Series and Term Values in the Arc Spectrum of Tellurium

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Tellurium was excited in an electrodeless discharge tube in such a manner that the arc lines could be distinguished from the spark. The spectrum was photographed in the visible and infrared, and series were found corresponding to those given in Fowler's *Report on Series in Line Spectra* for the first three elements of the oxygen group. From the limit thus established, which is the lowest level of Te II ($5p^3:{}^4S_{3/2}$), term values are given down to the lowest level of Te I ($5p^4:{}^3P_2$). The ionizing potential is found to be 72,667 cm^{-1} or 8.96 volts. A list of the wave-lengths of all the stronger lines, in addition to those classified, is given.

WHILE continuing the work on selenium,[1] using an electrodeless discharge tube, it was found that conditions could be obtained which gave an apparently perfect differentiation between arc and spark lines, and there seemed to be no reason why the method could not be applied with equal success to the study of the tellurium arc spectrum, for which no analysis had ever been made in the long wave-length region.

Such was found to be the case.

Apparatus and Procedure

A cylindrical fused quartz tube $8'' \times 1\text{-}3/4''$, with plane windows on the ends, was pumped to as low a pressure as possible (about 10^{-5} mm Hg) and baked at 550°C for two hours. Some tellurium was then slid in from the side tube, through which the exhaustion was taking place, which had been outside the oven during the baking process, and was vaporized with a bunsen flame, being allowed to recondense on cool parts of the tube. This was done several times and the tube sealed off.

A silver ribbon (it must be a material which will stand a temperature of 500°) was wound around the tube and the whole mounted in an electric oven, with windows opposite the ends of the tube. The terminals of the silver coil were connected to a condenser through a spark gap. A 5 k.v.a., 100 k.v. transformer supplied the power. A thermometer was placed in the oven with its bulb touching the tube in its cooler region (as shown by condensation of tellurium).

When at room temperature, the tube might be made to flash a few times by turning on the power, but it was generally black. As the temperature was raised, a steady discharge would begin at about 340° and continue as a bright ring type to about 470°, where there was a sudden change to a dull bluish glow throughout the whole tube, sometimes with bright scintillations scattered through it with more or less axial symmetry.

Numerous photographs were taken under various conditions of temperature and electrical circuit, and widely varying types of spectra were produced.

[1] R. C. Gibbs and J. E. Ruedy, Phys. Rev. **40**, 204 (1932).

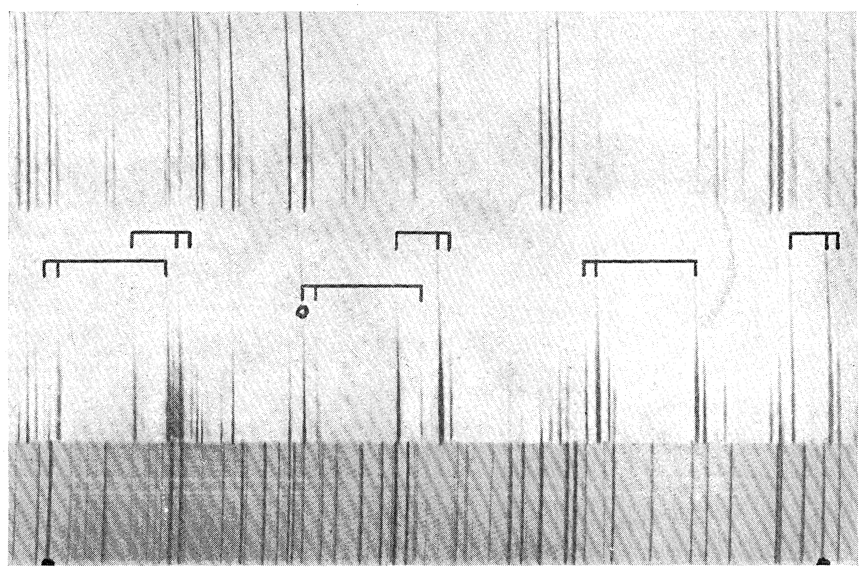
Spark lines were the easiest to obtain and were always present, except perhaps in the high temperature stage, where nothing but more or less continuous band structure could be made out. Some beautiful bands were obtained once in the region λ5500. In general, as the temperature was being raised from 340° to 470°, the arc lines would increase and the spark lines decrease in intensity.

