Conf - 810868--7

CONF-810868--7

DE83 007928

DOUBLY EXCITED STATES IN SOME LIGHT ATOMS

H. GORDON BERRY, ROBERT L. BROOKS, JONATHAN E. HARDIS,* and

W. J. RAY

Physics Division, Argonne National Laboratory, Argonne, Illinois 60439**

Abstract

We have identified a singlet transition in doubly excited helium:

$2p^2\ ^1D - 2p3d\ ^1D$, at $3298 \pm 2\text{\AA}$ with a full width of $54\text{\AA}$ or

$0.061 \pm 0.005\text{ eV}$. This width is in good agreement with a previous

measurement and theory for the width of the $2p^2\ ^1D_2$ state. We have

remeasured the decay rate of $1s^2 2p^2\ ^2P - 1s2p^2\ ^2P$ in Li I and find it is

in good agreement with theory. Several transitions in doubly excited

Li II have been identified in the $1000\text{\AA}$ region. No evidence was

found for doubly excited quartet transitions in Li I in the vacuum

ultraviolet. We present measurements of wavelengths and fine structure

of the $1s2s2p^2\ ^5P - 1s2p^3\ ^5S$ transitions in C III, N IV and O V.

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

* Also at Department of Physics, University of Chicago, Chicago, Illinois 60637.

** Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract W-31-109-Eng-38.

MASTER

1. Introduction

We have utilized the efficiency of the beam-foil light source in producing multiply excited states [1] to search for some weak transitions in such systems of two, three, and four electron atoms.

2. Doubly excited helium

A number of lines in the near ultraviolet spectrum of helium from the beam foil light source have been identified as coming from the doubly excited system of neutral helium [2,3]. These transitions are between doubly excited levels, the upper of which are essentially stable against autoionization. The lower levels are the $2p^2\ ^3P$ and $2s2p\ ^3P^0$ states, the latter of which autoionizes in about 10^{-13} s, giving a measurable half-width to these emissions of about 5 Å. No identifications in the singlet system have been made [4], principally because of the rapid autoionization of the $2s^2$, $2s2p$ and $2p^2$ singlet states. Also the greater configuration mixing in the singlet system reduces the probability of narrow-line electric dipole emission.

Considering the $n=2$ levels of the singlet system, the $2s^2\ ^1S$ and $2p^2\ ^1S$ levels are connected by electric dipole transitions only to $1P^0$ levels, all of which autoionize too rapidly for significant photoemission [5]. The remaining two levels, $2s2p\ ^1P^0$ and $2p^2\ ^1D$ can be the lower states for two Rydberg series from the $2pnp\ ^1P$ and $2pnd\ ^1D^0$ ($n \geq 3$) levels. The first two members of these two series are indicated in fig. 1 with wavelength estimates made from theory [6] and quantum defect calculations. Transitions from $2pnd\ ^1F^0$ are less likely but might be observable from higher n states for which autoionization rates are lower.

Using a 120-keV $^3\text{He}^+$ beam excited by a thin carbon foil, we have recorded spectra in the wavelength region of 2000—4500 Å. We have identified a very broad line shown in the bottom half of fig. 2 as the $2p^2\ ^1D-2p3d\ ^1D^0$ transition of doubly-excited neutral helium. The measured wavelength is $3298 \pm 2\ \text{Å}$ and the linewidth is $2\Gamma = 54 \pm 4\ \text{Å}$. Note from fig. 2 that the "blob" intensity at 3298 Å is much weaker than the previously observed HeI** transitions at 3013 Å and 2818 Å, although the peak area is of the same order of magnitude. Also, the "blob" intensity disappears rapidly a few mm from the foil, corresponding to the rapid decay of the $2p3d\ ^1D^0$ level ($\tau \leq 0.1\ \text{ns}$), while the singly-excited neutral helium lines remain strong. Our width $2\Gamma = 0.061 \pm 0.005\ \text{eV}$ agrees well with a previous experimental value of $0.072 \pm 0.018\ \text{eV}$ of Hicks and Comer [7] and the theoretical values of 0.0662 eV [8] and 0.0729 eV [9].

The first member of the 1P Rydberg series $2s2p\ ^1P^0-2p3p\ ^1P$ should occur at 4125 Å, but may be masked by many He I lines in this spectral region. Figure 3 shows a broad feature near 4300 Å, but we tentatively identify this rather as a band emission [10] of CH sputtered from the foil. Neither the 4300 Å nor the 3298 Å profiles were seen with an incident beam of H_2^+ projectiles (80-keV energy) on the carbon foil. The N_2^+ emission (fig. 3) is a function of target chamber vacuum and not of foil position relative to the point of observation.

