Polarized Molecular Fluorescence From Polarized Electron Impact

J.W. Maseberg,* J.E. Furst,† and T.J. Gay*

*Behlen Laboratory of Physics, University of Nebraska, Lincoln, NE 68588-0111, USA
†University of Newcastle-Ourimbah, Ourimbah NSW 2258, Australia

Introduction

Our experiment investigates low energy collisions between spin-polarized electrons and simple diatomic molecular targets. Polarization measurements of the resulting fluorescence due to exchange excitation are performed to measure any transfer of angular momentum. The scattered electrons are not detected. For the cases of H_2 and N_2 room temperature target molecules, experiments have shown significantly different values of spin transfer. For H_2 it has been found that the circular polarization fraction normalized to the incident electron spin, P_3/P_e, can be as large as $\sim 10\%$ [1]. However the Münster group has found N_2 gives $\sim 0\%$ [2], and this is now confirmed in a circumstantial manner by our result.

Apparatus

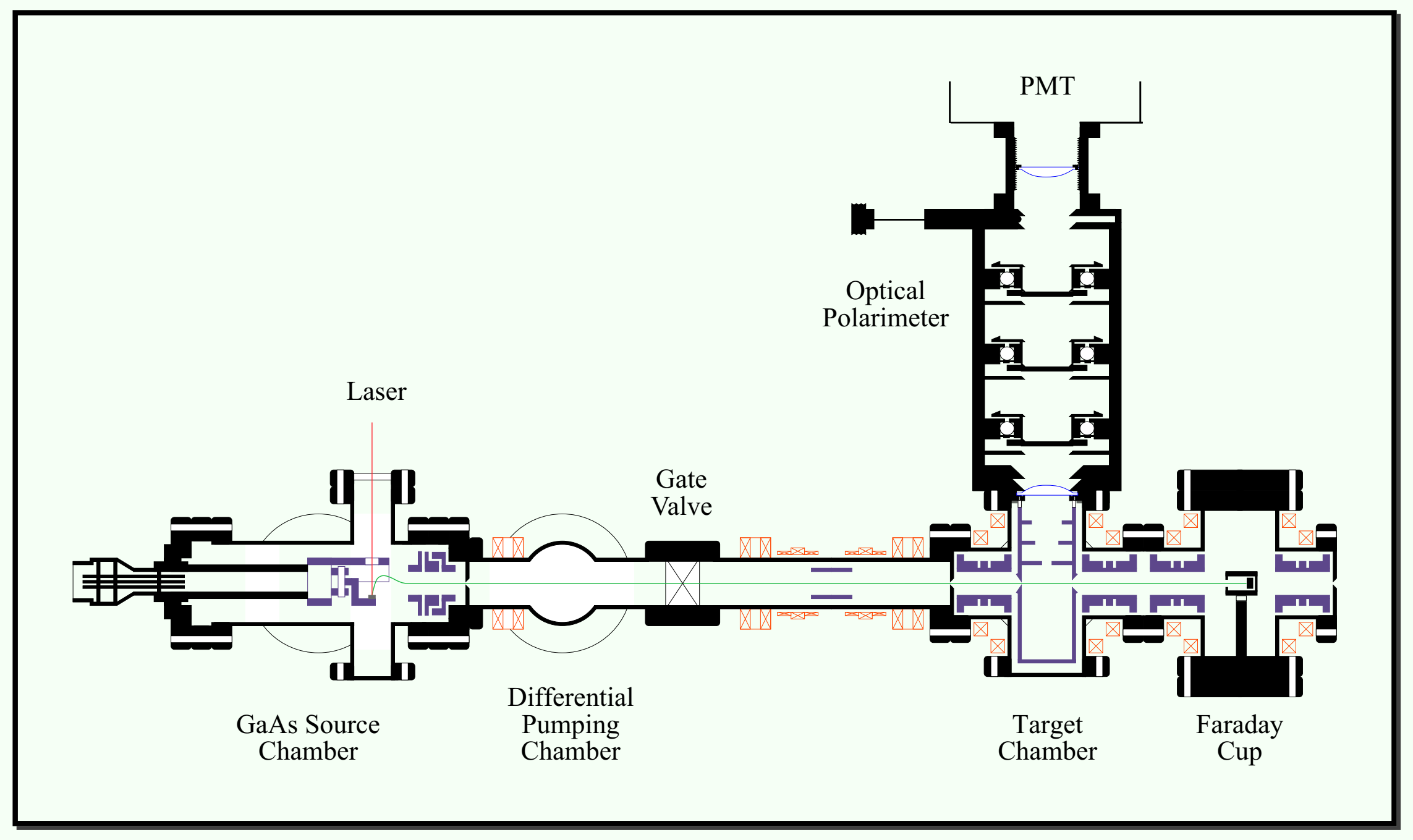

Figure 1: Beamline Schematic.

