MASTER**TEMPERATURE DEPENDENCE OF THE BEAM-FOIL INTERACTION**

by

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TEMPERATURE DEPENDENCE OF THE BEAM-FOIL INTERACTION

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Résumé. On a mesuré la dépendance d'énergie entre 50 et 200 keV du fraction de polarisation linéaire (M/I) du transition de He I $2s^1S - 3p^1P$, 5016 Å, sur la température de la cible de carbone. Les cibles sont chauffées par passage d'un courant électrique dans des fils de nichrome autour de la porte-cible, et la température était mesuré directement avec un pyromètre infra-rouge. Les mesures de Hight et al.¹ sont repliquées; les dépendances sur l'énergie et l'intensité du faisceau sont les mêmes, avec un bon correspondance entre chauffage externe et chauffage par le faisceau. Aussi, nous observons que le nombre γ des électrons secondaires produits par chaque ion incident diminue avec plus grande température de la cible. Ces deux effets nous donnent une explication plausible pour la variation de polarisation avec l'intensité du faisceau.

Abstract. We have measured the beam energy dependence between 50 and 200 keV of the linear polarization fraction (M/I) of the $2s^1S - 3p^1P$, 5016 Å transition in He I on temperature. The thin carbon exciter foils were heated externally by nichrome resistance elements. The measurements of Hight et al.¹ are duplicated; the energy and current dependences are the same assuming corresponding between beam heating and external heating. We also observe that γ , the number of slow secondary electrons produced per incident ion decreases, with increasing foil temperature. These two effects, in conjunction, offer a plausible explanation for the variation of polarization with beam current density.

INTRODUCTION

In recent studies of the interaction of fast ions with thin carbon foils, Hight et al.¹ have measured the electronic alignment produced in excited neutral helium. In particular, they found that the alignment of the $3p^1P$ state oscillates as a function of beam velocity and also varies with beam current density. The variation of alignment with beam current density, $\Delta A_0^C / \Delta J$, also oscillates as a function of beam velocity. In this paper we analyze the possible effects on the electronic alignment of the foil temperature, and in turn, of the secondary electrons produced by the ion moving through the solid. We present further measurements which explain some of the basic features of the observed alignment variations and discuss other contributing factors to the production of electronic alignment.

It has previously been shown² that the number of back-scattered secondary electrons produced when fast ions bombard solid targets is dependent on target temperature, and Sternglass³ has explained these results qualitatively. Hence, we may expect that secondary electron production may also vary with the foil temperature in fast ion collisions. We have therefore performed two experiments in attempting to relate the secondary

electron flux to the production of alignment in the fast ion beam. We have measured the alignment of the $3p^1P$, He I state at beam energies between 60 and 180 keV as a function of the foil temperature. Secondly, we have shown that the secondary electron flux varies as a function of the foil temperature for the same ion beam energies. The results show that the alignment variations observed by Hight et al.¹ are due to the foil temperature changes. The alignment dependence on the secondary electron flux may be present, but is not definitely shown by the experiments.

EXPERIMENT AND RESULTS

Experimental work was carried out with the University of Chicago's 250 keV accelerator. A typical beam-foil arrangement was used. The carbon foil was supported and externally heated by two glass ceramic plates sandwiching a length of nichrome, bent around the beam apertures. The temperature of the foil was measured by an infrared bolometer. The emissivity of the foil, knowledge of which was necessary to interpret the bolometer readings, was determined with a series of infrared transmission measurements. While the bolometer sighted on a small area of the 1/4" diameter foil

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Fig. 1 - Foil temperature (°K) vs. beam current (μA); 1/4" diameter beam aperture. $I_{He} =$ beam current with no foil in place.

($\sim 3\text{mm}^2$) the ion beam flux filled the entire foil aperture, so spatial variations of foil temperature were negligible.

Using the optical detection system described by Berry et al.⁴ we measured the linear polarization fraction Stokes parameter (M/I) for the $2s\ ^1S - 3p\ ^1P$, 5016 Å transition in He I. Beam energies were varied between 60 and 180 keV, with the carbon exciter foils being perpendicular to the ion beam in all cases.

