the literature on the one- and two vertex processes

- 1979 – Herold H. – the process $e\gamma \to e\gamma$ in magnetic field
- 1986 – Latal H.G. – the process $e \to e\gamma$ in magnetic field
- 1999 – Borovkov M.Yu., Kuznetsov A.V. and Mikheev N.V. – two vertex, one loop amplitudes $jf \to j'f'$ in magnetic field
- 2015 – Kuznetsov A.V., D.R. and Shlenev D.M. – generalize of previous result on the case of magnetized plasma
  The case of resonance have not considered
- 2016 – Mushtukov A.A., Nagirner D.I., Poutanen J. – resonant Compton scattering $e\gamma \to e\gamma$ in magnetic field of radio pulsar

Introduction

The main goal

We will investigate the tree-level two-point amplitudes for the transitions $jf \to j'f'$ in a constant uniform magnetic field and in plasma of charged fermions, for generalized vertices of the scalar, pseudoscalar, vector and axial vector types, with taking account of possible resonance on virtual fermion. As an application of the obtaining results, we will consider the reaction of resonance scattering $\gamma e \to \gamma e$ in the presence of a magnetized plasma of radio pulsars magnetosphere.

Introduction

Some notations

We use natural units $c = \hbar = k_{\rm B} = 1$, m is the electron mass, and $e > 0$ is the elementary charge, m_f and e_f are the fermion mass and the fermion charge, $\boldsymbol{B} = (0, 0, B)$.

The dimensionless tensor of the external magnetic field $\varphi_{\alpha\beta} = F_{\alpha\beta}/B$, and the dual tensor $\tilde{\varphi}_{\alpha\beta} = \frac{1}{2}\varepsilon_{\alpha\beta\mu\nu}\varphi^{\mu\nu}$.

Hereafter we use the following notations: four-vectors with the indices $\perp$ and $\parallel$ belong to the Euclidean {1, 2} subspace and the Minkowski {0, 3} subspace correspondingly. Then for arbitrary 4-vectors p_μ, q_μ one has

$$(pq)_\perp = (p\Lambda q) = p^\alpha \Lambda_{\alpha\beta} q^\beta = p^\alpha \varphi_\alpha{}^\rho \varphi_{\rho\beta} q^\beta = p_1 q_1 + p_2 q_2,$$

$$(pq)_\parallel = (p\widetilde{\Lambda} q) = p^\alpha \widetilde{\Lambda}_{\alpha\beta} q^\beta = p^\alpha \tilde{\varphi}_\alpha{}^\rho \tilde{\varphi}_{\rho\beta} q^\beta = p_0 q_0 - p_3 q_3.$$

Amplitudes of reactions $jf \to j'f'$ in the resonance region

The generalized amplitude of the transition $jf \to j'f'$ will be analyzed by using the effective Lagrangian for the interaction of a generalized current J with fermions in the form

$$\mathcal{L}(X) = \sum_k g_k [\bar{\psi}_f(X) \Gamma_k \psi_f(X)] J_k(X) \,,$$

where the generalized index $k = S, P, V, A$ numbers the matrices Γ_k: $\Gamma_S = 1$, $\Gamma_P = \gamma_5$, $\Gamma_V = \gamma_\alpha$, $\Gamma_A = \gamma_\alpha \gamma_5$; $J_k(X)$ are the operators of generalized currents (J_S, J_P, $J_{V\alpha}$ or $J_{A\alpha}$), g_k are the corresponding coupling constants, and $\psi_f(X)$ are the operators of fermion field.

Indeed, using this Lagrangian, one can describe a large class of interactions:

i) electromagnetic interaction, $k = V$, $g_V = -e_f$, $\Gamma_V J_V = \gamma^\mu A_\mu$

$$\mathcal{L}(X) = -e_f [\bar{\psi}_f(X) \gamma^\mu A_\mu(X) \psi_f(X)]$$

Amplitudes of reactions $jf \to j'f'$ in the resonance region

ii) the Lagrangian of the fermion-axion interaction, when $k = A$, $g_A = C_f/(2f_a)$, $\Gamma_A j_A = \gamma^\mu \gamma_5 \partial_\mu a(X)$, $a(X)$ is the quantized axion field, f_a is the Peccei-Quinn symmetry violation scale, C_f is the model dependent factor of order unity:

$$\mathcal{L}(X) = \frac{C_f}{2f_a}[\bar{\psi}_f(X)\gamma^\mu \gamma_5 \psi_f(X)]\partial_\mu a(X)$$

