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"FRONTIERS IN ASTROPARTICLE PHYSICS"

Relativistic theory of inverse beta-decay of polarized neutron in strong magnetic field

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Outline

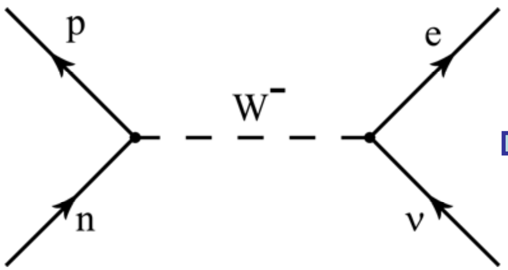
- ✓ *Solution of Dirac equation in magnetic field*
- ✓ *Lagrangian and matrix element of the process*
- ✓ *Law of energy conservation and critical magnetic fields*
- ✓ *General expression for cross-section of the inverse beta-decay*
- ✓ *Cross-section in super-strong, strong and weak magnetic field*
- ✓ *Effects of anomalous magnetic moments of nucleons*

Introduction

The inverse beta-decay of neutron in magnetic field

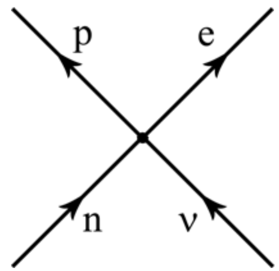
$$\nu_e + n \xrightarrow{B} p + e^-$$

1. Incoming neutrino is supposed to be relativistic and effects of neutrino non-zero mass are neglected.
2. The four-fermion weak interaction theory is relevant in our case.
3. We suppose that *Z* and *W* bosons are not affected by the magnetic field.



$$\frac{m^2}{m_W{}^2} \ll 1, \quad \frac{eB}{m_W{}^2} \ll 1$$

$$(B \ll m_W{}^2/e \sim 10^{24} G)$$



Four-fermion Lagrangian:

E.Fermi, 1934

$$\mathcal{L} = \frac{G}{\sqrt{2}} \left[\bar{\psi}_p \gamma_\mu (1 + \alpha\gamma_5) \psi_n\right] \left[\bar{\psi}_e \gamma^\mu (1 + \gamma_5) \psi_\nu\right],$$

$$\alpha = \frac{g_A}{g_V} = 1.26$$

Dirac equation in magnetic field

$$\left\{\gamma^\mu(p_\mu + eA_\mu{}^{ext}) - m\right\} \Psi(\vec{r}, t) = 0$$

Solution for $A_\mu{}^{ext} = (0, 0, xB, 0)$ A. Sokolov, *J. Phys. USSR*, 1945

$$\psi_e = \frac{1}{L}\begin{pmatrix} C_1 U_{n-1}(\eta) \\ iC_2 U_n(\eta) \\ C_3 U_{n-1}(\eta) \\ iC_4 U_n(\eta) \end{pmatrix} \mathrm{e}^{-i(p_0 t - p_2 y - p_3 z)},$$

where U_n are Hermite functions of order n

$$U_n(\eta) = \sqrt{\frac{eB}{2^n n! \pi^{1/2}}}\, e^{-\eta^2/2} H_n(\eta) \qquad \eta = x\sqrt{\gamma} + \frac{p_2}{\sqrt{\gamma}}, \quad \gamma = eB,$$

$$H_n(\eta) = (-1)^n e^{\eta^2} \frac{d^n}{d\eta^n} e^{-\eta^2}$$ - Hermite polynomials

Energy spectrum:

$$p_0 = \sqrt{m^2 + {p_3}^2 + 2eBn},\ \ n = 0, 1, 2, \ldots$$

number of Landau level in ***B***

Non relativistic case

$$p_0 \approx m + \frac{{p_3}^2}{2m} + n\omega,\ \ \omega = \frac{eB}{m}$$

cyclotron frequency

Spin coefficients:

$$\mu_3 \psi(\vec{r}, t) = \tilde{p}_\perp s \psi(\vec{r}, t),\ \ \tilde{p}_\perp = \sqrt{m^2 + 2\gamma n},$$

where polarization tensor

$$\mu_3 = m\sigma_3 + \rho_2[\vec{\sigma} \times \vec{P}]_3,\ \ \vec{P} = \vec{p} + e\vec{A},\ \ \rho_2 = \begin{pmatrix} 0 & -iI \\ iI & 0 \end{pmatrix},$$

$$C_{1,3} = \frac{1}{2}\sqrt{1 + s\frac{m}{\tilde{p}_\perp}}\ \sqrt{1 \pm s\frac{\tilde{p}_\perp}{p_0}}, \qquad C_{2,4} = \mp\frac{1}{2}s\sqrt{1 - s\frac{m}{\tilde{p}_\perp}}\ \sqrt{1 \mp s\frac{\tilde{p}_\perp}{p_0}},$$

s = ±1 is electron spin projection value (*s* = 1 corresponds to spin orientation parallel to direction of magnetic field ***B***).

