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Spectrum of Aluminum Vapor Distilled by a Tungsten Coil in Vacuum

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If a tungsten coil, charged with aluminum, is brought to incandescence in a vacuum of the order of 10^{-5} mm Hg, it evaporates a cloud of metal, which has been observed to emit a violet-blue light. The luminosity has been analyzed and found to be mainly a line spectrum containing Al I, Al II, W and impurity lines. The excitation is produced by collisions with the electrons emitted by the incandescent filament and accelerated by the potential drop across it. λ3443.6 behaves as an Al arc and not as an Al II line, as commonly listed.

One of the authors,[2] during his work on the deposition of aluminum films on the surfaces of astronomical mirrors, or of diffraction gratings, by evaporating the aluminum from electrically heated tungsten coils, observed that while the metal remained in the gas phase (a time of 10^{-4} to 10^{-3} sec. for each atom), it emitted a violet-blue luminescence, that can be seen with the naked eye. This work had as its purpose to study this luminescence.

Apparatus and Results

The experimental arrangement consists of a tungsten coil, made of wire of 0.030 inch in diameter, containing about 10 full turns of 1/4-inch diameter, loaded with small aluminum *U*'s, one in each turn, of 1 mm wire of 99.9 percent purity. The length of wire in each *U* is 10 to 12 mm. The coil is placed in a glass or metal bell jar, its ends being connected with terminals of a transformer, from which any alternating potential in steps of 1 volt can be drawn, up to 110 volts. The bell jar is in communication with a two-stage oil diffusion pump by means of a tube 12 cm in diameter. An intermediary liquid air trap was generally used.

The luminescence is observed through a glass or quartz window, protected from the distilling aluminum by a screen. (Otherwise it would become opaque in a few seconds.)

When the vacuum is of the order of 10^{-5} mm or better, the tungsten coil is heated to a moderate temperature, in order to allow the Al *U*'s to melt and distribute along its surface. At the same time, the aluminum is partially outgassed and cleaned of its oxide surface. Then, a potential difference of from 10 to 40 volts is applied across the coil and the luminescence observed or photographed through the window. The whole process of evaporation lasts from 10 to perhaps 50 sec., depending on the voltage applied.

The first visual observations, with a hand spectroscope, indicated that the luminescence consists of a line spectrum, containing many lines in the visible, among which the violet doublet 3961.5 − 3944.0 of Al is conspicuous. The spectrum was then photographed through a fast glass spectrograph and with the small Hilger quartz instrument, varying the potential difference applied across the coil. The plates show mainly lines of Al I, Al II and W. The aluminum oxide bands in the green, conspicuous in the air arc, are totally absent. The hydride bands, on the other hand, appear with great intensity. The following heads have been identified: 4405, 4368, 4354, 4345, 4259, 4241, 4067.

The measurement of the plates indicates the presence of the lines listed in Table I. As im-

Table I. *Wavelengths of lines observed in Al vapor from W coil.*

Al I	Al II	W	Al I	Al II	W
3961.5	4663.1	5071.7	2372.1	3586.5	4551.8
3944.0	4585.8	5069.2	2367.1	3458.2	4546.5
3480.5	4485.8	5054.6	2321.6	3057.2	4294.6
3443.6	4447.8	5053.3	2317.5	3050.1	4215.4
3092.8	4227.5	5015.3	2313.5	2816.2	4137.5
3082.2	4226.8	5006.2	2312.4	2669.2	4102.7
2660.4	3900.7	4982.6	2269.1	2631.7	4089.0
2652.5	3859.3	4886.9	2263.5	2475.3	4074.4
2638.2	3842	4843.0	2258.0	2369.3(?)	4008.8
2575.1	3703.2	4693.7(?)	2210.1		3881.4
2568.0	3655.0	4680.5	2204.6		3868.0
2378.4	3651.1	4659.9(?)	2174.0		2944.4
2373.1	3587.1	4613.3	2168.8		

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[1] Fellow of the John Simon Guggenheim Memorial Foundation.

