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EXPERIMENTAL OBSERVATION OF MAGNETICALLY INDUCED LINEAR DICHROISM OF VACUUM

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ABSTRACT

We report the first experimental observation of a magnetically induced linear dichroism of Vacuum: it has been possible to identify this property by observing the rotation α_{vac} of the polarization plane of a laser beam in vacuum (λ = 1064 nm) propagating through a $l_m = 100$ cm magnetic field of $B_0 = 5.5$ Tesla orthogonal to the radiation beam direction. The path l_m is contained in a 6.4 m long Fabry-Perot cavity to obtain an amplification factor of about $N_{pass} \simeq$ 52000. In these conditions we find a total rotation α_{vac}= $(2.2 \pm 0.3) \cdot 10^{-7}$ rad. A possible interpretation for this result is that there exists in nature a light (mass $= m_s$) neutral boson particle, coupled to two photons with inverse coupling constant M. Preliminary results from measurements of the rotation $\alpha(Neon, pr)$ with a mixture of Vacuum and Neon gas at different values of pressure are in reasonable agreement with such an interpretation, provided the particle's mass m_s and its two-photon inverse coupling constant M have (Heavyside - Lorentz rationalized units) respectively the values $m_s = (1.0 \pm 0.1)$ meV and $M = (3.8 \pm 0.35) \cdot 10^5$ GeV.

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1. Introduction

We report the first experimental observation of linear dichroism of Vacuum in the presence of a magnetic field. Data have been obtained with the PVLAS apparatus

PVLAS collaboration

Figure 1: Photograph of the entire PVLAS collaboration.

set up and operating at the Laboratori Nazionali di Legnaro (Legnaro, Padova, Italy) of the Istituto Nazionale di Fisica Nucleare. The PVLAS apparatus has been built specifically to obtain significant experimental information on the (quantum) Vacuum using optical techniques.

In particular, our full experimental program is to detect and measure the two following optical properties of Vacuum induced by the presence of a static strong magnetic field $\vec{B}_0$: [a]

- LINEAR BIREFRINGENCE

- LINEAR DICHROISM

This communication is a report on our latest experimental results obtained with the PVLAS apparatus on linear dichroism induced in Vacuum in the presence of a static magnetic field.

[a] In general, for any non-depolarizing medium on which a constant magnetic and electric fields are present there are 8 possible optical properties that could be observed (see for instance [1]).

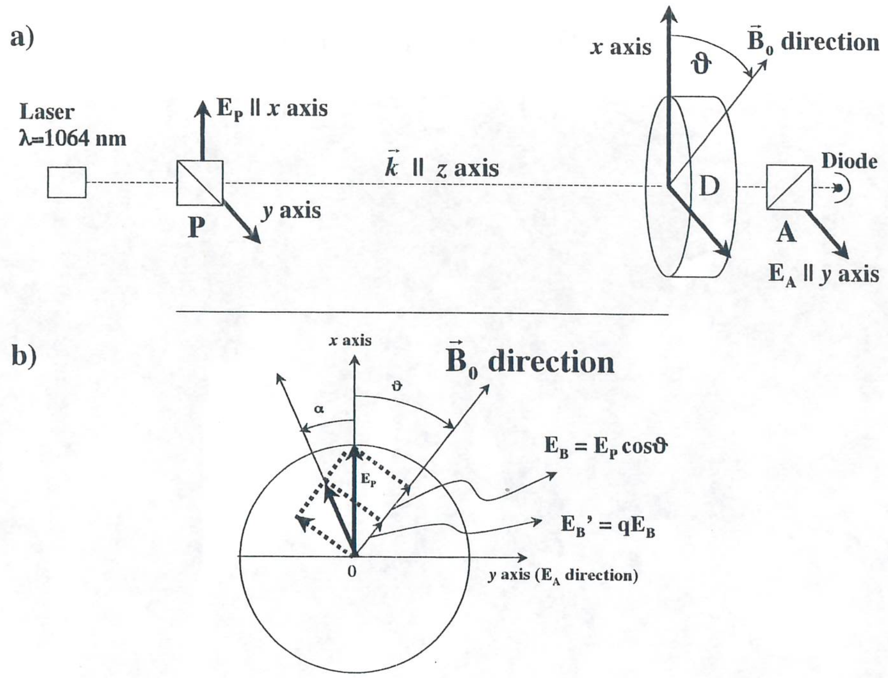

Figure 2: Simplified scheme showing the behavior of an isotropic ideal medium D becoming dichroic in the presence of a strong magnetic field $\vec{B}_0$. **P** and **A** are a pair of crossed polarizers (adjusted to extinction). **P** fixes the polarization vector, $\vec{E}_P$, along the x axis (consequently $\vec{E}_A$ will be along the y axis). $\vec{B}_0$ is a magnetic field directed at an angle ϑ from the x axis and lies in the x-y plane, orthogonal to the z axis. α is the apparent rotation induced by an absorption of the component of $\vec{E}_P$ parallel to $\vec{B}_0$ by a factor q.

Before presenting the results, let me briefly clarify the meaning of the title, by discussing the simple ideal experimental arrangement shown in Figure 2.

Referring to Figure 2 let us distinguish

$$\vec{E}_P = E_p \cos\vartheta \hat{u}_{||} + E_P \sin\vartheta \hat{u}_{\perp} \tag{1}$$

where $\hat{u}_{||}$ and $\hat{u}_{\perp}$ are respectively unit vectors parallel and perpendicular to the magnetic field $\vec{B}_0$.

