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THE FURNACE SPECTRUM OF PLUTONIUM

John G. Conway

May 12, 1953

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THE FURNACE SPECTRUM OF PLUTONIUM

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May 12, 1953

ABSTRACT

The spectrum of plutonium has been observed over the temperature range of 2000° to 2600° C and a wavelength coverage of 3476 to 6888 Å. The spectrum was excited in a modified King furnace.

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I. INTRODUCTION

There is very little information on the spectrum of plutonium which will aid in a term analysis. Tomkins and Fred¹ have measured some two hundred plutonium lines, and Dodge, Chrisney and Rollefson² have listed a thousand. In both these cases, however, the spectrum was excited by a high voltage spark with the plutonium deposited on copper electrodes. The low ionization potentials of the lanthanide elements and the expected low ionization potentials of the actinide series would give little hope in separating the first and second spectra by the usual arc and spark method. The furnace method as used by King³ is the most promising way of distinguishing the first and second spectra, and even in the furnace at higher temperatures King found an appreciable ion spectrum.

II. EXPERIMENTAL WORK

A modified King vacuum furnace was used for this work. A graphite tube $3/32$ inch thick, $17/32$ inch inside diameter, and $3\ 21/32$ inches long served as the heating element. Passing a thousand amperes at 11 volts through the graphite element heated it to approximately 2550°C (Figure 1).

A $1/4$ inch diameter tantalum tube was inserted axially in the graphite tube and was of sufficient length to extend from beyond the furnace vacuum wall to a point several inches beyond the heated

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portion of the heater element. The plutonium in the form of a hydroxide slurried in water was positioned so as to be centered in the hottest portion of the tube. Cesium nitrate crystals were also placed in the tantalum tube. King³ used cesium to suppress the ion spectra. The tantalum tube was loaded with the plutonium hydroxide in a ventilated gloved box. After loading, the tube was capped and transferred to the furnace, then uncapped and the vacuum fitting was attached. The tantalum tube had a twofold purpose: it served, (1) as a disposable liner to confine the radioactive plutonium and, (2) as a liner to prevent the formation of carbides of plutonium which would quickly use up all the sample.

The furnace and tantalum tube were then evacuated. This was followed by a heating at 800° to 1000° C to convert the hydroxide to oxide. The current was then adjusted to give the desired temperature and the spectra were taken.

The spectrograph used was a 21 foot, 15,000 line per inch Wadsworth mounted grating manufactured by Jarrell-Ash Company. The wavelength range covered was from 3476 to 8400 Å. From 6900 to 8400 Å no plutonium lines were observed. Eastman Kodak Company 103a0, 103aF, and ammonia sensitized 1 N photographic plates were used. The exposure times, adjusted to give usable spectra at low temperatures, were on the order of 60 minutes, and at the high temperatures the time was about 5 minutes, which was also the time required to burn out the graphite tube. The temperature ranges were 2600° to 2400° C, 2400° to 2200° C, and 2200° to 2000° C. Very few lines were visible in the lower temperature range. Figure 2 is a

portion of the plate showing the temperature variation. Spectrum 1) is a 5 minute exposure at 2550° C; 2), 15 minutes at 2300° C; 3), 10 minutes at 2175° C.

III. RESULTS

The lines observed in the furnace spectrum are listed in Table 1. The wavelengths were measured with a Bausch and Lomb spectrum measuring magnifier and should be accurate to approximately 0.1 Å. The intensities are on a 0 to 10 scale, but since the exposure time varied considerably, the intensities show only the relative change with temperature.

Fig. 1. Sketch of furnace used to obtain plutonium spectrum.

Fig. 2. Spectra of plutonium.

- A. Five minutes exposure at 2550° C.
- B. Fifteen minutes exposure at 2300° C.
- C. Thirty minutes exposure at 2175° C.

Table 1

Wavelength and Intensities of the Plutonium Furnace Spectrum

Wavelength (Å)	Intensity	
	2600°-2400° C	2400°-2200° C 2200°-2000° C
3476.54	2	1
3478.37	1	1
3484.38	1	1
3491.44	1	2
3496.25	0	1
3497.72	1	0
3498.50	1	1
3498.87	0	1
3508.44	0	0
3516.55	0	0
3517.33	0	0
3526.48	0	--
3533.54	0	0
3537.47	0	0
3539.30	0	0
3540.66	1	0
3547.27	--	1
3550.28	1	2
3553.16	0	--
3555.77	0	--
3558.12	0	--
3570.94	0d	--

Table 1 (Cont'd)

