BEAM FOIL SPECTROSCOPY OF HIGHLY IONIZED FLUORINE,
SILICON, AND COPPER BEAMS

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Introduction

The usefulness of a Tandem Van de Graaff accelerator in beam foil spectroscopy for studying properties of excited electronic states in highly ionised systems was discussed in some depth by Jordan (1), but comparatively little work has so far been reported in this field. The most fundamental aspect of such work would appear to be the possibility of making accurate atomic structure measurements in systems containing 1, 2 or 3 electrons, where such measurements can constitute a severe test of atomic structure theory. Another field of interest in this context is the study of spectra and lifetimes in ions of astrophysical and plasma-physics importance.

The ready availability of substantial beam currents of oxygen and fluorine with the Oxford Tandem Accelerator led us to begin measurements in highly ionised spectra of these elements with the aim of i) throwing some light on the relative excited state production cross-sections which are of interest in nuclear quantum beat studies (2), and ii) eventually obtaining accurate atomic structure measurements in the hydrogen-, helium- and lithium-like ions. More recently a universal ion source has become available and we have extended our work to silicon and copper ions.

A study of oxygen spectra at tandem energies has recently been published (3), and our work is in general accord with the previous study. We shall thus present here results of spectral surveys in the visible region of the spectrum on foil excited beams of $^{19}$F, $^{28}$Si and $^{65}$Cu. We first describe the experimental method; the results are then tabulated and an interpretation given. None of the spectral lines we have observed appears to have been reported before.
Experimental

The experimental set-up and associated electronics were of the standard type; the spectrum emitted from beams excited by passage through a thin carbon foil was analysed by a Hilger Ionospek 1300 Czerny-Turner monochromator which was modified to step in multiples of a 0.125 \( \text{Å} \) step on receipt of a command pulse. Optical spectra were recorded digitally using photo-electron counting, and the spectra were taken into a multi-channel analyser in multiscale mode. Beam current fluctuations were corrected for by ensuring that for each wavelength interval observed, photons were counted for fixed elapsed beam charge, typically \( 10^{-5} \text{coulombs} \). A typical scan of the complete visible region took about 10 hours (with 10 \( \text{Å} \) steps). The spectra were transferred from the HCA directly to a PDP-10 computer where they could be calibrated and analysed. The beam was focussed into the entrance slit of the spectrometer using 2 silica lenses, and the point of observation of the beam after the foil could be varied.

The spectrometer optic axis was set perpendicular to the beam axis to within a few milliradians, to avoid large first order doppler shifts. The spectra were calibrated both against the known spectrometer calibration, and in the case of fluorine, against known lines in \( \text{He-like} \) fluorine.

Results

1. Fluorine

A typical spectrum observed at 19 MeV is shown in figure 1. This is a scan of the spectrum using 4 \( \text{Å} \) per channel. The resolution was improved by the refocussing technique (4). Figure 2 shows a small part of this spectrum recorded with much better resolution (1 \( \text{Å} \) per step) in an attempt to observe the \( 1s3s^3S_1 - 1s3p^3P_0,1,2 \) transition of He-like fluorine.

The majority of lines observed are presented in table I; as is seen, most may be ascribed to transitions of the type \( \Delta n = 1 \) or 2 for large principal quantum number \( n \), first reported by Lennard (5) et al in \( \text{Ni} \) and \( \text{Fe} \) ions. Similar transitions appear to have been observed in all beam foil spectra of highly stripped ions in the visible region of the spectrum. The transitions in the region of 5150 \( \text{Å} \) which are as yet unidentified are of interest in that the \( 3s^3S - 3p^3P \) transitions of the helium-like ion are expected to lie in this region. It is tempting to ascribe the group of transitions 5147 \( \text{Å} \), 5155 \( \text{Å} \) and 5179 \( \text{Å} \) to the 3 strongest components of the \( 3s^3S - 3p^3P_2 \) hyperfine multiplet, the \( 3S_1 \) \( F=1, 3/2 \) to \( 3P_2 \) \( F=3/2,5/2 \) transitions, which are calculated (6) to lie at 5162.7, 5171.3 and 5184.4 \( \text{Å} \) without allowance for Lamb shift. There is however not sufficient evidence to identify positively these transitions, especially in the presence of other unidentified lines and the absence of the other, weaker, hyperfine components, and further