We have a magnetically induced linear dichroism in the dielectric D when there is a *selective absorption* of the laser radiation component $E_P \cos\vartheta$ (projection of $\vec{E}_P$ along $\hat{u}_{||}$) by the magnetized element D due to the presence of the field $\vec{B}_0$ interacting with the dielectric itself. Because of this property the component $E_P \cos\vartheta$, at the exit of D, will be reduced to:

$$E_B = E_P \cos\vartheta \Longrightarrow E'_B = (E_P \cos\vartheta)' = qE_P \cos\vartheta \tag{2}$$

with q a real number < 1: the component $E_P \sin\vartheta$ perpendicular to $\vec{B}_0$ remains unchanged. In Figure 2b) is shown the optical rotation, by an angle α, of the polarization plane as a consequence of the *selective absorption*. In fact looking at the figure it is easy to see that after the recombination of the final components $(E_P \cos\vartheta)'$ with $E_P \sin\vartheta$, the polarization plane at the exit of D is no longer orthogonal to the y axis but rotated by an angle α: thus projecting a detectable component along the $\vec{E}_A$ direction. One can show that at the exit of the analyzer **A** the extraordinary ray has, (in first approximation), the amplitude

$$E_A = E_P \left(\frac{q-1}{2}\right) \sin 2\vartheta \tag{3}$$

hence a (maximal) rotation signal of amplitude, for $\vartheta = -\pi/4$

$$\alpha = \left(\frac{1-q}{2}\right). \tag{4}$$

Notice that α non zero implies q different from 1.

Going back to our experimental set-up we can say that the PVLAS apparatus can be viewed as an elaborated inproved version of the arrangement just described with the essential difference that in PVLAS the dielectric D is replaced by the Vacuum which is here considered as a dielectric medium. Therefore, with this substitution in mind, we can say that in the PVLAS set-up a magnetically induced dichroism in Vacuum can be observed by detecting an apparent rotational signal α_{vac} of a linearly polarized radiation (probing laser) that goes through the magnetized Vacuum with its propagation vector $\vec{k}$ orthogonal to $\vec{B}_0$.

The vector $\vec{B}_0$ establishes an axis of anisotropy within the magnetized Vacuum medium.

Our experimental result[3)], for $|\vec{B}_0| = 5.51$ Tesla for a lenght $l_m = 100$ cm of the dipole magnet and $N_{pass} = 52000$, is:

$$\alpha_{vac} = (2.2 \pm 0.3) \cdot 10^{-7}\text{rad}. \tag{5}$$

which gives an observed rotation per pass:

$$\alpha = \left(\frac{q-1}{2}\right) = -(4.3 \pm 0.4) \cdot 10^{-12} \frac{\text{rad}}{N_{pass}} \tag{6}$$

Result (5) shows that the Vacuum, where a magnetic field is present, manifests the general property of linear dichroism. It also indicates that a small part of the parallel component of the incoming electromagnetic beam is missing after having traversed the magnetized l_m= 100 cm long Vacuum region. How can this be and where has the missing part gone?

There are no published theoretical predictions on the magnitude of a linear dichroism of Vacuum induced by a magnetic field involving the Euler-Heisenberg effective lagrangian $\mathcal{L}_{eff}$.

There has been a suggestion[2], however, to search for a linear dichroism of magnetized Vacuum due to the existence in nature of a very light neutral boson particle which couples to two photons. I will come back to this subject later.

Let me now present a schematic view of the PVLAS apparatus: see Figure 3.

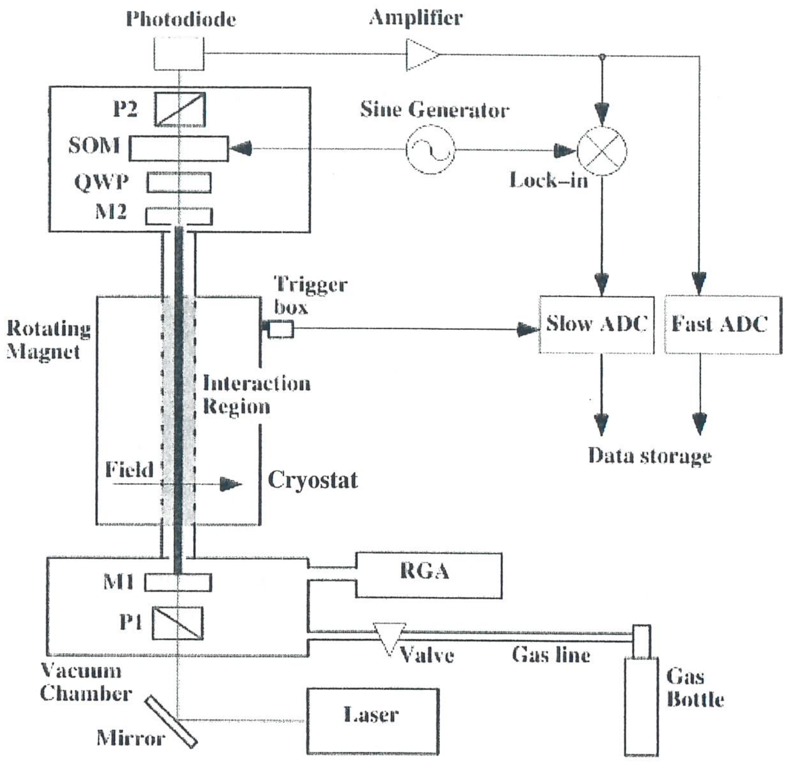

Figure 3: Schematic drawing of the PVLAS apparatus. P1 and P2 are crossed polarizing prisms, M1 and M2 are the Fabry-Perot cavity mirrors, QWP is a quarter-wave plate, SOM is the ellipticity modulator, and RGA is a mass spectrometer (objects not to scale).

