The status and prospects of the Q & A experiment with some applications

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Motivated to measure the QED vacuum birefringence and to detect pseudoscalar-photon interaction, we started to build up the Q & A experiment (QED [Quantum Electrodynamics] and Axion experiment) in 1994. In this talk, we first review our 3.5 m Fabry-Perot interferometer together with our results of measuring Cotton-Mouton effects of gases. We are upgrading our interferometer to 7 m armlength with a new 1.8 m 2.3 T permanent magnet capable of rotation up to 13 cycles per second. We will use 532 nm Nd:YAG laser as light source with cavity finesse around 100,000, and aim at 10 nrad/Hz$^{1/2}$ optical sensitivity. With all these achieved and the upgrading of vacuum, QED birefringence would be measured to 28% in about 50 days. Along the way, we should be able to improve on the dichroism detection significantly.

1 Introduction

In 1991, when Tsubono from University of Tokyo visited our Gravitation Laboratory in Tsing Hua University, we discussed the technical development of ultra-high sensitive interferometers for gravity-wave detection. During the last day before his departure, we pondered about how we could apply these developed techniques for fundamental physics and we discussed the possibility of doing the interferometric QED (Quantum Electrodynamics) tests. After analyzing the sensitivities, we believed that the QED birefringence would be measurable [1].

After the call for EOI's (Expression of Interest) of using the onsite SSC (Superconducting Super Collider) facilities in March, 1994 by DOE of USA, we submitted a joint EOI with a US team [2]. The topic of this EOI was chosen as one of the six topics for project definition study proposals. We then submitted such a proposal [3] in June and finished the study at the end of October, 1994 [4]. The project definition review was well-received. A five-year proposal [5] was submitted to the National Science Council of the Republic of China for the ROC part of the funding simultaneously. This proposal was approved in January, 1995 pending on the approval of the US proposal of the collaboration. Partial funding was allocated for the first year. However, due to lack of potential funding of the US counterpart, this program of collaboration was halted.

Nevertheless, in 1994, we started to build the experimental facility for the Q & A experiment (QED and Axion experiment) [6-8] acquiring two vacuum tanks of the laser-interferometric gravity-wave detector type and working on the measurement of mirror birefringence [9]. Since 1991 we have worked on precision interferometry – laser stabilization schemes, laser metrology and Fabry-Perot interferometers. With these experiences, we started in 1994 to build a 3.5m/7m prototype interferometer for measuring vacuum birefringence and improving the sensitivity of axion search as part of our continuing effort in precision interferometry. In June, 1994 in the Marcel Grossmann Meeting at Stanford, we met the PVLAS people, exchanged a few ideas and encouraged each other. We learned that PVLAS also started in the same year adapting their earlier scheme proposed in 1979 [10].

In 2002, we finished the first phase of constructing the 3.5 m prototype interferometer and made some Cotton-Mouton coefficient and Verdet coefficient measurements [11]. Starting 2002, we have been in the second phase of Q & A experiment. The results of our second phase on dichroism and Cotton-Mouton effect (CME) measurement have been reported in [12] and [13]. In section 2 and section 3, we review our achieved optical sensitivity and summarize our gaseous CME measurement results. We are starting the 3rd phase of our Q & A experiment extending the 3.5 m interferometer to 7 m with upgrades. These together with the goal of this phase will be presented in section 4. Section 5 concludes with discussion and outlook.

2 Achieved optical sensitivity

The schematic of the present setup of our second phase is shown in Fig. 2 of reference [12] and Fig. 1 of reference [13]. These references gave details of the experimental setup. Fig. 1 shows a picture of the experimental apparatus. Our 3.5 m prototype interferometer is formed using a high-finesse Fabry-Perot interferometer together with a high-precision ellipsometer. The two high-reflectivity mirrors of the 3.5 m prototype interferometer are suspended separately from two X-pendulum-double pendulum suspensions mounted on two isolated tables fixed to the ground using bellows inside two vacuum chambers. The sub-systems are described in [14-16, 12]. Our results in this phase give $(-0.2 \pm 2.8) \times 10^{-13}$ rad/pass with 18,700 passes through a 2.3 T 0.6 m long magnet for vacuum dichroism measurement, and limit pseudo-scalar-photon interaction and millicharged fermions meaningfully [12].

