Measurement and Reduction of Instrumental Asymmetries in an Electron Circular Dichroism Apparatus

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Introduction

Chiral Molecules

A chiral molecule is a type of molecule that cannot be superimposed on its mirror image. Chiral molecules are important in organic chemistry and biology. Below is an example of a simple chiral molecule.

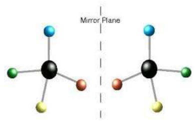


Fig 1 – Chiral Molecule
Image from http://www.simsoup.info /Origin_Issues_Homochirality.html

Circular Dichroism

Chiral molecules can differ in how they scatter left- and right-circularly polarized light. They generally exhibit an unequal imaginary refractive index for opposite polarization states, leading to preferential absorption of one polarization. This is called Optical Circular Dichroism (OCD).

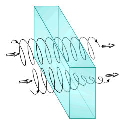


Fig 2 – Circular Dichroism
One state of polarization is preferentially absorbed.
Image from Wikipedia

Electron Circular Dichroism (ECD)

ECD is the term for an effect analogous to OCD, which describes how a beam of longitudinally polarized electrons will be attenuated based on the target chirality and the parallel or antiparallel relationship between the electrons spins and momenta.

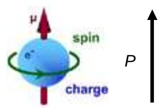
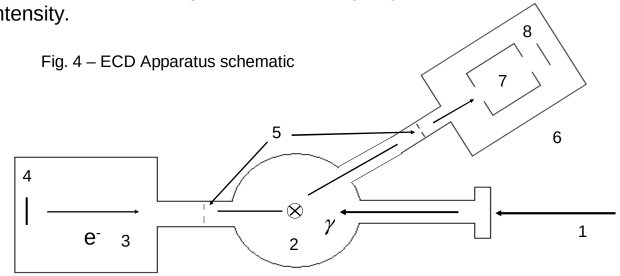


Fig 3 – An electron can have spin up or down. A longitudinally polarized electron has spin which is parallel or antiparallel to its momentum.
Image from http://itknowledgeexchange.techtarget.com/overheard/tag/spintronics/

Schematic of ECD Apparatus

1. Laser beam (γ); 2. Differential pumping chamber with perpendicular B-Field for guiding electron beam; 3. Polarized electron source chamber; 4. Gallium arsenide crystal to photoemit polarized electrons; 5. Differential pumping apertures; 6. Target chamber; 7. Chiral target cell; 8. Faraday cup to measure electron intensity.

Fig. 4 – ECD Apparatus schematic



Experiment

Instrumental Asymmetry

The experimental asymmetry is defined as $A = \frac{I^+ - I^-}{I^+ + I^-}$, where I^+ refers to the transmitted intensity of forward spinning electrons, and I^- to the transmission of backward spinning electrons. Instrumental asymmetries can lead to a false positive asymmetry. The instrumental asymmetry must be reduced to well below the expected asymmetry from ECD, which is ~10^{-4}.

Optical Setup

Instrumental asymmetry can be introduced by the optical setup in two ways: spatial variation or intensity variation. Spatial variation is due to unstable pointing accuracy of the laser. The purpose of this experiment was to measure and then reduce the instrumental asymmetry due to the optical setup, specifically the spatial variation of our laser on the target. There were two phases of the experiment: quantifying the variance of the laser under different laboratory conditions, and quantifying and reducing variation due to optical components. The full setup is displayed below:

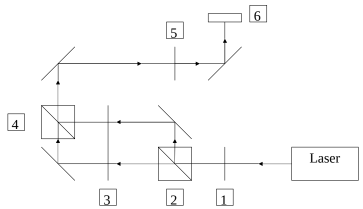


Fig. 5 – Optical Setup. The laser passes through a liquid crystal variable retarder (1) which adjusts for intensity asymmetry, then is split into orthogonal linear polarization states by a beam splitter (2). Only one state is allowed to pass through the chopper (3) at any given time. The beam is then recombined spatially by another beam splitter (4), but the oppositely polarized beams are not recombined temporally. The quarter-wave plate (5) converts the beam to orthogonal circular polarization states, which then reach the crystal or a detector (6).

Laser Diagnostics

A position sensitive photodiode interfaced with a computer was used to track the variation of the laser beam spot. This was very useful because the photodiode output a voltage that scaled proportionately to laser position. In order to establish a baseline, we first determined the variation of the laser spot under normal conditions, as well as several possible scenarios, such as:

- A roughing pump operating nearby
- A heat gun simulating changes in temperature/ventilation
- An overnight test to measure long term drift

By comparing the data sets, it was possible to determine the stability of the laser spot as a result of these factors.

Conditions	Variation (X)*	Variation (Y)*
Normal	1.460	1.18
Pump Vibrations	13.23	3.170
Heat/Air Currents	25.30	28.175
Long Term Drift	4.231	5.433
*Standard deviations in microns		

Table 1 – Variation (one std. dev.) of laser under different conditions.

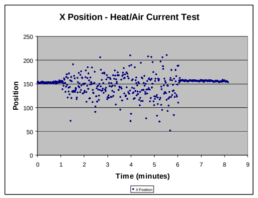


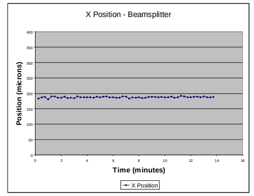
Fig. 6 – Chart of heat/air current test.

Results

Increasing Complexity

Next, optical components were added one by one and the resulting variation was measured until the entire optical setup was in place. In this way, the increased variation due to specific components could be quantified.

Component Added	Variation (X)*	Variation (Y)*
Mirror	2.990	3.79
Chopper	19.73	27.02
Beamsplitter^	2.01	2.85
Full Setup	32.12	36.00
*Standard deviations in microns		
^Chopper removed		



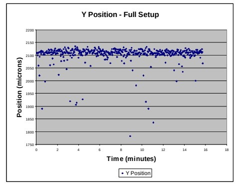


Table 2 (top left) – Variation of the beam spot with each added component.
Fig. 7(top right) – Beamsplitter test. The stability can actually be improved over the mirror setup with careful alignment.
Fig. 8 (bot left) – Full setup. Outliers are a result of clipping by the chopper and have been removed from variation calculations.

Improvements to Apparatus

There are several improvements which can be made to the apparatus, beyond the obvious (aligning the chopper to minimize clipping, aligning the beamsplitters properly, etc). We found that placing a lens with its focus at the target greatly increases the stability in any setup we tested.

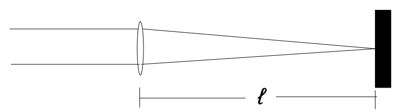


Fig. 9 – Lens with focal length ℓ placed in beam path greatly improves stability.

We also tried several combinations of a lens and aperture to see which combination worked best.

Combination	Variation (X)*	Variation (Y)*
Lens	1.15	4.05
Lens + Aperture	0.58	1.45
Aperture + Lens	0.37	1.45
*Standard deviations in microns		

Table 3 – The spatial variation improves by greater than an order of magnitude with the lens placed in the system, but is even better with an aperture in front of the lens.

Conclusion

Through this experiment, the spatial variation of the laser as a function of various environmental factors and optical components was measured. Methods were found to increase the laser stability. Combined with the technique of reducing intensity asymmetry [1], it is our hope that this apparatus will be able to detect ECD.

Acknowledgements

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Reference: [1] M.I. Fabrikant *et al.,* Appl. Opt. **47:13**, 2465 (2008)