

Positronium decay in a strong magnetic field

Andrew Koshelkin

National Research Nuclear University - MIPhi, Moscow, Russia

Mark Simanovsky

National Research Nuclear University - MIPhi, Moscow, Russia

6th International Conference on Particle Physics and
Astrophysics
(ICPPA 2022)

29 November-2 December 2022, Moscow, Russian Federation

01 December 2022

Contents

- ① Introduction
- ② Problem statement
- ③ Preliminary estimations
- ④ Decay width
- ⑤ Constraint dynamics for e^+e^-
- ⑥ Results

Introduction

Positrons \rightleftharpoons Positronium



Ordinary earthly life



Life of the Universe

Introduction

POSITRONIUM IN A MAGNETIC FIELD

- ① Both far astrophysical objects such as, for example, radio-pulsars, soft gamma-ray repeaters, cosmological gamma-ray bursts, and close one such as the Sun, for instance.
- ② The origin of the Galactic magnetic fields.
- ③ Dark matter
- ④ The natural laboratory to study fundamental interaction (a magnetic monopole, an unstable magnetized vacuum and so on).

Introduction

PREVIOUSLY

Kroupa and Robl, 1954

Ternov, 1968

Wunner, 1979

Daugherty and Bussard, 1980

Kaminker et al, 1987, 1990

Herold, Ruder , Wunner, 1985

Leinson and Perez 1979

Shabad and Usov (collapse) 1985

Introduction

OBSERVATION

Object	Magnetic field, G
SGR 1806-20	$8 \cdot 10^{14}$
PSR J1846-0258	$4.9 \cdot 10^{13}$
SGR 0418+5729	$7.5 \cdot 10^{12}$
Swift J1834.9-0846	$1.4 \cdot 10^{14}$
SGR 0501+4516	$1.9 \cdot 10^{14}$

$$B_c = 4,414 \cdot 10^{13} \text{ G}$$



Introduction

Relativistic dynamics of interacting particles !!!



Two-particles Green's function
(Bethe, Salpeter, Abrikosov, Koshelkin)

VS

Constraint dynamics
(Dirac, Todorov, Crater, van Alstine)

Problem statement

1. Para-positronium (ground state)
2. Strong magnetic field $a \equiv (e_0 B)^{-1/2} \ll a_B \equiv (m e_0^2)^{-1}$
 $(\hbar = c = 1)$

Preliminary estimations

No magnetic fields

$$\Gamma_0 = \frac{m\alpha^5}{2} = \frac{\alpha^2}{2m^2 a_B^3} \simeq \frac{\alpha^2 |\psi(0)|^2}{m^2}$$

In magnetic fields

$$\Gamma \simeq \frac{\alpha^2 |\psi_{||}(0)|^2 |\psi_{\perp}(0)|^2}{m^2} \simeq \frac{\alpha^2}{m^2 a_B a^2} = \frac{\alpha^2}{m^2 a_B^3} \frac{a_B^2}{a^2} = \frac{a_B^2}{a^2} \Gamma \gg \Gamma$$

