Hyperfine Structures of the Resonance Lines of Indium (In^{115})*

G. V. DEVERALL, K. W. MEISSNER, AND G. J. ZISSIS
Purdue University, West Lafayette, Indiana
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In the process of developing an atomic beam light source for use at high oven temperatures an investigation of the indium resonance lines at 4511A and 4101A was carried out. The employment of a well-collimated atomic beam, excited by electron impact, and of a Fabry-Perot interferometer made it possible to resolve clearly all components of the hyperfine structures of both lines. The complete resolution of the line 4511A has not been accomplished with other light sources by other investigators. The high spectroscopic accuracy led to values of the hyperfine splittings of the 5 $^2P_{\frac{1}{2},\frac{3}{2}}$ terms which agree within ± 0.0004 cm^{-1} with the values obtained by microwave methods. Furthermore, a precise value for the hyperfine splitting of the 6 $^2S_{\frac{1}{2}}$ term was obtained, namely 0.2814 ± 0.0005 cm^{-1}.

INTRODUCTION

DESPITE the great accuracy obtainable by the powerful microwave methods for the investigation of hyperfine structure, purely spectroscopic methods are still of value and importance especially as far as excited states are concerned. The application of proper light sources is necessary, however, and among the various possibilities the atomic beam light source ranks first as far as sharpness of the lines is concerned. In the process of developing an atomic beam source for use with higher oven temperatures, the hyperfine structure of the resonance lines of In^{115} at 4511A and 4101A was investigated. These lines offered an excellent check on the operation of the beam source and the spectroscopic equipment since some of the splittings involved were known exactly from microwave measurements. Furthermore, such an investigation promised to yield better agreement between spectroscopic and microwave results, as well as a precise value of the hyperfine splitting of the excited state 6 $^2S_{\frac{1}{2}}$.

Figure 1 shows the energy levels and transitions involved. The levels were spectroscopically investigated by Jackson in 1930 and in 1933,[1] and by Schüler and Schmidt in 1936.[2] The former used an air-cooled vacuum tube containing helium and $InCl_3$ excited by means of high-frequency voltage applied to external electrodes. The latter employed a liquid air cooled hollow cathode source. Since then microwave methods have been applied to measure the hyperfine splittings of the lower states. The most recent value for the $^2P_{\frac{1}{2}}$ state was given by Hardy and Millman in 1942,[3] while in 1950 Mann and Kusch[4] published their values for the $^2P_{\frac{3}{2}}$ state. It may be noted from Fig. 1 that the $^2S_{\frac{1}{2}}$ splitting can be directly measured twice from the 4511A line and twice from the 4101A line, giving four independent determinations of the desired splitting.

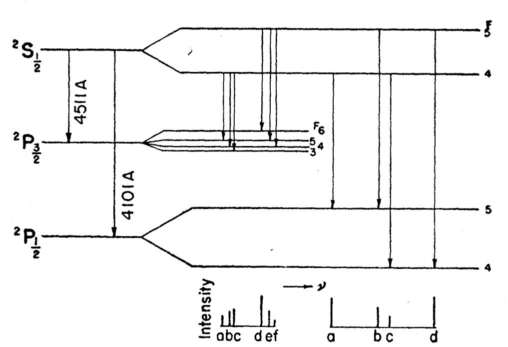

FIG. 1. Energy levels and transitions for the In^{115} resonance lines at 4511A and 4101A.

