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STARK EFFECT IN He II AND H

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INSTITUTE OF ADVANCED STUDIES

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STARK EFFECT IN He II AND H

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Abstract: The beam-foil light source was used for a study of the Stark effect on He II (λ4686 Å) and H_β. For the former, the p- and s-components were detected for transverse and longitudinal fields. The transverse field data suggest that levels of high j are underpopulated relative to their equilibrium numbers. The longitudinal-field data are anomalous. For H_β, splitting was observed but the arrangement precluded the detection of polarization. The data also imply underpopulation of levels of high j.

I. He II

INTRODUCTION

We have observed the Stark effect in the n = 4 to n = 3 transition in He II (λ4686). The light source, unlike the gas discharges used in previous Stark studies 1), consisted of $^3He^+$ ions which, accelerated to energies between 200 and 800 keV, were electronically excited by passage through a carbon foil (thickness ~ 6 μgm/cm^2). Light from the particle beam was slightly demagnified and then spectrally decomposed with a low resolution Jarrell-

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Ash spectrograph (reciprocal dispersion 64 Å/mm) fitted with 100 μ-wide entrance and exit slits. The dispersed light was detected with a cooled, selected 1P21, the output current from which was measured with a GR 1230 A electrometer or Keithley 417 picoammeter and recorded on a strip chart as the grating was rotated with a synchronous motor. A manually-operated switch put a marker on the strip chart every 10 Å, the uncertainty of marker location being ± 0.5 Å.

The particle beam, collimated by an aperture 2 mm in diameter, entered the 5 mm-wide gap between two parallel metal plates; application of a potential difference of 35 kV to the plates produced the external electric field. Although the plates were slotted to prevent their being struck by ~~charged particles, field plots showed that the~~ field was uniform to within 1% at the point at which the observations were made.

Two geometrical arrangements were used: the field was either transverse (vertical) or longitudinal (horizontal), relative to the (horizontal) beam velocity. See Fig. 1. In each case, the direction of observation was transverse (and horizontal) to the beam velocity. In the first arrangement, the deflection of the ion beam when the external field was on, made it impossible to monitor the particle current, and we relied on the constancy of the current over the minute-long scans. In the second arrangement, the beam was collected in a Faraday cup whether the field was on or off, but the collection of energetic (15 keV) electrons caused the apparent current to fall sharply when the field was on. (Reversal of the field direction filled the gap between the