Wavelength (Å)	Intensity	
	2600° - 2400° C	2400° - 2200° C 2200° - 2000° C
3587.99	1	1
3594.37	0	--
3607.42	1	--
3609.51	1	--
3611.87	2	2
3614.22	1	--
3615.01	1	1
3616.84	1	--
3618.93	1	--
3621.02	1	1
3626.51	2	--
3632.26	0	--
3637.49	1	1
3638.54	1	1
3641.64	1	--
3643.25	1	1
3643.77	1	--
3644.56	1	--
3645.34	1	1
3651.72	1	--
3654.33	1	1
3656.84	1	1
3658.10	1	1
3667.15	2	3

Table 1 (Cont'd)

Wavelength (Å)	Intensity	
	2600° - 2400° C	2400° - 2200° C
3668.19	0	--
3668.92	0	--
3670.55	1	1
3671.59	2	2
3676.04	1	--
3677.50	2	2
3678.39	1	1
3683.62	2	3
3686.50	0	0
3687.28	0	0
3688.33	1	1
3689.64	1	1
3692.25	1	--
3695.16	2	2
3695.81	0	--
3698.69	1	1
3699.37	1	1
3702.61	--	0
3703.66	1	0
3704.44	0	--
3705.75	1d	1d
3706.27	1	1
3711.50	0	0
3712.76	1	1

Table 1 (Cont'd)

Wavelength (Å)	Intensity	
	2600° - 2400° C	2400° - 2200° C 2200° - 2000° C
3713.86	1	1
3714.75	2	2
3718.56	1	1
3719.09	1	1
3720.13	1	1
3720.66	1	1
3721.44	1	2
3724.05	1	0
3725.89	1	1
3727.72	1	1
3728.76	1d	1d
3732.27	2	2
3733.21	0	--
3735.93	1	1
3737.65	1	1
3740.74	1	1
3743.67	1	--
3744.87	2	4
3746.81	1	1
3748.74	2	2
3753.60	1	4
3754.13	1	1
3755.17	1	1
3755.96	1	3

Table 1 (Cont'd)

Wavelength (Å)	Intensity	
	2600° - 2400° C	2400° - 2200° C 2200° - 2000° C
3757.79	2	2
3758.94	2	2
3760.67	2	2
3761.19	2	2
3764.59	2	2
3765.90	3	4
3767.46	2	2
3768.25	2	2
3771.39	1	--
3773.64	1	1
3774.42	1	3
3776.77	1	3
3777.40	2	1
3779.65	2	3
3784.41	0d	0d
3786.83	2	2
3787.34	2	2
3790.48	2d	2
3797.17	0	--
3798.90	2	2
3799.37	2	5
3800.94	2	2
3801.98	2	2
3803.55	2	1

Table 1 (Cont'd)

Wavelength (A)	Intensity		
	2600° - 2400° C	2400° - 2200° C	2200° - 2000° C
3805.85	2	5	
3808.26	2	4	
3809.04	2	3	
3809.30	2	3	
3811.40	2	2	
3813.49	2	2	
3814.80	2	2	
3816.40	2	2	
3819.38	3	4	
3821.05	2	3	
3823.67	0	0	
3823.88	0	0	
3829.05	1	1	
3829.68	1	1	
3834.86	1	1	
3835.43	2	5	
3835.85	1	1	
3836.90	2	4	
3838.99	2	4	
3842.13	2	5	
3844.12	3	4	
3846.05	1	1	
3847.10	1	1	
3848.14	0	0	

Table 1 (Cont'd)

Wavelength (A)	Intensity	
	2600° - 2400° C	2400° - 2200° C 2200° - 2000° C
3848.93	0	0
3850.91	2	6
3851.80	3	3
3856.09	3	1
3859.12	2	2
3860.33	0	--
3860.85	0	--
3862.42	3	3
3864.36	2	2
3869.59	3	3
3874.29	1	0d
3879.78	1	1
3881.09	1	1
3881.62	1	1
3882.40	1	0
3895.95	1	5
3898.09	1	1
3901.49	1	1
3903.84	1	1
3907.97	2	2
3910.38	2	2
3911.16	2	4
3911.63	2	1
3913.36	0	0

Table 1 (Cont'd)

Wavelength (A)	Intensity	
	2600° - 2400° C	2400° - 2200° C
3916.29	2	1
3919.48	1	1
3925.18	1	0
3925.70	1	1
3928.42	2	4
3931.04	1	0
3936.27	2	4
3938.36	2	2
3939.51	3	3
3939.93	0	--
3940.45	0	--
3941.50	2	4
3942.81	2	1
3953.20	2d	2
3956.08	2	3
3960.53	3	3
3967.48	2	2
3972.29	2	2
3974.23	2	2
3977.26	2d	2d
3979.62	2	4
3980.77	2	1
3983.12	2	3
3988.77	2	2