Matrix element

Total cross-section

$$\sigma = \frac{L^3}{T} \sum_{\text{phase space}} |M|^2,$$

Matrix element of process

$$M = \frac{G}{\sqrt{2}} \int [\bar{\psi}_p \gamma_\mu (1 + \alpha\gamma_5) \psi_n] \, [\bar{\psi}_e \gamma^\mu (1 + \gamma_5) \psi_\nu] \, \mathrm{d}x \, \mathrm{d}y \, \mathrm{d}z \, \mathrm{d}t$$

where Ψ_p and Ψ_e are exact solution of Dirac equation in magnetic field,

$G = G_{\mathrm{F}} \cos\theta_{\mathrm{c}}$, θ_{c} is Cabibbo angle, $\alpha = \frac{g_A}{g_V} = 1.26$.

Relativistic theory of inverse beta-decay of polarized neutron

Effects of *proton momentum quantization* and *proton recoil motion* are accounted.

Neutrino and neutron are not affected by magnetic field

$$\psi_n = \frac{1}{2L^{3/2}} \begin{pmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \end{pmatrix} \mathrm{e}^{-i(p_0^n t - \vec{p}_n \vec{r})},$$

$$N_{1,3} = s_n \sqrt{1 \pm \frac{m_n}{p_0^n}} \cdot \sqrt{1 \pm s_n \cos\theta_n} \cdot \mathrm{e}^{\mp i\varphi_n/2},$$

$$N_{2,4} = \sqrt{1 \mp \frac{m_n}{p_0^n}} \cdot \sqrt{1 \mp s_n \cos\theta_n} \cdot \mathrm{e}^{\pm i\varphi_n/2}.$$

$s_n = \pm 1$ is neutron spin projection value ($s_n = 1$ corresponds to spin orientation parallel to direction of magnetic field B).

Neutrino wave function

$$\psi_\nu = \frac{1}{2L^{3/2}} \begin{pmatrix} f_1 \\ f_2 \\ -f_1 \\ -f_2 \end{pmatrix} \mathrm{e}^{-i(\varkappa t - \vec{\varkappa} \vec{r})},$$

$$f_1 = -\mathrm{e}^{-i\varphi_\nu} \sqrt{1 - \cos\theta_\nu},$$

$$f_2 = \sqrt{1 + \cos\theta_\nu},$$

where θ_ν, φ_ν are polar and azimuthal neutrino momentum angles.

Neutrino energy

$$\varkappa = |\vec{\varkappa}|, \qquad (m_\nu \ll \varkappa)$$

Proton wave function

$$\psi_p = \frac{1}{L}\begin{pmatrix} C'_1 U_{n'}(\eta') \\ -iC'_2 U_{n'-1}(\eta') \\ C'_3 U_{n'}(\eta') \\ -iC'_4 U_{n'-1}(\eta') \end{pmatrix} \mathrm{e}^{-i(p'_0 t - p'_2 y - p'_3 z)},$$

where dashed quantities correspond to proton mass, number of Landau state, energy and momentum components.

Cross section of process

After integration over space-time and proton and electron momenta

$$\sigma = \frac{eB}{32\pi}\sum_{s,s'}\sum_{n,n'}\int_{\infty}^{\infty} |M|^2 \delta_0(p'_0 + p_0 - m_n - \varkappa)\Big|_{p_3=\varkappa_3-p'_3} \mathrm{d}p'_3,$$

where squared matrix element

$$|M|^2 = AI^2_{n',n-1}(\rho) + BI^2_{n',n}(\rho) + CI^2_{n'-1,n-1}(\rho) + DI_{n',n}(\rho)I_{n'-1,n-1}(\rho),$$

$A, B, C, D \sim {f_i}^2, {N_j}^2, {C_k}^2, {C'_l}^2$ are function of (s, s', s_n, p_3, p'_3, κ, cosθ).

