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ANGULAR DISTRIBUTION OF PHOTOELECTRONS AT 584 Å  
USING POLARIZED RADIATION

b:

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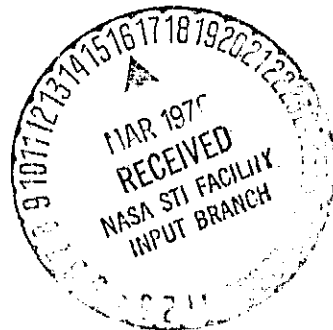
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ABSTRACT

Photoelectron angular distributions for Ar, Xe, N<sub>2</sub>, O<sub>2</sub>, CO, CO<sub>2</sub>, and NH<sub>3</sub> have been obtained at 584 Å by observing the photoelectrons at a fixed angle and simply rotating the plane of polarization of a highly polarized photon source. The radiation from a helium dc glow discharge source was polarized (84%) using a reflection type polarizer.



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## INTRODUCTION

Although the first measurements of the angular distribution of photoelectrons ejected from free atoms date back to 1931 it is only during the past ten years that interest has been revived in this area.<sup>1,2</sup> However, the majority of the published results have been concerned with the angular distribution of electrons ejected from the rare gases. The motivation has been to verify theoretical predictions that the angular distributions are sensitive to the kinetic energy of the electrons and to the orbital from which they are ejected. There are surprisingly few measurements of electron angular distributions from molecules. The most extensive work on molecules has been reported by Carlson and co-workers for discrete emission lines at 584 Å (HeI) and at 736, and 744 Å (NeI).<sup>3-6</sup>

The purpose of the present work is two-fold; (a) it presents angular distribution data at 584 Å for comparison with previously published results and (b) it presents a new technique that is simple and accurate to use. In addition, results are presented for ammonia for the first time.

## EXPERIMENTAL

In order to measure angular distributions of photoelectrons, the electron flux is measured as a function of angle relative to the plane of polarization of the radiation. Traditionally, this has been done by using unpolarized radiation and rotating the electron spectrometer or light source about an axis which is perpendicular to the beam axis.<sup>2,3,7,8</sup> These methods present several difficulties in that the interaction volume viewed varies and must be corrected for in the data analysis. Also, motion of the apparatus can cause shifting contact potentials and in the case of rotating

the detector, the electrons have different trajectories relative to residual magnetic fields.

Other workers have overcome the problem of varying interaction volume by using plane polarized synchrotron radiation and rotating the electron spectrometer about the beam in the plane perpendicular to the beam axis.<sup>9</sup> This method still retains the problems of contact potentials and magnetic field.

All these problems were alleviated in the present experiment by fixing the position of the electron spectrometer at 90° from the beam direction and then polarizing and rotating the plane of polarization of the beam.<sup>10</sup> This method was used in 1931 by Chaffee<sup>1</sup> using a transmission polarizer in the 2200 Å spectral region to determine the angular distribution of the photoelectrons ejected from potassium. However, no transmission polarizers exist for radiation below 1200 Å. Thus, a reflection type polarizer similar to that described by Horton, et al.<sup>11</sup> was used to polarize 584 Å radiation from a helium d.c. discharge lamp. This type of polarizer, however, produces partially plane polarized light. Provided the degree of polarization is known it is possible to determine the angular distribution as shown below.

It has been shown theoretically<sup>12,13</sup> that for dipole transitions the number of electrons  $N$  ejected per unit solid angle in a specific direction by plane polarized radiation is given by

$$N \propto \frac{\sigma}{4\pi} \{1 + \beta P_2(\cos\theta)\} , \quad (1)$$

where  $\sigma$  is the photoionization cross section,  $\beta$  is an asymmetry parameter that can take on values ranging from -1 to + 2,  $\theta$  is the angle between the electric vector and the electron direction, and  $P_2(\cos\theta)=3/2\cos^2\theta-1/2$ . Equation (1) has been generalized<sup>14,15</sup> to include the case of partially polarized or elliptically polarized radiation and takes the form

$$N \propto \frac{\sigma}{4\pi} \{ 1 + 1/2\beta\left(\frac{3}{g+1}(g \cos^2\theta_x + \cos^2\theta_y)-1\right) \} , \quad (2)$$

