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

J. Feeks¹, E. Litaker², and T.J. Gay²

¹Department of Physics, University of St. Thomas, St. Paul, MN 55105
²Jorgensen Laboratory of Physics, University of Nebraska-Lincoln, Lincoln, NE 68588

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.

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).

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.

Experimental

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:

Electronic 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.

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

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Variation (X)</th>
<th>Variation (Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>1.46</td>
<td>3.79</td>
</tr>
<tr>
<td>Pump vibrations</td>
<td>13.25</td>
<td>3.79</td>
</tr>
<tr>
<td>Heat/Air Currents</td>
<td>25.30</td>
<td>26.70</td>
</tr>
<tr>
<td>Long Term Drift</td>
<td>6.230</td>
<td>6.433</td>
</tr>
</tbody>
</table>

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.

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.

Table 3 (top right) – Variation of the beam spot with each added component. Fig. 8 (bottom 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.

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

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
The author would like to acknowledge helpful discussions and advice from Joan Dreiling. This research was funded by NSF Grant PHY-085629 and NSF REU Grant 25-0521-0143-001. Reference: [1] M.I. Fabrikant et al., Appl. Opt. 47:13, 2465 (2008)