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CHARGE OF IONS EMITTING SPECTRAL LINES

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Abstract: A modified technique has been applied to the beam foil light source to determine unambiguously and correctly the charge of the ions from which spectral lines are emitted. After transmission through the thin exciter foil, the luminous beam of ions passes through a transverse electric field of up to 80 kV/cm. The field introduces a Doppler shift which depends in magnitude on the charge state of the emitting ion and in sign on the direction of the field. In the spectral range from 1800 Å to 8000 Å, lines from carbon, nitrogen and neon were distinguished and assigned to various transition arrays. The present technique, unlike those previously used, is readily adaptable to the vacuum ultraviolet.

1. Introduction

A light source which produces light from ionized emitters usually contains a distribution of ionization states. To properly study spectral lines from the source it is necessary to assign the states of ionization to the lines under observation. Attempts to identify the ionization state using several different techniques have been made. In nearly all cases the data have been obtained from non-beam-foil sources. The techniques include: a) extrapolation of a distinct pattern of spectral lines along an isoelectronic sequence down to the neutral number, b) intensity measurements as a function of the voltage applied in a spark

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discharge, c) theoretical calculation of the level system which could give rise to the observed system.

The techniques mentioned above have been used quite successfully but in some cases have proved difficult to apply. It is now possible to use the beam-foil light source [1] to produce rigorously correct ionization state assignments.

Two different methods of ionization state assignment, both implementing the beam-foil source, have been used. The first method is to study the intensity of a spectral line as a function of the particle energy [2,3]. This is possible because of the energy dependence of the charge state distribution. This method, like the three techniques mentioned above, gives results that are suggested of the appropriate ionization state.

In the second method, which we have used, a spectroscopic study of the light is made after the beam passes through an electric field. Figure 1 illustrates the deflection of components of the beam that have different ionization states as the beam passes through the field. The deflecting field, which may be reversed in sign, gives a particle a transverse velocity component which is dependent on the ionic charge of the particle. This component introduces a Doppler shift in the wavelength of the emitting ion. It is possible to study the separate components of the beam by viewing in a plane normal to the field [4], and also to look at the composite beam by observing in the plane of the field [5].

The previous charge deflection experiments have used photographic plates as a photon detector. There are various reasons why photomultiplier detectors are to be preferred. These include direct read out, linearity of response and usefulness in the ultraviolet region. In this paper we describe the use of photoelectric detection in charge deflection identification of ionization states.

2. Experiment

A conventional beam-foil light source has been used in this experiment. A schematic diagram of the

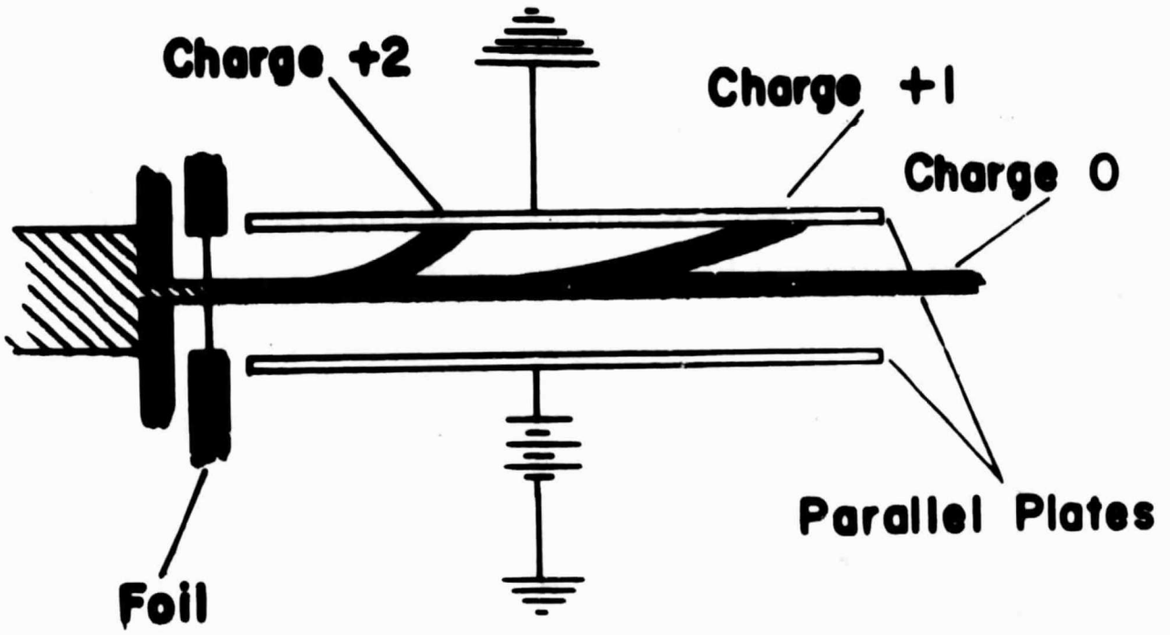

Fig. 1: Diagram of charge splitting apparatus.