General expression for cross-section

Integration over p'_3

$$\delta(\varphi(p'_3)) = \sum_i \frac{\delta(p'_3 - p'^{(i)}_3)}{|\varphi'(p'^{(i)}_3)|}, \; \varphi(p'_3) = \sqrt{\tilde{p}'^2_\perp + p'^2_3} + \sqrt{\tilde{p}^2_\perp + (\varkappa_3 - p'_3)^2} - m_n - \varkappa,$$

number of simple roots eq.: $\varphi(p'^{(i)}_3)=0$

Finally

$$\sigma = \frac{eB}{32\pi} \sum_{s,s'} \sum_{n,n'} \sum_{i=1,2} \frac{\left|M^{(i)}\right|^2}{\left|\frac{p^{(i)}_3}{p^{(i)}_0} - \frac{p'^{(i)}_3}{p'^{(i)}_0}\right|},$$

Where used substitution

$$p'_3 \to p'^{(i)}_3.$$

where $p'^{(i)}_3$ are simple roots equation $\varphi(p'^{(i)}_3)=0$.

Cross section of inverse beta-decay of polarized neutron in magnetic field, effects of *Landau quantization of proton momentum* and *proton recoil motion are accounted for exactly* for arbitrary magnetic field ***B*** and neutrino energy.

Energy conservation law

$$m_n + \varkappa = \sqrt{m^2 + 2\gamma n + (\varkappa_3 - p_3')^2} + \sqrt{m'^2 + 2\gamma n' + p_3'^2}$$

Critical magnetics fields: B_{cr}, B'_{cr}

1. Maximal number of electron Landau level

$$n_{\max} = \mathrm{int}\left[\frac{(\Delta + \varkappa_{\max})^2 - m^2}{2eB}\right], \qquad \Delta = m_n - m',$$

$n_{max} < 1$ (i.e.=0) if $B \geq B_{cr}$ - electron critical field strength

$$B_{\mathrm{cr}} = \frac{(\Delta + \varkappa_{\max})^2 - m^2}{2e}$$

If $B \geq B_{cr}$ then $n = 0$ (electron at lowest Landau level).

for different neutrino energies

$$B_{\mathrm{cr}} \approx 8.3 \times 10^{16}\ \mathrm{G}, \quad \varkappa_{\max} = 30\ \mathrm{MeV},$$

$$B_{\mathrm{cr}} \approx 1.1 \times 10^{16}\ \mathrm{G}, \quad \varkappa_{\max} = 10\ \mathrm{MeV},$$

$$B_{\mathrm{cr}} \approx 1.2 \times 10^{14}\ \mathrm{G}, \quad \varkappa_{\max} \ll\ m.$$

2. Maximal number of proton Landau level

$$n'_{\max} = \mathrm{int}\left[\frac{(\varkappa_{\max} + m_n - m)^2 - m'^2}{2eB}\right],$$

proton critical field strength

$$B'_{\mathrm{cr}} = \frac{(\varkappa_{\max} + m_n - m)^2 - m'^2}{2e}$$

for different neutrino energies

$$B'_{\mathrm{cr}} \approx 5 \times 10^{18}\ \mathrm{G}, \quad \varkappa_{\max} = 30\ \mathrm{MeV}$$

$$B'_{\mathrm{cr}} \approx 1.7 \times 10^{18}\ \mathrm{G}, \quad \varkappa_{\max} = 10\ \mathrm{MeV}$$

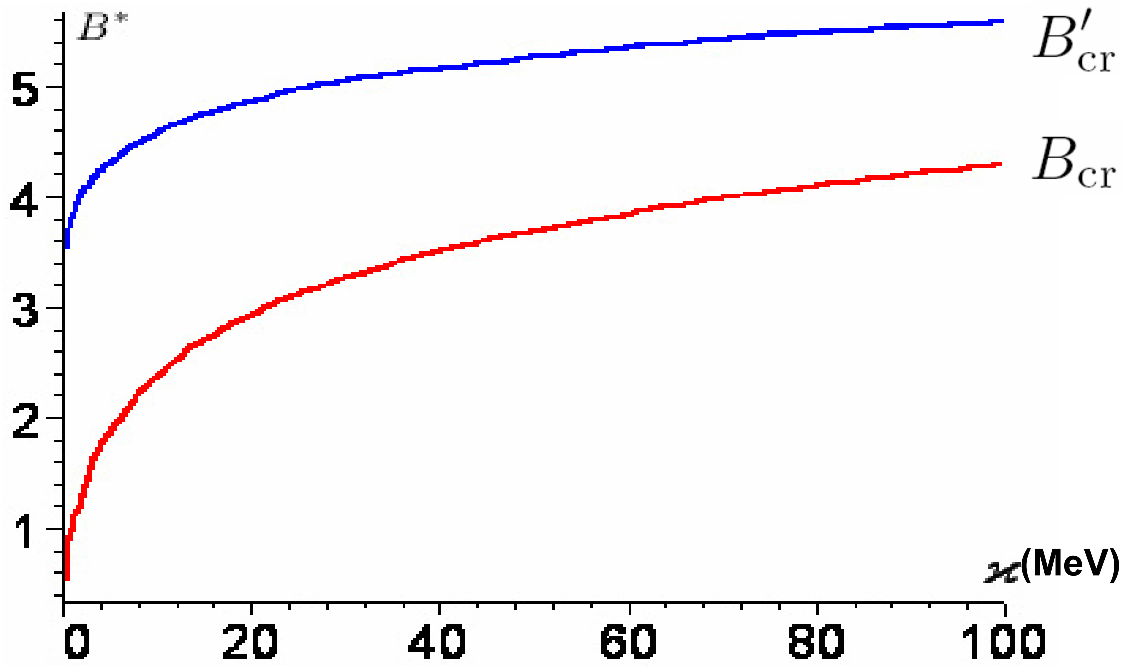
$$B'_{\mathrm{cr}} \approx 1.3 \times 10^{17}\ \mathrm{G}, \quad \varkappa_{\max} \ll m.$$

