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Observation of optical emission from beam-foil excited Li^-

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Résumé. — Nous avons vérifié par une méthode d'identification des charges par effet Doppler que la raie observée à 348,9 nm dans un faisceau de lithium excité par feuille de carbone est due à l'ion Li^- , en accord avec les prédictions théoriques de Bunge [5].

Abstract. — We have verified by a method of charge assignment by Doppler effect that the line observed at 348.9 nm in a lithium beam excited by a carbon foil is due to Li^- negative ion, in agreement with a calculation of Bunge [5].

Short lifetime levels of negative ions can arise from the capture of electrons in collision with neutral atoms, from the excitation of fast negative ions or by a two-step charge exchange process in fast positive ions. These negative ion states overlap the adjacent continuum of the neutral atom and their nature is strongly influenced by interaction of configurations. For the multiply excited levels deexcitation may occur either *via* auto-ionization or radiative decay.

Negative helium states have been seen in electron transmission type experiments [1] with single-electron emission into excited states and two-electron emission into the He^+ ground state as decay modes, or in trapped electron methods. But there are no measurements of negative ion resonance in lithium although they have been predicted [2]. In connection with a tunable laser photodetachment measurement from alkali negative ions by a JILA group [3], Norcross [4] calculated alkali negative ion bound states with configuration $np^2\ ^3P$ lying just below the first excited state of the neutral atom for every species except Li^- .

However, recently Bunge [5] reported on the existence of bound states of core excited negative lithium and the electric dipole transition between them, suggesting the possible occurrence of this radiation in the beam-foil source from a long lived $1s\ 2p^3\ ^5S^0$ level of Li^- .

It was known that fast Li^- is produced by beam gas and beam-foil collision but till Bunge's paper it had been never suggested that a negative ion could emit photons. However a low intensity emission had been observed for some time at different energies (from 50 keV to 450 keV in our laboratory) at $\lambda = 348.9$ nm,

near the wavelength calculated by Bunge for the E1 decay of $\text{Li}^- (1s\ 2p^3\ ^5S^0)$ into $\text{Li}^- (1s\ 2s\ 2p^2\ ^5P)$ (Fig. 1).

Fig. 1. — Beam-foil spectrum of lithium, 140 keV beam energy, 10 mm downstream from foil.

We have verified that this beam-foil excited line is really due to Li^- ion emission.

From the position of the $1s\ 2p^3\ ^5S^0$ Li^- level in the global energy diagram of lithium one would expect it to have an excitation function similar to the one for the quartet system of neutral Li^{**} [6]. In fact, from spectra recorded from 50 keV to 450 keV it results that the

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projectile velocity dependence of emission is about the same for Li^{**} ($1s\ 2s\ 2p\ 4P^0 - 2s\ 2p^2\ 4P$) 371.4 nm and the line observed at 348.9 nm. Thus this line could be emitted by a doubly excited state of neutral Li.

The direct and definitive evidence of Li^- optical emission was obtained by means of a Doppler shift experiment (Fig. 2).

Fig. 2. — Experimental apparatus for separation of charges by Doppler shift.

By accelerating monocharged Li^+ ions through high voltage V the lithium beam has an energy E (MeV/nucleon) and a velocity

$$v = \frac{c}{21.2} E^{1/2}.$$

The light emitted at atomic wavelength λ_0 by fast lithium is observed in the forward direction blue shifted by a quantity

$$-\frac{\Delta\lambda}{\lambda_0} = \beta = \frac{1}{21.2} E^{1/2}.$$

We apply an axial post-accelerating or retarding electric field by means of two parallel plates. The first one supporting the exciting carbon foil is grounded

and the second one, 5 mm downstream, is biased at voltage δV . The differential Doppler displacement due to the subsequent change in ion velocity will be

$$\frac{\mp \Delta\lambda}{\lambda} = \frac{1}{42.4} E^{1/2} \pm \frac{\delta V}{V}.$$

At 140 keV ($E = 2 \times 10^{-2}$ MeV/nucleon for $V = 140$ kV) the line at 348.9 nm will be observed Doppler shifted by 2.3 nm towards the blue wavelengths. By applying the additional $\pm \delta V = 7.5$ kV, a differential shift of light from monocharged ions will be ∓ 0.062 nm when observing the light emitted in the forward direction at the exit of the electric field plates.

In our experiment the light is observed at small angle θ ($\tan \theta \simeq 3/21$ and $\cos \theta \simeq 0.985$) so that the shift is practically equal to the shift calculated at 0° .

An advantage of the forward observation is to minimize the Doppler broadening for a given solid angle as compared to the observation at 90° . The lines are better defined and their shifts are easier to measure. A disadvantage of this device is to destroy the symmetry and to accept the light from a badly defined beam volume.

The lifetime of the upper level $1s\ 2p^3\ ^5S^0$ is an important parameter, the order of magnitude of which makes possible or not the experiment. We verified that the experimental lifetime is close to the 2.8 ns calculated by Bunge. The intensity being divided by about an order of magnitude from the foil to the exit of the high voltage plate, the shape of the line at 348.9 nm remains measurable at this point of the lithium beam.

The results are shown in figure 3. The apparent wavelength shifts have been determined from the displacement of the centre of gravity of the peaks. The line observed at 371.4 nm is seen to be insensitive to the post-acceleration or deceleration (Fig. 3a) confirming the assignment to a Li^{**} transition. The

Fig. 3. — Line shifts in accelerating (+) and retarding (−) field. The beam energy is 140 keV. The plate voltage is ± 7.5 keV. For reasons of statistics, the lines at 368.4 nm and 348.9 nm were recorded with larger spectrometer slits and time integration is different for every line.

well known line at 368.4 nm due to the transition $1s\ 3p-1s\ 4p$ in Li^+ is shifted towards blue wavelengths when applying a negative voltage which is accelerating for positive ions. The absolute value of this displacement is less than the calculated value due to the partial extension of the observed lithium beam volume between the plates inside the electric field. In the same conditions the previously un-assigned line at 348.9 nm is shifted by the same quantity, but towards the red part of the spectrum. This is a definitive demonstration of the negative nature of the charge carried by the lithium particle emitting light at 348.9 nm.

During the completion of this work we received a preprint from Berry [7] providing conclusive iden-

tification of the charge state of the lithium emission at 348.9 nm, and, since submission of our manuscript we have learned of another independent verification of Li^- identification by Mannervik [8]. Both these experiments differ from our work as they rely on the observation of the change of the decay curve in axial electric field related to change in lithium velocity.

Bunge [5] suggests that the two core excited states ($1s\ 2p^3\ ^5S^0$ and $(1s\ 2p^2)\ ^5P^e$) are the only bound states of negative lithium. We have begun the analysis by the same Doppler shift method of a number of unidentified lines present in beam-foil spectra [9] to verify this assertion.

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