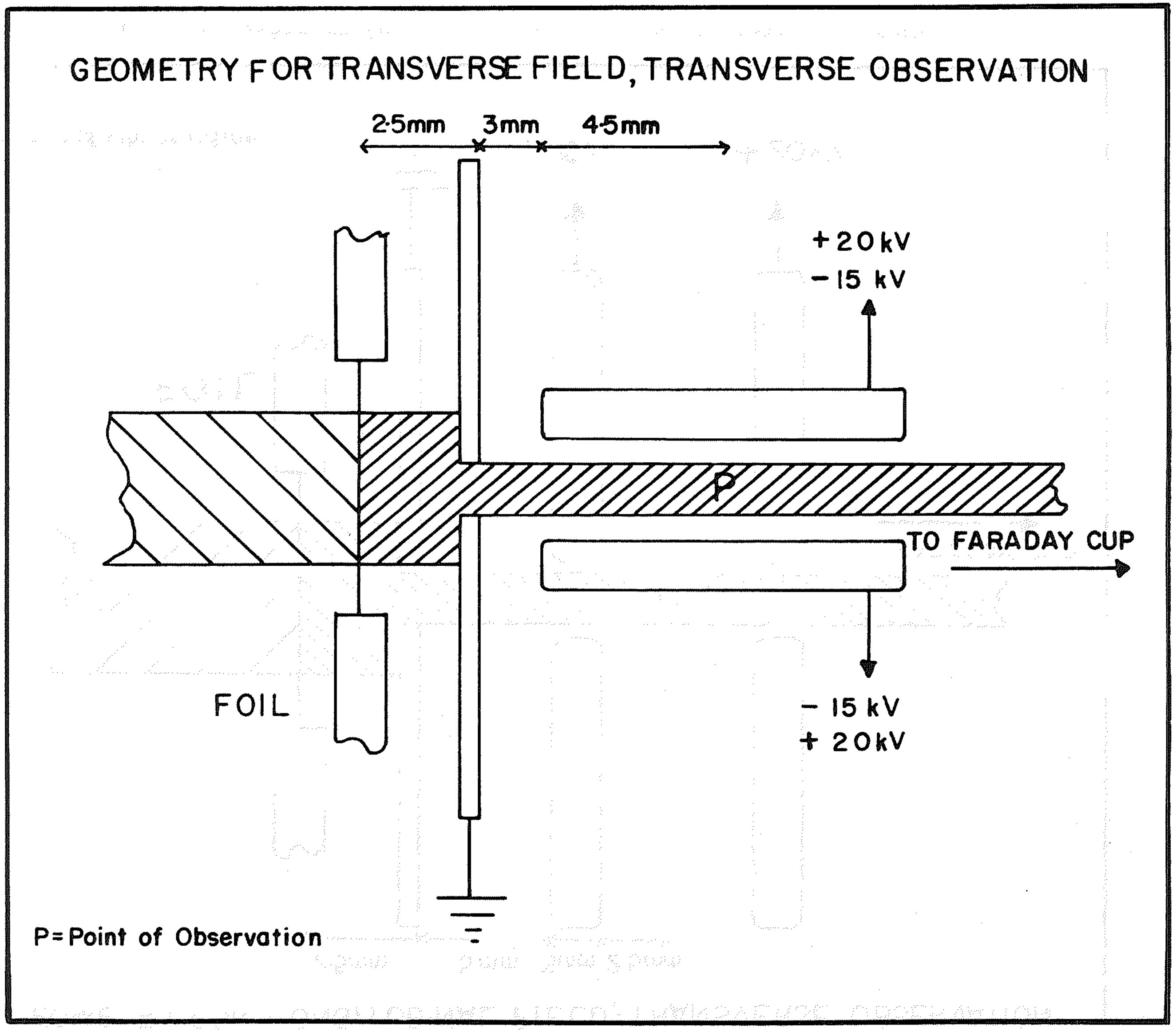

Fig. 1a: Geometry for transverse field, transverse observation.

