Reduction of Helicity-Dependent Asymmetries by Active Feedback

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We implemented an active feedback method to reduce instrumental electron asymmetries in our apparatus. Longitudinally spin-polarized electrons of opposite helicities are produced by rapidly flipping the circular polarization of light incident on a GaAs crystal. The electron beam propagates down the apparatus, and currents are measured on electron-optical elements. Our feedback system implements a lock-in amplifier, PID controller, and a liquid crystal retarder. Using our method, we are able to control instrumental asymmetry on the order of 10^{-7}.

This work was necessitated by a larger experiment involving electron circular dichroism in chiral molecules [1, 2]. In this experiment, polarized electrons with alternating forward and backward longitudinal spins collide with a chirally-pure molecular vapor target. The expected transmission current asymmetries, defined as

$$A = \frac{I\uparrow - I\downarrow}{I\uparrow + I\downarrow},$$

are of the order of 10^{-4}. In order to detect such small values, our instrumental asymmetries must be known to a value significantly better than this.

The apparatus used is shown in Fig. 1. Instrumental asymmetries arise if the two polarizations of electrons result in different currents as measured on an electron-optical element in the apparatus, especially those in the source chamber (shown in Fig. 2).

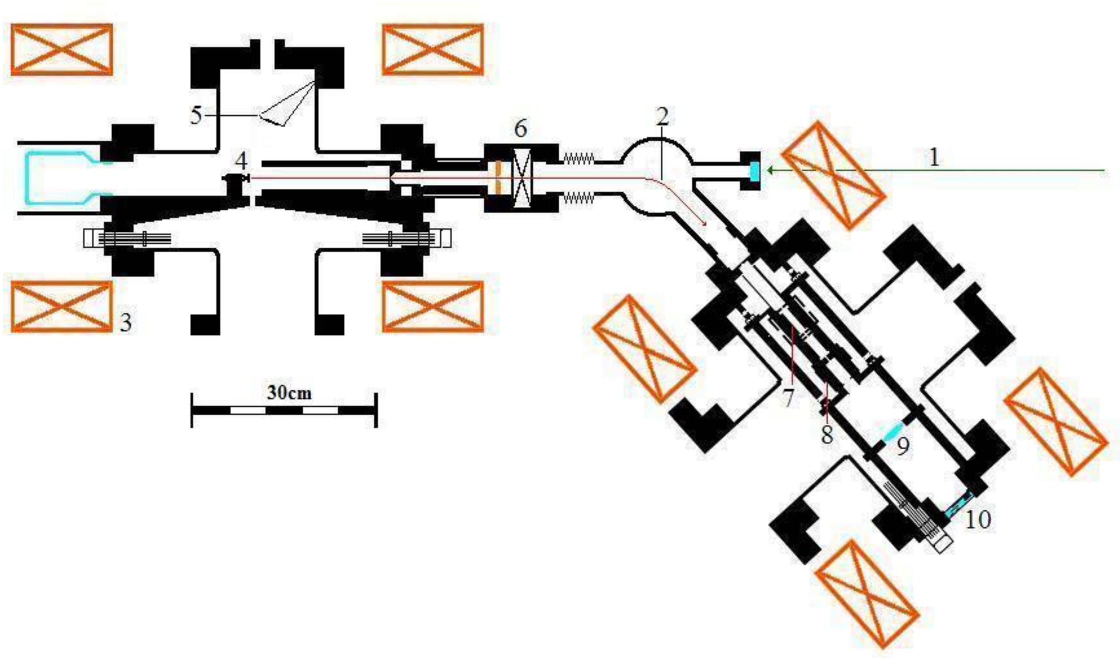

Fig. 1: ECD apparatus: (1) laser beam for GaAs source; (2) electron beam; (3) guiding magnets; (4) GaAs photocathode; (5) cesiators; (6) gate valve; (7) chiral target cell; (8) optical polarimeter target cell; (9) lens; (10) to optical polarimeter.

