originating in dx which will be counted is

$$dN=f(R_0-x)\lambda(x)dx$$

where the discontinuous factor

$$\lambda(x)=\begin{cases}1 \text{ if } x<(KR_0-l-A)/(K-1)\\ 0 \text{ if } x\geqq(KR_0-l-A)/(K-1).\end{cases}$$

The total number counted is then

$$N=\int_0^l f(R_0-x)\lambda(x)dx=\int_0^{(KR_0-l-A)/(K-1)} f(R_0-x)dx.$$

From this expression it follows at once that

$$dN/dA=-f\left[\frac{(l+A-R_0)}{(K-1)}\right]\Big/(K-1).$$

This expression is a maximum when f is a minimum, let us say for the value $f(R')$. R' is the value of the range at which the yield curve has a minimum, i.e., the value which was determined previously (cf. Fig. 2 for protons and Figs. 3–5 for deuterons). We see, therefore, that the value of A for which the integral curve is flattest, A', is related to R' by

$$f\left(\frac{l+A'-R_0}{K-1}\right)=f(R'),\quad \text{or}\quad \frac{l+A'-R_0}{K-1}=R'.$$

Now the value of K for protons, K_P, is approximately 4.2, while that for deuterons, K_D, is about 4.6, as may be computed by using the facts that momentum is conserved in the alpha-particle impact and that, for equal energies, a deuteron has nearly twice the range of a proton. We are thus led to the formula

$$\Delta A'\equiv A_p'-A_D'=(K_p-1)R_p'-(K_D-1)R_D'+\Delta R_0$$

which was used in the text of this paper.

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Spectral Characteristics of Electrically Exploded Mercury

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The spectrum obtained by sending 300 amp. from a 150-volt generator through a small stream of mercury is found to be characterized by great broadening of many of the lines, and by a strong continuous background. In the region between 2537 and 1950A, the continuous emission is strong enough, and sufficiently clear of emission lines, to be useful for absorption experiments. The continuous emission is ascribed to recombinations in which the kinetic energy plays a part, and the broadening of lines is ascribed to the strong electric fields of ions near the emitting atom.

Introduction

The spectra obtained by allowing a condenser charged to a high potential to discharge through fine wires were studied by Anderson[1, 2] and his colleagues. They obtained spectra characteristic of metallic vapors at very high temperatures. The character of the spectrum was observed to change quickly from continuous emission, to the spark spectrum, and then the arc spectrum of the metal. By confining the explosion to a small volume, the absorption spectrum of the metal was obtained. The spectra, both emission and absorption, extended far into the ultraviolet, because of the high temperatures developed.

A modified form of this source of light was adopted by Mott-Smith and Locher[3] to illuminate a Wilson cloud chamber, taking advantage of the high intrinsic brilliancy and the short duration of the light; however, instead of employing a high voltage condenser discharge, they used a very high current obtained by connecting a 150-volt storage battery of very low internal resistance directly across a tiny stream of mercury which served instead of a fine wire. A commutator arrangement was used to permit the current to flow for a very short time at the instant when the photograph of the cloud chamber tracks was desired.[4]

The present investigation was undertaken to see whether the spectrum obtained by the "explosion" of mercury includes a region of continuous emission suitable for use in absorption experiments, with particular reference to the region between 2500 and 1850A, in which quartz prisms provide good dispersion.

[1] J. A. Anderson, Astrophys. J. **51**, 37 (1920).
[2] Anderson and Smith, Astrophys. J. **64**, 295 (1926).
[3] Mott-Smith and Locher, Phys. Rev. **38**, 1399 (1931).

[4] The authors acknowledge with thanks the information and suggestions given them by Dr. Locher personally.

Experimental Procedure

The energy for exciting the mercury was obtained from a motor-generator capable of delivering 300 amperes at 150 volts. A magnetically operated switch was used to close the circuit momentarily through a threadlike stream of mercury. A bank of "dry electrolytic" condensers was put in parallel with the line side of the switch in order to help the initial current to build up rapidly.

The mercury stream was formed by allowing the liquid to flow under a head of about 10 cm through a hole 0.9 mm in diameter in a steel electrode to the flat face of another steel electrode directly below at a distance of about 1 cm. The electrodes were supported in a housing of pipe fittings, the lower one being insulated by means of a quartz tube. The housing carried a quartz window waxed on, a tube for draining off the mercury, and a pipe leading to an expansion chamber which prevented the occurrence of excessive pressures. Provision was made to blow air through the housing between flashes in order to keep the housing cool.