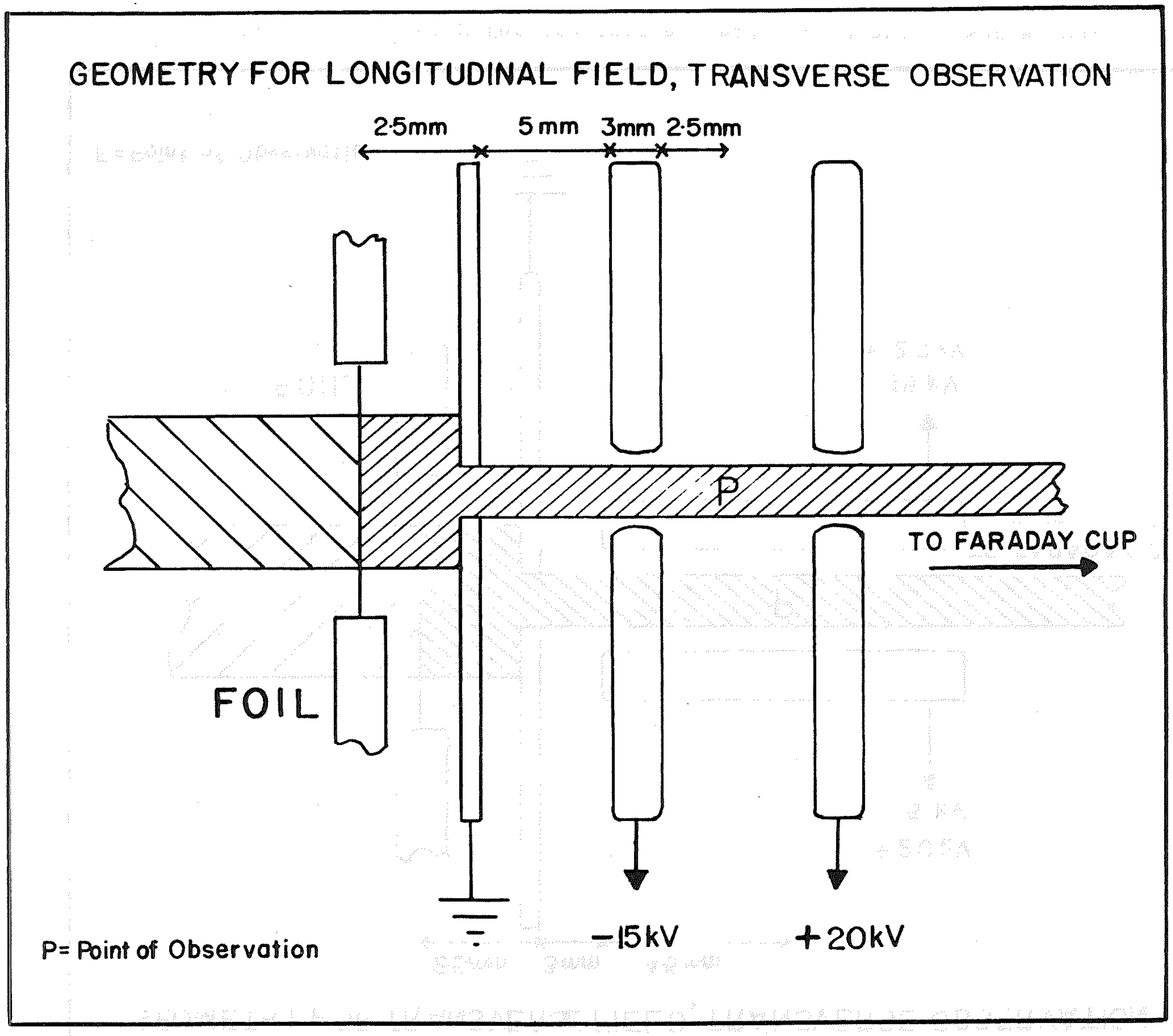

Fig. 1b: Geometry for longitudinal field, transverse observation.

plates with energetic electrons, liberated from the foil or aperture plate, and increased the noise in the system.) In neither case has any account been taken of the field-induced alteration in the energy of the incident ions.

The particle current, severely limited by the focal properties of the 2 MeV Van de Graaff accelerator we used, varied from 3 μa at 800 keV to 0.3 μa at 200 keV. However, there was a rapid change in the efficiency of excitation of $n = 4$ as the particle energy was varied, and the signals had about the same size over the entire energy range. The energy dependence of the intensity of λ4686 appears in Fig. 2.

In order to observe polarization effects, a plate of high-transmission polaroid was placed in front of the spectrometer's entrance slit and so rotated as to pass light with its electric vector either parallel (p) or transverse (s) to the lines of the applied field. Since reflection from the grating introduced some polarization, a larger fraction of the light was transmitted to the photomultiplier when the electric vector was vertical than when horizontal.

RESULTS

1. TRANSVERSE (i.e., VERTICAL) FIELD

A. P-observations (electric vector vertical) See Fig. 3

Relative to the three fiducial marks which are shown on each plot and for which the instrumental zero error in the wavelength scale has NOT been corrected, there is an obviously increasing red-shift as the particle energy is