If $B \geq B'_{cr}$, then $n' = 0$ (proton at lowest Landau level).

Three ranges of magnetic field strength

1. **weak field** **($B < B_{cr}$)**
2. **strong field** **($B_{cr} \leq B < B'_{cr}$)**
3. **super-strong field** **($B \geq B'_{cr}$)**

Critical magnetic fields strength



$$B'_{\rm cr} = \frac{(\varkappa_{\rm max} + m_n - m)^2 - m'^2}{2e},$$

$$B_{\rm cr} = \frac{(\Delta + \varkappa_{\rm max})^2 - m^2}{2e}, \quad \Delta = m_n - m',$$

where $B^* = \log \frac{B}{B_0}$, $B_0 = \frac{m^2}{e} = 4.41 \times 10^{13} G$, $\varkappa$ - neutrino energy (MeV).

Super-strong magnetic field ($B \geq B'_{cr}$)

Landau Level for electron and proton:

***n*' = 0** → **s' = +1,** $\vec{s}_p \uparrow\uparrow \vec{B}.$

***n* = 0** → **s = -1,** $\vec{s}_e \uparrow\downarrow \vec{B}.$

Cross section

$$\sigma_{n=n'=0} = \frac{eBG^2}{8\pi} \mathrm{e}^{-\varkappa_\perp^2/2\gamma} \sum_{i=1,2} \frac{\left(1 + \frac{p_3^{(i)}}{p_0^{(i)}}\right)}{\left| \frac{p_3^{(i)}}{p_0^{(i)}} - \frac{p_3'^{(i)}}{p_0'^{(i)}} \right|} \{a^{(i)} + b^{(i)} \cos\theta + s_n(b^{(i)} + a^{(i)} \cos\theta)\},$$

where

$$a^{(i)} = 3 + 2\alpha + 3\alpha^2 - 2(1-\alpha^2)\frac{m'}{p_0'^{(i)}} - (1 + 6\alpha + \alpha^2)\frac{p_3'^{(i)}}{p_0'^{(i)}},$$

$$b^{(i)} = -1 + 2\alpha - \alpha^2 + 2(1-\alpha^2)\frac{m'}{p_0'^{(i)}} - (1-\alpha)^2\frac{p_3'^{(i)}}{p_0'^{(i)}}.$$

recoil motion of proton

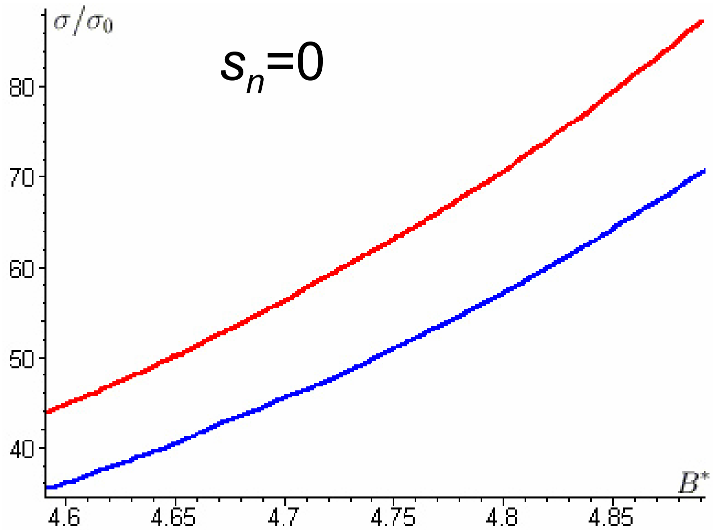
If we neglect proton momentum ($p'_3 << m'$)

$$\sigma_{n=n'=0}\Big|_{p'_0=m'} = \frac{eBG^2}{4\pi} e^{-\varkappa_\perp^2/2\gamma}\{a + b\cos\theta + s_n(b + a\cos\theta)\}\frac{\Delta+\varkappa}{\sqrt{(\Delta+\varkappa)^2 - m^2}},$$

