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OBSERVATION OF STRONG ORIENTATION EFFECTS FOR LEVELS IN HIGHLY IONIZED OXYGEN

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The method of beam-tilted-foil excitation has been applied to O IV and O VI at 4 MeV beam energy. Circular polarizations of nearly 30% have been observed and studied as a function of foil tilt angle. A new development for cascade-free lifetime measurements is discussed.

The purpose of this letter is to report the observation of a large degree of circular polarization in the light emitted by a highly ionized oxygen beam, excited by application of the beam-tilted-foil method. Since the discovery in 1974 of circularly polarized light in such excitation [1] a number of studies exploring this effect have appeared, e.g. refs. [2,3]. However, although measurements have indicated that the orientation for a level in HeI increases with beam energy in the range 100–400 keV [4], a recent study of highly ionized oxygen with 36 MeV beams [5] showed no detectable circular polarization for hydrogenic levels in O VII and O VIII. We have now studied levels in multiply ionized oxygen using 4 MeV beam energy and have found large circular polarization for a level in O VI, the effect being substantially smaller for a level in O IV.

The oxygen ions were obtained from the 3 MV Pelletron tandem accelerator in Lund and excited by passage through 20 $\mu g/cm^2$ carbon foils which were set at angles 0°–50° in steps of 10° to the beam direction. The state of polarization of the radiation emitted in a direction perpendicular to the beam and parallel to the foil tilt axis was determined through measurements using a transmission UV polarizer, the axis of which was set at angles of –45°, 0°, 45° and 90° relative to a direction parallel to the beam. (The definitions of the angles are as in fig. 1, ref. [1], θ being 90° in the present case.) An achromatic quarter-wave plate could be inserted between the excited beam and the polarizer with its fast axis parallel to the beam.

A Hanle depolarizer was mounted coaxially behind the polarizer with the axes of the polarizer and depolarizer accurately adjusted and rigidly fixed to each other so as to pseudo-depolarize the analyzed light, thus virtually eliminating all effects of instrumental polarization. The light was dispersed with a McPherson 35 cm monochromator and detected using a low-noise dry-ice cooled photomultiplier tube. For each configuration of the quarter-wave plate and polarizer the data were accumulated until a fixed amount of charge from the beam was collected in a Faraday cup with the requirement that the collection time vary by no more than 10% over each set of measurements. The beam current was kept at 0.6 ± 0.1 μA to reduce current dependent variations in excitation anisotropies which have recently been reported [6].

The polarization was measured for an O VI line at 3433 Å and an O IV line at 3737 Å. The former arises from $n = 6-7$ transitions in the hydrogenic part of the spectrum and it is a blend of 6h–7i, 6g–7h and 6f–7g components [7]. The O IV line is due to the 2p3p ^{4}D–2p3d ^{4}F transitions [8]. The circular polarization (S/I) for these two lines as a function of tilt angle is shown in fig. 1. The angular dependence is similar to that found earlier [3,4] and for the O VI line the circular polarization is approximately the same as that

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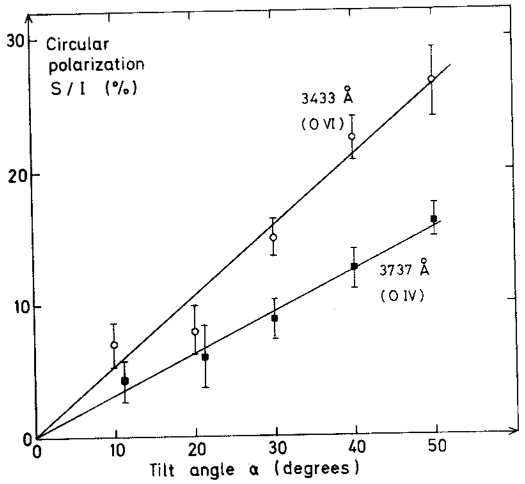

Fig. 1. Circular polarization of the 3433 Å O VI line (open circles) and the 3737 Å O IV line (filled squares) as a function of the tilt angle of the foil. The beam energy was 4 MeV. Error bars indicate statistical uncertainties and linear fits to the points are drawn only to guide the eye.

found by Pedrazzini et al. [3] in ArII using 800 keV ions. The circular polarization is about half as large for the O IV transition. Unfortunately the O VII 7–8 line (3889 Å) which was investigated in ref. [5] was too weak to allow polarization measurements at 4 MeV energy. The O VI and O IV transitions studied both exhibited a small linear polarization (M/I), of the order of a few percent, which monotonically decreased with increasing foil tilt angle. A more detailed study of the behavior of all three relative Stokes parameters (M/I, C/I and S/I) will be presented in a subsequent report.