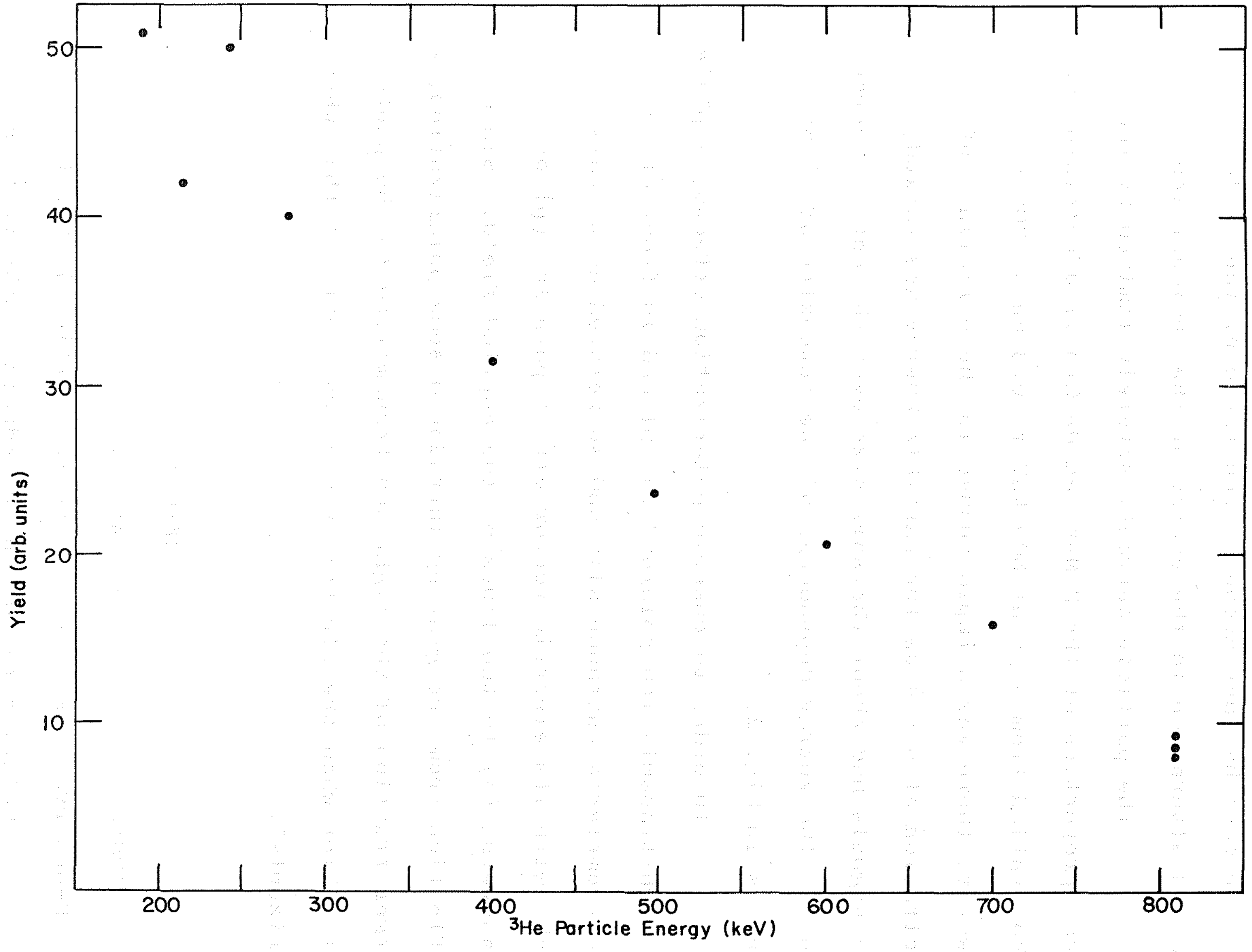

Fig. 2: Yield of λ4686 Å as a function of ^{3}He energy.

