The data obtained on leather are indicative of a compressibility that is intermediate between the compressibilities exhibited by most solids and those of liquids. The compression is not materially affected by moisture content. Values obtained for chrome-tanned leather and two types of collagen are in good agreement, but the compressions of vegetable and retanned leathers appear to be slightly different. Compressions of samples taken from different areas of the hide are in substantial agreement.

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Arc and Spark Spectra of Technetium

By William F. Meggers and Bourdon F. Scribner

Four milligrams of highly purified technetium, loaned by the United States Atomic Energy Commission, were used to obtain a description of the arc and spark spectra characteristic of this fission product. Solutions containing 50 to 200 micrograms of technetium were dried on copper electrodes and excited by electric arcs or sparks. A stigmatic concave grating of 22-feet radius was employed to photograph the spectra from 2200 to 9000 angstroms, within which limits more than 2,300 lines characteristic of Tc atoms or ions were recorded. Wavelengths were measured relative to iron standards, relative intensities were estimated on a scale of 1 to 1000, and almost every line was definitely assigned either to neutral Tc atoms or to singly charged (Tc^+) ions. The measured wavelengths range from 2261.30 to 8829.80 angstroms with average probable errors rarely exceeding ±0.01 angstrom. The average results of wavelength measurements and of intensity estimates for 2,121 lines in Tc I and Tc II spectra are presented. The strongest Tc I lines have wavelengths 4297.06, 4262.26, 4238.19, 4031.63, and 3636.10 angstroms. The strongest Tc II lines have wavelengths 2543.24, 2610.00, and 2647.02 angstroms. This description of Tc I and Tc II spectra will serve for spectro-chemical identification and for structural analyses of these spectra.

I. Introduction

In 1869, when the periodic chart of the atoms was first proposed, Mendeléeff [1][1] saw that the chemical elements homologous to manganese were missing in the two succeeding periods; he called these eka-manganese and dwi-manganese. This was the first hint of the possible existence of the element under discussion. In the following half century many attempts, both chemical and spectroscopic, were made to detect these homologs of manganese, but without success. Moseley's [2] discovery in 1913 of a quantitative relationship between Roentgen frequencies and atomic numbers proved that atomic numbers 43, 61, 72, 75, 85, and 87 were still unknown, and provided a new method of detection by means of Roentgen spectra. This method was applied in 1925 by Noddack, Tacke, and Berg [3], who reported finding, in material extracted from columbite, three K spectrum lines for atomic number 43 and five L spectrum lines for atomic number 75. These two atomic numbers are identical with the homologs of manganese, and the names masurium and rhenium were proposed for them. The discovery of rhenium was abundantly confirmed, and within a few years this new element became a commercial metal. In 1931 the arc spectrum of rhenium was described and interpreted by Meggers [4], who then inquired of the discoverers if a sample of masurium was available for spectroscopic investigation. The Noddacks [2] replied that they had succeeded in concentrating some masurium, and that they would send the first milligram that could be spared. Unfortunately that milligram never materialized, and it later appeared that the extraction of element 43 from natural sources would be unlikely or even impossible [5].

[1] Figures in brackets indicate the literature references at the end of this paper.

[2] In a letter dated Dec. 22, 1931, from W. and I. Noddak to W. F. Meggers.

After the discovery of artificial radioactivity in 1934, it became theoretically possible to manufacture any desired element by artificial nuclear transmutation. Thus element 43 was first prepared in 1937 in the Berkeley cyclotron by bombarding molybdenum with neutrons or deuterons. It was identified, and its radiochemical properties were investigated by Perrier and Segré [6], who named the element technetium [7] because it was the first new element to be produced artificially. The amount of technetium produced in this manner was so small that it could only be detected by means of its characteristic radioactivity, which is enormously more sensitive than either roentgen or optical spectra. However, soon after the discovery of uranium fission in 1939, it was found that element 43 occurs among fission products to the extent of 6.2 percent [8]. In 1948 the isolation of milligram amounts of element 43 from uranium fission was described by Parker, Reed, and Ruch [9]. With these samples the whole-number atomic mass was determined by Inghram [10] to be 99, the first optical spectrogram was made by Timma [11], and the Roentgen emission spectrum was photographed by Burkhart, Peed, and Saunders [12]. Thus far the published information on the optical spectra of Tc consists of estimated relative intensities and approximate wavelengths of 102 lines (4297.2 to 2461.7 A) attributed [11] to element 43. In the light of present information critical examination of those data discloses that possibly 46 of the 102 lines are identifiable as Tc I, and 32 as Tc II, but the remaining 24 do not belong to Tc.

In September 1948, the National Bureau of Standards applied to the United States Atomic Energy Commission for the loan of 5 mg of $^{99}_{43}$Tc with which to make descriptions and analyses of the atomic and ionic emission spectra of technetium. A 3-mg sample was delivered in January 1949. With this sample preliminary results were obtained for wavelengths and relative intensities of about 2,000 Tc lines. These results were reported at the Oak Ridge Spectroscopy Symposium on March 25, 1949 [13] and at the Buffalo meeting of the Optical Society of America on October 29, 1949 [14]. In July 1950 three additional milligrams of $^{99}_{43}$Tc were borrowed for the purpose of completing this description of arc and spark spectra and for the investigation of hyperfine structure of certain spectral lines. The purpose of this paper is to present the wavelengths and relative intensities of 2,121 lines that are characteristic of Tc atoms and ions. These data are suitable for spectrochemical identification and for structural analyses of the first two spectra of Tc. Details of the structural analyses of Tc I and Tc II spectra, and of the investigation of hyperfine structure in Tc spectral lines will be given in subsequent papers.

II. Technetium Spectrograms

The technetium samples came in the form of oxide. These samples were dissolved in dilute ammonium hydroxide to make solutions of known concentration, portions of which could then be added to spectroscopic electrodes so that a definite amount of Tc was deposited on each. Fifty or one hundred micrograms of Tc were dried on the flat-machined end of a copper rod ¼ in. in diameter and 1 in. long. Electrodes with approximately rectangular ends, 6 by 2 mm, were later employed to concentrate more of the light along the optical axis. Two such loaded electrodes were used when oscillatory discharges were employed for exciting the spectra, but when the direct-current arc was employed the best results were obtained by placing 200 μg on the anode. With a desire to economize material, the first spectrograms were made in the blue and ultraviolet with 50 μg on each electrode, but to obtain stronger spectrograms it was necessary to use 100 on each. Also it was desirable to choose light sources that would burn the entire added sample off the ends of the copper electrodes without predominant excitation of the copper spectra. Furthermore, it was necessary to choose two sources with sufficiently different excitation characteristics so that comparisons of spectral line intensities would permit positive assignment of the lines either to neutral atoms or to ionized atoms. These considerations led to the choice of two sets of excitation conditions available in the Applied Research Laboratory Multisource unit.

The spark spectrum was obtained from an oscillatory condenser discharge with the following circuit constants: capacitance 5 μf, charging voltage 940 v, inductance 100 μh, and resistance 0.4 ohm. The arc spectrum was obtained from an overdamped condenser discharge with circuit constants: capacitance 50 μf, charging voltage 940 v, inductance 400 μh and resistance 25 ohms. The gap between the electrodes was set at 4 mm.

Before any Tc spectrograms were attempted, experiments were made with Mo spectrograms, and source conditions were determined that gave a fivefold enhancement of Mo II lines over Mo I lines when the spark spectrum was compared with the arc. These source conditions described above were found to be suitable for an unambiguous separation of Tc I and Tc II lines.

It was immediately seen that the distribution of Tc I and Tc II lines resembled the distribution of first and second spectral lines of other metals; the second spectrum predominates in the ultraviolet and weakens in the visible, whereas the first spectrum is weak in the ultraviolet but predominates in longer waves. Because few Tc II lines are seen in the blue, the Tc spark spectrograms were not extended beyond 4700 A.