It was found that but a very short duration of arc after the explosion was sufficient to burn the electrodes seriously, and to bring out iron lines in the spectrum. The control devised to prevent this consisted of a relay connected so as to open the actuating circuit of the magnetic switch at a definite interval after the circuit was closed by hand. The delay of the relay was achieved by putting a large inductance in series with it, and was controlled by varying the voltage applied to it by a potentiometer arrangement. Tests with a 60-cycle impulse counter showed that the switch actually was closed for about 0.03 sec.

Conditions were varied by inserting various amounts of resistance in the line, by changing the voltage of the generator, and by confining the explosion within a 0.5-cc hole in a porcelain block provided with an opening 3 mm in diameter through which light was allowed to issue. The effect of high voltage condenser discharges on the same mercury stream was also studied by using about 20,000 volts from condensers with a capacity of 0.26 mf, charged by means of the rectified output of a high tension transformer.

Light from the exploding mercury was focused on the slit of a Féry quartz spectrograph by spectrum, with considerable overlapping, but with greatest intensity wherever arc lines are thickest. Balasse observed such a spectrum most strongly developed when the arc lines and spark means of a quartz lens, and it was found that six flashes were sufficient to produce a well-exposed spectrum photograph. One flash produced about as much blackening as a 15-second exposure of a quartz mercury Labarc. Twice as many flashes were required when the 20,000-volt condenser discharge was used.

Results

In Fig. 1 the region 3150 to 2150A is shown as obtained with the Féry instrument. It gives a comparison of the ordinary quartz mercury arc spectrum with the explosion spectrum. In Fig. 2 the region 2150 to 1850 is shown as obtained with a Steinheil quartz instrument, with an aluminum spark for comparison.[5] The plate was sensitized for this region by using Eastman ultraviolet sensitizing solution. The continuous emission is quite suitable for showing absorption from 2537A at least as far as 1950A. The absorption shown in the photograph is largely that of NO, which is produced from the air in the housing and which could be eliminated by producing the explosions in an inert atmosphere.

It was found that with increasing generator voltages, the continuous spectrum becomes stronger, first in the ultraviolet, and then also toward the longer wavelengths. This is obviously not a black-body type of continuous emission. A clue to the probable explanation is furnished by the work of Balasse,[6] who established the occurrence of a continuous emission resulting from the recombination of an electron with a positive on to form a neutral atom in an excited state. The energy radiated thus is the ionization energy of the atom, less the energy of excitation retained, in addition to the kinetic energy of the recombining electron with respect to the ion. As usual, the effect of kinetic energy of varying amounts in transitions is to yield a region of continuous emission. These regions might be expected to extend over a large range of the

[5] This spectrum photograph was made by the senior author in collaboration with Dr. P. J. Flory in some unpublished work on the absorption of the NO molecule in this region.

[6] Balasse, J. de phys et rad. **5**, 304 (1934).

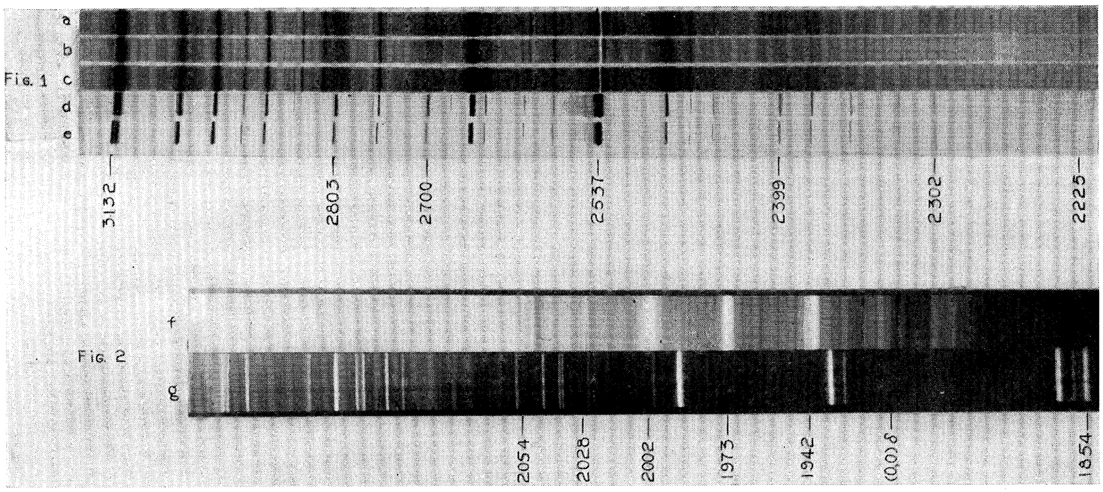

FIG. 1. Explosion spectrum of mercury compared with mercury arc. (a) 6 flashes at 150 volts; (b) and (c) each: 6 flashes at 125 volts; (d) Labarc, 160 sec.; (e) Labarc, 40 sec.