where  $g$  is defined by the ratio  $I_x/I_y$ ;  $I_x$  is the intensity of the radiation vibrating along the  $x$  axis and  $I_y$  is the intensity vibrating along the  $y$  axis. The degree of polarization  $P$  is related to  $g$  by the equation  $P = (g-1)/(g+1)$ . The angles  $\theta_x$  and  $\theta_y$  refer to the direction of the photoelectron with respect to the  $x$  and  $y$  axes, respectively, as shown in Fig. 1. Either the  $x$  or  $y$  axis must be oriented parallel to the direction of maximum polarization. In the present experiment  $\theta_y = 90-\theta_x$  and  $\theta_z=90^\circ$ . Thus, by measuring  $N$  at two different angles  $\theta_x$  and knowing  $g$ , the asymmetry parameter  $\beta$  can be found. The angle  $\theta_x$  was varied by rotating the polarizer.

The polarizer consists of three mirrors arranged so that the photon beam enters and exits on the same axis as shown in Fig. 2. A computer study, using known optical constants and Fresnel's equations,<sup>16</sup> was made to calculate the degree of polarization, at 584 Å, produced by various reflective materials and as a function of angle of incidence. The materials included silver, gold, osmium, glass, aluminum oxide, and platinum. Gold provided the best compromise between transmission and degree of polarization at the angles shown in Fig. 2.

The polarizer was first constructed using glass microscope slides coated with gold. However, because of scattering from the uneven surfaces of the slides, they were replaced by 1/4 wave optical flats with a research grade optical polish. A transmission of 10% was measured with a 1/2 M Seya monochromator. The degree of polarization was measured with a vacuum uv polarization analyzer<sup>17</sup> based on the 45° reflectance technique of Rabinovitch et al.<sup>18</sup> A value of 84% was obtained. These values were each within a few percent of the values predicted using the known optical constants for gold at 584 Å, namely,  $n = 1.07$  and  $k = 0.95$ . The plane of polarization was changed by rotating the polarizer about its axis. A laser was used in the extensive alignment procedure to insure that there was no deviation of the photon beam during rotation.

A cylindrical mirror electron energy analyzer was used with the photon beam incident at right angles to the axis of the analyzer. The entrance slit to the analyzer was masked so that only a 6° solid angle was viewed at 90° from the beam direction. The detector was a "Spiraltron" electron multiplier.

In order to eliminate errors caused by target gas pressure fluctuations or lamp intensity variations, the data were taken using multiscan techniques and with a multichannel analyzer. Data were taken for only two orientations of the polarizer because this provided better statistical results than curve fitting techniques.<sup>19</sup> However, initially data were taken as a function of angle to test for symmetry. The two positions were such that electrons were sampled in the direction of polarization and perpendicular to it.

The polarizer was set in one position while the energy analyzer scanned over one photoelectron energy peak in approximately two minutes.

This information was stored in one block of 128 channels in the multiscalar. The polarizer was then rotated by an electric motor to the other position. The energy analyzer scanned the same energy peak. This information was stored in the next 128 channels of the multiscalar. The motor then rotated the polarizer to the first position and the whole sequence was repeated. The motor drive was interfaced with the multiscalar so that the entire procedure was automatic. The data were transferred to punched paper tape and then directly to a computer. The computer integrated the area under the electron energy peaks. The ratio of these areas for the two polarizer orientations and the known degree of polarization were used with Eq. (2) to determine the asymmetry parameter.

The degree of polarization decreased slowly over a period of about one week due to contamination of the mirrors by pump oil and exposure to uv radiation. Consequently the degree of polarization was measured for every data run.

## RESULTS

The angular asymmetry parameters for Ar, Xe, N<sub>2</sub>, O<sub>2</sub>, CO, CO<sub>2</sub>, and NH<sub>3</sub> are listed in table 1. The data were taken with an energy resolution of 50 meV. In most cases the  $\beta$ -values are for specific vibrational levels as indicated. Where more than one vibrational level is given, the  $\beta$ -value was found to be the same for each level indicated. If no vibrational level is given, the  $\beta$ -value represents the average value taken over all the levels of the state.