EQUIPMENT

The spectroscopic equipment consisted of a Steinheil prism spectrograph and a Fabry-Perot interferometer with 60-mm diameter plates. The interferometer was mounted in parallel light between the collimator and the prism, and the resultant fringe patterns were photographically recorded. In order to clearly resolve all six components of the 4511A line and the four com-

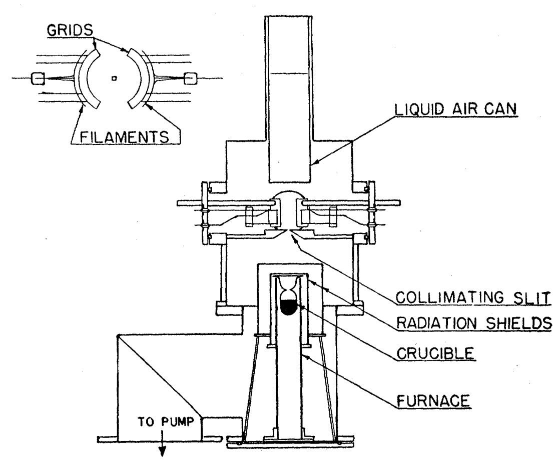

FIG. 2. Schematic drawing of the atomic beam light source.

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[1] D. A. Jackson, Proc. Roy. Soc. (London) **A128**, 508 (1930); D. A. Jackson, Z. Physik **80**, 59 (1933).
[2] H. Schüler and Th. Schmidt, Z. Physik **104**, 468 (1937).
[3] T. C. Hardy and S. Millman, Phys. Rev. **61**, 459 (1942). See also P. Kusch and H. M. Foley, Phys. Rev. **74**, 250 (1948).
[4] A. K. Mann and P. Kusch, Phys. Rev. **77**, 427 (1950).

TABLE I. Summary of results for level splittings $\Delta\nu$ in cm^{-1}.

Terms F		$\Delta\nu$ (spectroscopic)			$\Delta\nu$ (radiofrequency)[a]	
Reported by		DMZ*	SS[b]	J[c]	MK[d]	KF[e]
Estimated error		±0.0005	±0.001	±0.002	±0.00004	±0.0001
$6\,^2S_{\frac{1}{2}}$	5–4	0.2814	0.280	0.279		
$5\,^2P_{\frac{3}{2}}$	6–5	0.0583	0.057		0.05846	
	5–4	0.0376	0.037		0.03726	
	4–3	0.0225	0.026		0.02231	
$5\,^2P_{\frac{1}{2}}$	5–4	0.3808		0.379		0.3807

* Present authors.
[a] The value of the speed of light, c, used to convert rf data to wave numbers was taken from J. W. DuMond and E. R. Cohen, Am. Scientist **40**, 447 (1952) as $2.997902\pm0.000009\times10^{10}$ cm/sec.
[b] See reference 2.
[c] See reference 1.
[d] See reference 4.
[e] See reference 3.

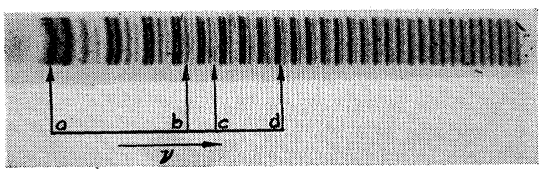

FIG. 3. Fabry-Perot interferometer pattern of λ4101A with 6.2-cm spacer. Four components belonging to the same order are indicated by arrows.

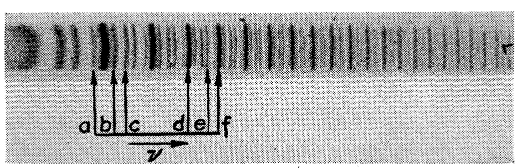

FIG. 4. Fabry-Perot interferometer pattern of λ4511A with 4.9-cm spacer. Six components belonging to the same order are indicated by arrows. Component f coincides with lower order of component d.

TABLE II. Summary of wavelength values of the In^{115} resonance lines in international angstroms.

Theoretical intensity	Interferometer Atomic beam			Grating Hollow cathode		Other investigators
	±0.0001	cg[a]	cg[a]	±0.001	±0.005	
33.9	4511.3287					
50.9	1.3211	1.3212			1.318	
53.9	1.3166		1.2972			4511.310[b]
100	4511.2833					4511.323
50.9	1.2714	1.2776			1.275	
18.5	1.2637					
100	4101.8054			1.804	1.808	
66.8	1.7581	1.7522	1.7504	1.757	1.755	4101.764[b]
36.4	1.7413			1.740		4101.773[c]
100	1.6940			1.693	1.698	

[a] The values given under "cg" are intensity weighted averages of components indicated by brackets.
[b] See reference 5.
[c] See reference 6.

ponents of the 4101A line, five different spacers were used, ranging in thickness from 1.0 to 6.2 cm.