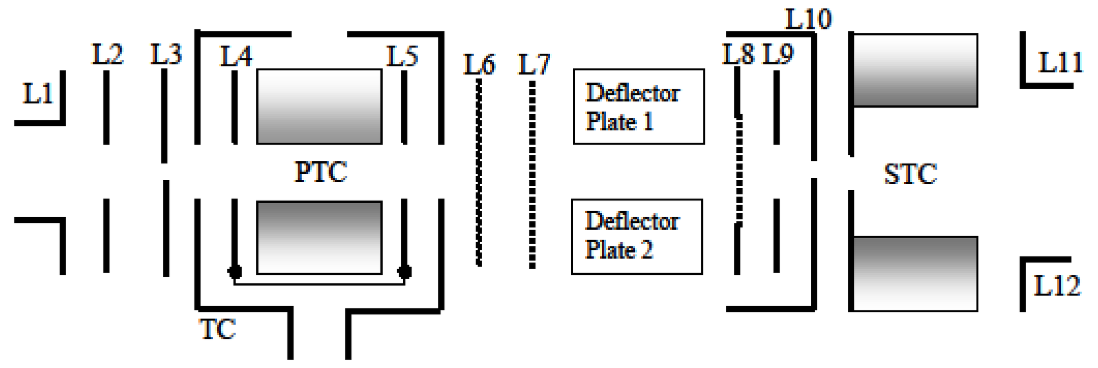

Fig. 2: Interactions between spin-polarized electrons and chiral molecules will be studied in the above target cell. Electrons propagate from left to right. L1 through L12-electron-optical elements; TC-target cell; PTC-primary target cell; STC-secondary target cell. L9 and L10 together act as a Faraday cup.

In order to reduce instrumental asymmetries, we have implemented an active feedback system. The electron beam of alternating (~1 kHz) polarization is produced by illuminating a GaAs crystal with a 785 nm laser beam of alternating helicity. The optical system is discussed in further detail in [3] and is shown in Fig. 3.