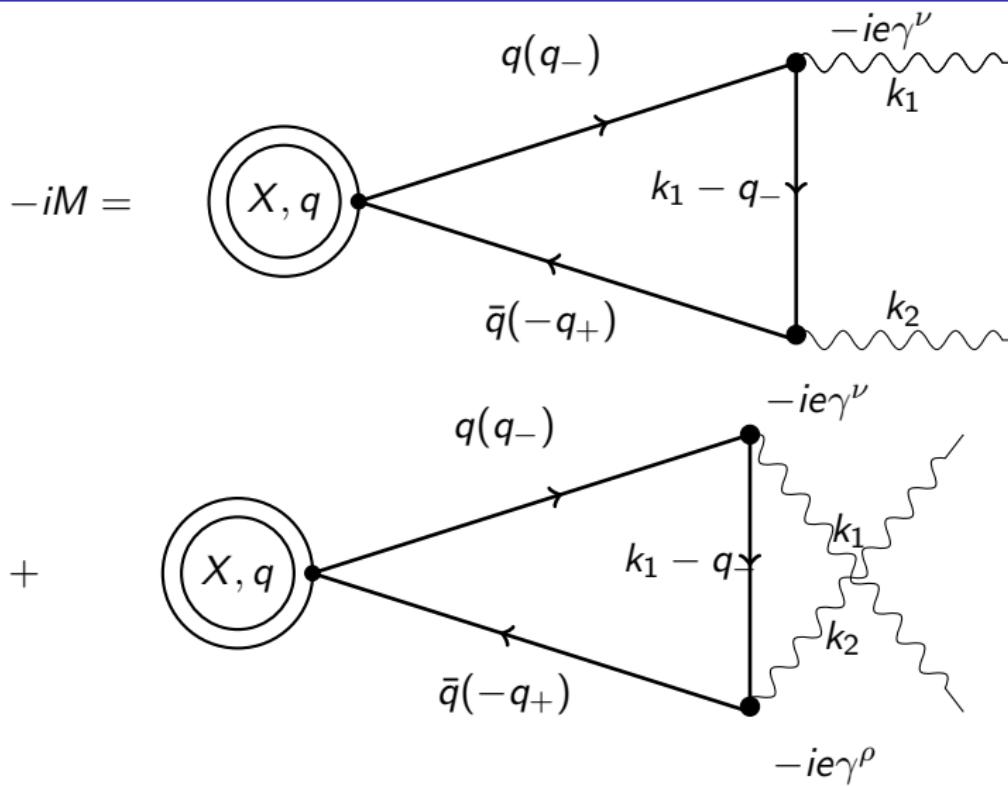


Enhancement annihilation !!!

Decay width

$$\Gamma = \frac{1}{2E2\omega \cdot 2\omega} \int \frac{d\mathbf{k}}{(2\pi)^2} \sum |M|^2 \delta(2E - 2\omega); \quad \omega = |\mathbf{k}| = k = E \quad (1)$$

Decay width



Decay width

$$|{}^1S_0> = \frac{1}{\sqrt{2}} \int d^3\mathbf{p} \psi(\mathbf{p}) \left(b_{\mathbf{p}}^{\dagger 1} d_{-\mathbf{p}}^{\dagger 2} - b_{\mathbf{p}}^{\dagger 2} d_{-\mathbf{p}}^{\dagger 1} \right) \quad (3)$$

H.Crater, 1991

Decay width

Constraint dynamics (Poincare, Dirac, Curie, Jordan, Todorov,
Crater, van Alstine)



gives (Todorov, Crater, van Alstine),



in an uniform magnetic field for the ground state .



$$\left(E_w^2 - m_w^2 + \frac{2\alpha E_w}{r} + \frac{\alpha^2}{r^2} + \Delta_R + \Delta_r - \frac{\alpha R_\perp^2 B^2}{4} - \frac{\alpha r_\perp^2 B^2}{16} \right) \Psi(\mathbf{R}, \mathbf{r})$$

$$E_w = \frac{2E^2 - m^2}{2mE}, \quad m_w = \frac{m^2}{E}, \quad \mathbf{R} = \frac{\mathbf{r}_1 + \mathbf{r}_2}{2}, \quad \mathbf{r} = \mathbf{r}_1 - \mathbf{r}_2.$$

Decay width

The ground state, the strong magnetic field $a \ll a_B$

$$\left(E_w^2 - m_w^2 + \frac{2\alpha E_w}{|z|} + \frac{\alpha^2}{z^2} + \frac{d^2}{dz^2} - \frac{1}{a^2} \right) \psi(z) = 0 \quad (5)$$

$$\begin{aligned} \psi(\mathbf{r}) &\simeq \frac{|z|}{a a_B \sqrt{2\pi}} \exp(-|z|/a_B) \exp(-r_\perp^2/8a^2) \\ E &\simeq \sqrt{m^2 + \frac{1}{a^2} - \frac{1}{2a_B^2}} \end{aligned} \quad (6)$$

Decay width

$$\Gamma_B = \frac{64\alpha^2}{\pi^{1/2} m^2 a_b a^2} (I_1^2 + I_2^2) \quad (7)$$

$$(I_1^2 + I_2^2) \simeq 1.2 \cdot 10^{-2} \quad (8)$$

We finally get

$$\Gamma \simeq \frac{0.3\alpha^2}{m^2 a_b a^2} = 0.6 \frac{a_b^2}{a^2} \Gamma_0 \quad (9)$$

Conclusion

- ① Based on the constraint formalism for the Dirac equation the positronium states in a strong uniform magnetic field is studied.
- ② The of a para-positronium is explicitly calculated.
- ③ The para-positronium decay is shown to be enhanced by a uniform strong magnetic field.

Acknowledgments

THANK YOU FOR ATTENTION!!!