Although the arc-like excitation provided by the ARL Multisource unit was satisfactory for the short wave region, it was disappointing for the visible and infrared, partly because it gave weak spectra and partly because it excited the spectra of atmospheric nitrogen and oxygen with such intensity that many portions of the Tc spectra were masked. Consequently, the spectral range 4500 to 9000 A was reobserved with a direct-current arc between ⅛-in. diameter Cu electrodes, the anode being charged with 200 μg of Tc. These direct-current arc spectrograms were made with an applied potential of 220v and a current of 7 amps.

The spectrograms were made with a concave grating of 22-ft radius, ruled with 15,000 lines per inch on an aluminized pyrex disk of 6-in. diameter. This grating was placed in a Jarrell-Ash instrument provided with a concave mirror of similar form, so that the spectrograph gave stigmatic slit images. A fixed slit of 20-μ width was used, and the maximum resolving power for sharp lines in the first order spectrum was about 50,000, the reciprocal linear dispersion being about 5 A/mm.

Three positions of the grating and 20-in. plate holder recorded the spectrum between 2100 and 9000 A with successive exposures on three types of photographic plates. The region 2200 to 4700 A was photographed on Eastman 103-uv sensitized plates, the region 4400 to 6900 A on II-F sensitized plates, and 6500 to 9000 A on I-N hypersensitized plates.

By sliding a slotted diaphragm in front of the slit, a series of adjacent spectrograms were made as follows: Iron arc, copper arc, technetium arc on copper, technetium spark on copper, copper spark, iron arc. Spark spectra were omitted in the visible and near infrared regions. The exposure durations were usually 1 sec for the iron arc, 45 sec for the copper blanks, and 30 sec for copper with technetium added. Preliminary tests with Mo added to copper showed that the sample was almost completely burned off in 30 sec. All exposures with Tc deposited on Cu were made with the electrodes mounted in a cylindrical brass cell provided with a quartz window and with an air exhaust through a glass-wool filter designed to trap, and thus conserve, most of the vaporized Tc for future recovery.

At least three satisfactory spectrograms were made for each of the three spectral ranges mentioned. This gave at least six independent determinations for lines appearing in the overlapping portions of these ranges. The positions of Tc spectral lines relative to iron standards were measured to 0.001 mm with an excellent 50-cm comparator constructed by the Gaertner Scientific Corp. In all, approximately 20,000 spectral line images were bisected to obtain the wavelengths of about 2,500 Tc and impurity lines. All lines appearing in the spectra of Cu plus Tc that were not duplicated or masked in the Cu comparison spectra were measured, even though some were easily recognized as impurities. The final values of all the impurity lines served as checks on the scale of wavelengths and on the amazingly high purity of the Tc samples. The principal impurities detected spectroscopically were calcium, magnesium, and silicon, which are common contaminants in chemical operations. Only the stronger lines of lithium, sodium, and potassium were present, and the same is true of iron, nickel, chromium, molybdenum, aluminum, bismuth, and platinum. No trace of ruthenium, rhenium, or any other metals was found. In the identification and elimination of impurity lines, consideration was given to relative intensities as well as to wavelengths. Thus, the line 2496.77 A, with intensity 200 in Tc II, cannot be confused with boron, 2496.778 A, because the stronger line of boron, 2497.733 A, had only intensity 10. A few doubtful coincidences of Tc and impurity lines are retained in table 1, and it is not likely that many Tc lines have been masked by impurities. The chief omissions may be real Tc lines hidden behind the principal lines of copper, 3248, 3274, 5106, 5153, 5218, 5700, 5782, 7933, and 8093 A.

TABLE 1. *Arc and spark spectra of technetium*

λ=wavelength: *c*=complex: *d*=double: *h*=hazy; *H*=very hazy: *w*=wide: *W*=very wide: *s*=shaded to shorter waves; *l*=shaded to longer waves.

λ	Intensity		λ	Intensity		λ	Intensity		λ	Intensity	
A	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark
8829.80	10*c*		8308.14	10		7981.86	1		7779.53	1	
8751.80	1		8254.48	2		7968.27	2		7777.17	3	
8737.95	5*cW*		8248.95	3		7965.41	5		7746.60	2	
8722.70	2		8237.08	15*c*		7963.86	1		7737.36	3	
8719.97	2		8228.65	1		7949.64	2		7705.70	1	
8716.77	1		8225.09	3*c*		7885.96	2*c*		7697.36	80*c*	
8707.21	9		8211.29	10		7874.72	5		7684.43	8	
8652.76	3*c*		8206.49	4		7871.16	50		7681.73	3	
8543.63	8		8205.24	10		7863.11	1		7675.32	1	
8537.66	2		8170.51	10		7861.36	30		7658.31	2	
8531.07	7		8160.89	2		7858.24	2		7624.49	7	
8522.56	2		8153.52	1		7856.32	7		7618.39	3	
8514.70	2		8146.52	1		7854.35	1		7579.20	40	
8481.37	1		8142.60	2		7848.35	1*c*		7573.99	15	
8404.00	1		8127.78	1		7817.67	150*c*		7550.98	1	
8383.68	3		8119.87	3		7816.72	5		7548.40	4	
8346.59	4*c*		8068.80	2*c*		7807.11	1		7545.45	3	
8319.09	2*c*		8045.30	2		7798.18	4		7543.32	7	
8315.49	4		8042.45	2		7792.96	100*cW*		7540.19	100*c*	
8309.17	10*cw*		7999.68	10		7782.92	2		7534.87	6	

λ	Intensity	
A	Arc	Spark
7471.75	1*c*	
7470.10	5	
7461.54	6	
7452.45	50*c*	
7434.08	10	
7405.33	15	
7402.57	4*cd*	
7396.79	8*c*	
7395.05	4*c*	
7366.28	2*c*	
7360.02	1	
7338.18	3	
7329.11	8*c*	
7322.34	10*c*	
7316.42	1	
7283.18	1*c*	
7256.05	4	
7251.53	1*c*	
7157.59	10*c*	
7156.78	1	
7141.23	8	
7093.08	4*c*	
7086.11	20*c*	
7071.38	3	
7048.49	2*c*	
7029.51	1	
7019.95	1	
7016.50	4	
7006.22	1*c*	
7002.33	7*c*	
6998.60	1	
6990.22	1	
6985.35	1	
6934.02	1	
6933.04	1	
6931.72	2*c*	
6907.50	2	
6876.69	2*c*	
6874.59	1	
6871.65	1	
6866.64	1	
6862.30	1	
6860.67	2	
6856.85	3	
6829.92	1	
6826.06	1	
6818.01	1	
6813.50	1	
6805.89	1	
6804.93	1	
6798.58	3	
6785.95	3	
6776.50	1	
6761.40	2	
6758.26	2	
6754.49	1*c*	
6753.28	1	
6747.45	1	
6733.76	1	
6731.18	2*cw*	
6687.03	3	
6673.64	9	
6661.95	1	
6661.36	1	
6648.35	2	
6627.87	3	
6625.54	40*cWs*	
6602.01	1	
6598.00	1*c*	
6595.16	1*c*	
6589.96	1	
6579.23	9	
6576.79	4	
6563.99	3	
6534.57	1	
6533.98	1	
6526.79	15	
6515.11	1	
6496.58	1*c*	
6491.65	15*c*	
6470.25	7	
6469.49	1	
6461.91	40	
6455.88	100	
6445.05	3*c*	
6412.90	1*c*	
6408.81	5	
6392.38	4	
6389.85	6	
6388.38	3*c*	
6356.71	10	
6354.83	15	
6312.15	10	
6310.40	4	
6306.16	1	
6305.00	3	
6303.98	1	
6296.72	1*c*	
6275.38	1	
6255.74	1	
6248.94	2	
6244.17	50*c*	
6239.67	2	
6236.77	1*c*	
6214.02	3	
6204.40	1	
6202.68	2*cw*	
6198.76	1	
6195.36	3	
6192.65	100*c*	
6184.68	5	
6183.75	2	
6182.65	3	
6163.55	2	
6145.91	1	
6132.21	8*c*	
6130.81	60	
6127.14	1	
6124.28	1	
6120.67	150	
6115.44	1	
6111.98	2	
6111.06	2	
6102.95	60*c*	
6099.38	20	
6093.71	2	
6085.22	100*cws*	
6069.77	4	
6066.15	1	
6065.08	20	
6063.91	3*c*	
6063.45	4	
6057.24	2	
6047.98	4	
6032.34	6	
6030.24	1	
6028.50	1	
6024.41	2	
6023.49	4	
6020.68	1	
6018.59	1	
6013.17	1	
6012.07	2*c*	
6010.17	2	
5997.12	1	
5996.67	2	
5993.19	1*cw*	
5986.76	1	
5980.57	4*cw*	
5974.79	1	
5968.98	1*c*	
5951.46	4	
5946.48	1	
5942.24	2*cw*	
5938.38	3	
5937.07	1	
5931.93	60	
5930.32	2	
5926.29	15	
5925.69	2	
5925.38	3*c*	
5924.47	100*cW*	
5923.35	10	
5921.34	1	
5919.42	1	
5915.74	1	
5908.57	2*c*	
5905.85	1	
5905.46	2	
5903.82	1	
5893.57	2	
5885.37	2*cw*	
5879.26	1	
5874.74	2	
5873.60	1	
5871.22	2	
5867.47	1	
5865.32	1	
5863.79	2*c*	
5853.29	2*c*	
5838.28	1	
5836.28	10	
5831.45	30	
5827.14	2	
5826.49	4*c*	
5823.09	1	
5821.24	1	
5819.11	1*c*	
5814.20	3	
5805.19	2	
5802.39	1	
5799.83	8*c*	
5794.62	9*c*	
5777.92	1	
5775.02	1	
5773.61	2	
5771.45	40*cw*	
5754.74	2	
5749.50	1	
5741.92	1*c*	
5737.52	1	
5725.32	40	
5721.08	1	
5719.52	1	
5696.61	1*c*	
5696.03	2	
5694.30	1*c*	
5692.22	1	
5689.05	15	
5688.74	2	
5687.31	15	
5685.52	1	
5680.93	1	
5678.46	2	
5675.14	1	
5672.15		
5667.59	*c*	
5667.03	1*c*	
5664.89		
5662.09		