Secondary electron yields were determined by measuring the current at a plate at +4000V 1 cm above the foils, which were grounded. The foils in this part of the experiment were mounted on non-heatable Al foil holders. The foils were heated by increasing the beam current density.

In order to demonstrate an equivalence between temperature and beam current effects, it was first necessary to obtain the relationship between current through the foil and foil

Fig. 2 - Linear polarization (M/I) of the $2s\ ^1S - 3p\ ^1P$ 5016 Å transition in He I vs. foil temperature. Ion energy = 122 keV.

Fig. 3 - $S_T (\Delta(M/I)/\Delta T)$ vs. beam energy (5016 Å). The line corresponds to the equivalent beam current data of Hight et al.¹ $S_j/12.05 = S_T$.

temperature. The temperature vs. current relationship is shown in Fig. 1. If the foil's heat loss is due to radiation, we expect foil temperature to go as $J^{1/4}$. This is in fact what we observe; if we fit the data of Fig. 1 to the functional form $a + bJ^{1/4}$ we obtain the curve shown, with a zero current intercept of $308 \pm 100^\circ\text{K}$, in good agreement with the data.

M/I was measured as a function of foil temperature at energies ranging from 60 to 180 keV. the beam current was kept at about 1 μA. The first point at all energies was taken without external heating, thus providing us with a base temperature of about 620° K. Current through the nichrome heater was then increased in steps until maximum temperatures of about 950° K were reached. A typical slope, at 122 keV is shown in Fig. 2.

Fitting a straight line to these points gives a slope, $S_T = \Delta(M/I)/\Delta T$ which we have determined as a function of energy. These results are shown in Fig. 3. We can compare these results with those of Hight et al. by assuming a simple linear relation between beam current and foil temperature. By fitting a straight line to the data of Fig. 1 and dividing its slope into the values obtained by Hight et al. for S_j , we get the equivalent value for S_T . For clarity, we have drawn a smooth line through Hight's data and transposed it to the equivalent S_T curve to obtain the line in Fig. 3.

M/I vs. beam energy for the cases of no heating and maximum heating are shown in Fig. 4.

The extremely good agreement between the high current results of Hight et al. and our

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Fig. 4 - Linear polarization fraction (5016 Å) vs. beam energy. The upper points were taken for foil temperatures of $920 \pm 20^\circ\text{K}$. The upper line represents the data of Hight et al. taken with beam currents which produce foil temperatures of 920°K ($\sim 29 \mu\text{A}/\text{cm}^2$). The lower points were taken with no heating. The line through them is drawn for comparison with the high temperature (current) data.

temperature data is the best demonstration that the current dependence of M/I is actually a temperature dependent effect.

In Fig. 5 we show the variation of electron flux with foil temperature at a beam energy of 175 keV. A marked decrease results from increasing the temperature.

DISCUSSION

In light of the above experimental results,

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Fig. 5 - γ (= (secondary electron current/beam current)) vs. foil temperature at 175 keV.

the following model seems to explain the increase of alignment with foil temperature. As the foil heats up, less secondary electrons are produced. These secondaries would surround the ion which had produced them as it emerged from the foil, producing an essentially random electric field in the rest frame of the ion. This field, of the order of $5 \times 10^7 \text{ V/cm}$ would tend to reduce any anisotropy produced by some initial polarization mechanism. As a result, for higher foil temperatures we expect higher degrees of anisotropy, or polarization. The character of the initial polarization production mechanism is still in question. The energy dependence of both S_T and M/I would seem to imply that if electric fields at the foil surface are involved, they would most likely be time dependent. Such fields would be produced by the polarization wake evidence in the foil bulk by the ion. One can determine the influence of the polarization wake on alignment by varying foil materials (i.e. plasma frequency). Such work has been done⁶ although not over a large enough energy range to provide a complete test.

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