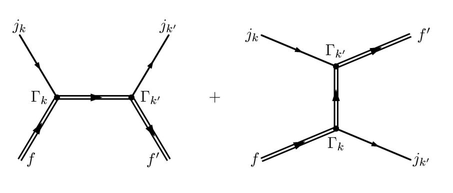
iii) the effective local Lagrangian of the four-fermion weak interaction, when $k = V, A$, $g_V = G_{\rm F} C_V/\sqrt{2}$, $g_A = G_{\rm F} C_A/\sqrt{2}$,

$$\mathcal{L}(X) = \frac{G_{\rm F}}{\sqrt{2}} \left[\bar{\psi}\gamma_\alpha (C_V + C_A \gamma_5)\psi\right] J_\alpha$$

where $J_\alpha(X) = \bar{\nu}(X)\gamma_\alpha(1 - \gamma_5)\nu(X)$ is the current of left-handed neutrinos; $C_V = \pm 1/2 + 2\sin^2\theta_W$, $C_A = \pm 1/2$, and $\theta_{\rm W}$ is the Weinberg angle. Here, the upper sign corresponds to neutrinos of the same flavor f $(\nu = \nu_f)$. The lower sign corresponds to the case of another neutrino flavors $(\nu \neq \nu_f)$.

Amplitudes of reactions $jf \to j'f'$ in the resonance region

The Feynman diagrams for the reaction $jf \to j'f'$. Double lines mean that the effects of an external field on the initial and final fermion states and on the fermion propagator are exactly taken into account



The S-matrix element in the tree approximation is described by the Feynman diagrams

$$S^{s's}_{k'k} = -g_k g_{k'} \int \mathrm{d}^4 X \mathrm{d}^4 Y \, j_k(X) j_{k'}(Y) \big[\bar{\Psi}^{s'}_{p',\ell'}(Y) \Gamma_{k'} \times$$

$$\times \hat{S}(Y, X) \Gamma_k \Psi^{s}_{p,\ell}(X) \big] + (j_k, \Gamma_k \leftrightarrow j'_k, \Gamma'_k) \, .$$

The currents $j_k(X)$ and $j_{k'}(Y)$ are represented as a plane wave solutions with amplitudes $j_k(q)$ and $j'_{k'}(q')$:

$$j_k(X) = \frac{e^{-\mathrm{i}(qX)}}{\sqrt{2q_0 V}} \, j_k(q) \,, \quad q^\alpha = (q_0, \boldsymbol{q})$$

$$j_{k'}(Y) = \frac{e^{\mathrm{i}(q'Y)}}{\sqrt{2q'_0 V}} \, j'_{k'}(q') \,, \quad q'^\alpha = (q'_0, \boldsymbol{q}')$$

Amplitudes of reactions $jf \to j'f'$ in the resonance region

Fermion wave functions $\Psi^{s'}_{p',\ell'}(Y)$ and $\Psi^{s}_{p,\ell}(X)$ are the solutions of Dirac equation in an external magnetic field. They are the eigenvalues of operator (A. Sokolov and I. Ternov 1974)

$$\hat{\mu}_z = m_f \Sigma_z - \mathrm{i}\gamma_0\gamma_5[\boldsymbol{\Sigma} \times \boldsymbol{P}]_z$$

where $\boldsymbol{P} = -\mathrm{i}\boldsymbol{\nabla} + e_f \boldsymbol{A}$, $\boldsymbol{\Sigma} = \gamma_0\gamma_5\boldsymbol{\gamma}$, $A^\lambda = (0, 0, xB, 0)$.

$$\hat{\mu}_z \, \Psi^s_{p,\ell}(X) = s \, M_\ell \, \Psi^s_{p,\ell}(X) \, , \quad s = \pm 1$$

$$\Psi^s_{p,\ell}(X) = \frac{e^{-\mathrm{i}(E_\ell X_0 - p_y X_2 - p_z X_3)} \; U^s_\ell(\xi)}{\sqrt{4 E_\ell M_\ell (E_\ell + M_\ell)(M_\ell + m_f) L_y L_z}}$$

$$V = L_x L_y L_z,$$

$$E_\ell = \sqrt{M_\ell^2 + p_z^2} \, , \quad M_\ell = \sqrt{m_f^2 + 2\beta\ell}$$