λ	Intensity		λ	Intensity		λ	Intensity		λ	Intensity	
A	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark
5661.52	2		5468.66	1		5240.92	1		4980.41	2	
5658.05	1		5467.36	1		5236.10	1		4978.52	1	
5655.99	5		5458.07	1c		5231.22	1		4976.34	150	
5644.93	50		5455.94	3		5230.28	1		4967.18	2	
5644.32	1		5455.08	2c		5228.67	2c		4956.32	1	
5642.12	100		5451.89	40		5227.53	4		4954.94	1	
5640.76	2		5450.41	1		5214.08	1		4948.79	1	
5637.77	1		5448.35	2		5208.52	2c		4948.06	8	
5636.83	3c		5447.76	1		5206.53	4		4947.04	2	
5636.24	2		5447.39	9		5202.10	1		4944.20	1	
5629.92	20		5444.25	2		5193.10	3		4938.79	2	
5625.20	1		5439.48	1c		5189.67	2		4936.10	1	
5620.45	200c		5425.93	1		5184.95	1		4933.79	1c	
5617.63	1		5423.05	5		5183.97	2		4929.71	1	
5616.76	1		5412.89	2		5178.05	1		4923.58	4	
5615.23	1		5411.92	2		5177.69	1		4920.65	3	
5611.46	2		5407.90	4		5174.79	100		4915.79	1	
5606.37	1c		5400.45	1		5167.75	1		4914.68	2	
5603.52	1		5389.30	2c		5161.77	80c		4913.01	15	
5602.22	10		5387.62	1		5150.58	10		4909.55	100	
5596.53	1c		5386.86	1		5139.25	10		4908.50	40	
5589.01	300cd		5383.45	1c		5136.12	2		4906.39	1	
5584.00	2		5382.64	1		5135.78	1		4900.01	1	
5580.19	1c		5377.39	1		5134.28	2c		4892.47	3	
5577.57	1c		5376.27	1		5122.14	1		4891.89	150	
5576.77	2		5375.19	30c		5120.59	3		4890.89	3	
5576.25	2		5366.02	1		5113.64	2		4889.41	1	
5575.41	1c		5364.01	1		5109.79	8		4888.69	2	
5572.85	2		5360.65	1		5104.33	30		4885.87	1	
5570.74	1c		5359.21	2		5103.23	10c				
5568.62	1c		5358.63	15		5102.51	2		4885.00	1	
5562.93	1		5356.63	6		5100.69	1		4876.96	2d	
5550.51	3		5353.48	50		5099.97	1		4874.76	1	
5545.79	1c		5350.85	1		5096.27	200		4870.76	3	
5543.60	2		5334.79	15		5090.74	3		4866.71	250	
5541.92	7		5328.42	1		5086.91	3		4863.29	1	
5540.55	1		5320.20	30		5083.94	2		4862.91	1	
5538.84	2c		5318.16	1		5069.54	2		4862.19	2	
5528.22	4		5317.51	2		5060.69	30		4861.19	1	
5524.08	6		5314.97	10		5058.32	2		4859.19	1	
5518.02	2		5311.13	1		5055.27	9		4857.19	2	
5514.16	1c		5305.31	4		5051.27	2		4853.57	400	
5513.58	1		5285.06	30		5032.44	3		4841.36	2	
5510.81	1		5279.31	1		5027.88	3		4835.40	30	
5506.85	9cw		5275.51	50		5026.79	5		4834.36	30	
5505.25	2		5274.82	2		5026.23	15		4831.33	3	
5502.93	2		5273.91	2		5024.68	1		4820.75	150	
5500.04	2		5273.20	1		5014.51	4		4816.79	9	
5495.96	1		5267.21	1		5010.72	1		4813.26	1	
5490.32	2		5266.30	1c		5005.73	2		4811.79	1	
5485.32	2		5261.44	6c		5002.67	3		4809.37	1	
5484.99	2		5254.74	2c		5000.82	1		4805.63	1	
5482.97	5		5251.39	2		4999.07	1		4800.62	1	
5482.83	3		5249.37	1		4995.00	15		4799.96	3	
5471.92	10		5246.97	2		4993.97	1		4791.62	4	