2. Apparatus

The set-up extends vertically. The $l_m = 100$ cm long interaction region where the light beam interacts with the magnetized Vacuum is contained within a high finesse Fabry-Perot optical resonator: this is defined by two dielectric multilayer (R = 11 meters curvature radius) high reflectivity mirrors (M1,M2) placed 6.4 meters apart, well outside the magnetic field.

The vacuum chamber of the 6.4 m long cavity is a quartz tube 25 mm in dameter passing through the room temperature bore of the 1.0 m long superconducting dipole magnet. The magnet is housed in a 4 m high cryostat which is fixed to a turntable. During data taking the turntable rotates at frequencies of about $\Omega_{Mag} = 0.3$ Hz around its verticle axis: it is actuated by a hydraulic motor. The general arrangement is such that the field $\vec{B}_0$ lies always on the horizontal plane. During normal operation the cryostat is filled with liquid He at 4.2 °K and the magnet is energised with a current of about 2000 A resulting in a constant 5.5 Tesla field over the l_m interaction region.

The heterodyne ellipsometer shown schematically in Figure 4a) consists of the pair of polarizing prisms, P1 and P2, together with an ellipticity modulator (Stress Optical Modulator = SOM). The SOM[4)] provides an ellipticity carrier signal $\eta(t)$ for the purpose of heterodyne detection of small ellipticities $\psi(t)$ which might be present in the beam.

The SOM is driven at a frequency of $\omega_{SOM} = 506$ Hz. However, when a properly aligned quarter wave plate (QWP) is inserted between the F-P cavity and the SOM modulator (QWP IN = configuration for rotation measurements), rotation signals $\alpha(t)$ will be transformed into an ellipticity $\psi(t)'$ with $\psi(t)' = \alpha(t)$. The resulting ellipticity signal $\psi(t)'$ will then beat with the SOM ellipticity carrier signal $\eta(t)$ and in this manner the rotation $\alpha(t)$ generated in the F-P cavity can be detected by the following analyzer P2.

The laser beam emitted by a 1064 nm, 100 mW CW output power Nd:YAG laser, is kept in resonance with the F-P cavity by means of an electro-optical feedback loop. The F-P cavity has the effect of amplifyng the optical path through the interaction region by a factor $N_{pass} = \frac{2F}{\pi}$, where F is the F-P finesse. Typically, we have $F \simeq 8 \cdot 10^4$. All optical elements from the input polarizer to the exit analyzer are kept under vacuum ($P < 10^{-7}$ mb) and in communication with the interaction region l_m.

The vacuum system has provisions for inserting test gases for calibration, checks and other purposes as we will see.

For data taking the magnet, after beeing cooled, is energised to a given field intensity value, then put in permanent mode via an ohmic multiblade switch and, once the power supply is disconnected, the turntable is set in rotation. In addition the laser wavelength is kept in resonance with the F-P and the polarizing prisms P1 and P2 are crossed to maximun extinction.

The intensitiy, I_{Tr}, of the signal transmitted by the analizer P2 (extraordinary ray) is given in expression (7) for the rotation $\alpha(t)$ measurements: I_0 is the light intensity before the analyzer P2.

$$\begin{aligned} I_{Tr} &= I_0\left[\sigma^2 + (\alpha(t) + \eta(t) + \beta(t))^2\right] \\ &\simeq I_0\left[\sigma^2 + \left(\eta(t)^2 + 2\alpha(t)\eta(t) + 2\beta(t)\eta(t) + \ldots\right)\right] \end{aligned} \tag{7}$$

where $\beta(t)$ represents birefringence noise present in all optical elements.