experimental apparatus is shown in fig. 2. The beam of ions passes through a thin carbon foil and after being collimated to a 2 mm cross section by a thin grounded plate, passes between two parallel metal plates. The plates have a 5 mm separation and it is possible to produce deflecting electrostatic fields of up to 80 kV/cm. The spectral lines, when observed in the horizontal plane (parallel to the deflecting field) are Doppler shifted, either to the red or to the blue, depending on the sign of the applied field. The parallel plates are slotted so that the beam may be observed while the particles are in the field.

Light from the beam is focussed on the entrance slit of a 1/3 meter, f/5.3, scanning monochromator. All windows and lenses are of quartz so that measurements in the ultraviolet can be carried out. The spectrally decomposed light is detected by a cooled EMI 6256S photomultiplier operated at -1300 volts. The signals from the photomultiplier (of the order of nanoamps) are amplified by a Keithley model 417A picoammeter and fed into a strip chart recorder. The monochromator contains a device which

produces a signal at 10 Å intervals through the wavelength scan. This signal is also fed into the strip charge recorder.

The monochromator calibration was checked with several standard source lamps. The line width observed for isolated intense lines is approximately 5 Å and we assign an uncertainty of ± 0.3 Å to the central wavelength. For other lines the uncertainty could be twice as great.

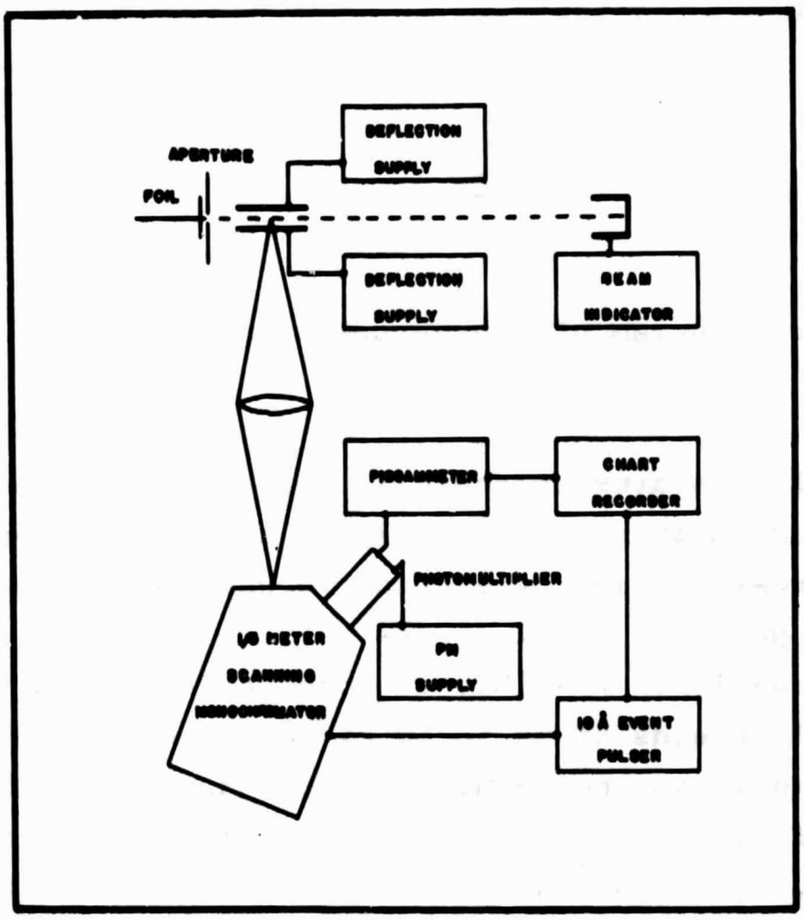

Fig. 2: Schematic of experimental apparatus used for ionization state assignment.

An indication of the amount of beam passing through the foil could be obtained by measuring the current collected in a shielded Faraday cup. The beam was not monitored during the experiment because the deflecting field sweeps the beam away from the cup. The stability of the beam was checked by observing the fluctuations in beam current when no deflecting field was applied. It was found that the beam stayed very steady over the short periods (1-2 mins.) required for the wavelength scans.

3. Results

Spectral lines from three elements, neon, nitrogen and carbon, have been studied in the wavelength range of 1800 Å to 8000 Å. The beam energies ranged from 600 keV to 1350 keV and the currents from 1/2 to 1 microamp. Because of severe Doppler broadening at longer wavelengths most of the emphasis has been placed on data taken in the 1800 Å to 5000 Å range.

