Comment on “Experimental Observation of Optical Rotation Generated in Vacuum by a Magnetic Field”

Adrian C. Melissinos
Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627, USA
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In a recent letter [1] the PVLAS collaboration reported the observation of optical rotation induced in vacuum by an external magnetic field. More recently [2] the same group reported also the observation of vacuum birefringence under similar conditions. In this comment I wish to point out that the reported results are excluded at the 95% confidence level by a previous experiment [3] carried out by the BRFT collaboration (Brookhaven, Rochester, Fermilab, Trieste). In Table 1 we summarize the relevant parameters of the two experiments.

Table 1. Comparison of the PVLAS and BRFT experiments

|                        | PVLAS [1, 2] | BRFT [3] |
|------------------------|--------------|----------|
| $B_e^2$ (Effective magnetic field) | 30           | 4 T$^2$ |
| $\ell$ (Length of magnetic field region) | 1, 2.32      | 8.8 m   |
| $\hbar\omega$ (Photon energy) | 1.16, 2.32   | 2.4 eV  |
| $\epsilon_T$ (Measured optical rotation) | $[170 \pm 22] \times 10^{-9}$ | 0.6 $\times 10^{-9}$ rad |
| $N_R$ (Number of passes) | $44 \times 10^3$ | 254      |
| $\psi_T$ (Measured ellipticity) | $[440 \pm ??] \times 10^{-9}$ | 51 $\times 10^{-9}$ rad |
| $N_E$ (Number of passes) | $44 \times 10^3 (?)$ | 578      |

The two experiments are conceptually similar with the following differences: (1) PVLAS uses a Fabry-Perot cavity to effect multiple reflections while BRFT used an optical delay line (2) PVLAS uses a fixed field magnet which is mechanically rotated. In the BRFT experiment the magnetic field was modulated by varying the excitation current. The ellipticity induced by QED effects [4] appears at a level $\sim 10^4$ times below the noise level of either experiment.

The PVLAS group attributes their signals to the existence of a scalar or pseudoscalar particle that couples to two photons [5]. The observed rotation/pass, $\epsilon$, and ellipticity/pass, $\psi$, are related to the coupling constant $g_{\gamma\gamma} = 1/M$ and to $m_\alpha$, the mass of the scalar/pseudoscalar through [6]

$$\epsilon = \left(\frac{1}{M}\right)^2 \frac{B^2 \omega^2}{m_\alpha^4} \sin^2 \left(\frac{m_\alpha^2 \ell}{4\omega}\right)$$

$$\psi = \left(\frac{1}{M}\right)^2 \frac{B^2 \omega^2}{m_\alpha^4} \frac{1}{2} \left[ \frac{m_\alpha^2 \ell}{2\omega} - \sin \left(\frac{m_\alpha^2 \ell}{2\omega}\right) \right]$$
In the above equations we have set $\hbar = c = 1$. We see that the limits on the value of the inverse coupling, deduced from the measured rotation and ellipticity, depend on the mass of the scalar/pseudoscalar. This is because for a given path length massive particles dephase (with respect to the laser beam) faster. The phase advance is $2\pi (\ell m_a^2/2\omega)$ and beyond this point the observable effects oscillate rapidly as a function of $m_a$, as can be seen in the figure.

In Fig. 1 we show the values of $M$ (in GeV) as deduced from the two experiments.

- PVLAS (from rotation) red
- BRFT (from rotation 95% confidence lower limit) cyan
- PVLAS (from ellipticity) green
- BRFT (from ellipticity 95% confidence lower limit) blue

The regions below the cyan and blue curves are excluded by the BRFT experiment, namely the PVLAS results are excluded for $m_a < 0.7 \times 10^{-3}$ eV. The most recent measurement of ellipticity by PVLAS coupled with their previous measurement of optical rotation fixes the mass and coupling at the intersection of the red and green curves, namely at $m_a = 1.3 \times 10^{-3}$ eV and $M = 3 \times 10^5$ GeV. This point falls on the envelope of the 95% exclusion limit of the BRFT experiment.

As can be seen in Fig. 1 the values of $(1/M, m_a)$ measured by PVLAS are in the region where their sensitivity is decreasing and where the BRFT sensitivity is already oscillating rapidly (because of the longer magnetic region). It is rather improbable that Nature has conspired to place the scalar/pseudoscalar mass and coupling exactly at the limit of the detectable phase space of both experiments.

That the PVLAS effect could be due to instrumental background is suggested from Fig. 2. Here a typical spectrum of the PVLAS experiment is reproduced from their publication [1]. The signal appears at the second harmonic of the rotation frequency, and there should be no signal at the first harmonic. Instead, a spurious signal is present, 25 dBV ($\sim 18$ times) stronger than the signal that is interpreted as new physics. The PVLAS group gives no explanation for this signal. It is clearly related to the rotating magnet field; it is an artefact introduced by the experimental setup. It follows that the same background could generate the second harmonic signal as well, especially when it is suppressed by an order of magnitude.

References

[1] E.Zavattini et al.(PVLAS Collaboration) Phys. Rev. Letters 96, 110406 (2006).
[2] E.Zavattini et al.(PVLAS Collaboration) Paper presented by U.Gastaldi at ICHEP-06, Moscow, 26/7-2/8, 2006. Preprint INFN-LNL-214(2006).
[3] R.Cameron et al. Phys. Rev. D47, 3707 (1993).
[4] See for instance, S.L.Adler, Ann. Phys. (NY) 67, 599 (1971)
[5] L.Maiani, R.Petronzio and E.Zavattini Physics Letters 175, 359 (1986)
[6] G.Raffelt and L.Stodolsky Phys. Rev. D37, 1237 (1986).
Figure 1: The inverse coupling $M = 1/g_{\alpha \gamma \gamma}$ in GeV as a function of the mass, $m_\alpha$ of the scalar/pseudoscalar particle in eV. (a) Cyan: BRFT limit from rotation (b) Blue: BRFT limit from ellipticity (c) Red: PVLAS detection from rotation (d) Green: PVLAS detection from ellipticity.

Figure 2: The PVLAS Fourier spectrum of the observed rotation signal (from [1]). The harmonics of the magnet rotation frequency are labeled. The signal appears at the second harmonic, however the first harmonic should be completely absent. The only possible interpretation of the first harmonic is that it is due to instrumental effects.