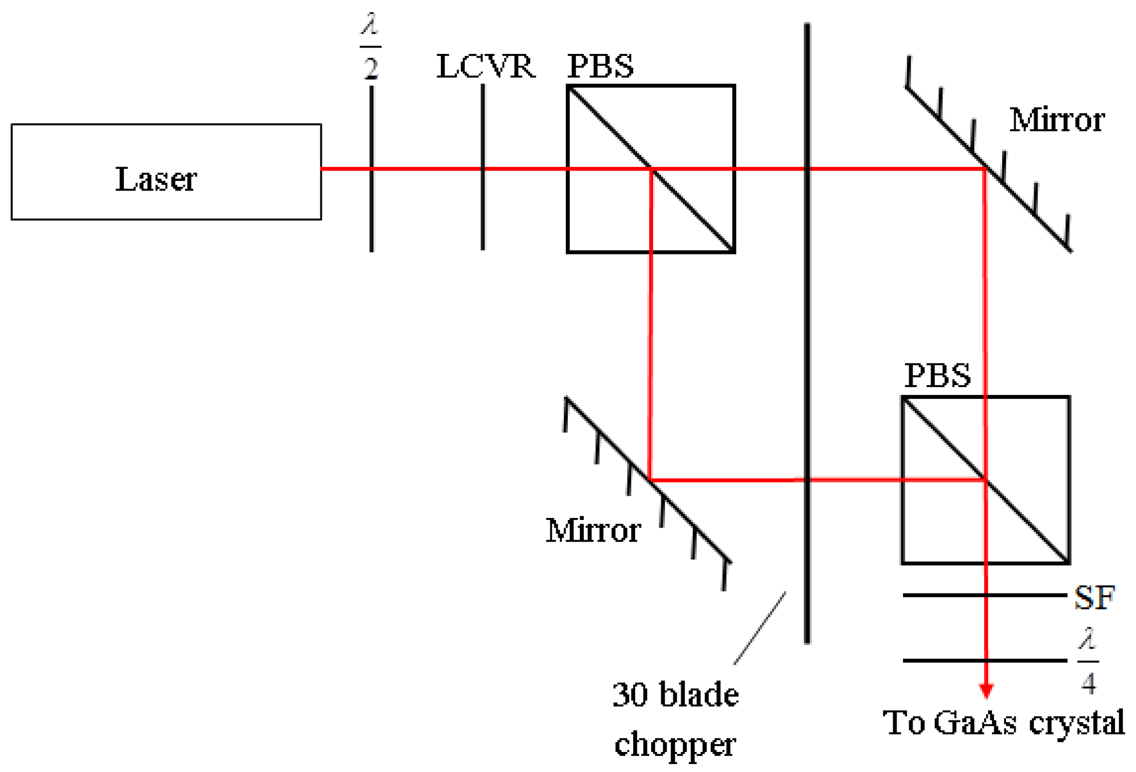

Fig. 3: Optical system used to produce light with alternating helicity. The laser beam passes through a half-wave plate and liquid crystal variable retarder (LCVR) to adjust the polarization. A polarizing beam splitter (PBS) separates the beam into two orthogonally polarized beams which pass through a mechanical chopper before being recombined by a second PBS. The beam finally passes through a spatial-filter/lens combination (SF) and quarter-wave plate before it is directed to the GaAs crystal.

Measurements of current on a given electron-optical element are monitored by a lock-in amplifier referenced to the rate of photon helicity reversal. The output of the lock-in amplifier is proportional to the asymmetry. This signal is sent to a PID controller, which outputs a voltage based upon the error between the measured value and a predetermined setpoint. The voltage is used to adjust the retardence of the LCVR which redistributes the intensity in the two optical helicity branches. Changes in the light intensities result in adjustments to the current for the two electron polarizations.

Using this feedback method, we have been able to reproducibly control asymmetries on various electron-optical elements to ~10^{-7}. We have additionally studied controlling the instrumental asymmetry on one element in the target cell while monitoring another. Table 1 provides a sample of such measurements.

Feedback	Asymmetry	SDM		Monitoring	Asymmetry	SDM
Crystal	2.6222E-02	1.5831E-06		FC	1.4587E-02	2.2003E-06
FC	2.5090E-03	5.0179E-07		Crystal	1.0303E-01	8.7036E-06
FC	2.5312E-03	7.1494E-07		L3	2.8065E-02	6.1059E-06
L3	2.3091E-03	1.0813E-06		FC	2.8109E-02	4.0632E-06
L3	2.3091E-03	1.1790E-06		Crystal	9.5651E-02	1.5964E-05
Crystal	2.6226E-02	1.1013E-06		L3	1.0991E-02	2.2869E-06

Feedback	Asymmetry	SDM		Monitoring	Asymmetry	SDM
Crystal	2.5445E-03	3.5747E-06		FC	4.4406E-04	1.4654E-06
FC	3.5525E-04	8.1486E-07		Crystal	6.4767E-03	1.6808E-05
FC	1.9095E-03	7.6601E-07		L3	9.6584E-04	1.7230E-06
L3	6.3501E-03	1.0125E-06		FC	1.5897E-02	1.9450E-06
L3	6.3723E-03	1.0946E-06		Crystal	5.5286E-02	2.7088E-05
Crystal	6.9807E-03	8.7480E-07		L3	2.5756E-03	1.1479E-06

Table 1: Example of data taken to characterize instrumental asymmetries. The first column shows the element on which the asymmetry is controlled. The next two columns give the asymmetry values and the standard deviation of the mean (SDM). The same information is then provided for the element that is being monitored.

We have studied effects of adding achiral gas to the target cell. Fig. 4 shows results for feeding back on L9+L10 and monitoring asymmetry on L3 while adding ~4 mTorr of argon gas (time 300-1000s). A small, repeatable shift on the order of 10^{-5} was observed. This should prove to be adequate to detect a chirally-dependent interaction between spin-polarized electrons and chiral molecules.