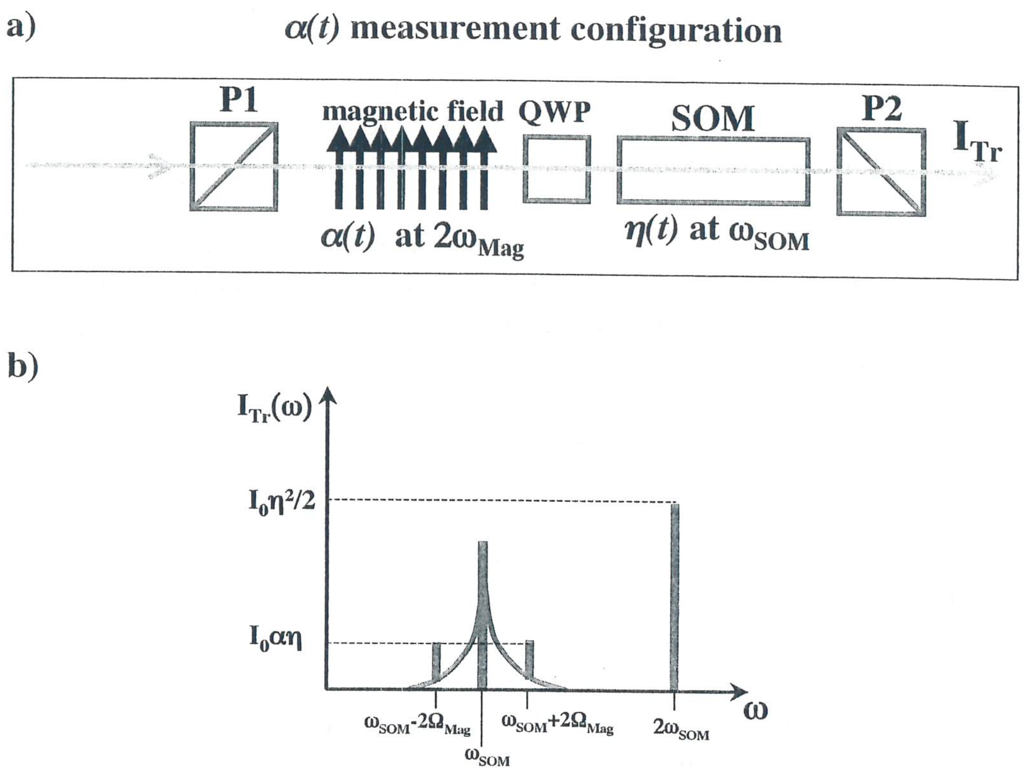

Figure 4: a) Schematic drawing for the measurement of a rotation $\alpha(t)$ induced by the magnetic field. b) Expected frequency spectrum of the transmitted signal where one can see the normalization peak at $2\omega_{SOM}$ and the two sidebands at $\omega_{SOM} \pm 2\Omega_{Mag}$ around the carrier frequency ω_{SOM}. The $1/\omega$ curve around ω_{SOM} is due to the slowly varying birefringence noise, $\beta(t)$. I_0 is the light intensity before the analyzer P2.

As can be seen in Figure 4b) and equation (3) the fact that the magnetic field $\vec{B}_0$ is rotating introduces 2 sidebands at $\pm\, 2\Omega_{Mag}$ ($\simeq$ 0.6 Hz) from the SOM 506 Hz frequency carrier signal. In fact

$$\begin{aligned} 2I_0\alpha(t)\eta(t) &= 2I_0\alpha_{vac}\cos(2\Omega_{Mag}t + 2\phi_{Mag})\eta_0\cos(\omega_{SOM}t + \phi_{SOM}) = \\ &= I_0\alpha_{vac}\eta_0\cos((\omega_{SOM} + 2\Omega_{Mag})t + (\phi_{SOM} + 2\phi_{Mag})) + \\ &+ I_0\alpha_{vac}\eta_0\cos((\omega_{SOM} - 2\Omega_{Mag})t + (\phi_{SOM} - 2\phi_{Mag})) \end{aligned} \quad (8)$$

By demodulating at ω_{SOM} the light intensity signal, I_{Tr}, after the analyser P2 with an in-phase reference signal, the amplitude of the sideband at $2\Omega_{Mag}$ is proportional to the rotation signal α_{vac} which we want to measure. The phase of the sideband at $2\Omega_{Mag}$ corresponds to the position of the turntable at which the field $\vec{B}_0$ direction is at 45 degrees with respect to the initial fixed polarization direction (fixed by P1).

Light transmitted through the analyzer P2 is detected by a PIN photodiode instrumented with a high gain ($G = 10^7$ V/A) transimpedance amplifier. The resulting voltage signal is directly fed to a computer for digitisation at a 8.2 kHz sampling rate ("fast" acquisition) and to a lock-in amplifier referenced at the $\omega_{SOM} = 506$ Hz frequency ("slow" acquisition). This demodulated signal is frequency analyzed and displayed on line by a spectrum analyzer, and subsequently fed to a second computer for digitisation and off-line analysis. The triggering and gate signals for the "slow" acquisition are obtained from a series of 32 marks placed around the circumference of the turntable; the marks are detected during the rotation of the platform by a trigger box. In this way, for every acquired data point the direction of the rotating magnetic field with respect to the fixed initial beams polarization direction (fixed by P1) is known and absolute phases can be determined for all acquired signals. The "fast" acquisition determines absolute phases by comparing the trigger signal with a reference clock.

The "fast" acquisition data are frequency analized off-line to yield amplitude and phase of the many quantities of physical interest.

Since data acquisition is synchronous with the rotating magnet this is a convenient unit for measuring frequencies.

A special site has been constructed, for seismic insulation, at the Laboratori Nazionali di Legnaro (L.N.L.) in order to host the PVLAS experiment (see Figure 5).

2.1. Calibration and checks

When a gas such as Neon or Nitrogen is inserted in the PVLAS interaction region l_m, and the QWP is removed, an ellipticity peak, proportional to the gas pressure, is observed in the spectrum at twice the magnet rotation frequency with well defined phase due to the well known Cotton-Mouton effect[5]. Also in this case the phase of the signal corresponds to the position of the turntable at which the field $\vec{B}_0$ direction is at 45 degrees with respect to the initial fixed polarization (defined by polarizer P1). Therefore the phase of the Cotton-Mouton ellipticity signals define the physical axis for dicroism measurements.

This procedure, which was often repeated, serves as a general verification of the apparatus.

Figure 6 shows the polar plot obtained from the Cotton-Mouton effect in Nitrogen and Neon gas calibration data. Here the amplitude and phase of the signal peak are plotted for several values of pressure. Notice how the data points lie on a straight line (axis of anisotropy introduced by the magnetic field direction = physical axis) and the birefringences due to Neon and Nitrogen come out with opposite signs, as