TABLE 1. *Arc and spark spectra of technetium*—Continued

λ	Intensity		λ	Intensity		λ	Intensity		λ	Intensity	
A	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark
4790.47	3		4616.86	9	5	4328.77	3	2	4146.21	1	
4789.48	2		4609.17	4*c*	3*h*	4324.85	1		4145.02	80*c*	50*c*
4787.69	2*c*		4608.00	2	1	4323.94	1		4141.28	3	2
4785.59	4		4602.72	2	1	4323.35	3	2	4139.85	5	4
4784.69	1		4594.06	2	1	4319.94	1*h*		4139.10	3	2
4783.92	2		4593.36	20	10	4318.65	2	2	4134.80	3	2
4780.56	1		4584.86	2	1	4314.03	1		4130.44	2	1
4779.84	1		4579.09	1		4312.48	1		4128.27	10	6
4776.33	2		4578.46	10	6	4310.21	3	2	4124.22	80	50
4773.86	2		4570.85	2	1	4308.59	2	1	4119.28	4	3
4771.53	150		4564.57	30	20	4307.78	1	1	4115.08	100	60
4762.35	2		4563.80	1	1	4305.82	4	3	4113.26	1	
4758.06	1		4562.94	1		4305.52	1		4111.37	2	1
4756.09	1		4558.73	1		4297.06	500	300	4110.21	10	6
4752.71	4		4557.06	6	4	4294.35	5	3	4106.69	2	1
4749.60	3		4552.85	5	4	4289.54	2	1	4106.21	1	
4746.02	1		4552.41	1		4286.31	1		4105.08	2	1
4741.24	1		4552.21	3	2	4278.91	40	20	4101.24	2	1
4740.59	200		4545.56	1		4277.53	1		4100.08	2	1
4739.53	1		4542.10	4	3	4274.95	3?	2?	4098.77	1	
4736.48	2*c*		4539.54	100	50	4266.16	1	1	4095.68	200	100
4719.28	100		4537.36	2	1	4262.67	100	50	4094.17	2	1
4717.76	10		4522.85	200	100	4262.26	400	200	4093.68	3	2
4716.76	1		4515.98	10	6	4258.61	1		4091.54	2	1
4714.20	2		4501.74	1		4257.33	1		4090.13	2	1
4706.90	6		4498.54	1*h*		4243.00	2	2	4089.23	1	
4702.83	1		4495.03	10	5	4239.55	2	1	4088.70	150	80
4694.28	3		4487.05	40	20	4238.19	300	150	4083.54	3	2
4689.77	1		4481.52	10	5	4232.09	2	1	4083.20	1	
4689.34	4		4473.65	1		4230.84	6	4	4079.81	1*h*	1*h*
4687.97	2		4465.61	2	1	4230.22	1		4077.71	2	1
4686.37	1		4463.82	2	1	4229.96	1		4069.01	2	1
4683.58	1		4454.81	5Ca?	4	4220.32	2	1	4060.84	1	
4678.88	2		4452.24	2	1	4218.61	30	15	4057.81	2	1
4673.05	2		4434.98	2	3	4215.51	1	1	4057.24	2*h*	1*h*
4672.82	2		4432.54	1		4214.22	1		4056.08	4*h*	3*h*
4672.17	5		4429.60	30	15	4212.42	1	2	4054.42	2*h*	1*h*
4669.30	100	40	4425.47	1*h*	2*h*	4211.43	2	1	4053.18	5	3
4664.32	2	1	4420.32	1		4206.58	9	6	4051.94	5	3
4660.21	30	10	4412.02	2	1	4201.86	2	1	4049.10	150	80
4656.99	1		4383.10	2	1	4199.46	2	1	4041.76	2	1
4654.64	2	1	4373.97	2	1	4198.31	1	4*h*	4041.52	2	1
4653.59	1		4370.73	2	1	4189.61	3	2	4039.23	10	6
4648.34	70	20	4370.10	2	1	4186.52	50	30	4037.09		3*h*
4647.57	2	1	4369.26	1		4176.28	100	60	4037.01	4*h*+*g*	
4646.61	1		4368.92	1		4174.46	1		4032.91	1	
4645.47	2	1	4363.03	2	1	4172.53	80	50	4031.63	300	200
4643.29	4		4361.95	1		4170.28	50	30	4029.08	1	1
4637.51	90	40	4359.25	4	3	4169.67	10	6	4026.19	3*h*+*g*	2*h*
4635.74	2	1	4358.49	3	2	4167.43	6	4	4025.42	1	
4633.13	2	1	4344.58	2	1	4165.62	80	50	4020.77	10	7
4631.33	1		4342.22	1		4161.53	1		4017.23	4	3
4630.57	20	10	4336.87	10	5	4160.02	1		4016.68	3	1
4624.97	2	1	4332.46	3	2	4153.64	1		4012.01	6	4
4622.71	3	2	4331.81		1	4147.61	2	1	4010.08	1	

λ	Intensity		λ	Intensity		λ	Intensity		λ	Intensity	
A	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark
4007.13	4	3	3854.05	1		3768.80	100	60	3696.74		1*h*
4004.69	3	2	3852.37	2	1	3768.35	1		3696.32	4	2
3996.95	2	1	3851.23	4	2	3763.98	2	1	3695.99	1	
3994.51	40	30	3847.59	7	4	3761.84	20	15	3694.34	1	
3994.03	2	1	3847.35	3	1	3759.19	1*h*	2*h*	3692.78	6	4
3992.06	1		3845.99	15	10	3758.56	15	10	3691.64	2*h*	2*h*
3987.77	3	2	3844.28	2*h*	1	3756.28	1	1*h*	3690.88	1*h*	
3984.97	200	100	3843.98	3	2	3755.24	5	3	3684.78	100	60
3982.18	2	1	3841.33	10	7	3754.41	60	40	3683.50	2	1
3980.36	4	2	3838.30	15Ca?	10	3754.09	3	2	3682.61	3	2
3979.63	4	2	3837.58	20	15	3752.93	1		3681.71	1	
3979.05	1		3832.82	5	3	3752.16	30	20	3680.55	1	2*h*
3975.02	5	10	3832.34	15*c*	10*c*	3749.96	8	5	3680.34	10	6
3971.48	1		3830.34	2	1	3746.87	200	100	3679.18	30	20
3970.21		2*h*	3829.28	4*d*	4*d*	3746.18	15	10	3678.41	2	1
3959.93		2*h*	3828.54	9	6	3745.04	6	4	3678.10	3	2
3959.52	3	2	3827.57	1		3744.82		2	3675.88	1	2*h*
3959.07	2	1	3824.46	6	4	3744.04	3	2	3675.57		2*h*
3955.74	4	3	3819.12	2*h*	4*h*	3742.81	4	3	3675.44	1	
3953.69	3	2	3818.09	3	2	3741.82	1		3673.27		1*h*
3951.83	3	2	3817.96	4	3	3737.71	2*h*	5*h*	3669.96	2	1
3950.38	2	1	3816.90	6	4	3737.44	4	3	3669.15	1	1
3947.11	20	15	3815.50	2	1	3736.93	4	5+Ca	3668.96	1	
3946.58	30	20	3814.64	5	3	3731.76	6	4	3667.51	2	1
3940.51		1*h*	3811.28	3	2	3730.85	1		3664.94	4	2
3040.04	1		3810.57	1		3729.19	4	3	3664.58		2*h*
3936.63	1	1*h*	3809.78	1	3	3727.37	3	3	3662.85	1	
3934.82	1		3808.62	1		3726.36	100*d*	70	3661.47	30	20
3929.37	1		3808.13	1		3726.19	2	1	3658.62	80	60
3928.85	1		3806.13	1		3724.41	50	30	3654.07	2*h*	1*h*
3927.57	2	2	3804.00	2	1	3723.71	30	20	3651.50	10	8
3923.67	4	3	3801.63	1	2*h*	3723.13	1	1	3650.37	1	
3922.13	2	1	3799.66	3	2	3718.88	300	150	3648.06	70	40
3919.38	6	4	3797.79	30	20	3717.32		2	3644.15	2	1
3917.73		1*h*	3797.45	7	4	3717.04	1		3643.01	1	
3916.52	1		3794.80	2	1	3716.80	2	1	3641.16	1*h*	1*h*
3905.76	1		3792.10	1		3715.96	9	6	3640.23	10	8
3905.51	2	1	3791.75	8	6	3714.52	2	1	3639.41	30	20
3899.86	7	4	3791.30	10	7	3713.87	2*g*?	1	3638.88	4	3
3899.11	1		3786.56	1*h*	2*h*	3712.84	5	3	3638.24	40	30
3893.23	2	1	3786.08	5	3	3712.28	20	15	3636.10	400	200
3892.14	20*c*	40*c*	3784.08	9	6	3711.40	1		3635.18	80*c*	60*c*
3889.14	2	1	3780.70	70	50	3710.13	2	1	3634.27		2*h*
3880.74	15	10	3779.72	2	1	3709.82	2	1	3633.28	3	2
3879.19	10	7	3779.40	50	30	3708.27	3	2	3630.42	3	2
3875.64	3	2	3777.30	15	10	3707.65	3	2	3628.90	1	
3869.32	1		3776.04	1		3706.72	3	2	3627.86	2	1
3868.26	15	10	3775.34	2	1	3706.05	2	3*h*	3627.38	30	15
3866.16	1*h*	3*h*	3773.43	3	2	3705.70	1		3625.58	4	3
3865.09	1		3772.78	1		3705.51	3	2	3619.79	1	3*h*
3864.12	10+Mo	7	3772.38	2	1	3704.83	6	5	3619.40	1	
3863.84	1		3772.08	3	2	3703.86	15	10	3618.96	4	2
3863.07	4	3	3771.44	1		3703.19	2	1	3616.36		2*h*
3856.74	10	7	3771.06	60	40	3697.76	1		3615.82	2	1
3854.34	1		3770.51	2	1	3697.43	2	1	3612.85		1

