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THE UNIVERSITY OF TOLEDO BEAM FOIL FACILITY

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The facility for experimental work in beam foil spectroscopy being developed at The University of Toledo involves several novel features which will be described here. These include:

1. Provisions for optically scanning the ion beam and automatically recording the data so obtained in a multichannel analyzer. Scanning is accomplished by moving a collimating lens and mirror parallel to the beam with constant velocity. The collimated beam is subsequently focused on the entrance slit of a Perkin Elmer $f/4.5$ grating monochromator. Single photons are detected and pulses are recorded in a multiscaler synchronized with the beam scanner.

2. A facility for making charge state identification of spectral lines using a technique which is compatible with the geometry employed for mean life measurements is being constructed. A set of parallel electric field plates can be raised in the observation chamber to beam level through vacuum feed-throughs and a transverse electric field applied. Light from the beam is observed through a slit located a distance L downstream along the plate and spectral wavelengths are determined for both directions of the applied electric field E. The net transverse Doppler shift induced can easily be seen to be $\Delta\lambda/\lambda = Z \cdot 2eEL/(2mc^2T)^{\frac{1}{2}}$, where T and mc^2 are the kinetic and rest energies of the ion beam respectively. Introduction of representative parameters shows that a shift of 2 Å/unit charge is easily attainable.

3. Use of nanosecond pulsed beam time of flight techniques to measure the energy of the ion beam after it emerges from the foil. This technique has been in routine use in this laboratory in nuclear physics experiments and its extension to these applications will be described.

1. Introduction

The facility for research in beam foil spectroscopy being developed at The University of Toledo involves a number of novel design features. Several of these will be outlined in the present paper. The research facility described here is based on a 400 keV Van de Graaff accelerator manufactured by High Voltage Engineering Corporation, a momentum-analyzing electromagnet and a feedback voltage stabilization system – all originally used in the study of the inelastic scattering of neutrons[1]). The suitability of such a system for research in beam foil spectroscopy is well known and will not be discussed. There are, however, several unusual features of the instrumentation system we will employ which we wish to describe.

2. The optical beam-scanning system

Several years ago, Kohl of our laboratory pointed out the advisability of sampling the position dependence of the emitted intensity as a function of distance from the foil in a time which is short compared with the time for degradation of the foil or beam fluctuations[2]). He proposed a very rapid sampling system based on a stigmatic monochromator aligned parallel to the beam with the exit slit scanned at kHz repetition rates by an ITT image-dissecting multiplier phototube. Unfortunately, funds for this project did not become available and it was never implemented. More recently, Bickel of The University of Arizona suggested a much simpler sampling technique[3]) which can be used if longer scan times are acceptable. In this approach, the foil itself is translated rapidly forth and back at constant speed while the monochromator views a fixed region in space. In the present work, designed for application over the visible and near-visible range of the spectrum, both the foil and the monochromator are held fixed while a series of observation points are rapidly scanned by means of an appropriate optical system.

The technique employed is illustrated schematically in fig. 1. Light from an observation point along the beam is collimated by lens L_1 and reflected by mirror M, oriented at 45° to the direction of incidence. Parallel light from the mirror is then focussed by lens L_2 onto the monochromator entrance slit. L_1 and M are rigidly mounted on a table which is translated parallel to the beam at constant velocity by a synchronous motor-driven precision ruling engine. The speed of translation is variable, as are the end points of the travel. Microswitches at the end points (denoted by 1 and 2 in fig. 1) in conjunction with a hybrid electronic system perform the logic operations necessary to start, stop and reverse the drive as well as to synchronize the drive to a multichannel analyzer. The analyzer is used in the multiscaling mode to accumulate the intensity vs position data. The analyzer is triggered when the drive leaves position 1 and the channel advance is gated off while the drive is being stopped and reversed at position 2. The rate of channel advance is determined by an external clock pulse and is adjusted to be commensurate with the cycling rate of the optical scanner.

A number of tests of this device have been made and

* Presented the paper.