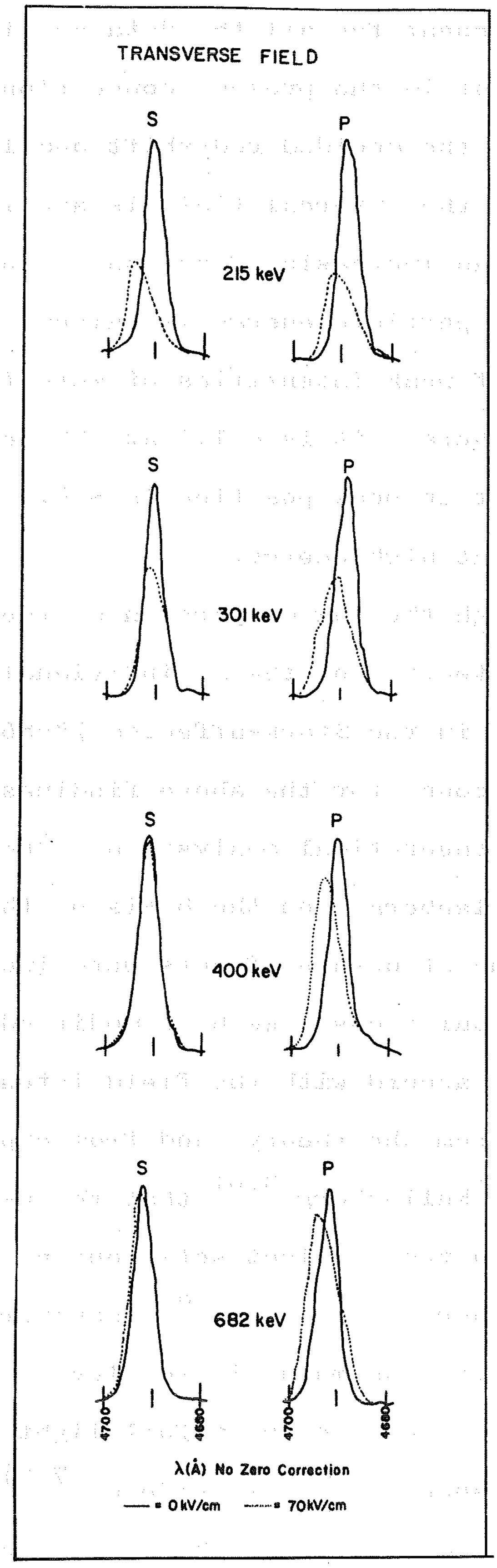

Fig. 3: Results of transverse field, transverse observation.

raised from 215 to 682 keV. This is merely the Doppler shift; it is present for all the data and is of no essential interest in the present connection. Of greater significance are the decided red-shift and line broadening which occur when the external field is applied. Figure 3 also shows that an increasing fraction of the light is p-polarized as the particle energy is raised. Thus, at 215 keV, the ratio of peak intensities of zero field to full field is ~ 2.5 whereas it is ~ 1.1 at 682 keV. At low energy, the shift in peak position is ~ 4.4 Å, whereas it is only ~ 2.5 Å at high energy.

Although the low dispersion of the spectrograph precluded the detection of the 26 individual p-components (some very weak) in the Stark-affected λ4686, one can qualitatively account for the above findings by referring to the complete theoretical analysis of λ4686 which was presented by Kullenberg 3) on the basis of the work by Schlapp 4). Fine structure effects were included in Kullenberg's calculations; we have modified his numerical results to be in accord with the field intensity we used. It is apparent from the theory, and from experimental work by Foster 5) and Kullenberg 3,6) that the p-components should split into two distinct sets, one at wavelengths longer and one shorter than 4686 Å. However, those results assume that the various magnetic sub-levels for n = 4 are equally populated. For the beam-foil light source used in the present instance, there is evidence 7,8) that levels of large j are excited less often than levels of small j; such a situation would give rise to the asymmetry and shift we observe. In particular, the j = 5/2 and 7/2 levels appear to be appreciably under-populated when the excited particles emerge from the foil. On the other hand, the reduction in asymmetry and shift with increasing particle energy suggests that the high j-value levels are more commonly populated populated the greater the particle energy.

B. S-observations (electric vector horizontal) See Fig. 3

These data show somewhat less consistency than the p-data. Thus only the lowest energy results contain any significant shift in peak position, and the red-ward asymmetry, prominent for energies of 300 keV and below, is less certain at the higher energies. The general trend of intensity with energy, however, resembles that for the p-components.

The theory shows that the most intense s-components should originate in the j = 5/2 and 7/2 levels, and that the corresponding transitions have wavelengths shorter than 4686 Å. Therefore the observations are consistent with the view, mentioned above, that the levels with large j-values are under-populated, the deviation from the equilibrium concentration being greatest at low particle energies.

2. LONGITUDINAL (i.e., HORIZONTAL) FIELD

The p-data (Fig. 4) resemble the foregoing as regards the variation of intensity with particle energy, but are very different in that the red-ward shift so clearly seen in the transverse field case is absent.