Amplitudes of reactions $jf \to j'f'$ in the resonance region

Our choice of the Dirac equation solutions as the eigenfunctions of the operator $\hat{\mu}_z$ is caused by the following arguments. Calculations of the process widths with two or more vertices in an external magnetic field by the standard method, including the squaring the amplitude with all the Feynman diagrams and with summation or averaging over the fermion polarization states, contain significant computational difficulties. In this case, it is convenient to calculate partial contributions to the amplitude from the channels with different fermion polarization states and for each diagram separately, by direct multiplication of the bispinors and the Dirac matrices. The result, up to a total for both diagrams non-invariant phase, will have an explicit Lorentz invariant structure. On the contrary, the amplitudes obtained with using the solutions for a fixed direction of the spin, do not have Lorentz invariant structure. Only the amplitude squared, summed over the fermion polarization states, is manifestly Lorentz-invariant.

Amplitudes of reactions $jf \to j'f'$ in the resonance region

We use the fermion propagator in the form of the sum over the Landau levels (A. Kuznetsov and A. Okrugin 2011)

$$\hat{S}(X, X') = \sum_{n=0}^{\infty} \sum_{s=\pm 1} \int \frac{\mathrm{d}p_0 \mathrm{d}p_y \mathrm{d}p_z}{(2\pi)^3} \times$$

$$\times \frac{\mathrm{e}^{-\mathrm{i}\,(p\,(X-X'))_{\parallel} + \mathrm{i} p_y\,(X_2 - X_2')}}{p_{\parallel}^2 - M_n^2 - \mathcal{R}_{\Sigma}^s(p) + \mathrm{i}\,\mathcal{I}_{\Sigma}^s(p)}\, \phi_{p,n}^s(X_1) \bar{\phi}_{p,n}^s(X_1') \,.$$

$$\phi_{p,\ell}^s(X_1) = \frac{U_\ell^s[\xi(X_1)]}{\sqrt{2M_\ell(E_\ell + M_\ell)(M_\ell + m_f)}}$$

$$\mathcal{I}_{\Sigma}^s(p) = -\frac{1}{2}\, p_0\, \Gamma_n^s \quad \text{(V. C. Zhukovsky et al. 1994)}$$

Γ_n^s is the total width of the fermion absorption for polarisation state s.

Amplitudes of reactions $jf \to j'f'$ in the resonance region

The real part of mass operator, $\mathcal{R}^s_\Sigma(p)$, define the modification (in comparison with the vacuum) of dispersion law of fermions in the magnetized plasma.

For most known astrophysical objects $B \lesssim 10^{16}$ G, and $\mathcal{R}^s_\Sigma(p) \sim \alpha m^2 \ln(B/B_e)$ is negligibly small.

(For example, the eigenvalue of photon polarization operator for mode 2 is $Re[\mathcal{P}^{(2)}(q)] \sim \alpha m^2 B/B_e$)

We neglect the influence of radiative corrections on the fermion dispersion

Amplitudes of reactions $jf \to j'f'$ in the resonance region

After that, the S - matrix element can be presented as

$$\mathcal{S}^{s's}_{k'k} = \frac{\mathrm{i}(2\pi)^3 \delta^{(3)}_{0,y,z}(P - p' - q')}{\sqrt{2q_0 V 2q'_0 V 2E_\ell L_y L_z 2E'_{\ell'} L_y L_z}} \, \mathcal{M}^{s's}_{k'k} \, ,$$

$$\mathcal{M}^{s's}_{k'k} \simeq \sum_{n=0}^{\infty} \sum_{s''} \int \mathrm{d}X_1 \mathrm{d}Y_1 \frac{(\ldots)}{P_\parallel^2 - M_n^2 + \mathrm{i}\,\mathcal{I}^{s''}_\Sigma(P)} + \ldots$$

$$P_\alpha = (p+q)_\alpha, \;\; \alpha = 0, 2, 3.$$

Amplitudes of reactions $jf \to j'f'$ in the resonance region

The two situations is possible.

i) If the Landau levels of real fermions higher than the level of virtual fermion, $\ell, \ell' \geqslant n$, then $P_{\parallel}^2 - M_n^2 \neq 0$. And the resonance is impossible. (A. Kuznetsov, D.R. and D. Shlenev 2015)

ii) If the Landau levels of real fermions lower than the level of virtual fermion $\ell, \ell' < n$, the solutions of the equation $P_{\parallel}^2 - M_n^2 = 0$ are exist and virtual fermion become real with the certain dispersion law.