λ	Intensity	
A	Arc	Spark
3612.14	1	1
3611.14	4	5
3609.90	2*h*	4*h*
3609.06	1	
3608.30	100	60
3607.66	5	3
3607.35	50	30
3604.77		1*h*
3599.74	2	1
3597.43	1	
3595.70	50	30
3594.93	2	1
3594.60	8	5
3593.49	9	5
3591.51	1	2
3591.20	1	
3589.89		2*h*
3587.96	80	50
3585.72	2*h*	1
3583.45	1	
3582.66	50	30
3582.10	15	10
3581.27	20	10
3580.08	20	15
3579.00	1	
3576.50		2*h*
3576.33	1	
3575.45	2	1
3574.61	2	1
3574.43	1	
3573.32	1	2
3573.07	1	
3572.65	1	3
3570.67	2	1
3568.87	20	10
3565.43	3*d*	1
3565.23	1	
3565.02		1*h*
3561.23	1	
3560.90	1	
3560.34	10	6
3559.77	5	3
3556.07	1	2*h*
3553.53	2	1
3550.66	100*c*	70
3549.74	150*c*	100
3541.78	50	30
3538.70	10	5
3538.13	4	2
3535.52	10	8
3534.87	3	2
3531.34	1	
3529.85	2	1
3527.96	1	
3526.19	7	4
3525.84	30	20
3522.11	1	
3521.29	1	
3519.43	1	2
3517.18	2	1
3515.18		1
3514.29	1	
3510.92	5	3
3508.27	3	2
3507.19	2	1
3506.13	2	1
3505.39	4	8
3503.80	1	
3503.58	1	
3503.35	1	3*h*
3502.73	50	30
3502.49	2	1
3501.55	1	2*h*
3501.26	4	2
3500.72	20	10
3499.15	2	1
3495.84	1	
3494.64	8	5
3494.15	1	
3493.41	8	5
3490.31	2	1
3486.25	50*c*	30
3484.61	1	
3482.69	1	2
3481.40	1	3*h*
3475.60	20	10
3475.18	2	1
3473.72	1	
3472.88	1	
3470.53	6	4
3467.95	1*h*	3*h*
3467.21		2*h*
3466.29	250*c*	150
3462.41		2*h*
3461.68	3+Ni	1
3458.00	1	1
3457.59	2	1
3457.25	15	8
3456.86	6	3
3456.48		1
3456.11		2
3454.08	1	
3453.01	1	
3451.05	6	4
3444.00		1*h*
3443.49	3	2
3442.25		2*h*
3441.09	1*h*	3*h*
3438.74	2	1
3438.24		2*h*
3437.45	4	2
3435.70	1	
3434.71	6	3
3431.76	2	1
3427.87	1	
3426.66		2
3425.40	1	
3424.33	2	6
3422.97	1	2
3421.47		1
3419.12	6	3
3418.58	1	1
3418.17	2	1
3418.07	2	1
3417.74	1	
3411.74	1	1
3411.63	3	9
3408.31	2	1
3407.27	3	2
3405.83	1	
3405.34	3	2
3403.91	2	1
3398.33	2	1
3394.20	8	5
3392.23	1	
3391.37	1	2
3390.81	1	3
3388.18	1	3
3386.68	2	1
3386.35	1	
3385.47		1
3382.65		1*h*
3380.39	2	1
3378.07		2*h*
3373.56	1	
3373.43	2	1
3372.80	1	
3371.90	1	
3371.59	1	
3366.76	10	6
3363.04	3	10
3362.62		1
3361.20	1	
3359.20	1*h*	1*h*
3350.86	2	1
3350.56	2	1
3348.47	1	2
3345.60	8	20
3339.23		1
3338.88		2*h*
3338.27		1*h*
3337.55	2	1
3334.53		1
3332.48	2	1
3331.75		1*h*
3330.79	3	2
3327.12	3	2
3325.56	7	4
3323.90		1*h*
3322.30	2	1
3319.27		1
3318.77		2*h*
3317.66		1
3315.81	2	7
3313.67	5	3
3312.53	2	8
3311.04	2	1
3310.65	8	5
3309.41	1*h*	2*h*
3305.91	6	3
3305.61	1	2*h*
3302.39	2	1
3301.98	4	15
3300.78	3	2
3298.85	15	60
3298.29		2
3297.36	2	5
3296.27	1	3
3293.63		1
3291.96	1	
3288.30		1
3287.18	5	10
3285.83	1	3
3284.77	1	
3282.41	20	50
3276.30	2	1
3272.55	1	2*h*
3272.12	3	2
3271.19	2	1
3270.62	2	1
3270.07	1*h*	2*h*
3269.81	1	4
3269.68	2	6
3269.43	1	2*h*
3266.92	15	80
3266.31	2	6
3264.67	2	4
3262.91	1	
3262.12	1	3
3261.94	8	5
3261.39	3	2
3259.93	2	1
3259.28	1*h*	
3256.34	10	50
3256.12	4	3
3254.96	1	4
3254.70	1	
3252.06	10	8
3250.39		1
3249.31		1

λ	Intensity		λ	Intensity		λ	Intensity		λ	Intensity	
A	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark
3244.19	10	8	3156.81	1	2	3062.39	3	2	2988.61		2Ca?
3242.29	1	1	3153.35	1		3062.13	2	1	2988.20	1	
3241.85	3	2	3153.17	1	2	3061.78		2*h*	2987.23		1*h*
3240.68		1	3150.26	2	1	3060.91		2*h*	2985.38	3	3
3239.79	1	1	3146.24	1	1	3060.69	2	1	2985.05	1	
3239.51	1	1	3146.00		1	3058.52	1	4	2984.40	5	15
3238.50		1	3145.62	1	3*h*	3057.52		2	2984.15	2	1
3237.02	200*c*	400*c*	3144.58		2	3057.34	2	1	2983.73	1	2*h*
3235.00		1	3144.17	1	2	3057.04	2	1	2982.55	10	40
3230.95	5	15	3143.63	1	2*h*	3055.47		1*h*	2980.84		1*h*
3230.02	3	2	3141.00	1*h*	3*h*	3053.10		1*h*	2979.76	2	3
3226.05	2	1	3140.67	1*h*	2*h*	3052.50	2	3	2976.57	15	40
3223.59	1	3	3139.99	1	1*h*	3051.57	3	2	2976.19	2	5
3220.73	3	2	3138.33	1	1	3049.05		1*h*	2973.67	4	3
3219.73	2	5	3136.61	2	10	3047.55	2	3	2970.76	1*h*	6*Hl*
3218.58	1		3133.35		1	3046.53	1	4	2968.79	1	
3218.25	1	3	3133.15	1	4	3045.30		2*h*	2967.13	3*hl*	10*Hl*
3217.48	2	1	3131.26	15	8	3044.71	1	3	2966.57	1	3
3217.12	1	2	3127.87	1		3043.78	1		2966.19	3	8
3216.53	1		3122.66	6	3	3043.08	1		2965.49		1
3215.80	1	1	3121.97	3	6	3042.66	2+Fe	1	2964.50	20	60
3214.90	1	1	3119.90	2	5	3040.90	1	1	2962.58		1
3213.29	1	1	3119.68	2	1	3040.63	1	1	2962.09	3	9
3212.01	80*c*	300*c*	3119.18	3	2	3038.24	3	2	2961.63	2	6
3208.87	1*h*	1*h*	3116.90	1		3037.91	15	50	2958.88	1*h*	2*h*
3202.84	8	5	3116.01	2	1	3036.90	2	1	2958.48		1
3200.98	1		3115.31		1	3034.61	2	1	2958.38	1	2
3198.49	2	1	3110.59	1	4	3033.64		1	2957.83	2	1
3197.72	2	1	3109.14	2	5	3033.18	2	1	2956.25		1
3197.53	3	2	3106.95	2	1	3032.07	1	2	2955.94	4	2
3195.68		2	3105.39	1	2	3029.22		1	2953.18	1	2
3195.21	50	200	3105.13	2	8	3026.89	10	20	2952.55	2	6
3192.35		1	3104.29	1		3026.44		1	2952.07	1	3
3192.07	2	1	3100.89	2	5	3025.28	3	2	2951.05	1	2
3191.63	1		3099.54	4	2	3023.71	4	3	2950.81	3	6
3190.36	6	20	3099.12	6	3	3022.22	1	3	2950.40	4	10
3189.71		1*h*	3098.58	2	5	3022.06	1		2950.26	1	3
3188.00		1*h*	3097.28	1	4	3019.19	2	4	2949.58	1	
3183.12	30	15	3095.77	2	2*d*	3017.25	6	4	2949.48	1	2*h*
3182.80	1	1	3093.64		2	3016.31	1		2949.25	2	1
3182.38	30	15	3090.26	2	1	3015.16	2	5	2948.64	20	60
3181.31	1	2*h*	3089.36	3	2	3009.76		1	2948.48	10	20
3180.31	5	3	3084.51		1*h*	3008.78		1	2948.10	1	2
3178.34		1	3083.31	2*d*	4*d*	3007.00	4	15	2947.12	2	1
3177.91	1	2	3081.10	1	1	3005.51	1	2	2946.58	1	2
3174.75	1	3	3079.92	1	3	3004.62		1	2946.21		1
3173.30	40	20	3077.70	3	10	3004.40	1	3	2945.53	1	3
3171.94	2*d*	2*d*	3076.27	3	2	3003.71	2	1	2942.92	10	30
3171.47	1	2*Hl*	3074.31	2	1	3003.03		2	2941.84		2
3170.38	2	6	3072.92	1	2	3001.05	5	15	2940.92		2
3169.27		1	3070.28	2	1	2996.88		1	2940.49		1
3165.15	1	4	3069.97	5	20	2994.12	1	2	2940.01	2	1
3161.70	5	3	3068.34	2	1	2993.94	1	1	2939.25		1
3158.07	1	2	3066.61	1		2993.77	1	3	2938.98	10	20
3157.66		1	3066.40		1	2992.87	1*h*		2936.93	4	15