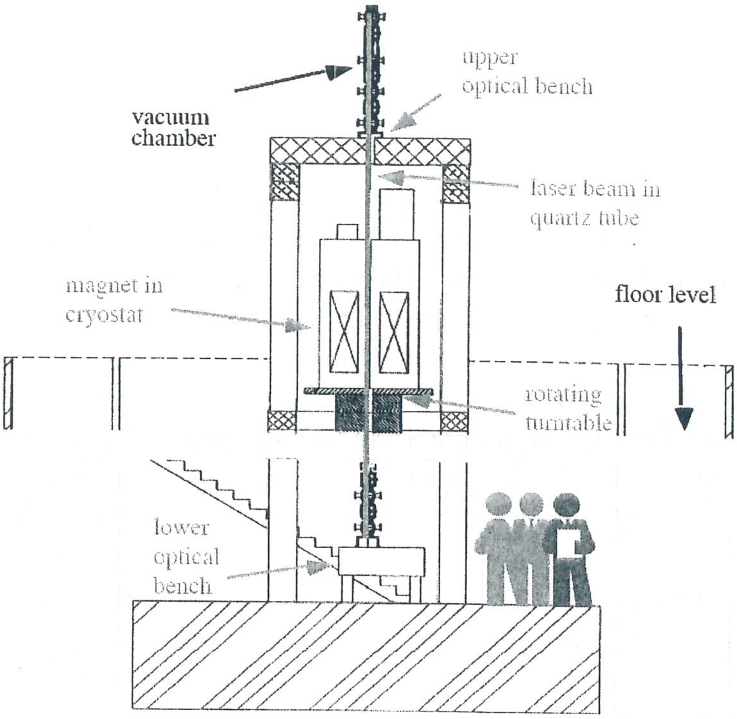

Figure 5: Schematic drawing of the PVLAS site showing the mechanical isolation of the optical benches from the hall and rotating turntable.

they should[5)].

3. Results

3.1. Rotation measurements in vacuum: α_{vac}

During the Vacuum data taking the residual pressure was always $P < 10^{-7}$ mbar. A genuine rotational signal, in Vacuum, must appear in the rotation measurement configuration (i.e. QWP inserted and propertly oriented: see Figure 3), at twice the rotation frequency of the magnet, $2\Omega_{Mag}$, and have its phase lying along the expected physical axis. Moreover, while QWP is in, the output signal from the ellipsometer must change sign when its fast axis and its slow one are inverted. Finally the signal must disappear at $\vec{B}_0 = 0$.

The sensitivity of the system is $S = 2 \cdot 10^{-7} rad/\sqrt{Hz}$.

Figure 7a) shows the amplitude frequency spectrum of the main signal demodulated at the $\omega_{SOM} = 506$ Hz carrier frequency when the magnet is off; in the same conditions Figure 7b) shows a typical amplitude frequency spectrum with the magnet

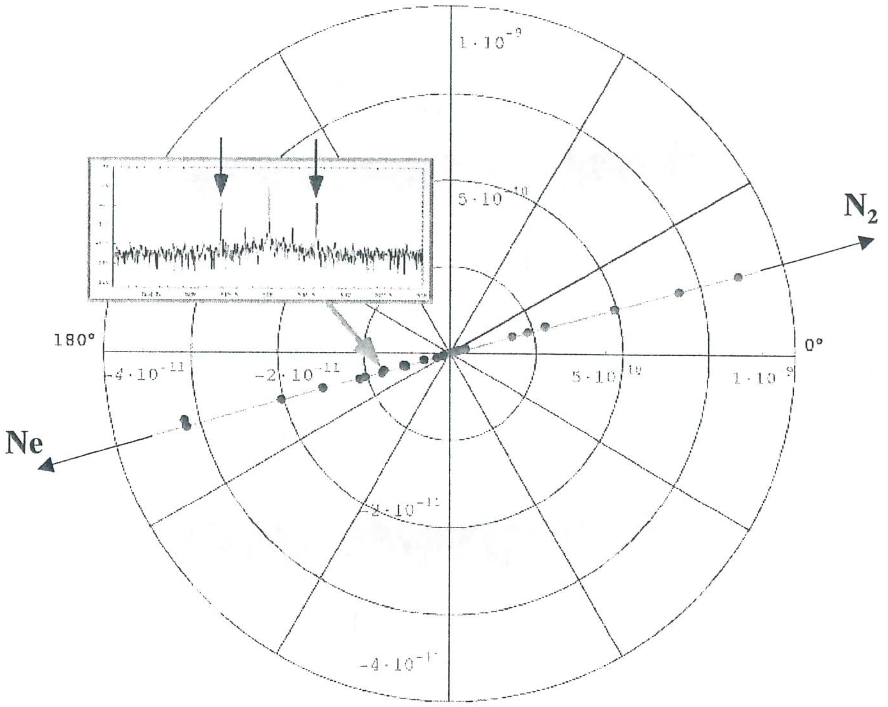

Figure 6: Polar plot showing the ellipticity signal (Cotton-Mouton effect) of Neon and Nitrogen gas at different pressures used for calibration. The phase of these signals determines the physical axis of the apparatus. They correspond to the position of the turntable for which the field is at 45 degrees with respect to the initial fixed polarization defined by P1.

on, ($\vec{B}_0 = 5.51$ Tesla) showing the sideband at twice the magnet rotation frequency: i.e. $2\Omega_{Mag}$.

The peak present at Ω_{Mag} is a systematic component which seems to be due to a mechanical movement of the apparatus. It is important to note that although this peak is always present when a magnetic field above about 3 Tesla is present, we have verified that its amplitude and phase are completely uncorrelated to the signal at $2\Omega_{Mag}$.

To summarize all available data on dichroism of Vacuum in which a magnetic field is present (of amplitude in the range $5 - 5.5$ T - and for different F-P cavity finesses) we normalized the amplitudes α_{vac} to a single pass in the cavity and determined the probability density for each peak signal vector (amplitude and phase). The average finesse during the data taking was about $F = 81000$, which corresponds to an average number of passes of $N_{pass} = 52000$.