Figure 2 shows a schematic sketch of the atomic beam light source used in the investigation. The operating temperature of the oven was about 1200°C, and the collimation was such that the effective temperature for Doppler width, in the region of observation, was about 6°K. Since all causes of line broadening, other than Doppler effect, were negligible compared to the natural line width, the resulting half-width of the lines observed was calculated to be about twice the natural half-width, or about 0.0015 cm^{-1}. The beam was excited by electron bombardment from two identical electron guns, each consisting of a filament-grid assembly. Since the grids were at the same potential, the beam was essentially unaffected by external electric fields. A careful check was also made to assure the absence of magnetic fields originating from the filaments or the furnace.

In Fig. 3 we see a photograph of the Fabry-Perot fringes obtained using a 6.2-cm spacer. In this case the overlap of orders is eight between the first and last component. Since the fringes are sufficiently sharp to permit comparator readings to be taken to within ±0.003 mm, the error in the determination of the fractional order number was small, and the splitting for the various levels could be found to less than ±0.0001A.

Figure 4 shows the pattern for the 4511A line using the 4.9-cm spacer. The two components b and c are the ones which had not been previously resolved by other investigators.

RESULTS

The results of all measurements for level splittings are shown in Table I. The value of the $6\,^2S_{\frac{1}{2}}$ splitting is found to be 0.2814 ± 0.0005 cm^{-1}.

The splittings were found from the central excess fractions of the different patterns and the values of the thicknesses of the interferometer spacers, which were determined with respect to krypton lines. The present spectroscopic results are in very good agreement with those obtained by microwave methods, and lead, within the limits of spectroscopic accuracy, to the same value of the quadrapole moment of In^{115} as obtained from microwave data.

The wavelengths of the indium resonance lines were also determined from the plates taken in connection with this investigation. The wavelengths were determined with respect to Kr λ4273.9700A, and corrected to 760-mm Hg pressure and 20°C. For the 4101A line, photographs taken with 1.0, 2.8, 4.9, and 6.2 cm were used, while the 2.8-, 3.9-, 4.9-, and 6.2-cm spacers were used for the 4511A line.

As the values obtained differed considerably from values given by other investigators,[5,6] measurements

[5] H. S. Uhler and J. W. Tanch, Astrophys. J. **55**, 291 (1922).
[6] G. R. Harrison, *MIT Wavelength Tables* (John Wiley and Sons, Inc., New York, 1939).

were made using a water-cooled hollow cathode source, operated at about 1-mm pressure of argon. The resonance lines were investigated first with a thirty-foot grating in the second order, and with iron and krypton comparison spectra. Components a and d of the 4101A line were resolved by this instrument while components b and c were not. The 4511A line complex appeared as two components. A further check was made with the hollow cathode using a Fabry-Perot interferometer as before, with a 1.0-cm spacer.

The results of the wavelength determination from the atomic beam and hollow cathode sources, together with values taken from literature, are given in Table II. Center-of-gravity values for various combinations of components are also given in this table to facilitate comparison.

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Intensity of Lyman-Alpha Line in the Solar Spectrum*

WILLIAM A. RENSE
Department of Physics, University of Colorado, Boulder, Colorado
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The Lyman-alpha line appeared on a rocket spectrogram recently obtained by a group at the Physics Department of the University of Colorado. The grazing-incident spectrograph had been pointed directly at the sun during the 28-second exposure by a biaxial sun-follower in an Aerobee rocket. The average altitude during exposure was 81 km. Lyman-alpha was the only line observed in the far ultraviolet. It is about 5 angstroms broad and exhibits, for the altitude range of the rocket during the exposure, a narrow emission center with broad emission wings. The total intensity outside the earth's atmosphere is estimated to be 0.05 microwatt/cm². Instrumental scattering could have masked the light of any faint far-ultraviolet continuum which may have penetrated to the atmospheric levels reached by the rocket during the exposure.