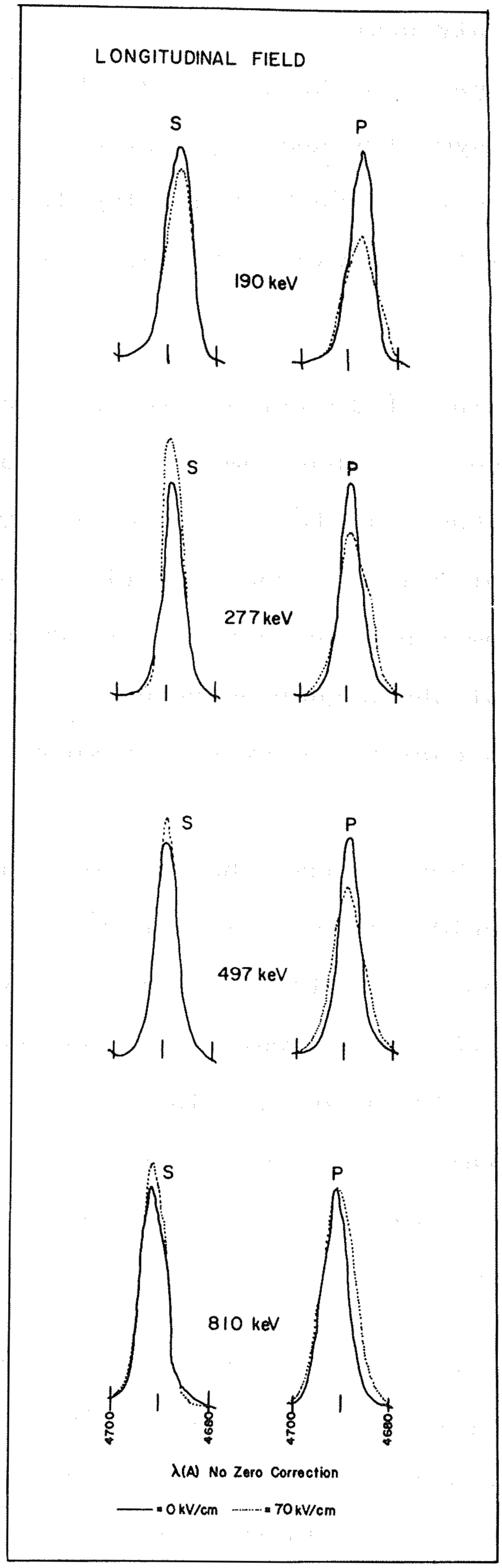

Fig. 4: Results of longitudinal field, transverse observation.

Furthermore, the broadening is less pronounced and tends to be symmetrical, relative to what is described in 1.A. The s-data (Fig. 4) are also lacking in shift and further fail to exhibit either broadening or an intensity dependence on particle energy.

This unexpected set of data led to a second study in which the point of observation was further (2.5 mm) in the field. The results, however, were unaffected. No instrumental difficulties appear likely to explain these data, and we conclude that they are caused by some still-unidentified connection between the direction of the applied field and the particle velocity. It has been suggested [9)] that hydrogen atoms emerge from the foil with angular momenta transverse to the beam velocity. Perhaps some such effect enters into our experiment and causes the difference between the transverse- and longitudinal-field results.

II. H

Studies were made of H_β (Fig. 5) which was excited by permitting 850 keV CH_4^+ ions to pass through the foil. That the line at 4861 Å was due to hydrogen rather than to a transition in carbon is justified by the behaviour of the line in the presence of the applied field. In this experiment, the field was horizontal, transverse to the particle velocity, and parallel to the direction of observation. Therefore, polarization of the light was neither expected nor seen. However, the line shows an obvious broadening (at 40 kV/cm) and splitting (at 80 kV/cm).