FIG. 2. Explosion spectrum of mercury with Al spark for comparison; plate sensitized with Eastman U–V solution. (f) 8 flashes; (g) condensed Al spark, 10 sec.

lines both were strong in his source. The explosion spectrum, on the contrary, shows few spark lines, but positive ions undoubtedly are present in great abundance immediately after the explosion.

As might be expected, pronounced self-reversal was observed for the resonance line, λ2537. At higher generator voltages, no additional reversals were observed. However, the confined explosion at 20,000 volts shows many absorption lines, corresponding with observations of Hori.[7] These lines have as their lower levels the three levels of the lowest ^3P state. That these levels are populated under the conditions is explained by the fact that $^3P_0$ and $^3P_2$ are metastable with respect to the ground state $^1S_0$, and that $^3P_1$ is repopulated by the absorption of λ2537 which brings the atom up from the ground state to that level.

Another characteristic of the explosion spectrum is the great broadening obtained for many of the lines, so much so that some are merged entirely with the continuous background, and others are as much as 100A wide. A summary of the ideas on the width of spectral lines was given by Weisskopf[8] in 1933. Two considerations stand out as being accountable for the extreme broadening observed here: impact damping, and Stark-effect broadening. The former merely means that if an atom in the process of emitting is struck by an ion or an electron, the quantum conditions are relaxed, and the frequency radiated differs from that of the unperturbed atom. This is substantially the same as a Stark effect produced by a rapidly changing field. Attention should be called to the fact that the earlier criteria for predicting large Stark effects, as quoted by Weisskopf, turn out to be accidental, as shown by the quantum-mechanical considerations of Condon.[9] The fields effective in shifting the energy levels of the atoms are not the relatively insignificant fields due to the voltage applied to the mercury stream, but the fields produced by positive ions formed by the explosion. Under the conditions of great density of vapor, the interatomic distances are quite small, and the corresponding fields are correspondingly enormous.

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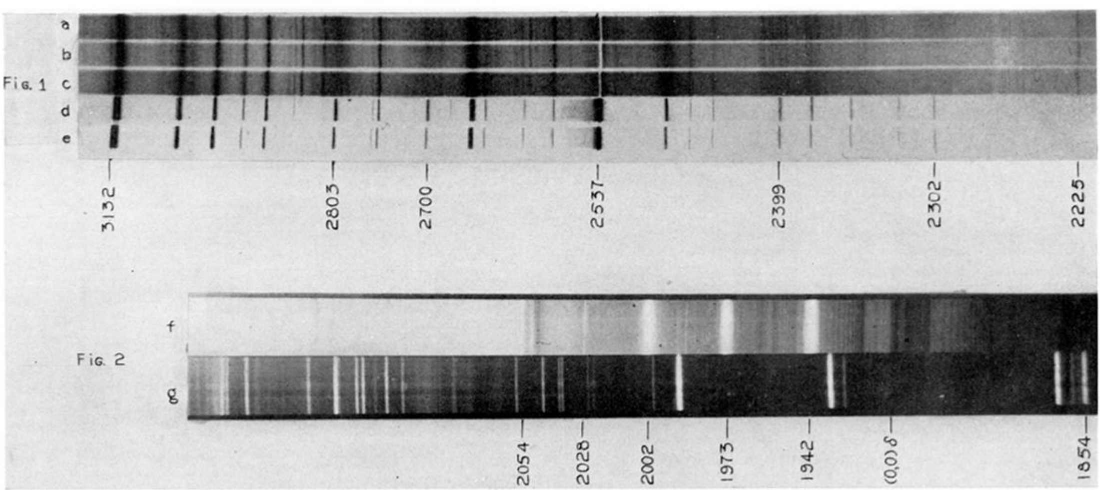
[7] T. Hori, Sci. Pap. Inst. Phys. and Chem. Research, Tokyo **4**, 59 (1926).

[8] V. Weisskopf, Physik. Zeits. **34**, 1 (1933).

[9] E. U. Condon, Phys. Rev. **43**, 648 (1933).



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