INTRODUCTION

AFTER rockets were first sent above the ozone layer the extension of the solar spectrum well into the ultraviolet below 2900A was soon realized. On October 10, 1946 a Naval Research Laboratory group[1] succeeded in obtaining spectrograms reaching to about 2200A with a normal-incidence grating spectrograph employing two slits and utilizing lithium fluoride beads to focus the sun's light on the slits. Later, Hopfield and Clearman[2] analyzed photographs taken with similar grating spectrographs flown in rockets on April 1 and July 29, 1947. Slightly better dispersion and resolution were realized, but nothing essentially new was added to the knowledge of solar ultraviolet radiation. A sun "homing" device in connection with two partially diffusing mirrors was employed to illuminate the slits of the July instrument. Over the past few years spectrographs have been repeatedly flown, mostly under the supervision of R. Tousey of the Naval Research Laboratory. A few salient results of all these investigations are the discovery of the emission cores in the center of the two Mg II lines near 2800A, the identification of many new Fraunhofer lines and the measurement of the intensity of the solar continuum down to about 2000A. It had been expected that Lyman-alpha, the first line of the hydrogen Lyman series, might be detected photographically in the solar spectrum, but no evidence of the line was ever thus obtained. (Lyman-alpha is actually a doublet resulting from the $1s^2S-2p^2P^o$ transition in the hydrogen atom; the wavelengths are 1215.668A and 1215.674A.) Intensity losses suffered in reflecting the sun's light into the slit are great for wavelengths below 1500A, so that decreased spectrographic speeds resulting from this fact might account for the failure. In the meantime, other methods were tried for detecting light near and around the 1216A region. Tousey, Watanabe, and Purcell[3] flew a thermoluminescent phosphor, $CaSO_4$:Mn, in rockets to heights of between 82 and 127 km. Evidence for radiation lying between 1050 and 1250A was obtained. The intensity was estimated to be about 0.04 microwatt/cm².

Recently detection of solar radiation between 1180A and 1300A has been made with the aid of photon counters flown in rockets.[4] The radiation was not present below 74 km. Atmospheric absorption coefficients calculated from the data are consistent with the assumption that the radiation is from Lyman-alpha.

After the successful development of a biaxial sun-follower by the University of Colorado Physics Department electronics group, under contract with the Air Force, it was thought that Lyman-alpha may be photographed using a grazing-incidence-type, low dispersion, grating spectrograph. The speed of this instru-

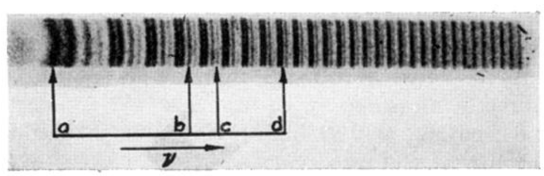
* The research reported in this paper has been sponsored by the Geophysics Research Directorate of Air Force Cambridge Research Center, Air Research and Development Command.

[1] Baum, Johnson, Oberly, Rockwood, Strain, and Tousey, Phys. Rev. **70**, 781 (1946).

[2] J. J. Hopfield and H. E. Clearman, Phys. Rev. **73**, 877 (1948).

[3] Tousey, Watanabe, and Purcell, Phys. Rev. **83**, 792 (1951).

[4] Byram, Chubb, Friedman, and Lichtman, J. Opt. Soc. Am. **42**, 876 (1952).



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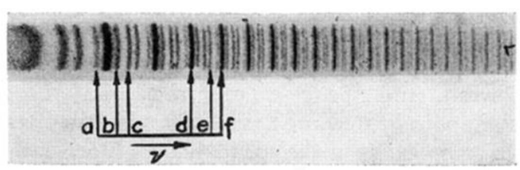

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