To obtain polarized electrons a GaAs photocathode is activated with cesium and oxygen to produce typical photocurrents of 5 μA/mW of incident 785 nm laser light. The electrons are electrostatically deflected by 90° and steered into a target cell to produce a beam with transverse polarization. Electrons pass through the target cell and are collected in a Faraday cup. The helicity of the laser determines the spin direction of the electrons. Differential pumping regions isolate the source pressure (1x10^{-10} Torr) from the target gas cell (1 mTorr). The target cell is topped with a vacuum lens to allow photons passage into the optical polarimeter. Three optical stages consisting of a quarter-wave plate (QWP), linear polarizer aligned parallel to the beam axis, and interference filter are followed by a GaAs photomultiplier tube. Data is aquired by rotating the QWP and collecting photons. Background counts are subtracted from the raw signal, which is then normalized to beam current and target pressure. The data is fitted to extract the relative, or integrated, Stokes parameters P_1, P_2, and P_3.

Procedure

To determine the polarization of the electron beam a helium optical electron polarimeter is used [3,4]. Excitation from the singlet ground state to the triplet 3^3P state ensures electron exchange. The L-S coupling between the electron spin and orbital angular momentum then gives a non-zero value of P_3 upon decay into the 2^3S (388.9 nm) state. The relative Stokes parameters are related to the electron beam polarization by $P_e = (6P_3)/(P_1 - 3)$. By measuring the transition near threshold (23.3 eV) contributions from cascade transitions can be avoided. For an unstrained GaAs crystal we recently measured P_e=19.3(0.3)%.

After determining the electron beam polarization the helium target was replaced with N_2. The interference filter (388±5 nm) allowed 6 different spectral lines to pass from exchange exited N_2 and N_2^+ transitions. At an energy of 30 eV a P_3/P_e value of 1(5)% was obtained.

Results

The transitions studied are shown in Table 1. The corresponding experimental results are shown in Fig. 2.

Investigator	Target	Filter (nm)	Transition	(ν_i - ν_f)
Green	H_2	588.3±0.3	$3d\pi^3\Pi_g$ - $2p\pi^3\Pi_u$	(1-1)
		600±10	$3d\sigma^3\Sigma_g$ - $2p\pi^3\Pi_u$ $3d\pi^3\Pi_g$ - $2p\pi^3\Pi_u$ $3s\sigma^3\Sigma_g$ - $2p\pi^3\Pi_u$ $3p\pi^3\Pi_u$ - $2s\sigma^3\Sigma_g$	
Hanne	N_2	337	$C_3\Pi_u$ - $B_3\Pi_g$	(0-0)
Current work	N_2	388±5	$A^3\Sigma_u^+$ - $X^1\Sigma_g^+$ $C^3\Pi_u$ - $B^3\Pi_g$ $A^3\Sigma_u^+$ - $X^1\Sigma_g^+$ $C^3\Pi_u$ - $B^3\Pi_g$ $C'^3\Pi_u$ - $B^3\Pi_g$	(3-13) (4-7) (0-11) (3-6) (0-8)
	N_2^+		$B^2\Sigma_u^+$ - $X^2\Sigma_g^+$	(2-2) (10-10) (1-1) (19-16) (0-0)

Table 1: Molecular transitions.

The discrepancy between the H_2 and N_2 data is thought to be due to the different coupling schemes [1]. The H_2 molecule rotates quickly due to its light mass, and the spin stays somewhat fixed in the lab frame. This weak coupling and high rotation corresponds to Hund's case (b). N_2 rotates more slowly, and the spin can follow the internuclear axis, thereby averaging out the observed value of P_3/P_e. This strong coupling and low rotation is designated Hund's case (a).