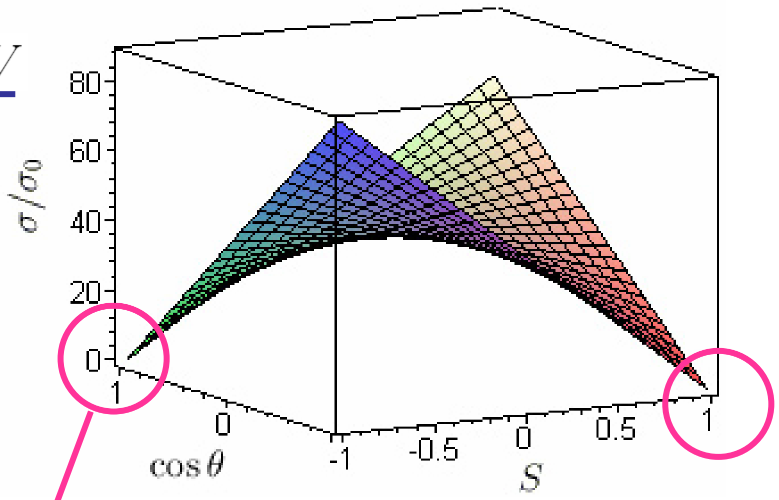
where

$$a = 1 + 2\alpha + 5\alpha^2,$$
$$b = 1 + 2\alpha - 3\alpha^2.$$

$\alpha = 1.26$ → $a = 11.5,\quad b = -1.24.$



$\varkappa = 10\ MeV$



— $\cos\theta = -1,$

— $\cos\theta = 1,$

$$B^* = \log\frac{B}{B_0},\quad B_0 = \frac{m^2}{e} = 4.41\times 10^{13}G$$

σ_o is cross section for B=0 case

$$\sigma(s_n\cos\theta = -1) = 0,$$

matter is *transparent* for neutrino!

Polarized neutron matter

Neutrons polarization:

$$S = \frac{N_+ - N_-}{N_+ + N_-},$$ $N_\pm$ – numbers of neutrons with $s_n = \pm 1$.

Cross section for polarized neutron matter:

$\sigma = 0$, if $S = -1$

$$\sigma_{n=n'=0}\Big|_{p_0'=m',\cos\theta=1} = \frac{eBG^2}{2\pi}\mathrm{e}^{-\varkappa_\perp^2/2\gamma}(1+\alpha^2)(1+S)\frac{\Delta+\varkappa}{\sqrt{(\Delta+\varkappa)^2-m^2}}$$

$\sigma = 0$, if $S = +1$

$$\sigma_{n=n'=0}\Big|_{p_0'=m',\cos\theta=-1} = \frac{eBG^2}{\pi}\mathrm{e}^{-\varkappa_\perp^2/2\gamma}2\alpha^2(1-S)\frac{\Delta+\varkappa}{\sqrt{(\Delta+\varkappa)^2-m^2}}$$

Neutrino asymmetry:

Totally polarized neutron matter is transparent for neutrino moving antiparallel to neutron polarization in super-strong field: $S\cos\theta = -1$.

Strong magnetic field ($B_{cr} \leq B < B'_{cr}$)

Available Landau level for electron and proton:

$$n = 0, \quad n'_{\max} = \mathrm{int}\left[\frac{(m_n + \varkappa - m)^2 - m'^2}{2eB}\right] \approx \mathrm{int}\left[\frac{m'(\Delta + \varkappa - m)}{eB}\right].$$