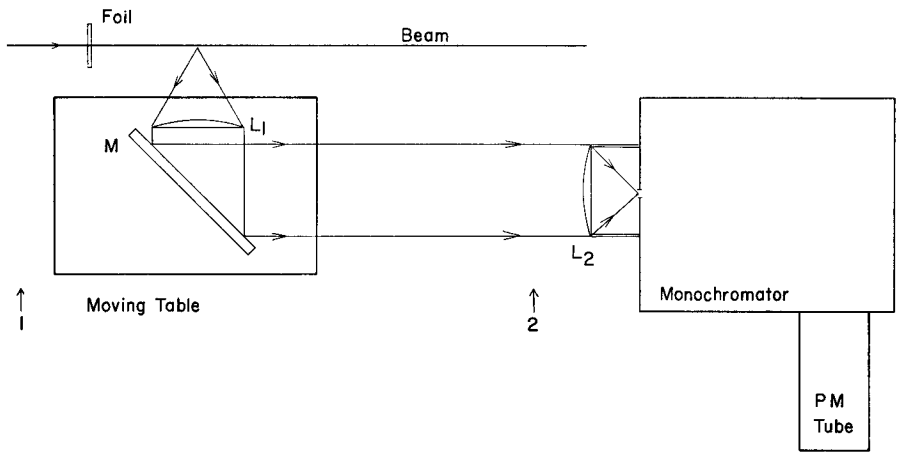

Fig. 1. Schematic diagram of the optical beam scanner.

it has performed most satisfactorily. For example, while the light collection efficiency at the monochromator is predicted to be independent of the optical path between L_1 and L_2, it is conceivable that aberrations might vitiate this conclusion. Thus, an experimental test of this prediction is important. A small panel lamp was mounted in a fixed position relative to the scanning table and was placed at the focal point of L_1. The drive was run back and forth through a distance of 10 cm and no change in the counting rate per channel was detected within the 1% statistical accuracy of the data obtained. Next, the panel lamp was mounted in a fixed position relative to the monochromator, and the scanner again placed in operation. The results are drawn in fig. 2. The two peaks are, indeed, mirror images of each other and the peak position and shape reproduce well in repeated trials. Finally, it was determined that the peak shape was

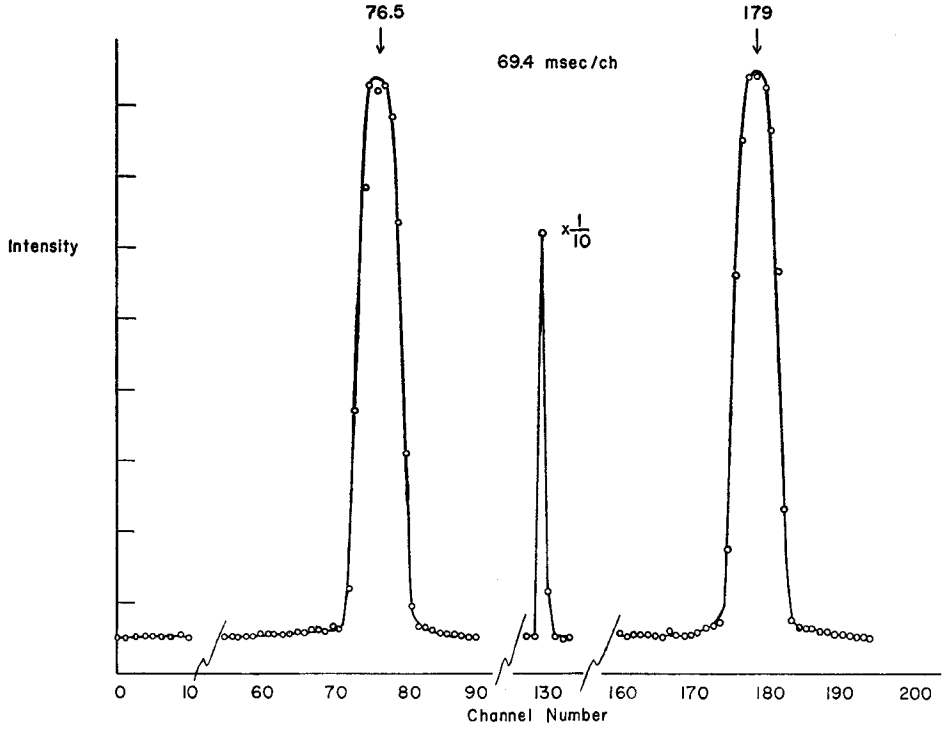

Fig. 2. Typical test results for the optical beam scanner.

independent of wavelength over the range 3800–7000 Å (negligible effects due to chromatic aberrations) and translation of the lamp position parallel to the beam (good velocity stability). Dead time corrections in the multiscaler were measured and are less than $\frac{1}{2}\%$ at counting rates up to 100000 counts/sec.