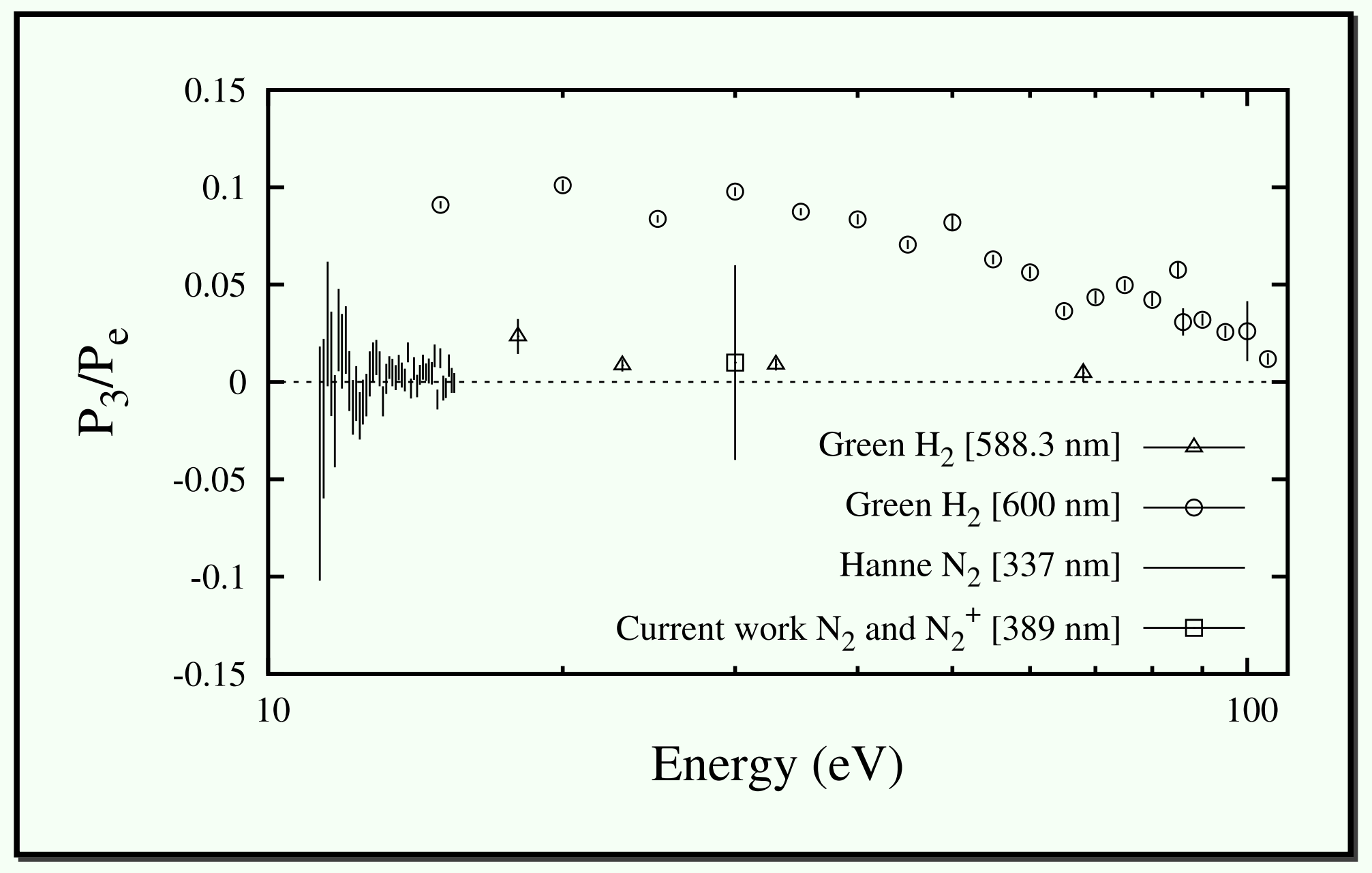

Figure 2: P_3/P_e versus incident electron energy for molecular fluorescence from H_2 and N_2.

Obviously this argument does not describe the low values for the H_2 588.3 nm line. It is worth noting that the 588.3 nm filter passes fluorescence due primarily to Σ-Π or Π-Σ transitions. In contrast, the lines passed by the 600 nm filter are almost exclusively due to Π-Π transitions. This might cause P_3 values to differ quantitatively.

Future Directions

We have procured a new interference filter with tighter bandwidth for our N_2 studies. At 380.5±1.25 nm the $C_3\Pi_u(\nu=0)$ - $B_3\Pi_g(\nu=2)$ triplet transition can be isolated and compared more directly to Hanne's data. Using diatomic molecules with various masses, for example H_2, D_2, N_2, NO, and O_2, will allow investigation of the rotational time-scale dependence of the measured spin transfer. Also, cooling and heating the targets would provide additional rotational separation. We plan to use D_2 immediately upon completion of N_2 data collection.

Acknowledgments

We thank Gordon Gallup, Bill McCurdy, and Tom Rescigno for useful conversations.

This research was supported by NSF Grant PHY-0354946.

References:

[1] A. S. Green *et al.*, Phys. Rev. Lett. **92**, 093201 (2004).
[2] C. Mette *et al.*, Verhandl. DPG (VI) **29**, 462 (1994).
[3] T. J. Gay, J. Phys. B **16**, L553 (1983).
[4] T. J. Gay *et al.*, Phys. Rev. A. **53**, 3 (1996).