Cross section

$$\sigma_{n=0} = \frac{eBG^2}{8\pi} \sum_{n'=0}^{n'_{\max}} \sum_{i=1,2} \frac{\left(1 + \frac{p_3^{(i)}}{p_0^{(i)}}\right)}{\left|\frac{p_3^{(i)}}{p_0^{(i)}} - \frac{p_3'^{(i)}}{p_0'^{(i)}}\right|} \left\{\left[(1+\alpha)^2\left(1 - \frac{p_3'^{(i)}}{p_0'^{(i)}}\right)(1+S)(1+\cos\theta)\right.\right.$$
$$+2\left[1 + \alpha^2 - (1-\alpha^2)\frac{m'}{p_0'^{(i)}} - 2\alpha\frac{p_3'^{(i)}}{p_0'^{(i)}}\right](1-S)(1-\cos\theta)\Bigg] I^2_{n',0}(\rho)$$
$$\left. +(1-\alpha)^2\left(1 - \frac{p_3'^{(i)}}{p_0'^{(i)}}\right)(1-S)(1+\cos\theta)(1-\delta_{n',0}) I^2_{n'-1,0}(\rho)\right\},$$

where $\delta_{n',0}$ is the Kronecker delta ($1 - \delta_{n',0} = 0$ for $n' = 0$).

Proton momentum quantization and recoil motion are accounted for *exactly*.

Cross section for the case $p'_0=m'$ (proton motion is neglected)

Bhattacharya, Pal, *Pramana J. Phys.*, 2004

$$\sigma_{n=0}\Big|_{p_0'=m'} = \frac{eBG^2}{2\pi}\{1+3\alpha^2+(1-\alpha^2)\cos\theta + 2\alpha S[1-\alpha+(1+\alpha)\cos\theta]\}\frac{\Delta+\varkappa}{\sqrt{(\Delta+\varkappa)^2-m^2}}.$$

If $\cos\theta = -1$ then cross section is

$$\sigma_{n=0}\Big|_{p_0'=m',\cos\theta=-1} = \frac{eBG^2}{\pi}2\alpha^2(1-S)\frac{\Delta+\varkappa}{\sqrt{(\Delta+\varkappa)^2-m^2}}.$$