3 Measurement of gaseous Cotton-Mouton effects

Upon passing through a medium with transverse magnetic field, linearly polarized light becomes elliptically polarized. Cotton and Mouton first investigated this in detail in 1905, and the phenomenon is known as Cotton-Mouton effect. We use our Q & A apparatus to measure the CMEs at wavelength 1064 nm in nitrogen, oxygen, carbon dioxide, argon, and krypton in a magnetic field B = 2.3 T at pressure P = 0.5-300 Torr and temperature T = 295-298 K. Our measured results are compiled in Table 1 [13]. For the Cotton-Mouton coefficient, we follow the convention of [17] and use the normalized Cotton-Mouton birefringence Δn_u at P = 1 atm and B = 1 T. Our results agree with the PVLAS results [18, 19] in the common cases (Kr, N_2, O_2) within 1.2 σ. For Ar and CO_2 at 1064 nm, our results are new.

4 Upgrades

We are currently upgrading our interferometer from 3.5 m armlength to 7 m armlength in the 3rd phase. We have installed a new 1.8 m 2.3 T permanent magnet capable of rotation up to 13 cycles per second to enhance the physical effects. Figure 2 shows the configuration with our new magnet. We are working with 532 nm Nd:YAG laser as light source with cavity finesse around 100,000, and aim at 10 nrad/Hz$^{1/2}$ optical sensitivity. *With all these achieved and the upgrading of vacuum, QED birefringence would be measured to 28 % in about 50 days.* Along the way, we should be able to improve on the dichroism detection significantly. To enhance the physical effects further, another 1.8 m magnet will be added in the future.

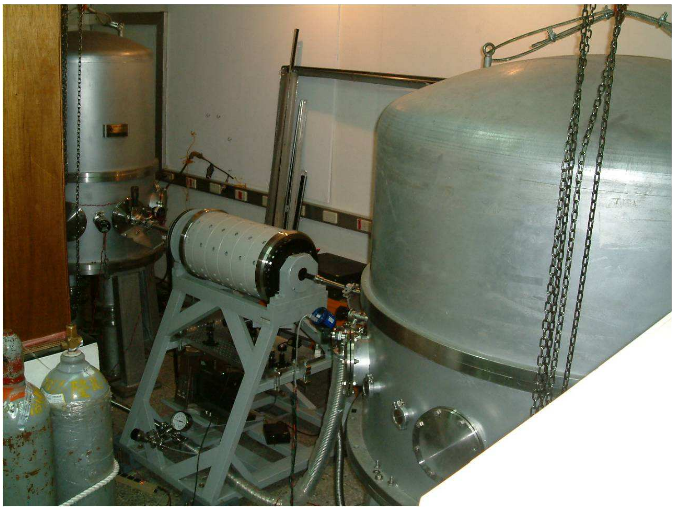

Figure 1: A picture of the experimental apparatus.

Figure 2: A picture of the new setup.

Gas	Normalized Cotton-Mouton birefringence Δn_u at P = 1 atm and B = 1 T
N_2	$(-\ 2.02 \pm 0.16^{\S} \pm 0.08^{\P}) \times 10^{-13}$
O_2	$(\ -1.79 \pm 0.34^{\S} \pm 0.08^{\P}) \times 10^{-12}$
CO_2	$(-\ 4.22 \pm 0.27^{\S} \pm 0.16^{\P}) \times 10^{-13}$
Ar	$(4.31 \pm 0.34^{\S} \pm 0.17^{\P}) \times 10^{-15}$
Kr	$(8.28 \pm 1.26^{\S} \pm 0.32^{\P}) \times 10^{-15}$

§: Statistical uncertainty
¶: Systematic uncertainty

Table 1: Measured Cotton-Mouton coefficients [13].

5 Discussion and outlook

We have heard a suite of motivations to search for (pseudo)scalar-photon interactions and to measure QED birefringence effect in this Patras 2009 workshop (See [20] and other articles in these proceedings; we refer the readers to various other experiments to the proceedings also). For QED birefringence, the next stage after detection is to measure the next-order effects which include hadron and potential new physical contribution [8]. This would be possible by extending the interferometer further with more rotatable permanent magnets. Many useful techniques have been developed in the Gravitational Wave Detection Community. We have advocated using relevant techniques [1]. Recently, there is a proposal to use the VIRGO facility [21]. Further progress in this experimental field is expected in the near future.

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