Amplitudes of reactions $jf \to j'f'$ in the resonance region

The square of the amplitude is factoring in the following way

$$|\mathcal{M}^{s's}_{k'k}|^2 \simeq \sum_{s''} \sum_{n=0}^{\infty} \frac{\pi}{P_0\, \Gamma_n^{s''}}\, \delta(P_\parallel^2 - M_n^2)\, |\mathcal{M}^{s's''}_{(n,s'')\to j'f'}|^2\, |\mathcal{M}^{s''s}_{jf\to(n,s'')}|^2$$

$$\mathcal{M}^{s''s}_{jf\to(n,s'')} = \frac{\exp\left[-\mathrm{i} q_x (p_y + p_y'')/(2\beta)\right]}{\sqrt{M_\ell M_n (M_\ell + m)(M_n + m)}} \left[\frac{q_y + \mathrm{i} q_x}{\sqrt{q_\perp^2}}\right]^{n-\ell} \mathcal{T}_k^{s''s},$$

where $\mathcal{M}^{s's''}_{(n,s'')\to j'f'}$ is the amplitude of transition from the some initial state jf into fermion with E_n'', p_y'', p_z'', s'' and n, $\mathcal{M}^{s's''}_{(n,s'')\to j'f'}$ is the amplitude of transition of the fermion from the state with $E_n'', p_y'', p_z'', s'', n$ into the some final state $j'f'$,

$$\mathcal{M}^{s's''}_{(n,s'')\to j'f'} = \mathcal{M}^{s''s}_{jf\to(n,s'')}(q \to q'\; E_\ell \to E'_{\ell'}).$$

Amplitudes of reactions $jf \to j'f'$ in the resonance region

The main part of the problem is to calculate the values $\mathcal{T}_k^{s''s}$ which are expressed via the following Lorentz covariants in the $\{0, 3\}$-subspace

$$\mathcal{K}_{1\alpha} = \sqrt{\frac{2}{(p\widetilde{\Lambda}p'') + M_\ell M_n}} \left\{ M_\ell (\widetilde{\Lambda}p'')_\alpha + M_n (\widetilde{\Lambda}p)_\alpha \right\}$$

$$\mathcal{K}_{2\alpha} = \sqrt{\frac{2}{(p\widetilde{\Lambda}p'') + M_\ell M_n}} \left\{ M_\ell (\widetilde{\varphi}p'')_\alpha + M_n (\widetilde{\varphi}p)_\alpha \right\}$$

$$\mathcal{K}_3 = \sqrt{2\left[(p\widetilde{\Lambda}p'') + M_\ell M_n\right]}$$

$$\mathcal{K}_4 = -\sqrt{\frac{2}{(p\widetilde{\Lambda}p'') + M_\ell M_n}} \, (p\widetilde{\varphi}p'')$$

Amplitudes of reactions $jf \to j'f'$ in the resonance region

and functions for $n \geqslant \ell$

$$I_{n,\ell}(x) = \sqrt{\frac{\ell!}{n!}}\, \mathrm{e}^{-x/2} x^{(n-\ell)/2} L_{\ell}^{n-\ell}(x)\,,$$

$$I_{\ell,n}(x) = (-1)^{n-\ell} I_{n,\ell}(x)\,,$$

$L_n^k(x)$ are the generalized Laguerre polynomials

Example:

$$\mathcal{T}_S^{--} = g_s j_s \mathcal{K}_3 [(m_f + M_\ell)(m_f + M_n) I_{n,\ell} - 2\beta\sqrt{\ell n} I_{n-1,\ell-1}]$$

Resonant Compton scattering

As an application of the obtaining results we calculate the photon absorption rate in the reaction $\gamma e \to \gamma e$ which can be defined in the following way (M. Chistyakov, D.R. 2009):

$$W_{\gamma e \to \gamma e} = \sum_{\ell, \ell' = 0}^{\infty} \int \frac{\mathrm{d}p_y \mathrm{d}p_z L_y L_z}{(2\pi)^2} \, f_{E_\ell} \, \frac{\mathrm{d}p'_y \mathrm{d}p'_z L_y L_z}{(2\pi)^2} \, (1 - f_{E_{\ell'}}) \;\times$$

$$\times \frac{\mathrm{d}^3 q' V}{(2\pi)^3} \, (1 + f_{\omega'}) \sum_{s, s'} \frac{|\mathcal{S}_{VV}^{s's}|^2}{\tau} \, .$$

Here $f_{E_\ell} = \{\exp\left[(E_\ell - \mu)/T\right] + 1\}^{-1}$ $(f_{E'_\ell})$, $f_{\omega'} = [\exp(\omega'/T) - 1]^{-1}$ are the initial (final) electron distribution functions and the final photon distribution function in the plasma rest frame, T is the temperature and μ is the chemical potential of the electron gas. In $\mathcal{S}_{VV}^{s's}$ need to put $m_f = m$, $g_V = e > 0$, $q^\alpha = (\omega, \boldsymbol{k})$ and $q'^\alpha = (\omega', \boldsymbol{k}')$, $j_\alpha = \varepsilon_\alpha(q)$, $j'_\alpha = \varepsilon_\alpha(q')$.

