THE ABSORTION SPECTRA OF TELLURIUM, BISMUTH, CHROMIUM AND COPPER VAPORS IN THE VISIBLE AND ULTRAVIOLET

By R. V. Zumstein

Abstract

Using a hot carbon tube at about 1600°C as the absorption cell, the spectra of these elements have been studied in absorption from 6000 to 2000A. The vapor of tellurium was dissociated into atoms by a simple device and 4 absorption lines were found. Two new arc lines were measured. The same arrangement gave 8 bismuth absorption lines, 4 being new. These are exactly the lines to be expected from the work of Ruark, Foote, Mohler and Chenault. Four new arc lines were measured in the spectrum of a 75 ampere arc. Chromium was placed directly in the carbon tube and 3 triplets were absorbed. Nineteen copper lines were absorbed, 10 being from the normal state in agreement with Shenstone and McLennan and McLay and 9 new ones from excited states.

THE absorption spectrum of tellurium vapor was investigated by Evans[1] at various pressures and temperatures. He found that if a small quantity of tellurium was gradually heated in an enclosed quartz tube, the vapor was opaque or showed absorption bands. As the vapor was heated, it became more transparent and the bands disappeared. At a temperature of about 1000°C and a sufficiently low pressure, the vapor was perfectly transparent from the visible to 2500A. His interpretation was that at low temperatures and high vapor pressures the molecules of tellurium vapor are composed of several atoms and that at high temperatures these molecules dissociate into atoms if the pressure is low so that there is slight chance of recombination.

Guided by Evans' experiments, I have modified the method used for manganese.[2] The tellurium was not placed directly in the carbon tube but in a small iron tube as shown in Fig. 1. C is the carbon tube heated by the torch T. The hottest part of the tube was at about 1600°C and the coldest at 800°C. Te is the tellurium in the small iron tube at about 500°C. Through a second tube N, a gentle stream of nitrogen flowed to displace the atmospheric oxygen from the tube. By this method four absorption lines were observed corresponding

[1] Evans, Astrophys. J. **36,** 228 (1912).
[2] Zumstein, Phys. Rev. **26,** 765 (1925).

to the arc lines 2385.793, 2383.268, 2259.02 and 2142.94. The first pair were sharp absorption lines but the last two were quite broad.

The tellurium arc for comparison was obtained by placing tellurium in the lower carbon of a 50 ampere arc. The spectrum so obtained was similar to that described by Uhler and Patterson.[3] To their list of 15 arc lines I would add a strong pair of reversed lines at 2001.87 and 1994.07. Their lines 2208.58, 2160.1 were observed as diffuse reversals and 2147.33, 2081.8 as sharp reversals. I have not been able to make any analysis of the tellurium arc spectrum beyond a guess that the lowest lying levels are rather widely separated p levels which would combine with s and d levels to give the sharp and diffuse lines observed in the arc spectrum. McLennan, Smith and Peters[4] have recently observed a group of tellurium arc lines in the near infrared.

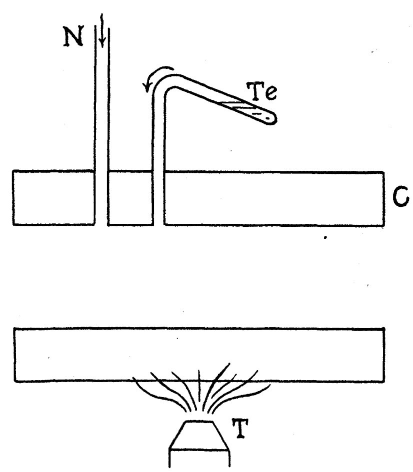

FIG. 1

Bismuth. Since some of the bismuth absorption lines appeared while studying the absorption spectrum of tellurium vapor, it seemed worth while to repeat the experiments with pure bismuth using the arrangement of Fig. 1. The 8 absorption lines observed are given in Table I. The first four of these lines were observed in absorption by Ruark, Mohler, Foote and Chenault.[5] They state that a band absorption extended from 2205A to the shorter wave-lengths. It may be that these bands were due to bismuth molecules which were dissociated in the present experiments. All of the absorptions are from the state

[3] Uhler and Patterson, Am. Journal of Science **186**, 135 (1913).
[4] McLennan, Smith and Peters, Trans. Roy. Soc. Canada, III, **39** (1925).
[5] Ruark, Mohler, Foote and Chenault, B. S. Sci. Papers, **19**, 484 (1924).

called $3d_2$ by Ruark, etc., and afford very good support of the analysis of the bismuth arc spectrum which they give.

A bismuth arc of 70 amperes gives an intense continuous spectrum extending from the visible to 1900A with the bismuth arc lines reversed. I have compared this arc with that given by Ruark, etc. between 2075 and 2000A. Their lines 2020.5, 2068.99 and 2073.2 were not observed and are perhaps not arc lines. Four new lines were found namely: 2064.4 (2*R*), 2057.4 (2*R*), 2041.8 (2*R*) and 2041.6 (2*R*). The difference in frequency of 2041.8 (48960) and 2582.1 (38718) equals $3d_1^B-3D_1^A$. Also the frequency difference of 2041.6 (48964) and 2224.2 (44946)

TABLE I

Bismuth absorption spectrum

λ(I.A.)	Intensity 70 amp. arc	Intensity Absorption	Series notation
3067.732	10R	10	$3d_2-\alpha$
2276.578	6R	5	$3d_2-\delta$
2230.626	10R	10	$3d_2-\epsilon$
2228.240	8R	9	$3d_2-\zeta$
2177.33*	3R	2	$3d_2-\eta$
2110.263*	8R	6	$3d_2-\theta$
2061.73*	10R	9	$3d_2-\iota$
2020.99*	3R	2	$3d_2-\kappa$

* New absorption lines

equals $3d_1^B-3D_2$. This enables us to classify these four bismuth lines and to evaluate two terms 2490 and 2486 which resemble several other bismuth terms in being a close pair. A classification of the bismuth arc spectrum has also been given by Kopferman[6] who indicates that 2582.1 comes from $3d_1^B$ which cannot be correct as it is not reversed and also from $3D_2$ which is possible.

