LOW VOLTAGE EXCITATION OF THE SPECTRUM OF CAESIUM

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Abstract

Spectrum of caesium for excitation voltages below ionization potential.— While the Bohr theory suggests that individual lines should appear in regular sequence as the corresponding voltages are reached, previous attempts to observe them have failed. In this study a large equipotential source of electrons was secured by fitting a nickel cylinder 10 cm long over an alundum tube heated internally by a tungsten spiral. With this as cathode although currents up to 1 milliampere were used, the current density and also the space charge effects were small. With this tube heated so as to give a pressure of .01 mm both visual and photographic observations showed definitely that lines in the principal series of Cs appear in the order and within 0.1 volt of the potential required by the theory. Lines in the diffuse and sharp series were more difficult to observe, but they also appeared below the ionization potential 3.9 volts.

THE energy of the electron impact on atoms necessary to excite the individual spectrum lines has been the subject of numerous investigations. The conception of energy levels within the atom leads one to expect that a given spectrum line should appear as soon as the energy of impact of the electron reaches a value sufficient to displace the electron in the atom to the corresponding level. Thus, by gradually increasing the energy of impact from the value corresponding to the first radiating or resonance potential to that corresponding to the ionizing potential, one should be able, as far as energy requirements go, to excite one line after another until the whole arc spectrum appears.

Most experimental results are in conflict with this view. For example, in the case of the alkalis, when the energy of the electron colliding with the atom reaches a value corresponding to the quantum of energy associated with the first line in the principal series, $1\sigma - 1\pi$, this line appears alone, giving the "single line spectrum." As the energy of impact is gradually increased no more lines appear until the ionizing potential is reached, when the whole arc spectrum, or "many lined spectrum," flashes out. Among other results supporting this view we mention those of Foote and Meggers[1] because they used caesium, the metal used in the investigation described in this paper. In view of the unexpected conflict between theory and the experimental results, it was decided to repeat the experiment with an apparatus which, while designed for other in-

[1] Paul D. Foote and W. F. Meggers, Phil. Mag. **40**, 80 (1920)

vestigations, was thought suitable for giving some information on this point.

The apparatus is shown diagrammatically in Fig. 1. It is essentially a three electrode tube with a nickel plate and grid as shown. The novel feature is the equipotential source of electrons. This consists of a close fitting nickel sheath, 10 cm long, surrounding an alundum tube heated internally by a tungsten spiral. (It is really used to lead the current into one end of the enclosed tungsten spiral, but the potential drop in the nickel sheath is less than .01 volt.)

The caesium was introduced by heating a mixture of caesium chloride and calcium turnings. According to Langmuir's discovery, caesium condensed on the surface of a metal adheres to it even up to a temperature of 800°C. This caesium covered nickel cathode formed a very convenient thermionic source and yielded a copious supply of electrons below a dull red heat. The apparatus was mounted in a furnace which could be maintained at a constant temperature to within 5° or 10° for hours.

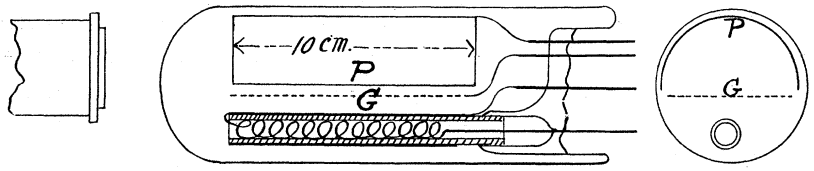

Fig. 1. Diagram of three electrode tube used.

The electrons were accelerated by a potential applied between the cathode on the one hand and the grid and plate joined together on the other, thus giving a field-free space between P and G. A milliammeter in the plate circuit measured the electrons passing across to P. In our experiments the current was maintained constant at a value never more than 1.0 milliampere. On account of the length of the cathode the current density was very small. The spectrum was photographed on panchromatic plates through a small Hilger quartz spectrograph. While the best available, this instrument proved rather inadequate because of the small dispersion in the visible spectrum and its insufficient light gathering power.

As in all experiments of this kind, it is necessary to ascertain how accurately the applied voltage measures the potential actually used inside the apparatus. Our method was to connect up the electrodes so as to measure the ionizing potential. Three runs gave us 3.9, 3.9, 3.85 volts respectively. The ionizing potential as calculated from the limit of the principal series is 3.88 volts. We may therefore conclude that there is

no correction to be made for contact difference of potential. This is no doubt due to the fact that all surfaces are covered by a condensed layer of the same metal caesium.

Theoretical Excitation Potentials

The following list gives the values of the calculated excitation voltages for lines in the caesium spectrum.