[2] John Strong, Publ. A. S. P. **46**, 18 (1934).

purities, appear the strongest lines of the Fe spectrum; 4924.0 of Zn II; 4810.5, 4722.2, 4680.1 and 3075.9 of Zn I; 4172.0, 4033.0, 2943.7 and 2874.2 of Ga; 3493.0 of Ni; 3274.0 and 3247.5 of Cu; 2881.6, 2516.1 and 2506.9 of Si; 2852.1 of Mg I; 2802.7 and 2795.5 of Mg II; 4046.6 of Hg; 2840.0(?) of Sn; 4861.3 of H; 3280.7 of Ag and 3261.0 of Cd. The last two were not in all the plates.

Discussion of Results

The presence of many lines of W is due to the fact that this metal dissolves partially in the molten Al coat of the filament and is carried away by the rapid evaporation of it. A quantitative determination of the concentration of W in the deposited Al films indicates the value. The other metals appearing as impurities are probably contained in the commercial Al wire used for the *U*'s, with the exception of Ag and Cd which are contaminations of the bell jar and Hg, which comes from the McLeod gauge. The presence of the AlH bands and of $H\beta$ indicate that the initial melting of the aluminum on the filaments leaves still a large amount of hydrogen occluded in it. This hydrogen then evaporates with the metal.

The intensity relation of the Al II to the Al I spectrum varies with the potential applied across the coil. With 10 volts, practically only the arc lines are present, with 40 volts the spark lines are nearly as strong as the former. It varies also with the distance from the coil: A photograph taken using a 40-inch bell jar, for which the spectrograph was focused to a region about 30 cm away from the coils, does not show the otherwise strongest Al II lines 2816.2 and 2669.2, although 20 volts were applied across the filament. The Al I spectrum appears as usual. This would indicate that recombination of the ions takes place rapidly, demanding the existence of a great number of free electrons. It is remarkable that in this case the line 3443.6, which is listed in Kayser among the Al II lines, but not classified, is present, in the absence of 2816.2 and 2669.2, as mentioned. This shows that 3443.6 does not belong to the Al II spectrum.

The doublets of the diffuse series of the Al arc are notably sharp and perhaps displaced in our case. This is in agreement with observations of other authors in low pressure or vacuum sources of Al light.[3]

The main question to be answered is how the spectra are excited. The foregoing observations pointed clearly to electronic collisions. The electrons are emitted by the hot filament and accelerated by the potential gradient along it. To test this assumption, we constructed an equipotential source of thermoelectrons, by coating a tantalum capsule with CaO, BaO and SrO and heating it internally, and an analogous equipotential source of Cd vapor. A suitable constant potential difference was set up between the two sources. The plate obtained shows Cd I and Cd II lines. Among the last, 2144 and 2265, which spring from the lowest excited level, appear clearly; 2749, which is the strongest Cd II line under normal conditions, is very weak, and the strong line 2313 does not show at all. This corroborates the assumption that the excitation is due to electronic collisions, controlled by the potential drop.

The method of controlled step by step excitation, by collisions with electrons, requires, usually, in order to obtain sufficient vapor density, the heating of the whole containing vessel to a suitable temperature. In this case the container is at room temperature and the density is determined by the number and temperature of the coils, exclusively. This may be an experimental advantage in some investigations.

During the Cd test experiment, it was remarked that the thermionic source of electrons had to be heated to a rather high temperature, in order to obtain enough intensity in the spectra. Dr. R. M. Langer suggested to us, that this observation indicates a high thermionic emissivity for the aluminum coated tungsten filament. This suggestion has been verified by us. The results of this investigation will appear in another publication.

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[3] M. Bögemann, Dissert. Münster 1917; J. Barnes, Astrophys. J. **34**, 159 (1911); J. H. Pollock, Proc. Roy. Soc. Dublin **13**, 202 (1912).