The total variance associated with the vectors representing each data run, is the quadrature sum of the statistical (internal) variance and of an additional (external) variance observed from run to run (assumed associated with stochastic Gaussian

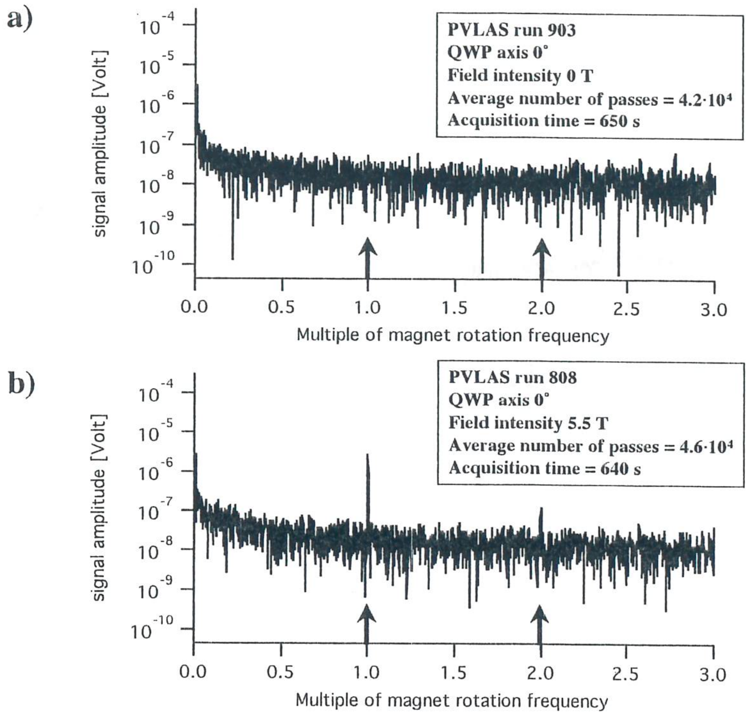

Figure 7: Amplitude frequency spectrum of the output signal of P2 for two different runs: B_0=0 and B_0=5.5T. The peak at twice the the rotation frequency of the magnet represents the apparent rotation signal α_{vac} due to magnetically induced linear dichroism.

processes). The origin of this extra non statistical external dispersion has a $1/f$ behaviour and has a standard deviation of about $1.4 \cdot 10^{-7}$ rad, for every run, with $N_{pass} = 52000$.

Figure 8 shows a polar plane in which the dotted line represents the oriented direction of the "physical axis" at 15.1 degrees ($\longrightarrow$ N2 : see Figure 6); broken lines represent the weighted average of the data, along with the estimated uncertainty regions, for the two possible orientations of the fast QWP axis. The solid lines represent the half-difference and half sum between the two vectors identified by the broken lines. The half-difference (longer solid line) represents the portion of the signal changing sign under a QWP's fast axis exchange. This is the behavior expected for a true dichroism signal. The ellipses at the tips of the vectors represent a 1σ estimated uncertainty region. The half-sum solid line (shorter one) represents a systematic error, comparable in length to the estimated 1σ error.

The length of the half-difference vector, which represents our final result in Vacuum ($N_{pass} = 52000$) is:

$$\alpha_{vac} = -N_{pass}\left(\frac{q-1}{2}\right) = (2.2 \pm 0.3) \cdot 10^{-7}\text{rad} \tag{9}$$

