STAGES IN THE EXCITATION OF THE SPECTRUM OF INDIUM

BY JOHN G. FRAYNE AND CHARLES W. JARVIS

ABSTRACT

The indium metal was vaporized at a temperature of 650°C in an iron cylindrical anode within a quartz tube. Electrons from an oxide-coated Pt filament passed through a helical grid into a force-free space where they collided with the atoms of indium vapor. The spectrum was viewed end-on through a transparent quartz window. At 3.3 volts the lines $2p_1-2s$ and $2p_2-2s$ appeared. At 4.2 volts the additional lines $2p_1-3d$ and $2p_2-3d$ appeared. At seven volts higher members of the series and several unclassified lines were present on the plates. At 13.2 volts the spectrum became very strong and the line 2306A appeared in addition to the recognized series lines. It is possible that the second arc spectrum was excited at this potential. The resonance lines were found to be less intense than the corresponding lines due to the metastable atoms.

INTRODUCTION

THE element indium is one of four members of the aluminum sub-group of Group III in the Periodic Table. The arc spectra of this group are characterised by series of well defined doublets and by the absence of the principal series found in the alkalis and alkali earths. Comparatively little research has been done on the spectra of this group. Mohler and Ruark[1] have studied the excitation by stages of the arc spectrum of thallium. Absorption spectra studies for thallium, indium and gallium have been made by Grotrian,[2] and also by Frayne and Smith.[3] Electrical resonance and ionization measurements on indium and gallium vapors have been made by Jarvis.[4] The indium used in this investigation was obtained from Mr. F. G. McCutcheon, Bartlesville, Oklahoma. Although some impurities were present it was found quite satisfactory at the temperatures employed.

EXPERIMENTAL PROCEDURE

On account of the high boiling point of indium it is necessary to heat the metal to a temperature of 650–700°C before the vapor pressure is sufficient to show any spectral lines on a photographic plate when bombarded with fourteen volt electrons for a period of five or six hours. This necessitated the use of quartz or porcelain tubing. In Fig. 1, D is a transparent quartz tube with an optically plane quartz window E. A is a cylindrical iron anode to which the nickel grid helix B is welded. The open end of the quartz tube was fitted with an iron cap C which was sealed vacuum tight with de Khotinsky cement and water cooled. The filament leads were brought out through a glass tube H which was cemented to the metal cap C. The indium metal

[1] Mohler and Ruark, J.O.S.A. **7,** 819 (1923).
[2] Grotrian, Zeits. f. Physik, **12,** 218 (1922) and **18,** 169 (1923).
[3] Frayne and Smith, Phys. Rev. **27,** 23 (1926).
[4] Jarvis, Phys. Rev. **29,** 442 (1927).

was placed in the anode A and heat was applied by the electric furnace F. As the temperature was raised the indium metal tended to deposit on the quartz window and cloud it. This difficulty was overcome by placing the window in the hottest portion of the furnace. With this arrangement the tube could be operated for about ten days before any deposition was noticed.

The indium vapor proved to be very active chemically at 700°C. It combined with fine filaments of tungsten, molybdenum or platinum and with

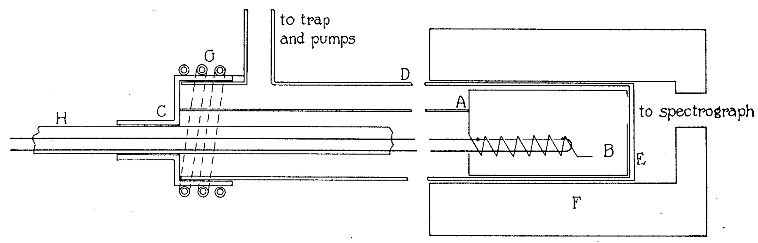

Fig. 1.

fine platinum strip. A 15 mil platinum oxide coated filament was found satisfactory, usually lasting about 120 hours. Electrons from this filament were accelerated through the nickel helix B into the force-free space between grid and anode where they collided with the atoms of the indium vapor. The resulting emission of spectral lines was viewed end-on through the opening in the anode. A Hilger E3 quartz spectograph was used throughout.

Experimental Results

The spectrum lines appearing at different anode voltages are given in Table I. It will be noticed that the first resonance line $2p_2-2s$ and the

TABLE I

Indium spectrum produced by electronic excitation.