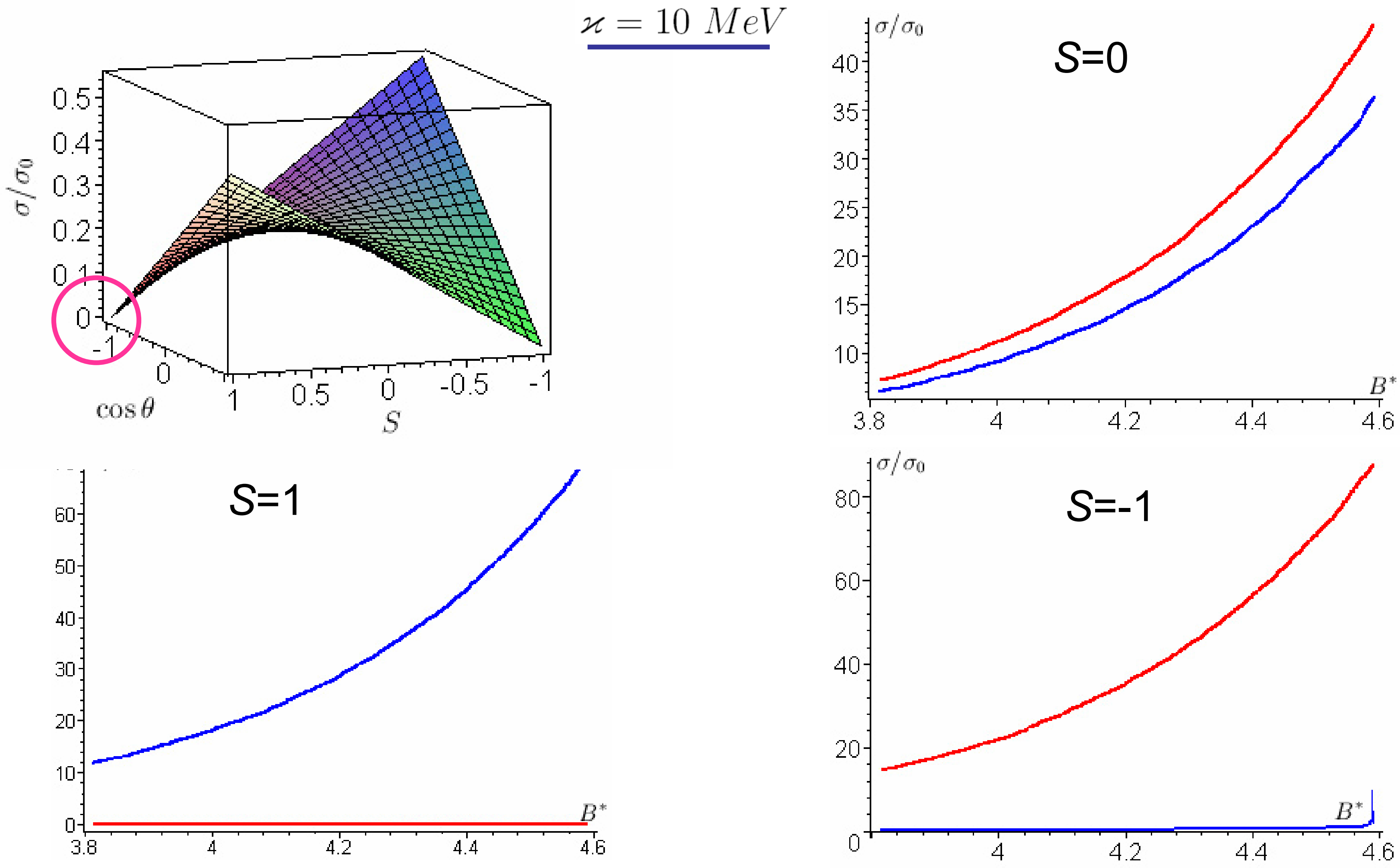
σ = 0, if S=+1

For neutron matter totally polarized parallel to magnetic field vector, S = +1, cross-section vanishes.

If $\cos\theta = 1, S = -1$ then

$$\sigma \sim (1-\alpha)^2 < 0.1, \;\; \alpha = 1.26.$$

Neutron matter is transparent for neutrino if $S \cos\theta$ = -1 in strong magnetic field.



$\cos\theta = -1,$

$\cos\theta = 1,$

$$B^* = \log\frac{B}{B_0},\ \ B_0 = \frac{m^2}{e} = 4.41\times10^{13}G$$

Weak magnetic field (B < B_{cr})

Many Landau levels are available for electron and proton

$$n_{\max} = \mathrm{int}\left[\frac{(\Delta + \varkappa_{\max})^2 - m^2}{2eB}\right], \quad n'_{max} \to \infty\,.$$

Cross section

$$\sigma\Big|_{p_0'=m'} = \frac{eBG^2}{2\pi}\sum_{n=0}^{n_{\max}}\{g_n[1+3\alpha^2+2S\alpha(1+\alpha)\cos\theta]$$

$$+\delta_{n,0}[(1-\alpha^2)\cos\theta+2S\alpha(1-\alpha)]\}\,\frac{\Delta+\varkappa}{\sqrt{(\Delta+\varkappa)^2-m^2-2\gamma n}}.$$

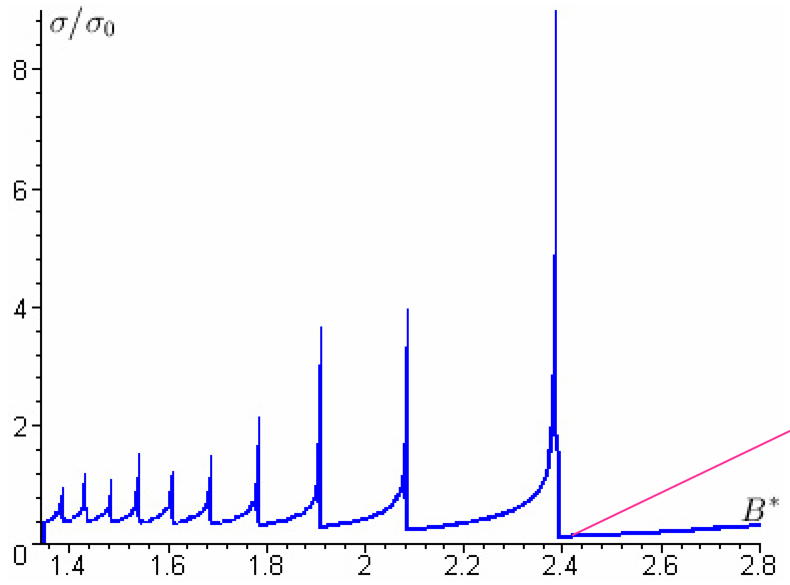
Bhattacharya, Pal, *Pramana J. Phys.*, 2004

Cross-section has resonance structure when

$$p_0 = \varkappa + \Delta = \sqrt{m^2 + 2\gamma n}, \qquad n \le n_{\max}.$$

allowed Landau energies

- ✓ N_{res} increases with neutrino energy for B = const,
- ✓ infinity high spikes smooth out if proton motion is accounted for.



$$\varkappa = 10\ MeV,$$

$$B^* = \log \frac{B}{B_0},\ \ B_0 = \frac{m^2}{e} = 4.41 \times 10^{13} G$$

B*cr*

Magnetic field-free limit

When the field is switching off, the maximum number of Landau level $n_{\max}$ is increasing to infinity, however

$$\lim_{B \to 0, n \to \infty} eBn = \frac{(\Delta + \varkappa)^2 - m^2}{2}, \quad n'_{max} \to \infty \ .$$