3. Doubly excited lithium

The lifetime of the $1s2p^2\ ^2P$ state of doubly excited Li I has been of recent theoretical interest. The earlier approximate measurement [11] of $\tau_{\text{expt.}} = 15 \pm 10\ \text{ps}$ was in strong disagreement with the calculations of

Fox and Dalgarno [12] ($\tau_{th} = 54$ ps). Nicolaides and Beck [13] have proposed an additional decay mode of radiative autoionization, the simultaneous emission of a photon and an electron, which reduces the theoretical lifetime to 41 ps.

Figure 4 shows our measurement of the decay curve of the $207.5 \text{ \AA}$ transition, $1s^2 2p^2 P^0 - 1s 2p^2 P$. The resulting lifetime of $\tau = 49 \pm 5$ ps suggests that the radiative autoionization rate may be smaller than expected. Beck, et al. [14] also propose that the $2p^3 4S^0$ level should decay by the same process. The transition of He^- at $319 \text{ \AA}$ (with a width of about $1 \text{ \AA}$) has not been observed, nor could any feature in the lithium beam-foil spectrum near $140 \text{ \AA}$ be assigned to the isoelectronic process in neutral lithium.

In the doubly-excited quartet system of Li I, a search was made for the transition $1s 2s 2p^4 P^0 - 1s 2p 3p^4 P$. Identification of this uv transition, predicted by Bunge [15] to be at $1680.1 \text{ \AA}$, would help to confirm the identification of the $5033 \text{ \AA}$ line from the same upper level $1s 2s 3p^4 P^0 - 1s 2p 3p^4 P$. No "closed loops" of observed sets of transitions [16] have yet confirmed Bunge's recent $4P^0$ and $4P$ identifications. Figure 5 shows a spectrum taken about 5 cm after foil excitation of a 700-keV Li^+ beam (delay time ~ 12 ns). The lifetime of the Li II transition is 0.99 ns [17], while that of the Li I ** transition is predicted to be 29.5 ns [15]. Hence, we estimate the Li I ** intensity at the foil to be less than 10^{-4} of that of the Li II transition, providing no confirmation of above identifications. The other uv quartet transitions are predicted [15] to be weaker than the $1680.1 \text{ \AA}$ line, and they were not observed.

In fig. 6 we show a spectrum with three transitions from doubly excited Li II. The $2p^2 3P - 2p 3d^3 D^0$ transition at $1036 \text{ \AA}$ has been observed

previously [11]. The wavelengths are compared with theory in table 1.

Note that the transitions ending on the $2s2p^3\ ^0P$ level are broadened slightly due to its high autoionization rate.

4. The $1s2s2p^2\ ^5P - 1s2p^3\ ^5S$ transitions of four electron systems.

The prediction by Bunge [18] that the $3489\text{\AA}$ line was the $1s2s2p^2\ ^5P - 1s2p^3\ ^5S$ transition in Li^- was quickly verified by two groups [19,20]. We hence now verified our preliminary identifications [19] of these transitions in several heavier ions of the isoelectronic sequence.

In fig. 7 we show the resolved fine structures of these transitions in C III, N IV and O V. The measured wavelengths are presented in table II, together with a multi-configuration Dirac-Fock calculation [21]. The fine structures are compared with theory [21] in fig. 8 and show excellent agreement.

5. Conclusions

We have assigned a very broad spectral profile to a singlet transition in doubly excited He I. Its width agrees well with previously measured Auger-electron-resonance widths from the $2p^2\ ^1D$ state. We have resolved the discrepancy between theory and experiment for the mean life of the $1s2p^2\ ^2P$ state of lithium and shown that its radiative autoionization rate may be small. We also present some new results in doubly excited Li I and Li II from vacuum UV measurements in the $1000\text{\AA}$ range.

The four-electron doubly excited system was identified originally in Li^- [18], and the results presented here in carbon, nitrogen and oxygen confirm previous preliminary identifications of the $1s2s2p^2\ ^5P - 1s2p^3\ ^5S$ transitions.