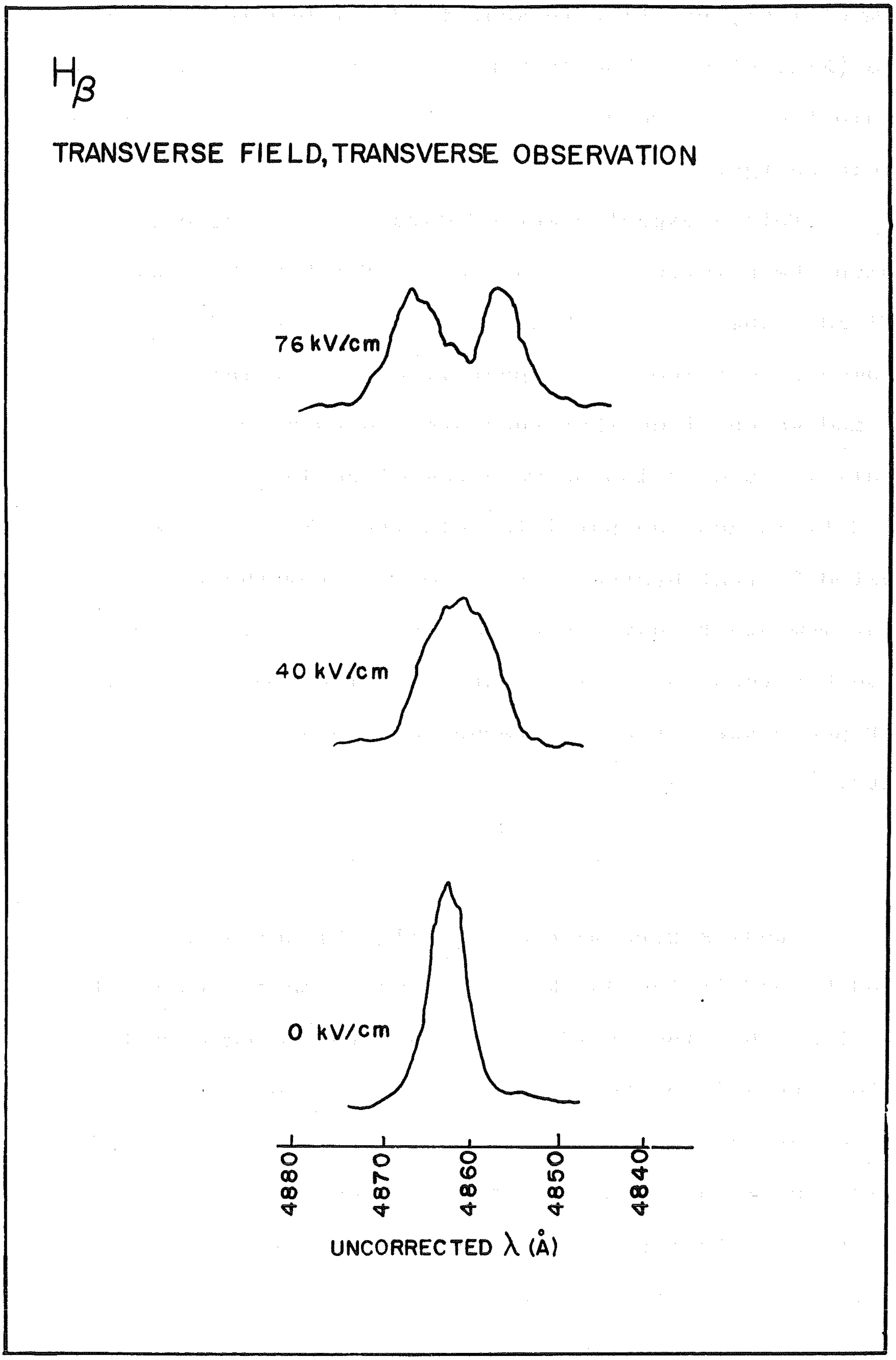

Fig. 5: Stark effect on H_β for several field strengths. Transverse field, observation in direction of field.

There is a clear preponderance of long wavelength components although the theory predicts 10) a symmetrical distribution. Bethe and Salpeter 1) have supplemented Schrödinger's original intensity calculations for H_α with another set in which it is assumed that the populations of the Stark levels are proportional to the product of levels' statistical weights and their mean lives. The mean life factor gives results in somewhat better agreement with the H_α data of Mark and Wierl 11) in which the radiative decay took place in a vacuum, whereas Schrödinger's calculations apply better when the decay occurs in a gas at moderate pressure. Thus it is not unexpected that the intensity pattern we have seen is different from the equilibrium distribution. Our data, as for the He II results, give evidence that the levels of high j, which theoretically contribute the short wavelength components, are underpopulated.

III. Further remarks

The above results suggest that the beam-foil light source can be used 12) successfully for experiments on the Stark effect. It is particularly interesting to point out that the combination of the present arrangement with the lifetime-type of experiment can give a direct comparison of measured and theoretical values for the mean lives of the Stark levels. In addition, extension of the present research to other elements can give information of utility in the diagnosis of plasma behaviour 13). The limitations on particle current and spectroscopic resolution are local rather than fundamental.

We thank the University of Arizona for the loan of the spectrograph. One of us (S.B.) is grateful for the fellowship which brought him to this laboratory.

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