Spectral analysis is performed with a Perkin Elmer $f/4.5$ grating monochromator. The detector employed in the tests made here was an RCA-8644 with an S-20 photocathode used as a single photon detector. Dark current for this tube is approximately 150 counts/sec at 85% single photoelectron counting efficiency at room temperature and can be reduced by a factor of about 3 by cooling to 5°C. Also available is an ITT FW4034 multiplier phototube with an S-20 cathode with only 10 counts/sec dark counting rate under similar conditions (room temperature) and an ITT FW4034 with an S-1 cathode and a dark count rate of 1 count/sec when cooled with dry ice.

3. Charge state identification

In designing a viewing chamber for use with the beam scanner, provisions were made for the use of applied electric fields to effect definitive charge state identification of observed spectral lines. Unlike most previously used schemes[4,5]) the technique employed here is compatible with the geometry used for mean life measurements. When not in use, the field plates are located in the viewing chamber below the beam level and do not interfere with the measurement of mean lives using the apparatus described earlier. When charge state measurements are to be made, the plates are raised to beam height through vacuum feedthroughs and a transverse electric field E is applied. This situation is illustrated in fig. 3. Radiation emitted at right angles to the beam is viewed by the optical system through a slit in one of the plates located a distance L from the foil, as shown. If fringing is neglected, the fractional change in wavelength of a spectral line when the electric field is reversed can easily be seen to be

$$\Delta\lambda/\lambda = Z \cdot 2eEL/(2mc^2T)^{\frac{1}{2}}, \qquad (1)$$

where T and $2mc^2$ are the kinetic energy and rest energy of the ion beam, respectively, and Z is the ion charge (in units of the electron charge, e). As an example, if one considers 400 keV oxygen ions, $E = 20$ kV/cm, $L = 1$ cm (corresponding to a flight time of approximately 5 nsec) and $\lambda = 6000$ Å, eq. (1) predicts

$$\Delta\lambda \cong 2 \text{ Å}/Z.$$

Of course, eq. (1) is an oversimplification and is not exact. It is adequate, however, to allow prediction of the order of magnitude of the effect expected. In practice, the system can be calibrated by measuring $\Delta\lambda$ for any one known spectral line. In order to facilitate accurate Doppler shift measurements, the monochromator is being modified to allow a photographic plate to be inserted just in front of the exit slits.

4. Beam velocity measurement

In order to accurately measure mean lives, the velocity of the ion beam after it leaves the foil must be precisely known. At the relatively low energies to be employed here, uncertainties in dE/dx and foil thickness often make a measurement of the velocity of the outgoing ions imperative.

A convenient method of accomplishing such a measurement is the use of nanosecond pulsed beam time of flight techniques, and instrumentation for this purpose was constructed some time ago as part of the nuclear physics research facility[6]). The basic principle is illustrated in fig. 4. The ion beam passes through a pair of transverse deflection plates to which a 5 MHz rf driving voltage is applied, as shown. Those ions

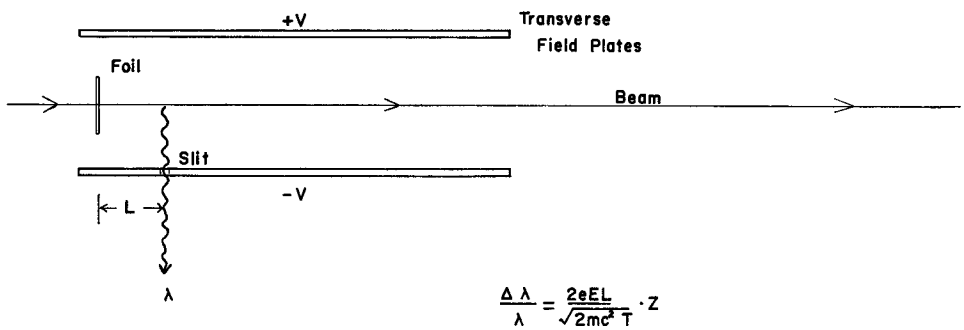

Fig. 3. Schematic diagram of the configuration for charge state identification.