	Principal Series		
$1\sigma - 1\pi$	λ 8521 λ 8943	1.45 volts 1.38	infra red
$1\sigma - 2\pi$	λ 4555 λ 4593	2.71 2.68	blue
$1\sigma - 3\pi$	λ 3876 λ 3889	3.18 3.17	ultraviolet
$1\sigma - 4\pi$	λ 3612 λ 3617	3.42 3.41	ultraviolet
$1\sigma - 5\pi$	λ 3477 λ 3480	3.55	ultraviolet
$1\sigma - 6\pi$	λ 3398 λ 3400	3.63	ultraviolet
	Diffuse and Sharp Series		
$1\pi - 4\delta$	λ 6983 λ 6973	3.21 volts	red
$1\pi - 4\sigma$	λ 6587 λ 6355	3.31	red
$1\pi - 5\delta$	λ 6215 λ 6010	3.42	orange
$1\pi - 5\sigma$	λ 6035 λ 5839	3.48	yellow
$1\pi - 6\sigma$	λ 5846 λ 5664	3.55	yellow
$1\pi - 6\sigma$	λ 5746 λ 5569	3.58	yellow
$1\pi - 7\delta$	λ 5635 λ 5466	3.63	yellow

Visual Observations

Preliminary observations were made by the rested eye, carefully shielded from stray light, on the color of the light seen in the field-free space between the plate and the grid. Electron currents were about .1 to .2 milliamperes, the furnace temperature of 130° C giving a vapor pressure of .01 mm.[2] As the accelerating potential was raised from zero,

[2] D. H. Scott, Phil. Mag. **47,** 32 (1924)

nothing was seen until a dim blue haze appeared between 2.8 and 3.0 volts. This is no doubt due to the excitation of the blue doublet λ4555 – λ4593, which should appear at 2.7 volts. The discharge became faintly red at between 3.3 and 3.5 volts and yellow at 3.6 volts. On comparison with the table of theoretical excitation potentials it will be seen that these observations are in fair correspondence. In each case, however, the color appeared at a potential about .1 to .2 volt higher than the theoretical value. This is possibly due to the fact that the number of collisions resulting in excitation is small as we pass through the threshold value of the voltage but increases rapidly beyond that point.

The color tended to appear first around the metal boundaries P and G before spreading out into the space, showing that even under these conditions of feeble electron current and low pressure there was still a residual space charge effect.

Photographic Observations

A set of exposures was taken on a panchromatic plate at 3.8, 3.7, 3.5, and 3.3 volts. The furnace temperature was maintained constant between 135° and 140° C. The electron currents used were 1.05, .40, .20, and .10 milliampere, respectively, for the different accelerating potentials. The exposures were 3, 9, 18 and 36 hours, respectively.

The plate showed satisfactory evidence of a step by step excitation, especially in the principal series. The following table gives the means of the estimates made independently by two observers; the numbers being purely arbitrary.

Table I

Behavior of lines of the principal series

Lines :	$1\sigma-1\pi$	$1\sigma-2\pi$	$1\sigma-3\pi$	$1\sigma-4\pi$	$1\sigma-5\pi$	$1\sigma-6\pi$
Wave-lengths:	λ8521	4555	3876	3612	3477	3398
	8943	4593	3889	3617	3480	3400
Theoretical voltages	{1.48	2.41	3.18	3.42	3.55	3.63
	{1.38	2.68	3.17	3.41		
Applied voltage						
3.3	Too far in	10	trace	—	—	—
3.5	infra-red	9	8	trace?	—	—
3.7		7	9	8	trace	—
3.8		9	12	10	6	trace

This table shows convincing evidence of a step by step excitation of the lines of the principal series. There is no particular significance in the change of intensity in any one line from one exposure to the next, but

what is significant is that there are important relative changes in the intensity distribution as we step up from one voltage to the next.

With regard to the lines of the sharp and diffuse series in the red and yellow the results are not so clear cut. None of the lines appears with 3.3 or 3.5 volts. They all appear at 3.7 and 3.8 volts except $\lambda 6983 - \lambda 6973$ for which the plate was probable insensitive. With regard to the change in appearance of these lines in going from 3.7 to 3.8 volts all that can be said is that the lines $1\pi - 6\sigma$ and $1\pi - 7\delta$, in the yellow, seem to increase in intensity relatively more than the lines in the red. This would be in agreement with the behavior of lines that have just recently passed their excitation values. However, accurate observations were very difficult on account of crowding of the lines in this region and the small light gathering power of the spectrograph.

The evidence, however, is decidedly in favor of step by step excitation of the different lines. Undoubtedly a spectrograph of greater light gathering power and much longer exposure would give results corresponding more closely to the theoretical values.

While this work was in progress a paper by Hertz[3] appeared in which he finds step by step excitation in the spectra of Ne, He and Hg, and a paper by Eldridge[4] reports step by step excitation for Hg.

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[3] G. Hertz, Zeit. f. Phys. **22,** 18 (1924)
[4] J. A. Eldridge, Phys. Rev. **23,** 685 (1924)