Chromium. The absorption spectra of chromium and copper vapors were investigated by placing a piece of the metal in the carbon tube and heating it directly to about 1600°C. The method was the same as that used for manganese.[2] Three chromium triplets were observed in absorption as shown in Table II. The first two triplets had been previously observed in absorption by Grotrian and Gieseler[7] and by McLennan and McLay.[8] In fact these nine lines and many others were obtained in the chromium absorption spectrum by King[9]. In King's experiments, the vapor was at only one temperature, 2600°C. He

[6] H. Kopfermann, Zeits. f. Physik **21,** 322 (1924).
[7] W. Grotrian and H. Gieseler, Zeits. f. Physik **22,** 245 (1924).
[8] McLennan and McLay, Trans. Roy. Sco. Canada, **III,** 89 (1925).
[9] A. S. King, Astrophys. J. **60,** 291 (1924).

obtained absorptions from the normal state and from some of the excited states. It is not therefore obvious from his results that the triplet 2366, 2365, 2364 are transitions to the normal state which does follow from the present experiments. The threefold ^7p term defined by this triplet should combine with the 5^7s term (see Gieseler's article on the arc spectrum of chromium[10]) to give a triplet in the infrared of wave-lengths 18716, 18661, 18585A. Randall and Barker[11] found a chromium triplet at 18717.0 ($I=20$), 18654.2 (30), 18583.5 (30). The agreement appears to be satisfactory.

TABLE II

Chromium absorption spectrum

λ(I.A.)	ν	Series
4289.726	23304.98	4^7s-4^7p
74.802	386.34	
54.341	498.81	
3605.330	27728.83	4^7s-4^7p
593.483	820.24	
78.688	935.25	
2366.85	42237.5	4^7s-5^7p
65.96	53.3	
64.74	75.1	

Copper. It seemed desirable to repeat my former experiments on the absorption of copper vapor,[12] using the large Hilger spectroscope, size E_1, which is now available. Shenstone,[13] McLennan and McLay,[8] and Stücklen[14] have recently studied this problem. Shenstone gives evidence for a pair of metastable states (one is the X term introduced by Randall[15]) which are not far removed from the normal state ($\Delta\nu=$ 13245.4 and 11202.5).

With the copper vapor at about 1200°C, I obtain a series of absorption lines which appear to come from copper atoms in the normal state. When the temperature is increased to 1600°C, most of these lines increase in width and a group of faint absorption lines appear which I think are due to copper atoms in excited states. These two groups are given in Table III.

All of the absorption lines from the normal state were obtained by Shenstone and by McLennan and McLay. The three lines 2492, 2441

[10] H. Gieseler, Zeits. f. Physik **22**, 243 (1924).
[11] Randall and Barker, Astrophys. J. **49**, 58 (1919).
[12] Zumstein, Phys. Rev. **25**, 523 (1925).
[13] Shenstone, Phil. Mag. **49**, 952 (1925).
[14] Stücklen, Zeits. f. Physik **33**, 562 (1925).
[15] Randall, Astrophys. J. **34**, 1 (1911).

and 2244 were narrow absorption lines at the highest temperature. The remainder from the normal state widen out with increase of temperature. All of the absorption lines from the metastable states were sharp. The narrow pair, 2199.73 and 2199.57 were observed as two reversals in the arc as noted by Shenstone and Stücklen. They were absorbed as two narrow absorption lines by the vapor. At high temperatures a group of absorption bands appeared from 2275 to 2228A as found by Stücklen in the copper spark under water. Because of these bands, one cannot be certain if there was faint absorption at some of the arc lines in this region. By changing the inductance and

TABLE III

Copper absorption spectrum

Wave-lengths from normal state	Wave-lengths from excited state
3273.976	5105.551*
3247.550	2392.629* very faint
2492.142 sharp	2293.832*
2441.625 sharp	2230.071*
2244.240 sharp	2227.74*
2225.665	2215.65* very faint
2181.68	2214.56*
2179.91	2199.73*
2165.06	2199.57*
2024.3	

* New absorption lines

capacity of the circuit of the under water spark, Stücklen obtained a group of copper arc lines which were considered to come from the normal state. The grouping so obtained is considerably different from that afforded by the more direct method of heating the vapor in a tube with a torch.

The present experiments show very clearly that the copper atom has one or more metastable states which differ in frequency from the normal state by about 10,000 cm^{-1}. They do not show the exact value of this difference. In the copper arc spectrum, there are pairs in the visible and near ultraviolet having the frequency difference of 248.4, which is that of the two lines 3274 and 3247. If any of these pairs should show the faint absorption corresponding to the metastable states, then we can evaluate with certainty the terms which correspond to the metastable states. According to Shenstone's work, we should expect that the green line 5105 would be absorbed and at slightly higher temperature the yellow pair 5782. and 5700. I have frequently studied the copper absorption in the visible but always with negative results. Recently we have received from A. Hilger and Co. a glass prism and lens to fit their E_1 quartz spectrograph. Having available therefore a dispersion of 12A per mm at 5700 A, I have returned to the problem and find that in the visible spectrum only the green line 5105 is faintly absorbed at the highest temperatures. The fact that the yellow pair was not absorbed is not an argument against Shenstone's work because the absorption of the green line 5105 was only observed on a small fraction of the plates taken. To obtain the yellow pair in absorption would require a still higher temperature.

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