ENERGIES AND LIFETIMES OF THE 4s4d ^{1}D AND 4p^2 ^{1}D IN Ga II

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Four new classifications of ^{1}D and ^{1}S levels in Ga II have been made with a sliding spark source and the lifetimes of the 4s4d ^{1}D and 4p^2 ^{1}D levels have been measured using beam–foil excitation.

Knowledge of the level schemes and oscillator strengths for members of the Zn I isoelectronic sequence is of particular interest because of the contamination problems its high-charge members impose upon controlled fusion devices [1]. It has been suggested that lifetime measurements for resonance levels of some members of this sequence may be hampered by severe cascading from higher lying levels [2]. Such cascade effects can be identified and accounted for by methods [3] which incorporate measurements of the cascade decay curves into the analysis, if there exists detailed knowledge of the level scheme. Unfortunately, level schemes for members of the Zn I sequence are incompletely known even for its rather low members. We have therefore undertaken a combined program of high wavelength resolution sliding spark measurements and time-resolved beam–foil studies for this sequence with the aim of classifying levels which can cascade into the 4s4p ^{1}P^0 resonance level and determining their cascade contributions to its beam–foil-excited decay curve.

In the Zn I sequence, with the resonance transition 4s^2 ^{1}S$_0$–4s4p ^{1}P$^0_1$, the ^{1}P level may be strongly populated by transitions from the low members of the 4s*n*s and 4s*n*d series, and important contributions may also be expected from the 4p^2 configuration. The 4p^2 ^{3}P term is known in Zn I through Br VI [4,5]. A comparison with the analogous Mg I sequence [6] shows that the AEL [5] levels 4s4d ^{1}D in Ge III through Se V should be given the designation 4p^2 ^{1}D. It is most probable that the levels reported in AEL as 4p^2 ^{1}D in Ge III and 4p^2 ^{1}D and ^{1}S in As IV should be discarded. The Ge III analysis was questioned also by Martin and Kaufman [4].

This means that one of the two ^{1}D levels of 4s4d and 4p^2 is missing throughout the sequence. In Zn I, 4p^2 ^{1}D is estimated to appear above the ionisation limit [4]. In Ga II the two ^{1}D levels are expected to be strongly mixed, making the configuration designation arbitrary [7].

A spectroscopic investigation has now been carried out in order to establish the missing ^{1}D level in Ga II. A sliding spark with a Lavaite spacer and Al electrodes was used as a light source, where a bore in the lower electrode was filled with metallic gallium. The discharge circuit contained a 16 μF capacitor, a rotating spark gap and a variable resistor, where the capacitor voltage, the pulse repetition frequency and the resistance were adjusted so as to give spark pulses with the peak current 30, 80 or 200 A at the average current 0.5 A.

The spectrum was recorded in a photographic 3 m normal incidence vacuum spectrograph. Exposures with different peak currents were used to distinguish between ionisation stages. All the previously reported Ga II lines [8] in the region 1100–2000 Å could be confirmed, except λ1227. Four new Ga II lines were found, as shown in table 1. The identification of the strong line at 1802.28 Å as the transition between 4s4p ^{1}P^0 and the missing ^{1}D term is confirmed by the weak intercombination line at 1291.36 Å. The new term has been designated 4s4d ^{1}D, while the previously known ^{1}D has been changed to 4p^2 ^{1}D. An isoelectronic plot of the known 4s4d and 4p^2 levels in

Table 1
New Ga II lines below 2000 Å.

Int.	Wavelength (Å)	Wavenumber (cm^{-1})	Combination
1	1291.379	77 436.6	4s4p $^3P^0_2$–4s4d $^1D_2$
4	1539.902	64 939.2	4s4p $^1P^0_1$–4p^2 $^1S_0$
1	1586.278	63 040.7	4s4p $^1P^0_1$–4s6s $^1S_0$
9	1802.284	55 485.2	4s4p $^1P^0_1$–4s4d $^1D_2$

the Zn I sequence is shown in fig. 1.