Table 1 (Cont'd)

Wavelength (A)	Intensity	
	2600° - 2400° C	2400° - 2200° C 2200° - 2000° C
3990.34	2	4
3992.95	0	--
3997.14	1	1
4006.03	2	2
4006.81	1	0
4010.47	2	2
4011.52	2	3
4014.66	0	--
4015.44	0	--
4017.27	0	--
4019.89	1	1
4023.02	1	2
4027.05	2	1
4029.56	0	0
4031.65	0	0
4032.76	2	2
4035.47	2	4
4036.20	2	2
4038.98	2	4
4042.38	1	1
4047.24	1	0
4048.39	1	1
4049.96	1	1
4052.05	1	1

Table 1 (Cont'd)

Wavelength (A)	Intensity	
	2600° - 2400° C	2400° - 2200° C 2200° - 2000° C
4052.58	1	1
4055.03	2	5
4055.56	2	2
4059.43	1	1
4062.67	0	0
4063.04	0	--
4063.56	0	--
4070.10	3	3
4072.97	2	2
4075.06	1	1
4075.59	0	--
4082.23	2	2
4085.79	3	3
4085.94	0	0
4088.66	1	1
4090.23	1	1
4092.11	2	3
4095.20	1	1
4095.46	1	1
4097.03	3	3
4101.74	2	2
4102.26	2	2
4106.34	0	0
4110.89	2	1

Table 1 (Cont'd)

Wavelength (A)	Intensity		2200° - 2000° C
	2600° - 2400° C	2400° - 2200° C	
4115.07	1	--	
4119.57	3	3	
4132.86	2	4	
4135.21	1	1	
4151.26	3	3	
4151.63	3	3	
4157.59	2	2	
4159.89	3	3	
4171.14	3	3	
4172.70	2	2	
4177.04	0	0	
4181.23	2	2	
4182.80	2	2	
4183.79	3	5	
4192.47	2	2	
4206.59	2	6	
4208.32	2	4	
4215.49	1	--	
4221.97	2	2	
4224.11	2	2	
4232.38	2	2	
4235.46	2	2	
4238.24	3	3	
4247.13	0	--	

Table 1 (Cont'd)

Wavelength (Å)	Intensity	
	2600° - 2400° C	2400° - 2200° C
4250.53	2	2
4253.61	0	--
4260.83	1	1
4259.16	0	--
4260.99	1	1
4261.82	2	5
4269.62	2	4
4281.02	2	2
4310.29	2	2
4310.81	2	2
4320.43	0	--
4333.25	1	--
4366.20	2	2
4367.24	4	4
4374.46	1	0
4379.79	0	0
4381.00	0	0
4392.08	3	3
4398.36	1	--
4402.81	3	3
4404.90	4	6
4409.50	2	2
4414.31	2	2
4415.62	1	0

Table 1 (Cont'd)

Wavelength (A)	Intensity	
	2600° - 2400° C	2400° - 2200° C
4424.88	2	2
4433.66	3	5
4436.02	0	--
4438.89	2	2
4446.74	1	0
4455.63	3	3
4473.11	0	--
4476.51	0	--
4479.02	2	1
4484.88	2	2
4494.02	0	--
4498.74	1	--
4506.95	3	5
4520.96	1	0
4521.49	1	0
4524.62	0	--
4534.04	0	--
4552.08	0	--
4553.39	2	3
4577.08	0	--
4578.49	0	--
4580.38	0	--
4582.16	0	--
4586.34	1	--

Table 1 (Cont'd)

Wavelength (A)	Intensity	
	2600° - 2400° C	2400° - 2200° C
4593.92	0	--
4594.29	0	--
4607.26	3	6
4608.58	1	1
4615.37	0	--
4624.52	2	2
4625.56	1	1
4630.79	0	--
4634.35	1	1
4636.13	1	1
4645.18	1	1
4645.70	0	0
4646.48	1	1
4649.88	2	2
4690.22	2	2
4695.81	1	2
4713.14	2	4
4716.95	0	--
4721.12	2	3
4725.56	1	2
4731.15	1	1
4735.74	2	4
4753.72	0	0
4754.27	1	1

Table 1 (Cont'd)

Wavelength (Å)	Intensity	
	2600° - 2400° C	2400° - 2200° C
4781.15	1	1
4799.16	1	0
4811.17	1	1
4814.46	2	4
4850.32	0	1
4870.68	0	1
4893.91	1	3
4911.14	1	1
4916.36	0	--
4917.26	0	--
4921.44	1	1
4969.72	0	--
4989.30	1	3
4999.48	0	--
5044.37	1	2
5078.56	0	2
5183.38	0	--
5269.51	0	0
5304.90	0	1
5310.64	0	0
5317.95	0	1
5381.17	2	5
5418.17	1	2
5476.40	2	3