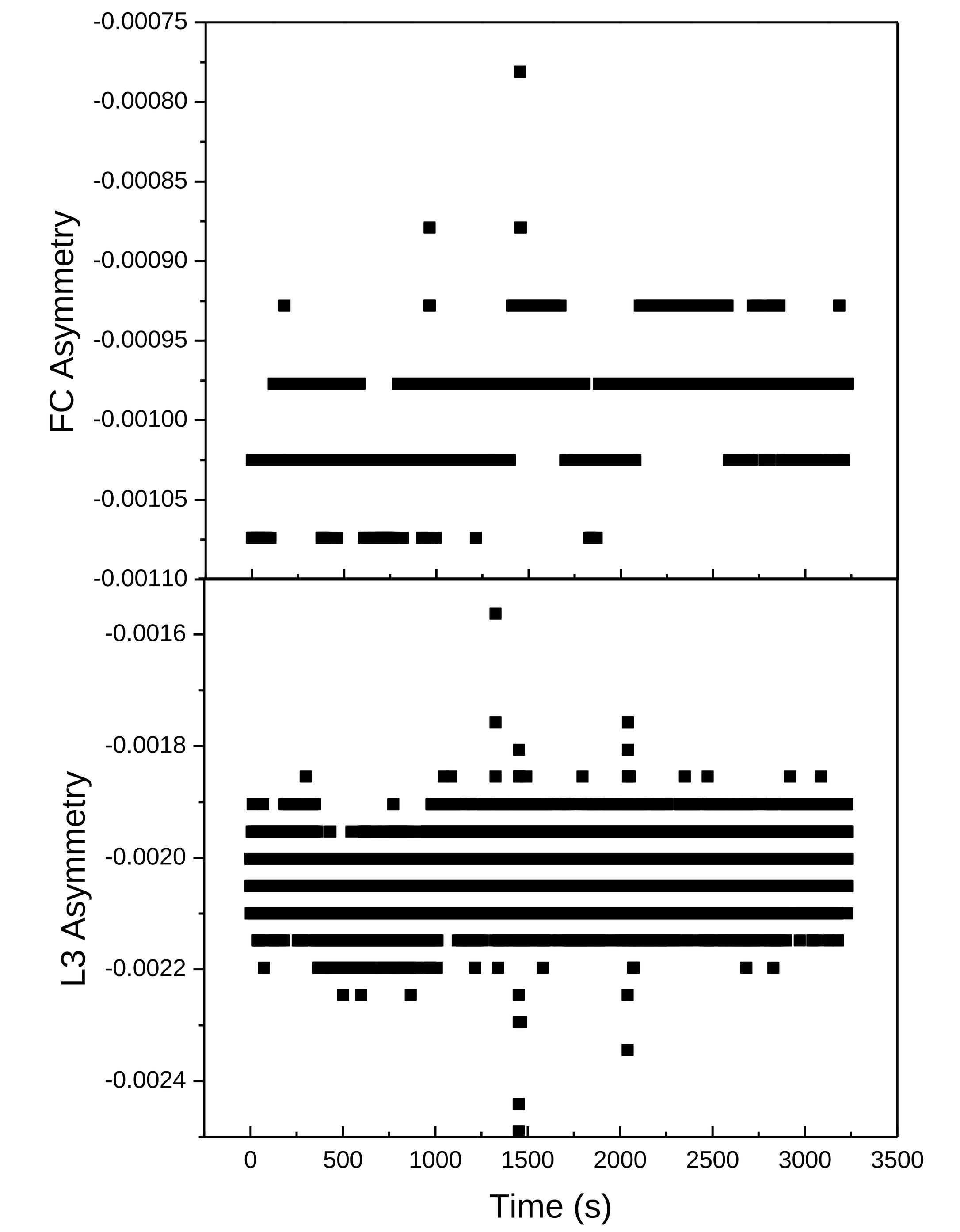

Fig. 4: Sample of data taken with argon gas. Top: feeding back on FC, bottom: monitoring L3.

References:
[1]. K.W. Trantham, M.E. Johnston, and T.J. Gay, J. Phys. B **28**, L543 (1995).
[2]. S. Mayer and J. Kessler, Phys. Rev. Lett. **74**, 4803-4806 (1995).
[3]. M.I. Fabrikant, K.W. Trantham, V.M. Andrianarijaona, and T.J. Gay, Appl. Opt. **47**, 2465 (2008).

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