λ	Intensity		λ	Intensity		λ	Intensity		λ	Intensity	
A	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark
2934.65		1	2890.47	2	6	2845.06	5	3	2800.79	2	6
2933.94	15	30	2889.23	30	80	2843.78	1	1	2800.46	1	3
2932.94	1	2	2888.48	10	10	2843.35	1	3	2797.75	3	6
2932.12	1	3	2887.76	20	10	2842.30		2	2796.72	15	30
2931.56	1	2	2887.43		1	2840.38	30	100	2795.78	100	200
2931.14	3	8	2886.10	2	5	2839.87	2	10	2795.08	2	4
2930.50	3	2	2885.55	2*h*	6*h*	2838.88	1	3	2794.55	4	2
2930.05	2	5	2884.76	1	2	2838.56	8	15	2794.24	15	30
2929.53	2	8	2883.51		1	2836.91		1*h*	2793.67		1
2928.45	4	10	2882.39	5	10	2836.13	10	30	2792.98		2
2928.20	10	5	2881.32		2*h*	2835.63	2	1	2792.09	1*h*	2*h*
2927.32	1	3	2881.15	2	2	2834.75	1	2	2790.46	2	2
2925.10	1	3	2880.43	20	60	2834.32		2	2790.28	1	1
2924.87	1	1	2879.15	4	10	2833.60	15	40	2789.27	20	40
2924.27	3	10	2878.70	3	8	2831.19	30	100	2788.90	2	3
2923.35	20	40	2877.18		1	2830.87	1	3	2788.81	1	2
2922.75	10	20	2874.12	2	4	2829.62	1*h*	2*h*	2787.95	2	6
2921.94	8	4	2873.93		1	2829.09	1	2	2787.65		1
2921.52	4	15	2873.68	2	1	2828.07	15	8	2787.26	2	1
2921.07	15	60	2872.24	5*cw*	15*cw*	2826.18	10	30	2785.60	15	7
2919.66		1	2871.98	1	2	2825.98	2	1	2785.30	2	5
2915.86		1	2871.45	1	2*h*Cr?	2825.35	15	40	2785.15	1	2
2914.24		1*h*	2870.43	2	6Cr?	2825.06	10	30	2784.74		1
2913.81	1	1	2870.31		2	2822.92	1*h*	2*h*	2784.39	1	3
2913.17	15	10	2869.51	2	1	2821.62	10	20	2782.08	30	15
2912.01	2	4	2869.30	6	10	2821.37	30	100	2781.24	2	1
2911.71	1	2	2868.81	1	1	2820.19	2	6	2779.81	10Mg?	15
2910.70	1	2	2868.11	5	3	2819.48	2	1	2778.93	5	6
2910.23	20	40	2867.22	1		2819.06	1	2	2778.13	2	4
2909.09	3	10	2866.09	20*c*	60*c*	2818.65	2	6	2777.65		1
2907.99	2		2864.91		2	2817.62	3	7	2777.33	40	100
2907.63	2*h*	4*h*	2864.51	10	5	2817.29	1	2	2776.57	1	2
2906.90	1*h*	2*h*	2863.54		1	2817.01	5	10	2776.06	2	4
2906.63	6	20	2863.35	2		2816.51	2	6	2775.61	10	30
2906.26	1	2	2862.77		1	2815.97	2	4	2775.08	1	2
2904.96	1		2861.70	2	8	2814.99	2	4	2774.29	1	2
2903.84	3	2	2861.35		1	2814.88	20	10	2773.79	15	50
2902.93	1	2	2860.98	2	1	2814.64	2	4	2773.32	2	6
2902.54	1	2	2860.78	30	60	2814.20	15	30	2772.06	1	2
2902.15	15	40	2859.13	40	40	2813.80	10	20	2771.80	1	3
2900.69	5	15	2857.15	15	10	2813.50	2*d*	3*d*	2771.22	10*c*	30*c*
2899.37		1	2855.66	2	2	2813.00	1	3	2769.07	1	2
2896.58	1	2	2853.64		1*h*	2811.62	80	200	2768.40	1	2
2896.36	15	10	2853.28		1	2811.15		1*h*	2768.10		1
2895.48	2	5	2851.23		1	2810.24	4	8	2767.34	1*h*	3*h*
2894.83	2	5	2850.97	8	8	2810.06	1		2766.90	10	5
2894.34	6	3	2850.18		1	2809.66	20*c*	60*c*	2765.98	3	1
2893.90	1	3	2849.21	4	3	2808.38	15	8	2765.73	3	7
2893.47	5	2	2847.88		1	2807.93	3*d*	6*d*	2765.52		1
2893.18	5	2	2847.68		1	2807.43		1*h*	2764.51		1
2892.78	10	30	2846.74	5	15	2807.09		1*h*	2763.25	2	8
2892.35	5	20	2846.62	1	3	2806.65	2	5	2762.36	10	5
2891.34	2	5	2846.40	15	50	2805.19	1	3	2762.16	7	3
2891.20	1	3	2845.78		1	2803.35		1	2761.29	1	3
2890.81	20*c*	60*c*	2845.46	1	2	2803.03	5	10?	2760.40	1	