Resonant Compton scattering

In the conditions of magnetars and radio pulsars $\mu = 0$ and the photon has two polarization with vectors

$$\varepsilon_\alpha^{(1)}(q) = \frac{(q\varphi)_\alpha}{\sqrt{q_\perp^2}}, \qquad \varepsilon_\alpha^{(2)}(q) = \frac{(q\tilde{\varphi})_\alpha}{\sqrt{q_\parallel^2}}$$

The width $\Gamma_n^{s''}$ can be represented in the form (H. Weldon, 1983)

$$\Gamma_n^{s''} = \Gamma_n^{(abs)\, s''} + \Gamma_n^{(cr)\, s''} \simeq \Gamma_{e_n \to e_{\ell'} \gamma}^{(abs)\, s''} \left[1 + \mathrm{e}^{-(E_n'' - \mu)/T}\right]$$

Resonant Compton scattering

$$\Gamma^{(abs)\, s''}_{e_n \to e_{\ell'} \gamma} = \sum_{\ell'=0}^{n-1} \sum_{s', \lambda'} \int \frac{\mathrm{d}p'_y \mathrm{d}p'_z L_y L_z}{(2\pi)^2} (1 - f_{E_{\ell'}}) \times$$

$$\times \frac{\mathrm{d}^3 q' V}{(2\pi)^3} (1 + f_{\omega'}) \frac{\left| \mathcal{S}^{s' s''}_{e_n \to e_{\ell'} \gamma^{(\lambda')}} \right|^2}{\tau}$$

is the width of the electron absorption in the process $e_n \to e_{\ell'} \gamma$.

Resonant Compton scattering

The mode 1 photon absorption rate

$$W_{\gamma^{(1)} e \to \gamma e} = \frac{\alpha\beta}{2\omega} \sum_{\ell=0}^{\infty} \sum_{n=n_0}^{\infty} \sum_{\epsilon=\pm 1} \times$$

$$\times \frac{f_{E_\ell^\epsilon}(1 - f_{E_\ell^\epsilon + \omega})}{\sqrt{(M_n^2 - M_\ell^2 - q_\parallel^2)^2 - 4q_\parallel^2 M_\ell^2}} \times$$

$$\times \Big\{ [2\beta(n+\ell) - q_\parallel^2](I_{n,\ell-1}^2 + I_{n-1,\ell}^2) -$$

$$-8\beta\sqrt{\ell n} I_{n,\ell-1} I_{n-1,\ell} \Big\},$$

Resonant Compton scattering

The mode 2 photon absorption rate

$$W_{\gamma^{(2)} e \to \gamma e} = \frac{\alpha\beta}{2\omega} \sum_{\ell=0}^{\infty} \sum_{n=n_0}^{\infty} \sum_{\epsilon=\pm 1} \times$$

$$\times \frac{f_{E_\ell^\epsilon}(1 - f_{E_\ell^\epsilon + \omega})}{\sqrt{(M_n^2 - M_\ell^2 - q_\parallel^2)^2 - 4 q_\parallel^2 M_\ell^2}} \times$$

$$\times \left\{ \left[\frac{(2\beta(n-\ell))^2}{q_\parallel^2} - 2\beta(n+\ell) - 4m^2 \right] \times \right.$$

$$\left. \times (I_{n,\ell}^2 + I_{n-1,\ell-1}^2) - 8\beta\sqrt{\ell n} I_{n,\ell} I_{n-1,\ell-1} \right\},$$

Resonant Compton scattering

Here

$$E_\ell^\epsilon = \frac{1}{2q_\parallel^2}\left[\omega\left(M_n^2 - M_\ell^2 - q_\parallel^2\right) + \right.$$
$$\left. +\epsilon k_z\sqrt{\left(M_n^2 - M_\ell^2 - q_\parallel^2\right)^2 - 4q_\parallel^2 M_\ell^2}\,\right].$$

The lower limit of the summation over n is defined by energy and momentum conservation law in the following way

$$n_0 = \ell + \left[\frac{q_\parallel^2 + 2M_\ell\sqrt{q_\parallel^2}}{2\beta}\right],$$

where $[x]$ is the integer part of x.