The circuit finally adopted was an oil condenser of 0.003 mf. capacity, a spark gap of 3/8'' between brass rods mounted in a glass tube through which air was blown transversely, and 15 turns of 1/4''×1/32'' ribbon, spaced

Te 370°

Te 470°

Fe



λ6678 λ8046

$6p^3P-9d^3D$ $6p^3P-8d^3D$ $6p^3P-7d^3D$

$6p^5P-8d^5D$ $6p^5P-7d^5D$

$6p^5P-9s^5S$

Fig. 1.

1/8'', around the tube. The procedure was to take one exposure at about 370° and another beside it on the plate, of equal length, at about 470°, with the iron comparison spectrum next to it. A Zeiss 3-prism spectrograph was used for all pictures, and an image of the bright ring in the discharge tube was focused on the slit in such a manner that the outer edge just overlapped the comparison prism. The different parts of the length of a spectrum line on the plate show the radiation coming from regions of different distance from the axis of the tube. The photographic plate was so diaphragmed that the length of a line would just cover the region from the center of the tube to one edge. Fig. 1 is an enlargement of such a plate. Due to the curvature of the lines and the shifting of the plate holder, the tops of the 470° lines do not match up with the bottoms of the 370° lines, but under a comparator this causes no difficulty. Most of the stronger lines, of whose which are intensified at the higher temperature, have been classified and definitely belong to the tellurium arc spectrum. The first members of the triplet and quintet series of *OI*, and also $H\alpha$ are present and behave similarly to the tellurium arc lines. Mercury is also weakly present as an impurity, but the intensity of its lines is somewhat diminished at the higher temperature.

The spectrum was photographed from λ3750 to λ11,287, but very few arc lines were found below λ5000, and careful measurement was not made in that region. Four types of Eastman plates were used. They were: hypersensitive panchromatic, λ5000—λ6680; infrared sensitive N, λ6680—8050; infrared sensitive A, λ8050—λ9080; infrared sensitive B, λ9080—λ11,287. The maximum length of exposure was seven hours in the longest wave-length region, though the crucial lines at λ9700 and λ10,000 were obtained in a few minutes. The new region opened to photography by the recent infrared B plates was lacking in standards, but Dr. Meggers of the Bureau of Standards, kindly supplied a list of iron wave-lengths up to λ10,500, and the mercury line at λ11,287 was used beyond that.

The dispersion varied from 12A per mm at λ5000 to 135A per mm at λ11,000. Wave-lengths were calculated using the Hartman formula, the entire region of sensitivity of each plate being covered at once, and a correction curve of intermediate iron standards plotted. No deviation greater than 1A was found, except for the range λ9000 to λ11,287, where it was as large as 4A. The calculations thus could be corrected to at least the accuracy of the settings on the lines. Throughout the entire region the accuracy of the measurements should be about one frequency number.

Results

The lines of tellurium, analogous to those in oxygen, sulfur, and selenium, observed and classified by Runge and Paschen[2] in 1897, and listed in Fowler's *Report* have never been observed. By extrapolation from this known group, the positions of the tellurium lines can be roughly predicted. The only wave-lengths published for that region[3] are almost meaningless. The present work indicates about 180 lines as belonging to the arc spectrum of tellurium between λ5000 and λ11,100. Some 60 of these have been classified and are shown in Table I, the arrangement of which has been made similar to the tabulations in Fowler. In both the triplet and quintet diffuse series the lines are generally obviously multiple and the wave-lengths hence inexact. Within the limits of this inexactness, both series are nearly Rydbergian, but the limits thus determined are necessarily uncertain. In the case of the quintet sharp series, the lines are sharp and the separations consistent. (The absence of one of the lines in the second member is due to a strong spark line falling exactly where it should be.) A Hicks formula was adjusted to fit the $^5P_2-{}^5S_2$ frequencies for $n=9$, 10, and 11,

[2] C. Runge and F. Paschen, Astrophys. J. **8**, 70 (1898).