Concerning the two remaining lines of table 1, the identifications must be considered as tentative, supported mainly by the Ritz diagram of the *ns* ^{1}S and ^{3}S series shown in fig. 2. The level values for the new ^{1}S and ^{1}D terms are given in table 2, based on the AEL value of 4s4p $^1P^0$. Obviously, the knowledge of Ga II is still quite fragmentary, the only new contribution since 1929 [8] being a precision measurement of the 4s4d ^{3}D–4s4f $^3F^0$ transition by Bidelman and Corliss [9]. New observations are needed throughout the region 800–8000 Å.

Beam–foil measurements for gallium were obtained with the 400 keV heavy-ion accelerator at the Research Institute for Physics in Stockholm. Post-foil beam velocities were determined using an electrostatic energy analyser. The experimental set up has been described elsewhere [10]. Decay curve measurements were made for the 4s4p $^1P^0$ level and for its cascades from 4s5s ^{1}S and (following the labels of table 2) from 4s4d ^{1}D and 4p^2 ^{1}D. The $^1P^0$ and ^{1}S decay curves exhibited heavy cascading, and an ANDC [3] study of their jointly analysed decay curves is in progress and will be presented elsewhere [11]. The ^{1}D decay curves were both essentially cascade free, and the values extracted by curve fitting methods for their lifetimes are given in table 3.

The 4p^2 ^{1}D decay curve posed special experimental problems because of its long lifetime. At the 200–300 keV beam energies for which Ga II lines are strongly excited, this lifetime corresponds to a flight path of 4–5 cm. We have made calculations based on the theoretical formalism of Meyer [12] which indicate that at these energies the angular scattering at the foil causes the beam to diverge to such an extent that its effective radius can increase by one mm or more (depending upon the foil thickness) over such a path

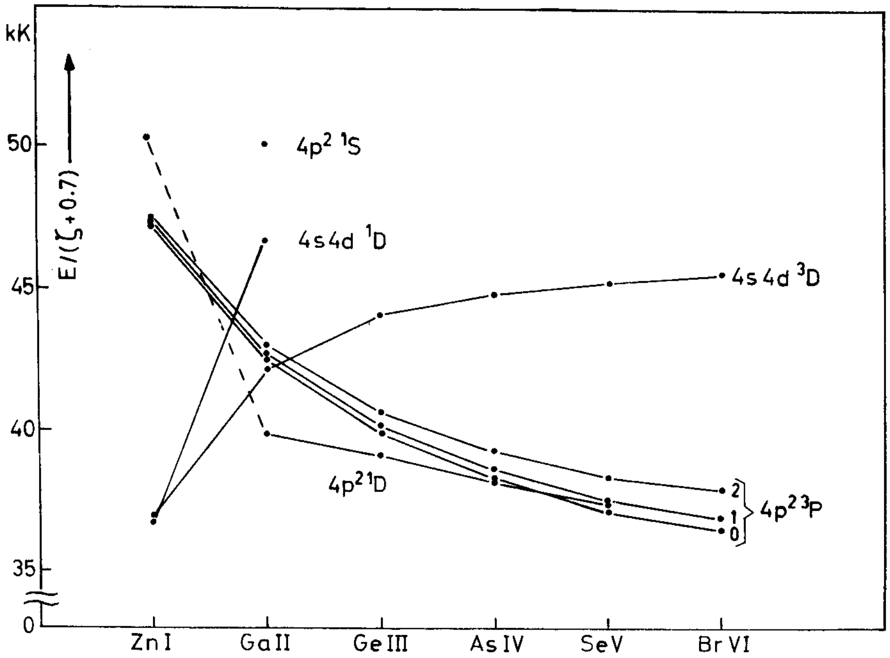

Fig. 1. The configurations 4s4d and 4p^2 in the Zn I isoelectronic sequence. The 4p^2 ^{1}D term has not been observed in Zn I. The point in this diagram corresponds to a lower limit estimate by Martin and Kaufman [4].