Cross section

Kerimov, *Izv. Ak. Nauk USSR,* 1961

$$\sigma_0 = \frac{G^2}{\pi}\left[1 + 3\alpha^2 + 2\alpha S_n (1+\alpha)\cos\theta\right](\Delta + \varkappa)\sqrt{(\Delta + \varkappa)^2 - m^2}.$$

Effects of anomalous magnetic moments

Proton energy in magnetic field

$$p'_0 = \sqrt{\left(\sqrt{m'^2 + 2eBn'} - s'k_pB\right)^2 + {p'_3}^2}, \qquad k_p = \frac{e}{2m'}\left(\frac{g_p}{2} - 1\right),$$

where proton's Lande factor: $g_p = 5.58$

Neutron energy in magnetic field

$$p_0^n = m_n - s_n k_n B, \qquad k_n = \frac{e}{2m_n}\frac{g_n}{2},$$

where neutron's Lande factor: $g_n = -3.82$.

Taking into account these modifed expressions for proton and neutron energies, we can repeat all calculations applying substitutions:

$$m' \to m'^* = m' - k_pB, \quad m_n \to m_n^* = m_n - s_n k_n B.$$

In super-strong magnetic field there is range of neutron matter polarization *S* for which the matter becomes transparent for neutrinos:

$$m_n - s_n k_n B + \varkappa \geq m + m' - k_pB.$$

Conclusions

1. We have developed relativistic theory of inverse beta-decay of polarized neutron in magnetic field, accounting for proton momentum quantization and recoil motion.

2. Closed general expression obtained for cross-section of process in magnetic field.

3. For three ranges of background magnetic field ($B > B'_{cr}$, $B_{cr} \le B \le B'_{cr}$, $B < B_{cr}$) we have calculated the cross-section and discussed its dependence on neutrino energy, angle θ and neutron polarization *S*. Proper treatment of super-strong field:

$$\sum_{n'=0}^{\infty} \sigma(n,n')\Big|_{p'_0=m'} \neq \sigma(n,n')\Big|_{n'=0}$$

4. Cross-section asymmetry.
We have shown that polarized neutron matter is transparent for neutrino and super-strong field if $S\cos\theta = -1$ and in strong field if *S*=1 and $\cos\theta = -1.$

5. Developed relativistic treatment of cross-section can be applied to other URCA processes in magnetic field with two particles in initial and final states

$$p + \bar{\nu}_e \leftrightharpoons n + e^+,$$

$$e + p \rightarrow n + \nu_e ,$$

that are important for star cooling and also producing asymmetry in neutrino distribution.

- ✓ Crossing symmetry makes it possible, that squared matrix elements are the same.
- ✓ What remains to be done is to change appropriately phase volume of the process.

Weak reaction rates in magnetic field

Inter-conversion between *n* and *p* in magnetic field through

$$\nu_e + n \leftrightharpoons e + p,$$

Inverse beta-decay

$$p + \bar{\nu}_e \leftrightharpoons n + e^+,$$

$$n \to p + e + \bar{\nu}_e,$$

n/p ratio in various astropartical processes such as

I. Big-Bang Nucleosynthesis

- Greenstein, 1969;
- Matese, O'Connel, 1969, 1970;
- Cheng, Schram, Truran, 1993;
- Grasso, Rubinstein, 1995,1996, 2001.

II. Neutron Star Cooling and Kick Velosities

- Chugai, 1984;
- Dorofeev, Radionov, Ternov, 1984;
- Loskutov, Zakharov, 1985;
- Studenikin, 1988.

- H.Duan, Y.-Z. Qian, astro-ph/0401634, January 30, 2004

Neutrino processes

$$\nu_e + n \leftrightharpoons e + p, \quad p + \bar{\nu}_e \leftrightharpoons n + e^+,$$

in magnetic field $B \leq 10^{16}$ G
(non-relativistic approach to neutron and proton motion)

✓ Neutrino asymmetry and reduction of supernova cooling rate.

- S.Shinkevich, A.Studenikin, *Pramana J. Phys*, 65, 2 (2005), hep-ph/0402154, February 15, 2004

Relativistic theory of inverse beta-decay of polarized neutron

$$\boxed{\nu_e + n \rightarrow p + e^-}$$

in strong and super-strong magnetic field

✓ Effects of proton momentum quantization and proton recoil motion are included.

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