[3] J. C. McLennan, H. G. Smith, and C. S. Peters, Trans. Roy. Soc. Canada **19**, 39 (1925).

$$\nu = 18{,}475.9 - \frac{109{,}737}{(n - 4 + 0.0232 + 0.1057/(n - 4))^2},$$

TABLE I.

$6s^5S_2 - np^5P_{123}$

Int.	λ (air)	ν (vac.)	Δν	n
30	10089.0	9909.1	39.2	
40	10049.3	9948.1	335.7	6
50	9721.2	10284.0		
4	5178.9	19303.7	113.3	
7	5148.7	19417.0	250.9	7
8	5083.0	19667.9		

$6p^5P_{123} - nd^5D_{(01234)}$

Int.	λ (air)	ν (vac.)	Δν	n
15	7759.1	12884.6		
6	7754.4	12892.4	337.0	7
10	7556.8	13229.4		
6b	7552.8	13236.4	37.5	
5	7531.5	13273.9		
4	6843.9	14607.5		
20b	6837.6	14621.0	336.2	
8b	6690.0	14943.7		8
4b	6686.7	14951.0	43.3	
4	6670.6	14987.0		
3	6409.4	15597.8		
8	6405.9	15606.3	337.9	9
8bs	6273.5	15935.7	44.8	
6	6255.9	15980.5		
2b	6162.4	16223.0		
6b	6160.2	16228.8	336.9	10
3	6034.9	16565.7	38.8	
4b	6020.8	16604.5		
3b	6005.0	16648.2	334.9	
1bs	5886.5	16983.3	34.4	11
3bs	5874.6	17017.7		

b—broad
bl—broadened toward longer λ
bs—broadened toward shorter λ

$6p^5P_{123} - ns^5S_2$

Int.	λ (air)	ν (vac.)	Δν	n
8	8771.2	11397.8	335.8	
12	8521.4	11732.0	40.3	8
8	8492.2	11772.3		
4	7230.3	13826.9	336.4	9
4	7058.6	14163.3		
4	6606.3	15132.9	335.8	
4	6462.9	15468.7	38.8	10
3	6446.7	15507.5		
2	6277.7	15925.0	335.7	
1	6148.1	16260.7	39.2	11
1	6133.3	16299.9		

$6s^3S_1 - np^3P_{120}$

Int.	λ (air)	ν (vac.)	Δν	n
1	11084.5	9019.2	140.8	
1	10914.0	9160.0	30.5	6
0	10877.8	9190.5		
8	5789.1	17269.1	59.8	
6	5769.1	17328.9	107.6	7
7	5733.5	17436.5		

$6p^3P_{120} - nd^3D_{(123)}$

Int.	λ (air)	ν (vac.)	Δν	n
8	10149.2	9850.4	31.1	
8	10117.2	9881.5	138.2	6
15	9977.6	10019.7		
10bs	8082.5	12369.0	32.4	
30bs	8061.4	12401.4	137.6	7
20	7972.9	12539.0		
8	7280.9	13730.8	32.9	
20bl	7263.5	13763.7	138.5	8
15bl	7191.1	13902.2		
3b	6870.3	14551.4	33.1	
20bl	6854.7	14584.5	138.9	9
10b	6790.0	14723.4		
3b	6628.7	15081.8	34.8	
8bl	6613.4	15116.6	138.2	10
6bl	6553.3	15254.8		
1b	6469.5	15452.8	30.7	11
7b	6456.7	15483.5		
8b	6349.7	15744.4		12
8bs	6273.5	15935.7		13

