Stars as Laboratories for Fundamental Physics: Errata

Georg Raffelt

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut),
Föhringer Ring 6, 80805 München, Germany

18 October 2021

E-mail: raffelt@mpp.mpg.de

Abstract. Corrections of errors in my book *Stars as Laboratories for Fundamental Physics* (University of Chicago Press 1996) that have been brought to my attention. Feedback on further errors are welcome to include corrections here.

Introduction

Since my book *Stars as Laboratories for Fundamental Physics* was written more than a quarter century ago, astroparticle physics and cosmology have evolved beyond recognition. The same applies to the topics covered in this book so that an update or a new version would be very welcome. Despite being obsolete on many subjects, the book still seems to help some researchers as a first introduction to the ideas, especially because "axions and relatives" currently enjoy a lot of popularity. Unfortunately, there are some errors in the book that may have caused others to waste time. If more issues are brought to my attention I will include them in an update to these notes.

3.2.3 Pseudoscalars

In the matrix element for atomic transitions Eq. (3.7) a second term is missing that was pointed out much later by Pospelov, Ritz and Voloshin (2008) [1]; see also Ref. [2]. The correct equation should be

$$\mathcal{M}_{\rm pseudoscalar} = \frac{g}{2m_e}\,\frac{1}{\sqrt{2\omega}}\left\langle f\middle|e^{i\mathbf{k}\cdot\mathbf{r}}\,\boldsymbol{\sigma}\cdot\mathbf{k}-\omega\boldsymbol{\sigma}\cdot\mathbf{v}\middle|i\right\rangle, \tag{3.7}$$

where $\mathbf{v}$ is the electron velocity. It turns out that the axioelectric effect becomes a factor of 2 larger than originally thought.

In atomic transitions where the orbital matrix element factorizes from the spin part, the axioelectric rate scales in a simple way relative to the corresponding photonic processes, see Redondo (2013) [3], where the solar axion emission was calculated using the tabulated photon opacities.

5.2.2 Plasmon Decay and Coalescence

In Eq. (5.15) a factor $\omega_{\rm T}^2$ is missing. (Thanks to Edoardo Vitagliano.)

6.3.4 Lowest-Order QED Calculation of the Polarization Tensor

This section was aiming at the dispersion relations of transverse and longitudinal plasmons, following Braaten and Segel (1993) [4] who provided beautiful analytic approximations. The expressions for the polarization tensor that obtain after dropping $(K^2)^2/4$ in Eq. (6.36) are accurate to lowest order in α only in the neighborhood of $\omega \sim k$ and thus are only useful to find the dispersion relations. *They should not be used in the off-shell regime.* After dropping this term, Braaten and Segel arrive at their Eqs. (A16) and (A17), corresponding to Eqs. (6.37) in the book except for a factor $(\omega^2 - k^2)/k^2$ because of the change of gauge from Coulomb to Lorenz.[1] These integrals can be done in the classical, relativistic and degenerate limits, leading to Eqs. (A45) and (A46) of Braaten and Segel. These correspond to Eqs. (6.38) in the book, which however should read

$$\pi_{\rm L}(\omega, k) = \omega_{\rm P}^2 \frac{\omega^2 - k^2}{\omega^2 - v_*^2 k^2} \left[1 - G\left(v_*^2 k^2/\omega^2\right)\right], \tag{6.38a}$$

$$\pi_{\rm T}(\omega, k) = \omega_{\rm P}^2 \left[1 + \tfrac{1}{2} G\left(v_*^2 k^2/\omega^2\right)\right]. \tag{6.38b}$$

The expression for $\pi_{\rm L}$ given in the book mistakenly assumes the on-shell condition.

To obtain the dispersion relations one needs to solve $\omega^2 - k^2 = \pi_{\rm L,T}(\omega, k)$. Inserting this implies that we need to solve the transcendental equations as given in the book

$$\omega^2 - k^2 = \omega_{\rm P}^2 \left[1 + \tfrac{1}{2} G\left(v_*^2 k^2/\omega^2\right)\right] \qquad \text{Transverse} \tag{6.44a}$$

$$\omega^2 - v_*^2 k^2 = \omega_{\rm P}^2 \left[1 - G\left(v_*^2 k^2/\omega^2\right)\right]. \qquad \text{Longitudinal} \tag{6.44b}$$

These are identical with Eqs. (18) and (19) of Braaten and Segel and do not depend on gauge.

Notice also that after dropping the $(K^2)^2/4$ in the original integral, the polarization functions depend only on the ratio $n = k/\omega$ and not on ω and k separately. For travelling waves this is simply their refractive index that gives us the wavenumber in terms of the frequency by $k = n\omega$. Inserting this relation in Eq. (6.44) one can solve for $\omega(n)$ and then $k(n) = n\omega(n)$. So one obtains an explicit parametric representation $[\omega(n), k(n)]$ of the dispersion relation.

6.5.1 Millicharged Neutrinos

In the seventh line after Eq. (6.80), in the expression for $\Gamma_{\rm T}$, the factor $\omega_{\rm P}^3$ should be simply $\omega_{\rm P}$. (Thanks to Edoardo Vitagliano.)

8.2.1 Equation of Motion for Mixed Neutrinos

In the second part of Eq. (8.10), the r.h.s. should be $e^{iKz}\rho_\omega e^{-iKz}$ with a sign change in the exponentials. (Thanks to Oddharak Tyagi.)

[1] What was called Lorentz gauge in the book should be spelled Lorenz gauge.

References

[1] M. Pospelov, A. Ritz and M. B. Voloshin, “Bosonic super-WIMPs as keV-scale dark matter,” Phys. Rev. D **78** (2008) 115012 [arXiv:0807.3279].

[2] A. Derevianko, V. A. Dzuba, V. V. Flambaum and M. Pospelov, “Axio-electric effect,” Phys. Rev. D **82** (2010) 065006 [arXiv:1007.1833].

[3] J. Redondo, “Solar axion flux from the axion-electron coupling,” JCAP **12** (2013) 008 [arXiv:1310.0823].

[4] E. Braaten and D. Segel, *Neutrino energy loss from the plasma process at all temperatures and densities*, Phys. Rev. D **48** (1993) 1478 [arXiv:hep-ph/9302213].