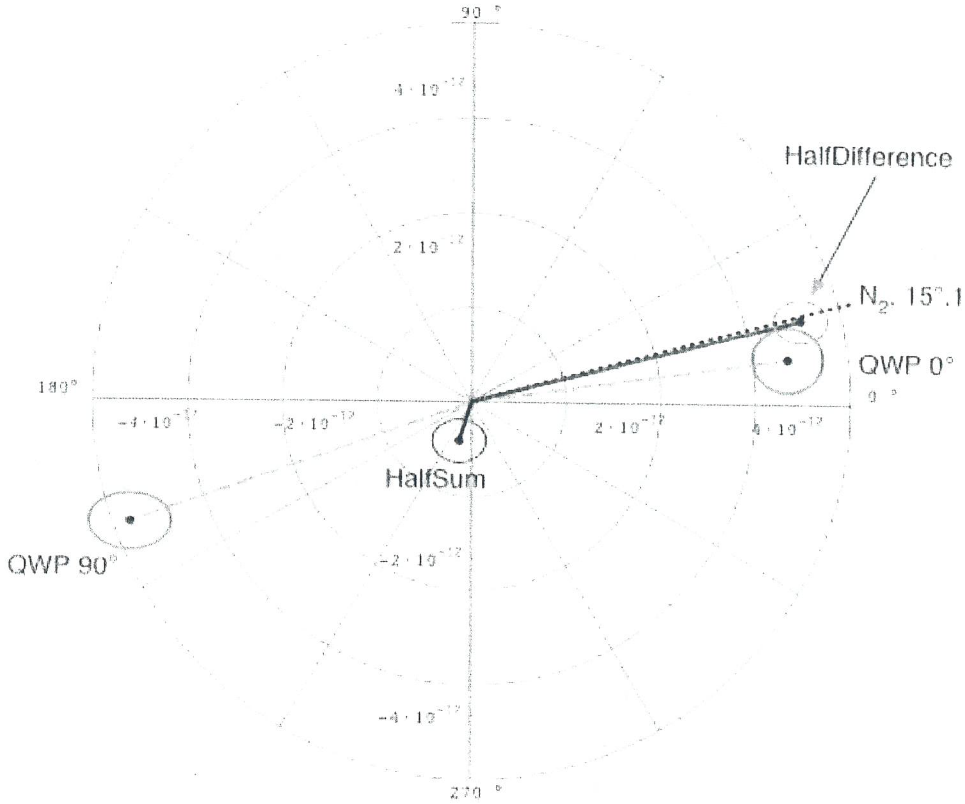

Figure 8: Polar plot showing the weighted average vectors representing rotations observed in vacuum, α_{vac} with the field on and with the QWP at 0° and 90° (broken lines). Angles are measured in degrees and amplitudes in rad/pass. The dotted line at 15.1° is in the direction of the physical axis defined in Figure 6. Ellipses at the tips of the vectors represent 1σ estimated uncertainty regions. Solid lines give the half-sum and half-difference of the average vectors of the two QWP positions: the half-difference corresponds to the portion behaving as an optical dicroism; the half-sum corresponds to a systematic error. The phase angle of 0° corresponds to the trigger position on the turntable.

Given this result (assuming that we are not being fooled by an error in the measurements) one asks how can q be different from 1? Is it a real absorption or a mixing of the photon with some spin-zero neutral very light particle[2,6)]?

Following this second possibility, for which the expected mathematical expression for α_{vac} is (in natural Heavyside-Lorentz units)

$$\alpha_{vac} \quad = \quad -\sin 2\vartheta \left(\frac{B_0 l_m}{4M}\right)^2 N_{pass} \left(\frac{\sin x}{x}\right)^2$$

$$x = \frac{l_m}{2}\left[\frac{k_m^2}{2k} + (n-1)k\right]$$

$$k = \frac{2\pi}{\lambda};\, N_{pass} = \frac{2F}{\pi};\, k_m = \frac{m_s c}{\hbar} \quad (10)$$

with the index of refraction n = 1. m_s and M are respectively the mass and inverse coupling constant to two photons of the hypothetical light neutral boson. In Figure 9 we plot the pairs (m_s, M) calculated from equation (10) having fixed α_{vac} to the measured value (9). The dotted lines represent a 2σ spread on the measured dichroism.

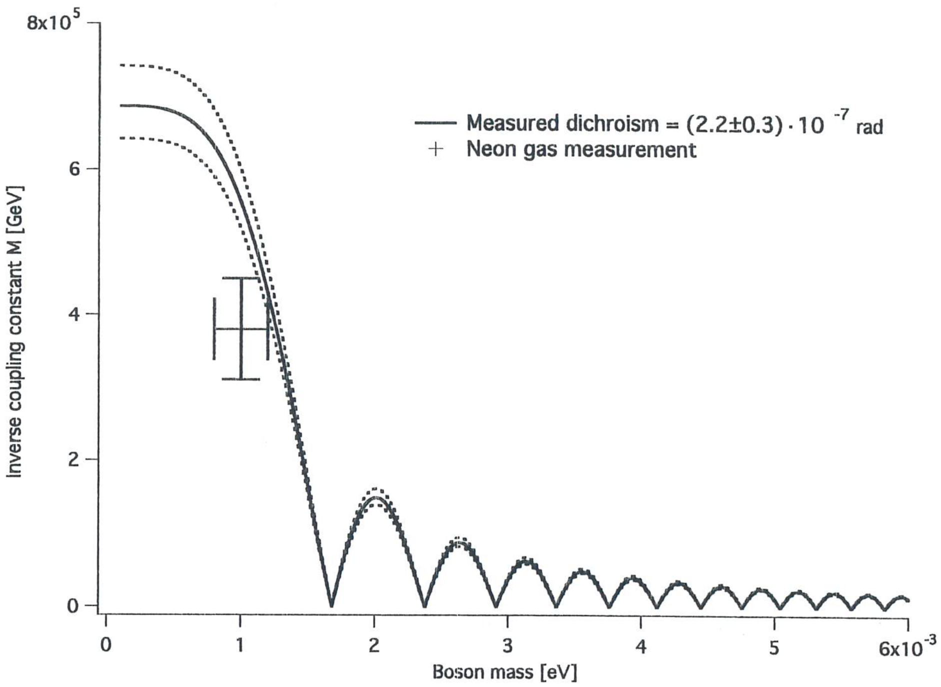

Figure 9: Plot of expression (10) having fixed B_0=5.5T, N_{pass}=52000, $n-1$=0 and α_{vac} taken from (9). The region between the dotted lines represents a 2σ interval on the measured value given in (9). Superimposed is the pair of values of m_s and M obtained from the best fit shown in Figure 10. Here too the error bars represent a 2σ interval.

We remark that since, as seen in Figure 8, the observed dichroism signal in Vacuum has the same phase as Nitrogen shown in Figure 6, the eventual boson responsible for the apparent rotation (9) should be a pseudoscalar particle[2)].

3.2. Preliminary results of rotation measurements in gas

These measurements were done with $\vec{B}_0 = 5.5$ Tesla, QWP IN at 0° and $N_{pass} =$ 52000. If the observation of an apparent rotation signal α_{vac} is due to the existence of a light, neutral boson, in these conditions the experimental results for the dichroism in Neon gas as a function of pressure should agree, within the errors, with the expected mathematical expression (10) where

$$n - 1 = 6.7 \cdot 10^{-5} p \tag{11}$$

with the pressure p in atmospheres at NTP condition. The fact that we are taking data in the dichroism configuration, i.e. QWP IN, suggests that in these conditions one filters out the rather large signal due to the Cotton-Mouton effect: in reality a fraction of this signal still arrives at the analyzer P2 due to the non ideal optical elements. However (and this has been verified experimentally by us) this spurious signal is proportional to the pressure of the neon injected. This contribution can therefore be subtracted out from the data by proceeding with a proper fit.