Investigations of the dependence of the Stokes parameters on beam energy and foil material for selected states in C, O, and F, using the Lund Pelletron in the energy range 1–20 MeV are also underway. The present study has already been extended to 9 MeV where preliminary data for the O VI 3433 Å line (tilt angle 40°) give an S/I of 11 ± 2% and thus much lower than at 4 MeV. It is interesting to note that Liu et al. [9] found that the orientation for a level in O II decreased from 9.6 to 7.2% when the beam energy was increased from 540 to 1080 keV. In a study of beam–solid interaction with 0.6–3 MeV Ar^+ ions Berry et al. [10] also observed that S/I for the scattered, excited ions had a maximum in the neighborhood of 1 MeV, the value being about 30% lower when 2.5 MeV ions were used. The reduction of S/I for a given transition when the ion energy is increased to several MeV has thus been established in a few cases. It is however too early to explain the different results in the present work and in ref. [5] as entirely being due to different beam energies. As already noted the transitions studied were not the same, the present results being for lower ionization states with more core electrons involved, as well as for lower principal quantum members.

The high circular polarization for transitions in highly ionized atoms, observed in this experiment, offers possibilities for measurements of fine and hyperfine structure for highly stripped systems, using the zero-field quantum beat techniques [11,12]. Such studies are thus possible even if there is very little alignment (small M/I) which seems to be the case in many beam-foil experiments with heavier projectiles, including the present study.

This large anisotropy can also permit cascade-free measurements of level lifetimes. The difference between the normalized intensities for right and left hand circularly polarized light will decay as a single exponential (as a function of time after excitation, i.e. the distance from the foil) if there is no transfer of orientation by cascading from higher levels. A recent measurement for Ar, by Christiansen et al. [13] has actually shown that transfer of orientation is negligible for 4s–4p transitions in ArII.

We have now found that a substantial reduction of cascades can be achieved in the decay curve for the 3433 Å line in O VI if the normalized difference between the right hand and left hand circularly polarized light is determined. Indeed the replenishment ratio [14] decreased by approximately a factor of ten in a preliminary experiment, showing that transfer of orientation by means of cascading is small also in the present case. This method is a further development of a procedure used by Berry et al. [15] which is based on measurements of the difference between the intensities for linearly polarized light, parallel and perpendicular to the beam. However, since S/I is frequently much larger than M/I the data-taking times are more realistic in differential orientation measurements for lifetime determinations. In our test study using 4 MeV ions we thus found that the normalized difference for right and left hand polarized light corresponds to about 25 pulses/s (O VI, 3433 Å line, $\alpha = 40°$) close to the foil, which should be compared to a counting rate of about 300 pulses/s in a conventional beam-foil measurement of the same transition ($\alpha = 0^\circ$, no polarizing elements used) under otherwise identical conditions.

This new development for cascade suppression is worth pursuing, since there are many cases where cascading effects severly limit the present accuracies in lifetime measurements. The preliminary results indicate that this differential technique can be applied to highly ionized systems which are not easily accessible to the beam–laser excitation technique [16]. It is worth emphasizing however that the lines of main interest in multiply ionized atoms are usually $\Delta n = 0, 1$ transitions between low-lying levels, because here the effects of configuration mixing can be very dominant. In a majority of cases the transition wavelengths are below 1000 Å, an inconvenient region for polarization measurements. However, cascade-reduced measurements for higher levels as well as for branches in more convenient wavelength regions are expected to eliminate many uncertainties in studies of level lifetimes and initial populations.

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