TABLE 1. *Arc and spark spectra of technetium*—Continued

λ	Intensity		λ	Intensity		λ	Intensity		λ	Intensity	
A	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark
2760.13	1*h*	3*h*	2714.67	2	4	2671.02	2	6	2635.77	1	3
2758.72		2	2714.58	3	6	2670.84	1	2	2634.92	150	300
2757.58	1	3	2712.62	10	30	2670.12	4	7	2630.30		1*h*
2757.25	2	4	2711.94	1*h*	2*h*	2669.85	1	2*h*	2629.52		1*h*
2757.01	1	2	2711.50	2	6	2669.67	1	2*h*	2627.97	5*c*	15*c*
2756.50		1	2710.76	5	15	2668.95	5*d*	15*d*	2626.66		1
2755.77	10	5	2710.54	3	8	2668.30		1	2626.42	1	3
2753.06	1	3	2708.81	10	5	2667.80	1	2	2625.99	5	15
2752.30	1	3	2707.89	30	100	2667.18	1	2	2625.51	20	60
2751.49	15	40	2707.34	2	3	2665.76	8	20	2624.38	2	6
2749.30	3	8	2706.94	1	3	2665.10	2	6	2622.83	2	4
2749.21	3	8	2702.96	30	100	2664.69	4*h*	10*h*	2620.80	2	5
2747.40	2	5	2702.47	2	5	2663.95	2	4	2620.30	1	2
2744.35		1	2702.30	2	1	2663.17		1	2619.94	3	10
2743.84	10	30	2701.65	2	4	2662.66	7	20	2619.30	3	10
2742.76	1	2	2700.67	2	4	2662.32	5	3	2618.77	1	2
2742.54		2*h*	2699.80	2	6	2661.66	10	30	2617.58	2	6Fe?
2741.17	3	8	2699.42		1	2661.17	1	3	2616.07	7	20
2740.02	3*h*	10*hl*	2697.60	1	2	2660.91	15	30	2615.88	30	15
2739.28	1	2	2697.39	2	5	2658.59		2	2615.15	1	3
2738.83	40	150	2696.56	15	30	2658.19		2	2614.63	1	3
2737.99	4	2	2694.79	2	5	2657.98		1	2614.24	50	30
2737.69	4	10	2694.56		1	2657.59		1	2613.28	3	10
2737.14	2	6	2693.76	4	10	2657.34	2	1	2610.90	1	3
2736.85	30	100	2693.13	4	2	2657.04		1	2610.66		2
2736.52	3	10	2691.82	8	30	2654.90	1	1	2610.00	400	800
2736.23	8	7	2691.32	6	20	2654.32	7	3	2609.04		1
2735.94	2	4	2690.69	1		2653.75	2	6	2608.88	30	10
2735.16	3	8	2690.46	1	2	2653.58	2	1	2608.15	3	9
2733.80	1	2	2688.27	6	15	2653.39		1	2607.26	3	9
2733.24	1	2	2688.07	1	2	2652.90	3	8	2605.83	1	2
2732.89	10	5	2687.34	2	7	2652.36	50	150	2605.41	10	30
2730.53	20	10	2686.04	1	3	2652.10	1	1	2604.88	5	15
2730.19	1	2	2685.41	10*c*	30*c*	2651.81		1	2603.74	2	6
2729.73	1*h*	2*h*	2684.97		1	2650.60	5+*g*?	10	2602.55	3	7
2728.48	4	2	2684.51	5	15	2650.42	1		2602.11	10	20
2728.33		1	2684.22	1	2	2650.21		1	2600.92	1	3
2727.62	2	6	2683.90	3	1	2649.19	10	20	2599.41	1	3
2727.08	3	8	2683.73	1	2	2648.32	20	60	2598.63	2	5
2726.70	30	15	2683.14	5	4	2647.02	300	600	2597.21	15	30
2726.18	2	4	2682.77	10	20	2646.26	10	20	2596.78	5	10
2725.66	15	40	2682.67	10	20	2645.60	2	4	2595.75	2	1
2724.20	10	30	2682.33	3	8	2645.38	2*d*	2	2593.68	2	1
2723.75	2	6	2681.60	1	2	2644.51	40	150	2593.61	2	5
2723.40	5	15	2681.21	30	100	2643.02	15	40	2593.26	2	1
2723.02		1	2680.96	2	6	2642.54	1	2	2593.06	6	20
2721.56		1	2680.67	3	8	2642.38	3	1	2592.82	6	4
2719.80	1	3	2679.43	1	2	2642.13	1	2	2591.15	1	2
2719.31	10	20	2679.03	1	3	2641.28	2	1	2589.88	6	3
2718.19	1	2	2678.58	5	10	2640.49	1	2	2588.93	3	8
2716.69	4	10	2675.64	2	7	2640.17	10*c*	20*c*	2587.77	1	4
2716.55	4	10	2675.24	20	50	2639.33	1	3	2586.89	1*h*	4*h*
2715.84	4	10	2674.61	1	2	2639.07	2	4	2586.71	2	3
2715.47	3	8	2673.85		1	2638.80	2	6	2586.27		1
2715.21	2	1	2673.43	20	50	2636.35	6	6	2585.91	3	4Fe?

Table 1. *Arc and spark spectra of technetium*—Continued

λ	Intensity		λ	Intensity		λ	Intensity		λ	Intensity	
A	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark
2585.49		1h	2550.05	3	10	2503.56	1		2461.86	1	
2585.06	1d	4d	2549.74		1	2503.29	1	4	2461.67	1	4
2584.59	1h	2h	2549.35		1	2502.36	2	1	2461.52	2	
2583.09		2	2547.94	20	50	2501.86		1	2459.67	1	
2582.22	3h	10hl	2547.01	1	4	2501.38		2	2458.99	2	1
2581.00	3	7	2545.75	1	2	2501.00	3	1	2456.47	2d	
2580.86	2	4	2545.55	3	2	2500.65		1	2456.17		1
2578.78	15h	40hl	2544.42	4	8	2500.10	1	1	2455.95		3h
2578.31	15	40	2543.24	500	1000	2499.60	1	4	2454.48		1
2577.87	10	20	2541.38	2	6	2497.24	10	20	2453.97	1	3
2577.02	1	2	2540.60	2	5	2496.77	100	200	2453.70	2	1
2576.30	10	30	2540.46	1h	3h	2495.04		1	2452.42	3	7
2576.12	1		2538.99	2	1	2494.14	2	1	2451.76	1	3
2575.59	2	1	2538.70	1	4	2493.44	4	5	2450.63	2	4
2575.24	5	10	2538.03	1h	2h	2492.73	6	3	2450.10	2	4
2575.08	5	10	2537.52	1	2	2491.26	2	1	2449.12	2	6
2574.45	6	10	2537.39	1	2	2491.06	3	6	2448.62	1	4
2573.88	1h	2h	2534.59	5	15	2490.85	1		2447.89	4	7
2573.49	1	2	2533.48	2	1	2490.71		2h	2447.45	1	3
2573.38	1	2	2532.97	4	10	2490.11		3h	2446.86	1	
2573.17	1	2	2532.04	2	8	2489.47	4	6	2445.78	1	
2572.92	1	2	2531.38	3	10	2489.06		3	2445.57	1	3
2571.57	2	3	2530.35	15	40	2488.03		3h	2444.01		2h
2571.18	2	4	2528.10	1	2	2487.98	2	3	2442.52		1
2569.89	5	15	2527.63	3	10	2487.74		1	2441.51		1
2569.64		1	2525.77		1	2487.24	2	5	2441.32		1
2568.67	1	2	2525.27	1	3	2487.04	2	3	2439.09	1	
2568.39	1	2	2525.05	1		2486.48	2	1	2438.76	1	3
2567.74	3d	8d	2523.88	2	5	2485.59	3	8	2437.00	3	2
2567.52	1	2	2523.41	5c	15c	2484.58	2	5	2436.81		2
2567.04	30	100	2522.50	4d	10d	2482.60		1	2435.84	4	2
2566.33	2h	5h	2521.86	2	3	2481.17		1	2435.63		2
2566.03	3	10	2521.64		1	2481.00		1	2434.85		1
2565.67		1	2521.07		1	2480.70	5	2	2434.38		2
2565.17	1	3	2520.65	1	3h	2479.24		2	2433.75	1	
2564.67	3	5	2520.04	2	4	2478.83		2	2432.62		2
2563.32	1		2519.83	1	2	2477.80	1	2	2431.39		1
2563.12	1	1	2519.42	1	3	2477.52		1	2431.11		1
2562.82	2	1	2519.17	10+Si	15d	2476.90		1	2429.55	1	3
2562.55	1	2	2517.15	5	20	2476.29	1	5	2423.25	15	7
2562.01	2	6	2516.85	5	15h	2475.15	3	5	2421.29	1	3
2561.15	1	3	2516.26	2	4	2474.11	3	10	2420.79	1	3
2560.63	4	2	2515.92	1	3	2473.15		2	2418.69	1	2h
2560.17		1	2513.60	1		2472.13		2	2418.05	2	1
2559.43		1	2512.96		1	2471.29	1	3	2417.82		1
2559.21	1		2512.27	1	2	2467.53	1h	4h	2417.53	1	4
2559.00	1	3	2511.28	1	3	2467.07		2	2417.10		1
2558.62	40	150	2510.17	5	3	2466.88	4	2	2416.70		1
2558.22	10	30	2509.45		1	2465.75	2	1	2416.23	4	2
2557.40	2	5h	2508.83	2	2	2465.10	5	3	2414.47	2	6
2556.84	1	2d	2508.39		1	2464.82		1	2412.62	1	
2556.10	3	8	2507.99	3h	8h	2464.48	3	7	2411.30	1	3
2554.78	1	3	2507.14	15	30	2463.70	15	8	2410.20		1
2554.36	1h	2	2505.04	2	7	2463.53		2h	2408.82	1	
2550.78		1	2503.98	5	20	2462.11	1	2	2408.16	2	6