Argon was used as a standard to insure the proper working of the apparatus. A value of  $\beta=0.95\pm 0.02$  was obtained. This compares favorably

with other literature values, some of which are given in table 1. No corrections are made to the data other than subtracting out any background of scattered electrons, which in the case of argon was negligible. The fact that the system consistently reproduced the argon  $\beta$ -value through several realignments and for a variety of values of the degree of polarization gives confidence that the system is working (P varied from 65 to 84%). Where other data exist for comparison the overall agreement is good. We verify the anomalous behavior between the  $v=0$  and  $v=1$  vibrational levels of the ground electronic states of  $N_2$  and  $CO$  originally observed by Carlson.<sup>3</sup> For the  $O_2^+$  ground state Morgenstern et al. and Carlson disagree. Our results support the negative  $\beta$ -value found by Carlson. However, there is a major disagreement between our values and Carlson's for the B-state of  $CO^+$ . This measurement has been repeated several times, yielding the same results. No other published values exist for comparison. In a similar vane we disagree with the  $\beta$ -value given by Morgenstern et al. for the B-state of  $O_2^+$ . In both cases the B-state electrons represent the lowest energy electrons (0 to 1.5 eV) and thus the most difficult to measure by more conventional methods. The present technique is ideally suited for low energy electrons where contact potentials or varying magnetic fields would tend to give false results. Thus, we have a high degree of confidence in our values. The error bars given in table 1 represent standard deviations.

#### ACKNOWLEDGEMENT

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## FIGURE CAPTIONS

Figure 1. Ejected electron direction in terms of  $\theta_x$ ,  $\theta_y$ ,  $\theta_z$  relative to the photon direction and direction of polarization. The X axis is the direction of maximum polarization.

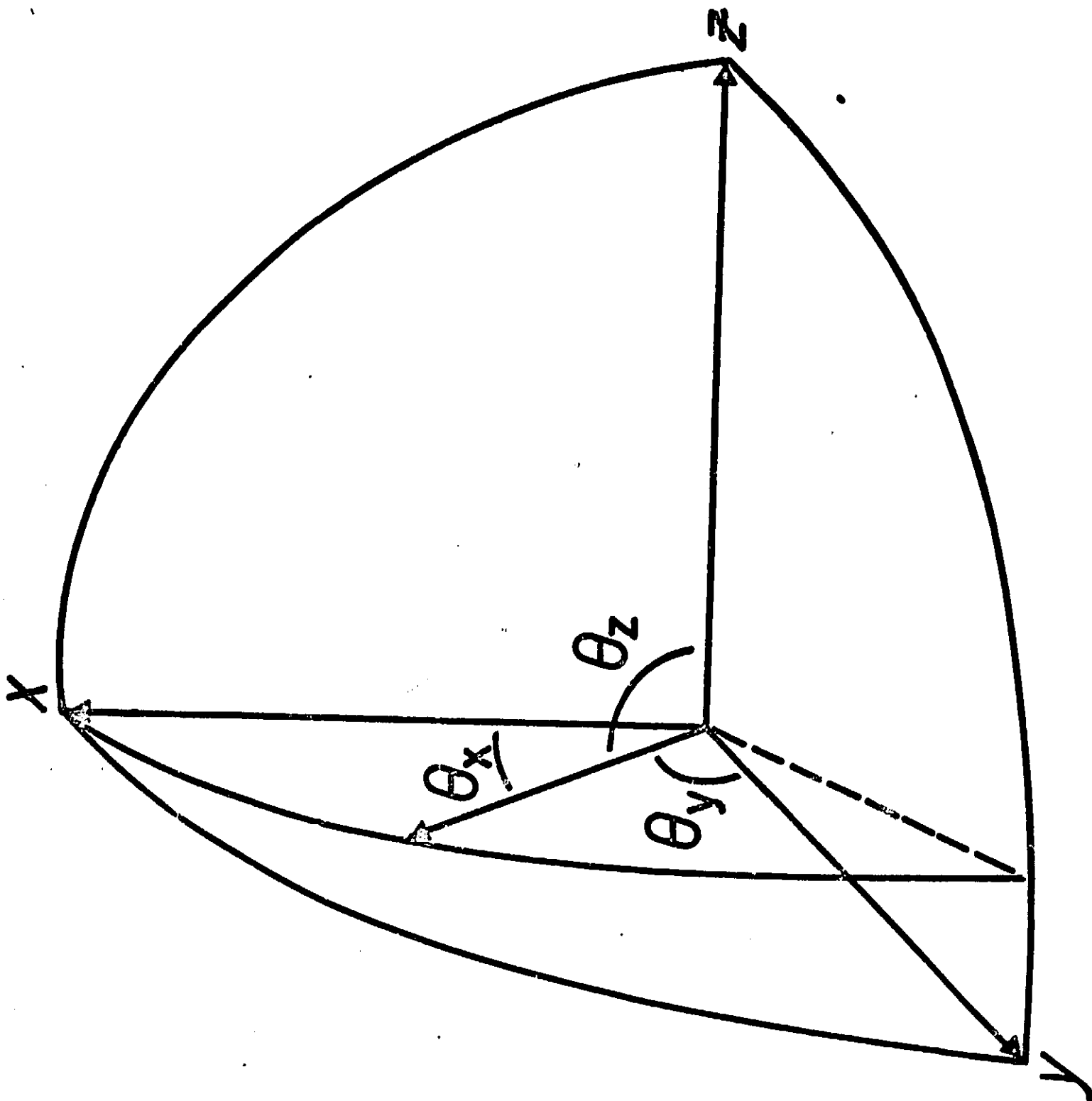
Figure 2. Schematic diagram of the rotatable reflection type polarizer.