Notation	3.3 v.	4.2 v.	6.9 v.	13.2 v.
$2p_1-2s$	4511.31 *A*	4511.31	4511.31	4511.31
$2p_2-2s$	4101.76	4101.76	4101.76	4101.76
$2p_1-3d$		3258.56	3258.56	3258.56
		3039.35	†3051.19	3051.19
$2p_2-3d$			3039.35	3039.35
			*2957.01	2957.01
$2p_1-3s$			2932.63	2932.63
			‡2858.30	2858.30
			*2836.91	2836.91
			*2775.35	2775.35
$2p_2-3s$			2753.88	2753.88
$2p_1-4d$				2710.26
$2p_1-4s$				2601.75
$2p_2-4d$				2560.15
$2p_1-5d$				2523.08
				‡*2306.07

* Listed as unclassified lines in the arc by Uhler and Tanch.
† Listed as an arc line by Kayser and Runge.
‡ Listed as a spark line by Exner and Haschek.

line of the metastable atom $2p_1-2s$ appear at the lowest voltage. The emission current was 0.3 m.a. and the time of exposure was 40 hours. At 4.2 volts the corresponding pair of lines resulting from transitions to the $3d$ level appeared in addition to the previous two lines. The current at this potential was about 0.6 m.a. and the exposure was for 24 hours. At 6.9 volts some higher members of the series appeared as well as several unclassified arc lines. Four of the latter are listed by Uhler and Tanch as arc lines. The line 3051A is given as a spark line by Exner and Haschek. The current at this potential was about 1.5 m.a. and the exposure lasted 14 hours. At 13.2 volts the arc became very brilliant the whole space between grid and anode being filled with a bluish-violet color. Up to this point the illumination was too weak to be observed by the eye. An exposure of three hours was found sufficient at this potential. A strong unclassified line 2306A appeared there. Several lines in the visible and near ultra-violet appeared here also, but they have been all traced to oxygen and other gaseous impurities.

Discussion

It was found that the intensity of the lines $2p_1-2s$ and $2p_1-3d$ were consistently stronger than $2p_2-2s$ and $2p_2-3d$. This was especially notable at the lower voltages. Mohler and Ruark[1] found a similar occurrence with thallium lines and attributed it to the fact that the resonance radiation was partially absorbed in the cool vapor above the furnace. Here, however, there was no column of cool vapor in the path of the light. Further, Frayne and Smith[3] have shown that at this temperature the $2p_1-2s$ is just as prominently absorbed as the $2p_2-2s$ line. This seems to indicate the return of atoms from the $2s$ or $3d$ levels to the $2p_1$ is more probable than to the $2p_2$ level. However, the work of Jarvis[4] by electrical method used for determination of resonance potentials indicated sharper and stronger current voltage breaks for the transition $2p_2-2s$. Since absorption spectra show that many indium atoms are in the metastable state at 700°C the valence electron may be ejected directly from the $2p_1$ directly to the $2s$ level. If all of these should return to the $2p_1$ in addition to others ejected to the $2s$ from the $2p_2$ state one can see that the $2p_1-2s$ line might be much more intense than the corresponding resonance line.

The entire arc spectrum should appear at 6.9 volts. It was found that several unclassified lines appeared at this potential. It is difficult to believe that these lines belong to the so-called second arc spectrum, being produced by multiple excitation. The small electron current, 1.4 m.a., makes this rather improbable. If these are bonafide arc lines the energy level diagram for indium must be much more complicated than one representing only the well known p, s and d levels. All attempts to prove these to be combination lines have been futile.

At 13.2 volts there was evidence of strong ionization. The electron current increased very rapidly at this stage and the glow in the tube was very noticeable. It is possible that two electrons were removed at this potential and the resulting spectrum might be considered as a second arc. Undoubtedly many lines in these spectrum must lie in the far ultra-violet and, of course, could not be observed with an ordinary spectrograph. It is quite possible that the line 2306A may correspond to the 1855A line in the Aluminum spectrum.

Antioch College,
Yellow Springs, O. (J.G.F.)
Ohio Wesleyan University,
Delaware, O. (C.W.J.)
February 1, 1927.