References

- [1] H. G. Berry, *Physica Scripta* 12 (1975) 5.
- [2] H. G. Berry, J. Désesquelles and M. Dufay, *Phys. Rev. A* 6 (1972) 600.
- [3] R. L. Brooks and E. H. Pinnington, *Phys. Rev. A* 22 (1980) 529.
- [4] W. C. Martin, *J. Phys. Chem. Ref. Data* 2 (1973) 257.
- [5] R. P. Madden and K. Codling, *Astrophys. J.* 141 (1965) 364.
- [6] J. Calloway, *Phys. Lett.* 66A, (1978) 201; L. Lipsky, R. Anania and M. J. Coneely, *At. Data & Nucl. Data Tables* 20 (1977) 127.
- [7] P. J. Hicks and J. Comer, *J. Phys.* B8 (1975) 1866.
- [8] P. G. Burke and A. J. Taylor, *Proc. Phys. Soc.* 88 (1966) 549.
- [9] A. K. Bhatia, *Phys. Rev. A* 6 (1972) 120.
- [10] E. Hulthén, *Z. Phys.* 11 (1922) 285.
- [11] J. P. Buchet, M. C. Buchet-Poulizac, H. G. Berry and G. W. F. Drake, *Phys. Rev. A* 7 (1973) 922.
- [12] J. L. Fox and A. Dalgarno, *Phys. Rev. A* 16 (1977) 283.
- [13] C. A. Nicolaides and D. R. Beck, *Phys. Rev. A* 17 (1978)
- [14] D. R. Beck, C. A. Nicolaides and G. Aspromallis, *Phys. Rev. A* (in press).
- [15] C. F. Bunge, *J. Phys. B* 14, (1981) 1.
- [16] H. H. Bukow and G. Heine, *Phys. Lett.* 82A (1981) 79.
- [17] W. L. Wiese, M. W. Smith and B. M. Glennon, Atomic Transition Probabilities, p. 20, NSRDS-NBS 4 (1966).
- [18] C. F. Bunge, *Phys. Rev. Lett.* 44 (1980) 1450.
- [19] R. L. Brooks, J. E. Hardis, H. G. Berry, L. J. Curtis, K. T. Cheng and W. J. Ray, *Phys. Rev. Lett.* 45 (1980) 1318.
- [20] S. Mannervik, G. Astner and M. Kisielinski, *J. Phys.* B14, (1980) L441.
- [21] K. T. Cheng, in ref. 19, and to be published.

Table I. Wavelengths in Doubly excited Li II

Transition	Observed Wavelength nm	Calculated Wavelength nm
$2p^2\ ^3P - 2p\ 3d\ ^3D^0$	103.65 ± 0.02	103.66^a
$2s2p\ ^3P^0 - 2p\ 3p\ ^3D$	98.93 ± 0.03	97.12^b
$2s2p\ ^3P^0 - 2p\ 3p\ ^3P$	90.28 ± 0.03	90.29^a

^aH. Doyle, M. Oppenheimer and G. W. F. Drake, Phys. Rev. 5A, 26 (1972).

^bIsoelectronic extrapolation from HeI.

Table II. Transition Energies and Wavelengths for $1s2s2p^2\ ^5P_J - 1s2p^3\ ^5S_2$

Ion	J = 1	J = 2	J = 3	Average	Theory	Units
C III	101.543 ± 0.005	101.609 ± 0.005	101.631 ± 0.005	101.606 ± 0.005	98.9	nm
	98480 ± 5	98416 ± 5	98395 ± 5	98419 ± 5		cm^{-1}
N IV	82.460 ± 0.005	82.547 ± 0.005	82.601 ± 0.005	82.555 ± 0.005	80.7	nm
	121271 ± 7	121144 ± 7	121064 ± 7	121131 ± 7		cm^{-1}
O V	69.336 ± 0.005	69.457 ± 0.005	69.548 ± 0.01	69.475 ± 0.01	68.2	nm
	144226 ± 10	143974 ± 10	143786 ± 20	143936 ± 20		cm^{-1}

Figure Captions

- Fig. 1 Energy diagram of observable electric dipole transitions in the singlet system of doubly excited HeI.
- Fig. 2 Beam-foil spectra of helium between 2800 and 3400 Å. The lower spectrum is taken at the foil, and the upper spectrum at about 2 mm down beam.
- Fig. 3 Beam-foil spectrum of helium between 4250 and 4450 Å. The emissions identified from molecules, N₂ at 4268 Å and CH at 4311 Å are discussed in the text.
- Fig. 4 Decay curve for the $1s^2 2p^2 \ ^2P^0 - 1s2p^2 \ ^2P$ transition at 207 Å. The spatial integration length corresponded to about $60 \mu \approx 15$ ps.
- Fig. 5 Beam-foil spectrum of lithium near 1682 Å, showing no evidence for the $1s2s2p^4 \ ^4P^0 - 1s2p^3 \ ^4P$ transition at 1680.1 Å. The spectrum is taken at a delay of 12 mean lifetimes of the Li II, $2p^1P - 3d^1D$ transition, and 1/3 the lifetime of the 1680.1 Å transition.
- Fig. 6 Beam-foil spectrum of lithium near 1000 Å, showing some doubly excited Li II transitions.
- Fig. 7 Wavelength scans over the fine structures of the $1s2s2p^2 \ ^5P - 1s2p^3 \ ^5S$ transitions of C III, N IV and O V.
- Fig. 8 Theoretical (open circles, ref. 21) and experimental (closed circles) fine structures in C III, N IV and O V. The crosses are the O V results of Livingston and Hinterlong, Phys. Lett. 80A, 372 (1980).

Fig. 1

Fig. 2

Fig. 3

Fig. 4

FIG. 5

Fig. 6

Fig. 7

ANL-P-16,255

Fig. 8