in which the number 18,475.9 is the limit. For $n=8$, the frequency calculated was 52.2 larger than the observed value. Doing precisely the same for the corresponding lines of selenium, the limit obtained was 10 greater than that established by more accurate means, and the frequency calculated for the transition from the next lower term was 51.2 larger than the observed value. From this similarity it seems that the limit of the tellurium series should be 18,466, which is not at variance with the roughly obtained limit of the quintet diffuse series. McLennan, McLay, and McLeod[4] have established the separation of the $6s^5S_2$ and the $6s^3S_1$ terms through observations in the ultraviolet, and it is by this means that the triplet principle and diffuse series are brought into the term scheme, rather than by the use of a limit of uncertain accuracy, which, however, agrees well enough with the limit thus indirectly set. Table II gives the terms so far identified, including those of McLennan,[4] and also indicates those to be expected, which go to the ^2D and ^2P limits. Doubtless some of the 120 remaining unclassified lines are transitions involving these terms, but none of them has been identified in sulfur or selenium, and it is a long way to extrapolate from oxygen. The ultraviolet wavelengths given by McLennan,[4] and by LaCroute[6] might be expected to be of assistance here, but nothing conclusive has been found, and another investigation of this region is proposed before further analysis is attempted. Table III gives the wave-lengths, in order, of all the classified lines, and the stronger of the unclassified ones which are thought to belong to the tellurium arc spectrum. All the terms listed under "Transition" are built on the ^4S limit. Intensities are comparable only over short wave-length ranges.

The separations of the $6p^5P_{123}$ levels show considerable departure from LS coupling, while those of the $6p^3P_{012}$ are extremely irregular. The partially resolved ^5D terms seem to show little uniformity as they approach their limit, which was likewise the case in selenium. It would be interesting to examine these more closely, but no instrument of sufficient resolving power was available at the time this research was in progress, to make the attempt worth while.

The absence of any triplet series in Runge and Paschen's[2] observations on sulfur and selenium (the terms listed as triplets in Fowler's *Report* are the quintets) would lead one to expect them to be weak in tellurium, whereas they are nearly as strong as the quintets. The possibility that the series here listed as $^3P-{}^3D$ going to the ^4S limit, is a series going to one of the doublet limits, seems to be ruled out by the narrowness of the separation of the terms, if for no other reason.

The second members of both the triplet and quintet principal series were chosen because they were the only lines on the plate in the expected regions.

With the quite complete analysis of the oxygen spectrum[7] as a starting

[4] J. C. McLennan, A. B. McLay, and J. H. McLeod, Phil. Mag. **4,** 486 (1927).

[5] J. C. McLennan and M. F. Crawford, Nature **124,** 874 (1929).

[6] M. P. LaCroute, Jour. Phys. Rad. **9,** 182 (1928).

[7] R. Frerichs, Phys. Rev. **34,** 1239 (1929); and Phys. Rev. **36,** 398 (1930). J. J. Hopfield, Phys. Rev. **37,** 160 (1931).

TABLE II.