λ	Intensity		λ	Intensity		λ	Intensity		λ	Intensity	
A	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark	*A*	Arc	Spark
2407.87	1		2384.66	4	10	2360.44		1	2316.72		1
2407.11	1	3	2382.98	1		2354.08		1	2315.32		2
2405.13	1		2382.39		2	2353.16		1	2313.91		1
2404.10	5	15	2382.05	6	3	2349.17		1	2300.97		1
2400.90	1	3	2376.05	7	15	2346.59		2	2300.44		1
2398.67	7	20	2373.77		1	2345.17	1	3	2299.96		1
2396.64		1	2369.05		2	2344.84	1	3	2298.14	4	10
2394.97	2	1	2368.35		1	2344.71		1	2292.14		1
2394.49		1	2368.01		1	2341.67		2*h*	2291.64		1
2393.42		1	2367.67		1	2331.78		2	2285.47	1	3
2392.02	2	1	2366.55	2	4	2329.49		1	2282.41		1
2390.93		1	2365.91		2	2328.41	1	3	2280.33		2
2389.36		1	2365.53		1	2327.69		1	2272.45		1
2386.03		1	2361.80	2	2	2324.57	1		2271.14	1*d*	4*d*
2385.32		1	2360.78		2	2318.74		1	2266.24		2
									2261.30		1

III. Results

The results of this investigation are presented in table 1, where wavelengths and relative intensities of 2,121 spectral lines characteristic of technetium atoms and ions are given. In this table the wavelengths represent the averages of two to six independent determinations. Several hundred faint lines that were measured only once on the strongest spectrograms have been omitted from table 1, but some of these may be reported later if any confirm predictions from atomic energy levels.

The average probable error in these wavelengths is believed to be less than ±0.01 A. There are three reasons for this belief, namely, computed probable errors of lines measured on six spectrograms, agreement of the wavelengths of impurity lines with their accepted values, and the average difference between the measured values of classified lines and their values computed from atomic energy levels derived from these observations [14].

In addition to six-figure wavelengths, estimated relative intensities of arc and spark lines of Tc are given in table 1. These intensities range from 1,000 for the strongest line to 1, which represents the weak lines whose reality is unequivocal because they were observed two or more times. In the spectral range in which arc and spark intensities were compared (4700 to 2200 A) Tc I lines have nearly double intensity in the arc, whereas Tc II lines have about treble intensity in the spark. Most of the Tc II and Tc I line-intensities thus differ by a factor of 5 or 6, and their assignment is unambiguous. A few lines, mostly faint ones, appear to have about the same intensity in arc and spark, but naturally a few approximate coincidences of Tc I and Tc II lines may be expected.

Occasionally the intensity numbers are accompanied by literal symbols having the meanings given in the table. Some of these symbols are especially significant for Tc spectra because they suggest hyperfine structure due to interaction of valence electrons with atomic nuclei. This hyperfine structure was observed in manganese spectra and in rhenium spectra, unresolved by gratings in the former case but easily resolved in the latter. The hyperfine structure of Tc lines appears to be intermediate between Mn and Re. Many Tc lines, especially among longer waves, appear as flat-topped images, four or five times as wide as the slit. These lines are under investigation with interferometers.

Besides a general resemblance of Tc spectra with those of Mn and Re, we can now define in detail the analogous spectral lines of the three elements or their ions. For neutral atoms of Mn, Tc, or Re the resonance lines are known as $d^5\,s^2\,{}^6S_{2\frac{1}{2}}-d^5s^1\,p^1\,{}^6P_{3\frac{1}{2},\,2\frac{1}{2},\,1\frac{1}{2}}$, and the respective wavelengths are 4030.76, 4033.07, 4034.49 A in Mn; 4297.06, 4262.26, 4238.19 A in Tc; and 3460.47, 3464.72, 3451.88 A in Re. For singly ionized atoms of Mn, Tc, or Re the resonance lines are known as $d^5\,s^1\,{}^7S_3-d^5\,p^1\,{}^7P_{4,3,2}$, and the respective wavelengths are 2576.10, 2593.73, 2605.69 A for Mn^+; 2543.24, 2610.00, 2647.02 A for Tc^+; but not yet revealed for Re^+. Full details concerning the interpretations of lines in the first two spectra of Tc will be divulged in another paper. The above-mentioned resonance lines of Tc and Tc^+ are probably useful for detecting this element in concentrations of 10^{-7}; the fact that they cannot be found in any spectral tables excluding fission products may be regarded as proof that technetium is not spectroscopically detectable in nature.

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Dissociation Constants of 4-Aminobenzophenone Calculated From Ultraviolet Spectra at Several Temperatures

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Many of the physical-chemical properties of compounds of low solubility are difficult to determine because of the necessarily small concentrations of material. In many cases advantage may be taken of measurements of the absorption spectra if the bands occur in favorable ranges of the spectrum. The diphenyl ketones fall in this category and have been the subject of recent studies.

The ultraviolet absorption spectra of several concentrations of benzophenone, 4-aminobenzophenone, and 4,4′-diaminobenzophenone have been measured and their molar absorbencies determined. The dissociation of 4-aminobenzophenone, a weak base, has been carefully studied at temperatures from 10° to 40° C in 5-degree steps. Dissociation constants for each temperature, as well as activity coefficient terms, have been calculated. The heat of dissociation has also been determined.

I. Introduction

The acidic or basic properties of many slightly soluble compounds have not been determined because of experimental difficulties in applying the usual titration or electromotive-force methods to very low concentrations. Diphenylketones, such as benzophenone, 4-aminobenzophenone and 4,4′-diaminobenzophenone, are practically insoluble in water and fall in this category. They are colorless in aqueous solution, but their aromatic structure suggests that their ultraviolet spectra may be used to study some of their chemical properties. Accurate spectrophotometric measurements of concentrations as low as 10^{-4} or 10^{-5} molar can now be made at many temperatures. The observed changes in spectral absorbancy with changes in hydrogen-ion concentrations can be used to calculate dissociation constants and other related thermodynamic quantities.

The molar absorbancies of the molecular and ionic states of benzophenone, 4-aminobenzophenone, and 4,4′-diaminobenzophenone were first determined and compared. The parent compound, benzophenone, has no group to ionize, and its spectral curves are identical whether the material is in aqueous, acid, or basic medium. 4-Aminobenzophenone is a weak base and does not dissociate appreciably in aqueous solution, as demonstrated by identical curves of the free base in water and in various concentrations of alkali. Moderately strong acid is required to effect complete dissociation, as evidenced by the entirely different absorbancy curve in the near ultraviolet. 4,4′-Diaminobenzophenone has two groups whose dissociation ranges overlap, and extensive experimental data will be required to determine the constants.

A comprehensive study of the dissociation of 4-aminobenzophenone has been made at several temperatures, and the constants at 10°, 15°, 20°, 25°, 30°, 35°, and 40° C have been calculated and are reported in this paper. Hydrochloric acid was used to control the hydrogen-ion concentrations at various stages during the dissociation. The contribution of the 10^{-5}-M base to ionic strengths of 10^{-3} and 10^{-2}-M hydrochloric acid is so small that it can be neglected—thus the hydrogen-ion concentration may be taken as that of the known amount of hydrochloric acid.

The limiting spectral absorbancy curves of the free base and of the ionized compound do not change with change in temperature in the range studied, which is very fortunate. At a given temperature, then, all changes in absorbancy for one dissociation series may be attributed solely to the dissociation reaction. Another favorable factor is that 4-aminobenzophenone dissociates over a pH range of 1 to 3, where the temperature has little influence upon pH values.