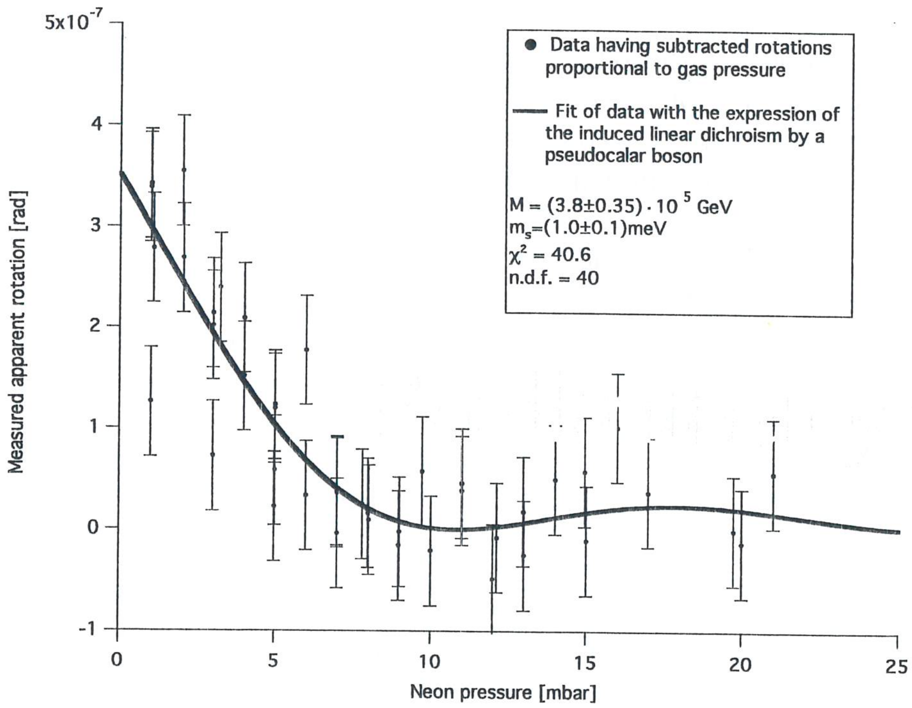

Figure 10: Preliminary results obtained from measurements of $\alpha(Neon, pr)$ with Neon (at different pressures) present in the interaction region l_m ($\vec{B}_0 = 5.5$ Tesla, QWP IN at 0° and $N_{pass} = 52000$). The solid curve represents the best fit with expression (10). The resulting estimated mass, m_s, and inverse coupling constant, M, are given in the legend.

In Figure 10 are plotted the measured values of dichroism $\alpha(Neon, pr)$, for different values of pressure with the best fit curve with expression (10) superposed. The values for m_s and M from the best fit are:

$$\begin{aligned} m_s &= (1.0 \pm 0.1)\text{meV} \\ M &= (3.8 \pm 0.35) \cdot 10^5\text{GeV} \end{aligned} \tag{12}$$

This pair of values has also been plotted in Figure 9.

4. Conclusions

1) We have experimental evidence of magnetically induced dichroism of Vacuum. Namely, considering a linearly polarized laser beam traversing a Vacuum region in which a magnetic field is present, we observe that its parallel component to the $\vec{B}_0$ vector diminishes. Such a change can be observed by measuring the consequent apparent rotation α(vacuum) of the polarization plane (see Figure 3). In the conditions $\vec{B}_0 = 5.5$ Tesla, $l_m = 100$ cm, $N_{pass} = 52000$) we obtained:

$$\alpha_{vac} = (2.2 \pm 0.3) \cdot 10^{-7}\text{rad} \qquad (13)$$

There are no published theoretical predictions to explain value (13) using QED. However, it is possible to explain this result by assuming the existence of a light boson provided its mass and the inverse coupling constant to two photons are located along the curve plotted in Figure 9 in which the mathematical formula (10) is taken with $n = 1$.

The spin-zero light boson should be a pseudoscalar.

2) In order to gain further insight on our results for α_{vac} we have extended the measurements looking at the apparent rotation $\alpha(Neon, pr)$ of a mixture of Neon (at some pressure) with Vacuum. The aim was to see if the results agree with the expected mathemathical expression given in (10), with $n-1$ given in expression (11). As Figure 10 shows, the fit of the data to the expression (10) is rather good: in this procedure, however, a particular pair (m_s, M) is identified:

$$\begin{aligned} m_s &= (1.0 \pm 0.1)\text{meV} \\ M &= (3.8 \pm 0.35) \cdot 10^5\text{GeV} \end{aligned} \qquad (14)$$

The pair corresponding to the best fit is plotted in Figure 9 along with the possible (m_s, M) pairs determined from α_{vac}.

I close by saying that our data, so far, are not in contradiction with the existence of a light pseudoscalar boson in nature provided the pair (m_s, M) are the ones indicated above .

What next ?

a) Complete the analysis of the data taken in the past in order to determine the magnetically induced linear birefringence of Vacuum ψ_{vac}. With these results we should be able to judge, more firmly, the agreement of our data with the hypothesis of the existence of a light pseudoscalar neutral particle.

b) Eliminate some deficiencies discovered during the past data taking: this mainly to improve the sensibility of the aspparatus.

c) Install a 532 nm wavelength green laser in order to see if the changes in the signal will follow the expected expression (10).

d) Externd our mesurements injecting in the Vacuum other gasses (helium) in order to confirm or not the interpretation adopted so far.

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