TABLE 1

ANGULAR DISTRIBUTION ASYMMETRY PARAMETER  $\beta$  FOR PHOTOELECTRONS EJECTED FROM VARIOUS GASES BY 584 Å RADIATION

Gas	State	Present Work	Carlson <sup>a</sup>	Morgenstern <sup>b</sup>	Dehmer <sup>c</sup>
Ar	$2P_{1/2, 3/2}$	0.95±.02	0.85±.05	0.95±.02	0.89±.04
Xe	$2P_{3/2}$	1.78±.04	1.45±.05	1.71±.02	1.77±.05
	$2P_{1/2}$	1.64±.04	1.35±.05	1.64±.06	1.63±.05
N <sub>2</sub>	$X^2\Sigma_g^+$ v=0	0.68±.05	0.5 ±.1	0.69±.03	
	v=1	1.5 ±.1	1.4	1.4 ±.03	
	$A^2\Pi_u$ v=0,1	0.37±.05	0.3 ±.1	0.43±.04	
	$B^2\Sigma_u^+$ v=0	1.36±.1	1.25±.1	1.25±.04	
O <sub>2</sub>	$X^2\Pi_g^+$ v=1,2	-0.27±.05	-0.3 ±.1	0.04±.05	
	$a^4\Pi_u$	.39±.1	0.4 ±.1	0.55±.07(v=3)	
	$b^4\Sigma_g^-$	.57±.1	0.7 ±.1	0.73±.05(v=0)	
	$B^2\Sigma_g^-$	1.04±.2	---	1.35±.07(v=1)	
CO	$X^2\Sigma_g^+$ v=0	0.95±.05	0.8 ±.1		
	v=1	0.56±.07	0.4		
	$A^2\Pi_u$ v=0,1	0.31±.05	0.3 ±.1(v=2)		
	$B^2\Sigma_u^+$	0.28±.05	1.0 ±.2		
CO <sub>2</sub>	$X^2\Pi_g$ v=0,1	-0.14±.05	-0.1 ±.1		
	$A^2\Pi_u$ v=0,1,2	0.80±.05	0.8 ±.1		
	$B^2\Sigma_u^+$	-0.65±.05	-0.4 ±.1		
	$C^2\Sigma_g^+$	1.15±.05	1.3 ±.2		
NH <sub>3</sub>	$^2A_1$	0.82±.1			
	$^2E$	0.21±.1			

<sup>a</sup>From ref. 3, 4, 5<sup>b</sup>From ref. 20, 21<sup>c</sup>From ref. 22



$h\nu$