Figure 3 illustrates parts of the spectral scan at a neon particle energy of 950 keV. The Doppler shifts, when deflecting fields of +70 kV/cm and -70 kV/cm are applied, can be clearly seen. Application of the field does not change the separation of the two lines in the set at the left of the diagram. This shows that these two lines arise from the same ionization state. On the other hand the change in separation of the lines in the other two cases shows that the two lines in each set arise from different ionization states.

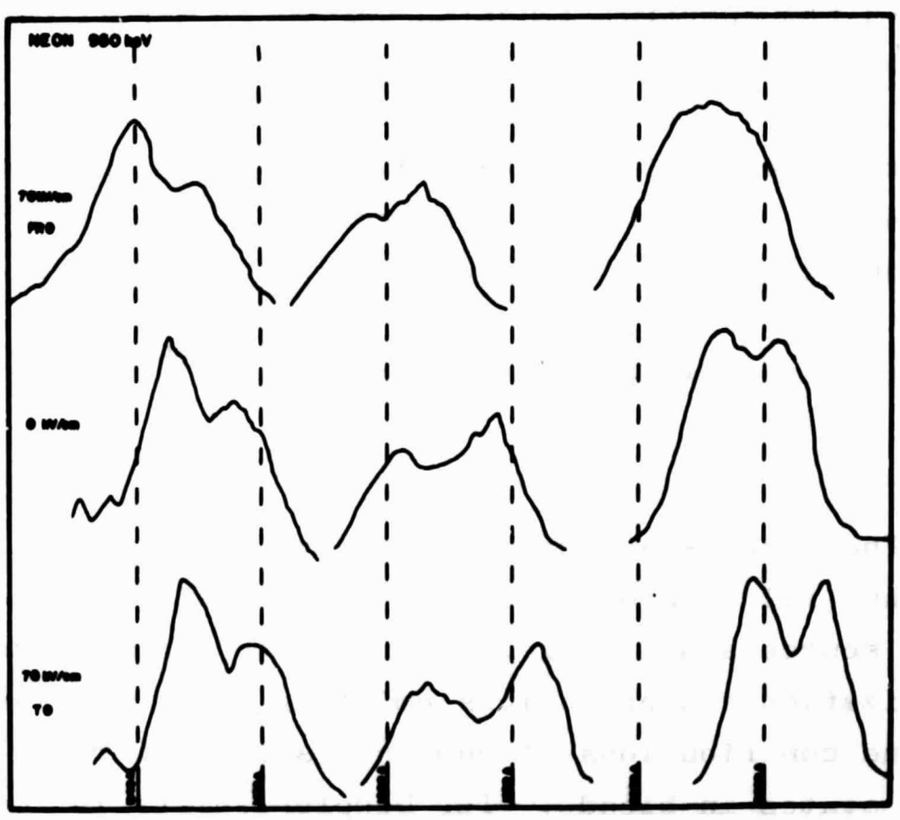

Fig. 3: Examples of typical spectral lines in neon showing Doppler shift effect with application of deflecting field.

From this we can see that, although this method cannot be used to resolve overlapping lines arising from the decay of ions in the same charge state, it can sometimes do so when the ions are in different charge states. In some cases the levels may be completely resolved when the field is applied, on others only a broadening may be seen. It must be remembered that the Stark effect can also cause line broadening [6] but in this case the nature of the broadening is independent of field direction.

Data on neon have been taken at particle energies of 600 keV and 950 keV in the spectral range of 1800 Å to 5200 Å. 75 spectral lines have been clearly observed and all but 7 lines have been identified with listed transitions [7,8,9] in Ne II through Ne VII. Ionization states have been assigned to the 7 previously unknown lines. In addition, ionization states have been assigned to 9 lines where the ionization states has been previously reported as uncertain. These lines arise from unclassified neon transitions.

Thirty spectral lines in carbon at a particle energy of 650 keV have been seen. In nitrogen 60 lines have been identified at particle energies of 610 keV and 1350 keV. A wavelength range of 1800 Å to 6000 Å has been used for both carbon and nitrogen. All observed lines in carbon and nitrogen can be assigned to known transitions in ions with charge states II through IV and the assignments of the charge states agree with previous results [7,8,9].

4. Summary

The results of the measurements described in this paper further illustrate the simplicity of using the beam-foil light source and a deflection field to unambiguously assign ionization states to ions emitting spectral lines and to determine contributions of components of different ionization states in blends. The Doppler shifts introduced by the deflecting field are easily measured. Through the use of photoelectric detection, it is possible to use the charge deflection method in the ultraviolet and vacuum violet ranges. This advantage, coupled with the benefit of being able to study any element that can be used in the beam-

foil source, greatly increases the possibilities of using this method to assign ionization states to emitting ions.

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