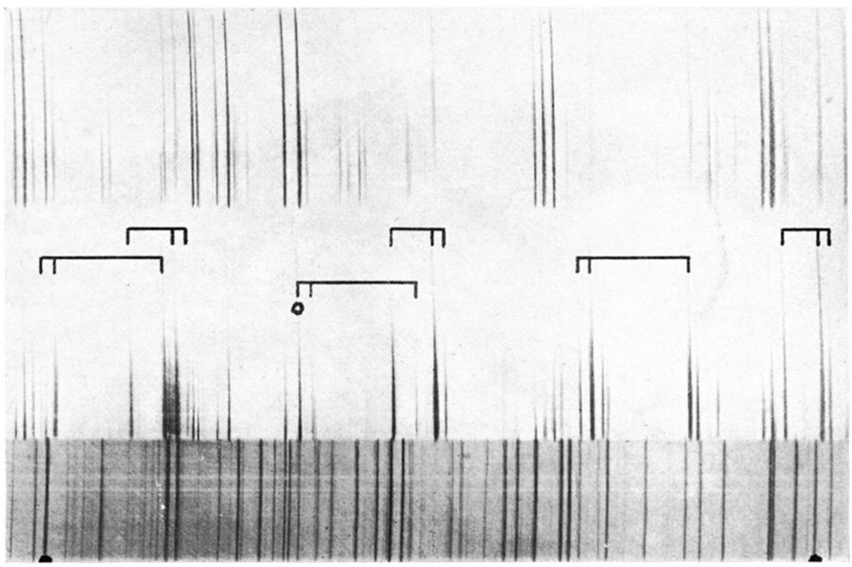
	$5p$	$^3P_2$:72667 $^3P_0$:67960 $^3P_1$:67916	$^1D_2$:62108	$^1S_0$:23199 (McLennan[5])
		$4s^24d^{10}5p^3$:^4S	$4s^24d^{10}5p^3$:^2D	$4s^24d^{10}5p^3$:^2P
	$6s$	$^5S_2$:28414 $^3S_1$:26014	^3D ^1D	^3P ^1P
$5s^24d^{10}5p^3$	$6p$	$^5P_1$:18505 $^5P_2$:18466 $^5P_3$:18130 $^3P_1$:16992 $^3P_2$:16854 $^3P_0$:16821	$^3(PDF)$ $^1(PDF)$	$^3(SPD)$ $^1(SPD)$
	$5d$	^5D ^3D	$^3(SPDFG)$ $^1(SPDFG)$	$^3(PDF)$ $^1(PDF)$
	$7p$	$^5P_1$:9110 $^5P_2$:8997 $^5P_3$:8746 ^3P :8745 ^3P :8685 ^3P :8578		
	$6d$	^5D $^3D_{123}$:6972		
	$8s$	$^5S_2$:6734 ^3S		
	$7d$	$^5D_2$:5230 $^3D_{123}$:4453		
	$9s$	$^5S_2$:4303 ^3S		
	$8d$	$^5D_2$:3522 $^3D_{123}$:3090		
	$10s$	$^5S_2$:2997 ^3S		
	$9d$	$^5D_2$:2530 $^3D_{123}$:2269		
	$11s$	$^5S_2$:2205 ^3S		
	$10d$	$^5D_2$:1900 $^3D_{123}$:1737		
	$11d$	$^5D_2$:1483 $^3D_{123}$:1370		

TABLE III.