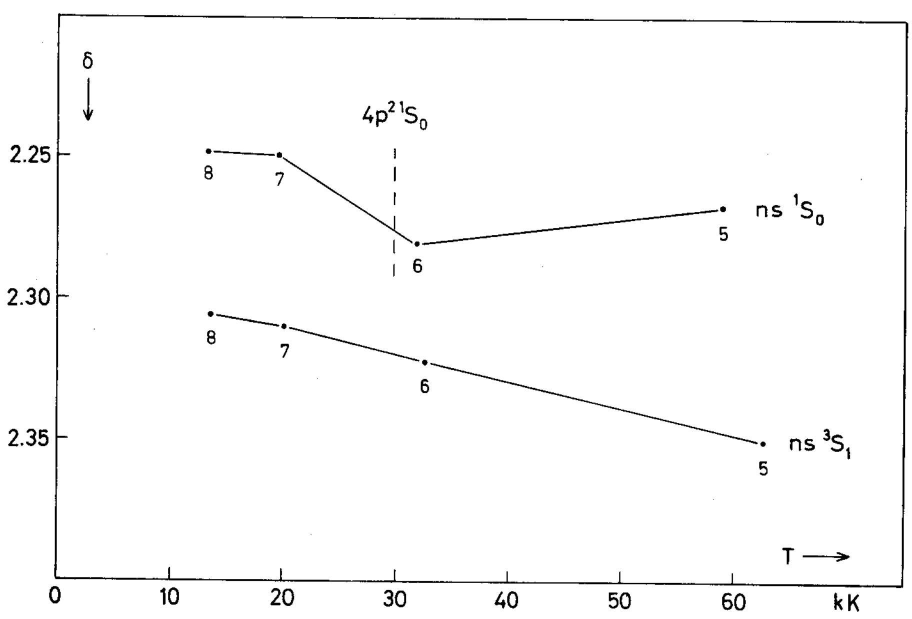

Fig. 2. Ritz diagram showing the series 4s*n*s in Ga II. The ^{3}S series is unperturbed, while the ^{1}S series is strongly affected by the term $4p^2\,{}^1S$.

length. Thus light emitting ions could increasingly move outside the optical viewing region at distances further from the foil, which could shorten the apparent lifetime if no corrections were made. Therefore measurements were made for a variety of foil thicknesses from 2 to 10 $\mu g/cm^2$ (the thickness in energy loss units being accurately determined using the energy analyser), and the fitted effective lifetimes were extrapolated to zero foil thickness. At a 2$\mu g/cm^2$ foil thickness the fitted lifetimes were about 1% below the reported value, while at 5 and 10 $\mu g/cm^2$ thicknesses the fitted values were, respectively, about 8 and 30% low.

Table 2
New levels of Ga II. Level values based on AEL value of $4s4p\,{}^1P_1^0$ = 70 700 cm^{-1}.

Designation	Level (cm^{-1})
$4p^2\,{}^1D_2$	107 719 a)
$4p^2\,{}^1S_0$	135 639.2
$4s4d\,{}^1D_2$	126 185.2
$4s6s\,{}^1S_0$	133 740.7

a) AEL level value. Previously designated $4s4d\,{}^1D_2$

Table 3

Transition	Wavelength (Å)	Upper level lifetime (ns)
$4s4p\,{}^1P^0 - 4p^2\,{}^1D$	2700	54 ± 5
$4s4p\,{}^1P^0 - 4s4d\,{}^1D$	1802	0.73 ± 0.07

No theoretical estimates for the $4p^2\,{}^1D$ lifetime are presently available, but our $4s4d\,{}^1D$ lifetime is in reasonably good agreement with a recent theoretical calculation of 0.65 ns by Froese Fischer and Hansen [13]. An earlier measurement of the $4p^2\,{}^1D$ by Andersen and Sørensen [14] yielded 15.8 ns, but the authors reported this value with the explicit caution that lifetimes longer than 25 ns could have been underestimated in their measurement, and a recent measurement [15] yields a much longer value, consistent with our result.

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