Table 1 (Cont'd)

Wavelength (Å)	Intensity		
	2600° - 2400° C	2400° - 2200° C	2200° - 2000° C
5482.14	1	1	
5486.32	1	1	
5498.32	3	5	
5510.59	2	2	
5517.64	1	1	
5537.21	1	1	
5537.74	1	1	
5549.38	1	4	
5561.98	3	5	
5570.68	3	4	
5580.86	1	--	
5590.78	3	5	
5592.60	2	4	
5630.45	3	6	0
5667.51	2	2	--
5682.65	2	4	0
5712.30	3	6	--
5733.02	2	2	--
5748.16	2	2	--
5770.11	1	0	--
5788.12	1	1	--
5807.17	2	2	--
5835.88	2	1	--
5838.76	2	4	2

Table 1 (Cont'd)

Wavelength (A)	Intensity		
	2600° - 2400° C	2400° - 2200° C	2200° - 2000° C
5853.53	2	2	--
5864.88	5	4	2
5880.89	3	3	--
5893.07	2	2	--
5901.89	0	--	--
5925.81	2	2	--
5937.06	2	1	--
5939.73	1	--	--
5944.05	1	0	--
5945.12	3	2	0
5952.43	2	1	--
5970.72	0	--	--
5977.33	0	--	--
5979.36	0	--	--
5983.14	6	5	2
5992.55	0	--	--
5995.09	0	--	--
5996.87	0	--	--
5999.41	2	1	--
6000.42	2	1	--
6012.67	2	0	--
6020.74	0	--	--
6024.86	0	--	--
6026.33	0	--	--
6027.60	0	--	--

Table 1 (Cont'd)

Wavelength (A)	Intensity		
	2600° - 2400° C	2400° - 2200° C	2200° - 2000° C
6029.63	0	--	--
6032.17	1	0	--
6055.29	0	--	--
6056.05	0	0	--
6090.09	2	--	--
6092.12	4	3	2
6100.50	4	2	--
6102.79	1	0	--
6105.33	0	--	--
6110.91	0	--	--
6111.34	0	--	--
6119.13	3	2	--
6121.93	3	1	--
6138.44	3	2	--
6149.87	1	0	--
6155.56	2	1	--
6161.86	3	0	--
6175.98	2	1	--
6192.64	7	5	3
6195.89	3	2	0
6203.21	0	--	--
6213.37	0	--	--
6214.64	1	1	0
6224.29	1	--	--

Table 1 (Cont'd)

Wavelength (A)	Intensity		
	2600° - 2400° C	2400° - 2200° C	2200° - 2000° C
6233.18	1	--	--
6251.47	2	--	--
6256.34	3	1	--
6258.33	0	--	--
6268.49	1	--	--
6273.82	1	0	--
6278.90	1	0	--
6286.27	1	--	--
6296.17	1	--	--
6309.99	1	--	--
6321.93	1	--	--
6325.49	1	--	--
6366.13	0	1	1
6380.86	0	--	--
6411.59	1	1	--
6432.42	1	2	1
6439.43	2	0	--
6449.95	3	2	1
6462.90	1	--	--
6473.83	2	1	0
6476.62	1	--	--
6477.89	1	--	--
6481.45	1	--	--
6486.96	6	5	4

Table 1 (Cont'd)

Wavelength (A)	Intensity		
	2600° - 2400° C	2400° - 2200° C	2200° - 2000° C
6489.43	8	7	5
6498.73	1	--	--
6503.71	0	--	--
6527.33	1	--	--
6535.30	6	5	3
6544.24	4	3	1
6561.16	0	--	--
6565.53	0	--	--
6576.35	2	1	--
6578.38	0	--	--
6580.16	2	1	--
6595.15	0	--	--
6608.86	7	5	3
6611.91	0	0	--
6614.45	0	--	--
6619.02	1	0	--
6621.31	1	0	--
6627.91	4	3	2
6673.07	3	2	1
6675.47	0	--	--
6740.38	2	1	--
6767.16	3	1	--
6772.39	3	2	--
6785.34	3	2	--

Table 1 (Cont'd)

Wavelength (Å)	Intensity		
	2600° - 2400° C	2400° - 2200° C	2200° - 2000° C
6813.03	0	--	--
6880.10	3	2	0
6887.63	3	2	0

Note: 1) Where no intensity is indicated no line was visible.

2) "d" indicates diffuse.

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IV. REFERENCES

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