Int.	λ (air)	ν (vac.)	Transition	Int.	λ (air)	ν (vac.)	Transition
1	11084.5	9019.2	$6s^3S_1-6p^3P_1$	8	7280.9	13730.8	$6p^3P_0-8d^3D$
1	10914.0	9160.0	$6s^3S_1-6p^3P_2$	20bl	7263.5	13763.7	$^3P_2-8d^3D$
0	10877.8	9190.5	$6s^3S_1-6p^3P_0$	4	7230.3	13826.9	$^5P_3-9s^5S_2$
8	10149.2	9850.4	$6p^3P_0-6d^3D$	15bl	7191.1	13902.2	$^3P_1-8d^3D$
8	10117.2	9881.5	$6p^3P_2-6d^3D$	4	7058.6	14163.3	$^5P_2-9s^5S_2$
30	10089.0	9909.1	$6s^5S_2-6p^5P_1$	3b	6870.3	14551.4	$^3P_0-9d^3D$
40	10049.3	9948.1	$6s^5S_2-6p^5P_2$	20bl	6854.7	14584.5	$^3P_2-9d^3D$
15	9977.6	10019.7	$6p^3P_1-6d^3D$	5	6843.9	14607.5	$^5P_3-8d^5D$
14	9955.5	10042.0		20b	6837.6	14621.0	
7	9900.9	10097.3		10b	6790.0	14723.4	$^3P_1-9d^3D$
10	9867.0	10132.0		8b	6690.0	14943.7	$^5P_2-8d^5D$
7bl	9840.5	10159.2		4b	6686.7	14951.0	
8	9783.6	10218.5		4	6670.6	14987.0	$^5P_1-8d^5D$
50	9721.2	10284.0	$6s^5S_2-6p^5P_3$	8	6660.2	15010.4	
5bl	9206.3	10859.1		3b	6628.7	15081.8	$^3P_0-10d^3D$
6	9071.3	11020.7		8bl	6613.4	15116.6	$^3P_2-10d^3D$
8	9042.2	11056.3		4	6606.3	15132.9	$^5P_3-10s^5S_2$
30	9003.7	11103.6		6bl	6553.5	15254.8	$^3P_1-10d^3D$
15	8850.3	11296.0		1b	6469.5	15452.8	$^3P_0-11d^3D$
15	8830.4	11321.4		4	6462.9	15468.7	$^5P_2-10s^5S_2$
6	8789.1	11374.6		7b	6456.7	15483.5	$^3P_1-11d^3D$
8	8771.2	11397.8	$6p^5P_3-8s^5S_2$	3	6446.7	15507.5	$^5P_1-10s^5S_2$
50	8757.8	11415.3		3	6409.4	15597.8	$^5P_3-9d^5D$
20	8700.6	11490.3		8	6405.9	15606.3	
7bl	8632.1	11581.4		8b	6349.7	15744.4	$^3P_2-12d^3D$
5	8599.5	11625.3		2	6277.7	15925.0	$^5P_3-11s^5S_2$
12	8521.4	11732.0	$6p^5P_1-8s^5S_2$	8bs	6273.5	15935.7	$^5P_2-9d^5D$
8	8500.8	11760.4					$^3P_2-13d^3D$
8	8492.2	11772.3	$6p^5P_1-8s^5S_2$	6	6255.9	15980.5	$^5P_1-9d^5D$
7	8469.8	11803.4		2b	6162.4	16223.0	$^5P_3-10d^5D$
15	8355.8	11964.2		6b	6160.2	16228.8	
10	8291.1	12059.2		1	6148.1	16260.7	$^5P_2-11s^5S_2$
10	8276.6	12078.9		1	6133.3	16299.9	$^5P_1-11s^5S_2$
10	8251.5	12115.6		3	6034.9	16565.7	$^5P_2-10d^5D$
10bs	8082.5	12369.0	$6p^3P_0-7d^3D$	4b	6020.8	16604.5	$^5P_1-10d^5D$
30bs	8061.4	12401.4	$6p^3P_2-7d^3D$	3b	6005.0	16648.2	$^5P_3-11d^5D$
20	7972.9	12539.0	$6p^3P_1-7d^3D$	1bs	5886.5	16983.3	$^5P_2-11d^5D$
5	7819.5	12784.9		3bs	5874.6	17017.7	$^5P_1-11d^5D$
15	7759.1	12884.6	$6p^5P_3-7d^5D$	8	5789.1	17269.1	$6s^3S_1-7p^3P$
6	7754.4	12892.4		6	5769.1	17328.9	$6s^3S_1-7p^3P$
6	7575.7	13196.4		7	5733.5	17436.5	$6s^3S_1-7p^3P$
10	7556.8	13229.4	$6p^5P_2-7d^5D$	4	5178.9	19303.7	$6s^5S_2-7p^5P_1$
6b	7552.8	13236.4		7	5148.7	19417.0	$6s^5S_2-7p^5P_2$
5	7531.5	13273.9	$6p^5P_1-7d^5D$	8	5083.0	19667.9	$6s^5S_2-7p^5P_3$

point, it should be possible to carry on a simultaneous investigation of the other three elements of the group with a much increased effectiveness over an attack on one alone, and such a procedure is now contemplated.

Valuable advice and assistance were rendered during the course of this investigation by Professor R. C. Gibbs and Dr. C. W. Gartlein, for which the author wishes to express his thanks.



Te
370°
Te
470°
Fe
λ6678
λ8046
$6p^3P-9d^3D$
$6p^3P-8d^3D$
$6p^3P-7d^3D$
$6p^5P-8d^5D$
$6p^5P-7d^5D$
$6p^5P-9s^5S$

Fig. 1.