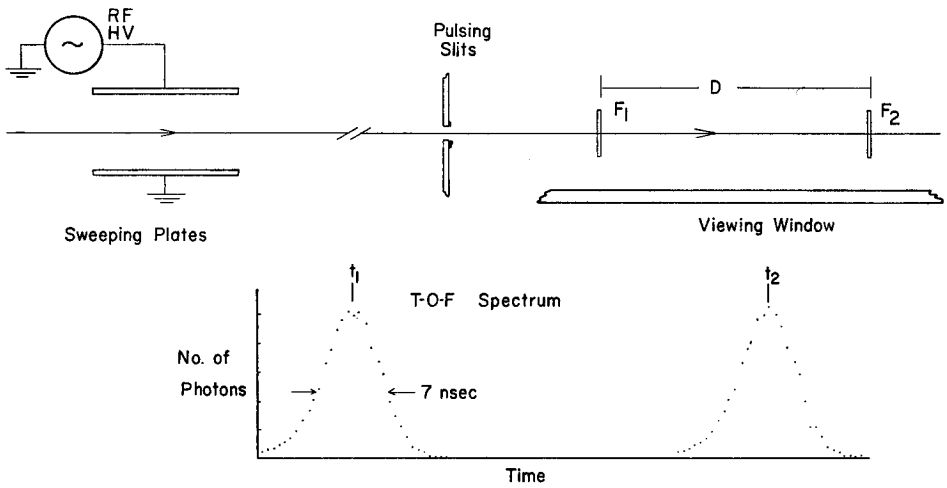

Fig. 4. Schematic diagram of the pulsed beam time of flight facility.

which traverse the plates near the zero of the rf cycle will be undeflected and will also pass through the pulsing slits located about 1m beyond the sweeping plates; ions traversing the plates at other times will experience a net deflection and will strike the slits. The result is a series of ion pulses occurring every 100 nsec with a width determined by the details of the pulsing system. In the system described here, 7 nsec widths are routinely obtained.

Timing is done by use of fast leading-edge discriminators and a time-to-pulse-height converter. The converter can be started at a fixed arbitrary point of the rf cycle and stopped when a photon is detected from a point directly in front of foil F_1. A typical spectrum would appear as shown in the lower part of fig. 4. The detector can then be moved to view light emitted directly in front of foil F_2 and the procedure repeated. The result will be a shift in the position of the peak from T_1 to T_2 corresponding to the flight time over the distance D, and the velocity is given directly by $V = D/(T_2 - T_1)$. $T_2 - T_1$ can easily be obtained using this system to an accuracy of 1–2 nsec. For the example of a 400 keV oxygen ion chosen before, a choice of $D = 20$ cm would therefore give rise to a determination of V accurate to 1–2%. In practice, in order to minimize dead time losses, the time-to-height converter is started by the signal from the phototube and stopped by the signal derived from the rf. Except for a reversal of the time axis, this does not change the use of the system described above.

5. Conclusions

Most of the facility described in this paper is now in operation. The final components will be completed shortly, and it is expected that the system will prove to be most useful in carrying out an active program in beam foil spectroscopy.

The authors wish to thank Mr. G. Buenning, head of our machine shop, who constructed many of the components of the system described herein, and Mr. M. Nissen and Mr. B. Ryan for help with the electronic instrumentation. One of us (RMS) wishes to thank Dr. S. Bashkin for the hospitality of his laboratory where he received an introduction to beam foil spectroscopy and to the Hebrew University of Jerusalem, under whose hospitality many of the ideas described here were developed.

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Discussion

PINNINGTON: How far downstream from the foil were you looking?

SCHECTMAN: 1 cm downstream. For the example of 400 keV O^+ ions, that corresponds to 5 nsec. This is a compromise between a large Doppler shift and the beam light decaying away.

BICKEL: Can you measure energy losses with your method?

SCHECTMAN: Mean energy losses, yes. But I guess we can measure only crude energy loss distributions because of the 7 nsec beam width which has to be unfolded. Electrostatic analyzers can do much better.