Resonant Compton scattering

Following the authors (A. Mushtukov et al., 2016), we introduce the process $\gamma e \to \gamma e$ cross section integrated over the initial electrons, with the distribution function f_{E_ℓ} for $\mu = 0$, as follows

$$\sigma^*_\lambda = \frac{1}{N_e} \int \frac{\mathrm{d}W_{\gamma^{(\lambda)} e \to \gamma e}}{j} \,,$$

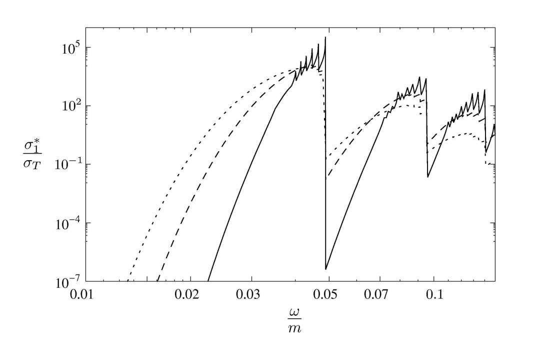
where $j = |(p\tilde{\varphi}q)|/(E\omega V)$ is the flux density of the incident particles in the longitudinal subspace with respect to the magnetic field direction,

$$N_e = \frac{\beta}{(2\pi)^2} \sum_{\ell=0}^{\infty} (2 - \delta_{\ell,0}) \int\limits_{-\infty}^{\infty} \mathrm{d}p_z f_{E_\ell}$$

is the electron density in an external magnetic field.

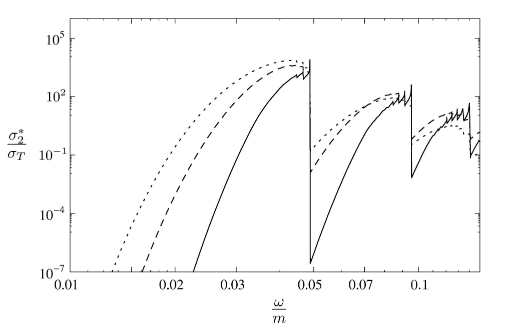
Resonant Compton scattering

The cross section of mode 1 photon, $\gamma^{(1)} e \to e$ at $B = 5 \times 10^{12}$ G, $T = 20$ keV, $\mu = 0$ and $\theta = 90^\circ$ – solid line, $\theta = 60^\circ$ – dashed line, $\theta = 30^\circ$ – dots



We note that the photon absorption rates for both modes have narrow maxima corresponding to the photon energy values $\omega_{n\ell} = (M_n - M_\ell)/\sin\theta$, well known in the literature

The cross section of mode 2 photon, $\gamma^{(2)} e \to e$ at $B = 5 \times 10^{12}$ G, $T = 20$ keV, $\mu = 0$ and $\theta = 90^\circ$ – solid line, $\theta = 60^\circ$ – dashed line, $\theta = 30^\circ$ – dots



These results are in good agreement with the corresponding results of paper A. Mushtukov et. al. 2016, obtained by cumbersome numerical calculations

Conclusion

- We have calculated the tree-level two-point amplitudes for the transitions $jf \to j'f'$ in a constant uniform magnetic field and in plasma of charged fermions, for generalized vertices of the scalar, pseudoscalar, vector and axial vector types, with taking account of possible resonance on virtual fermion.
- It was shown, that in the case of δ - functional approximation of the resonant peaks, the amplitude square of process $jf \to j'f'$ is factoring by squares one vertex amplitudes of subprocesses of initial state transition into the fermion on the Landau level n and transition of the fermion with level n into final state $j'f'$.

Conclusion

- As an application of the obtaining results, the reaction of resonance scattering $\gamma e \to \gamma e$ in the presence of a magnetized plasma was considered. The photon absorption rate in this process was obtained. It is represented in a simple analytical form, convenient for further analysis.
- It was shown, that the use of δ - functional approximation of resonant peaks in the resonance region is in good agreement with the corresponding results of paper A. Mushtukov et. al. 2016, obtained by cumbersome numerical calculations.

Thank you!!!