

Measurement of Cathode Emission by Use of the Electron Microscope

G. W. FOX AND F. M. BAILEY*

Physics Laboratory, Iowa State College, Ames, Iowa

(Received July 30, 1940)

The electron microscope has been used in connection with photographic technique to make quantitative measurements of electron emission from the oxides of barium, strontium, and calcium. The instrument proves to be an excellent emission comparator. Time lapse exposures allow the observation of activation processes in detail. The emitting properties of barium compounds other than the oxide are compared.

I. INTRODUCTION

ELECTRON microscope studies of thermionic emission from alkaline earth oxides have revealed much information concerning the nature of such emitting surfaces. The work of Heinze and Wagener,^{1,2} and Benjamin, Huck and Jenkins,³ deals with the activation processes and show the dependence of emission properties on the particle size. Fluorescent image pictures have previously provided only qualitative information concerning the pattern of electron emission. The technique of intensity measurement by photographic means as applied to spectroscopy made it appear possible to determine current strength quantitatively from photographs of the fluorescent electron image.

Precise measurement of the temperature of an oxide-coated cathode is difficult, but absolute temperature determinations can be avoided by comparing the emission of two or more substances under the same conditions. In the electron microscope the cathode samples can be heated on the same base metal and the emission from each can be focused to show its pattern on a fluorescent screen. The intensities of such images are independent of the total area of the cathode, and the brightness or intensity per unit area on the screen is a measure of the current emitted from the corresponding area on the cathode surface. The current density at the cathode surface can be obtained by multiplying

the density at the screen by the square of the linear magnification.

The objectives of this investigation were: (1) To make quantitative measurements of emission currents photographically, and to test the method by obtaining thermionic emission curves for BaO, SrO, and CaO. (2) To investigate the use of the electron microscope as an emission comparator. (3) To compare the electron emitting properties of barium compounds other than the oxide.

CONSTRUCTION OF THE MICROSCOPE

The apparatus is shown diagrammatically in Fig. 1. It was patterned after the design employed by McMillen and Scott.⁴ The main body of the instrument was constructed from 45-mm Pyrex tubing with an inside coating of Aquadag to provide a conducting field-free space. This coating along with the anode ring *A* was maintained at a potential of three thousand volts.

A reflecting fluorescent screen *R* was enclosed at the upper end of the tube. Although this type of screen necessitates photographing through a curved glass surface, this objection was overruled by two principal advantages. As outlined by Maloff and Epstein⁵ they are: (1) An increase of fifty to one hundred percent in screen efficiency due to direct viewing. (2) An increase in maximum contrast obtainable caused by the absence of halation. Both conditions result in a greater range of useful photographic exposure.

The cathode assembly was introduced into the main tube at the ground glass joint *G* and

* Now at General Electric Company, General Engineering Laboratory, Schenectady, New York.

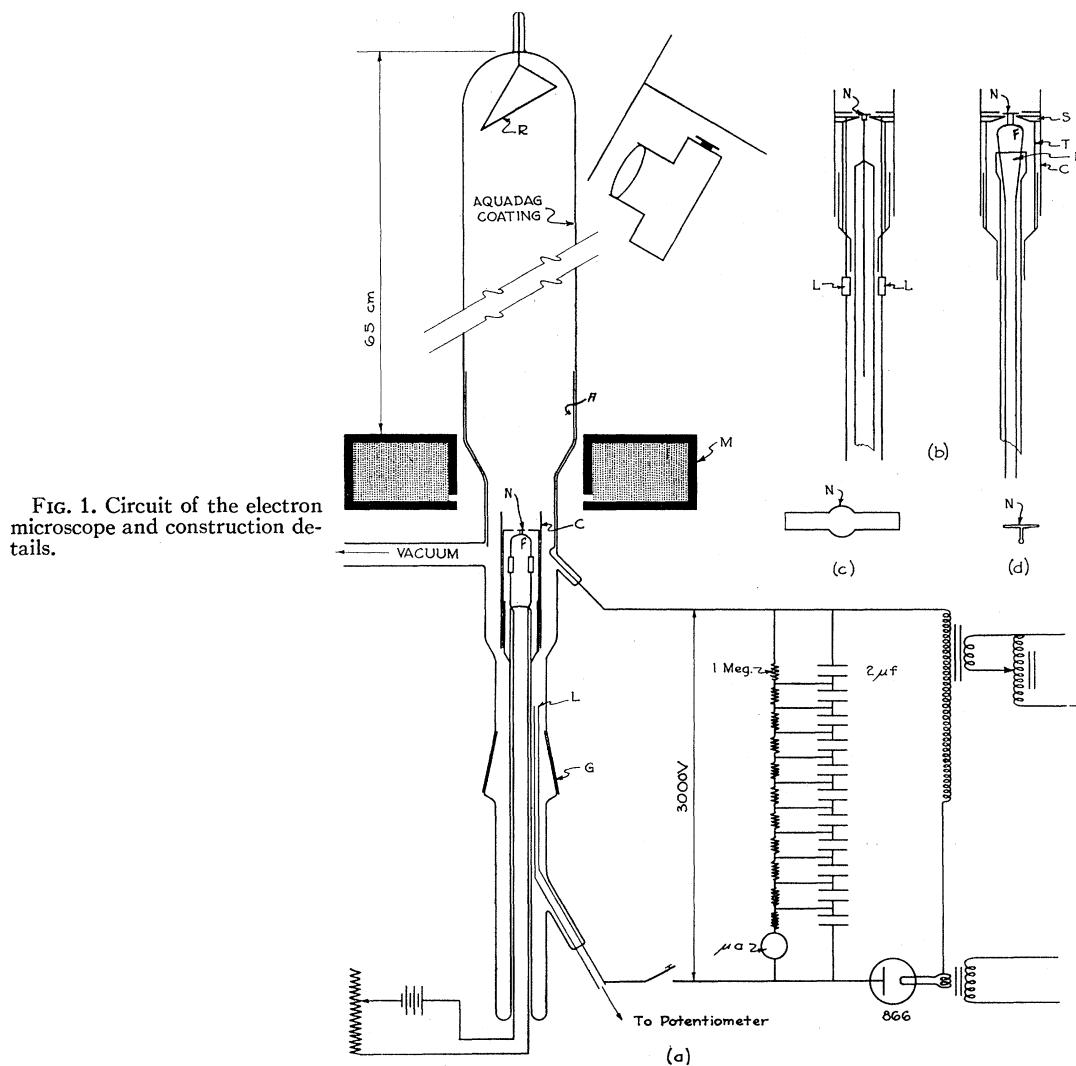
¹ W. Heinze and S. Wagener, *Zeits. f. tech. Physik* **17**, 645 (1936).

² W. Heinze and S. Wagener, *Zeits. f. tech. Physik* **20**, 16 (1939).

³ M. Benjamin, R. Huck and R. C. Jenkins, *Proc. Phys. Soc.* **50**, 345 (1938).

⁴ J. H. McMillen and G. H. Scott, *Rev. Sci. Inst.* **8**, 288 (1937).

⁵ I. G. Maloff and D. W. Epstein, *Electron Optics in Television* (McGraw-Hill, New York, 1938), p. 231.



sealed with Picein wax. This assembly was made of a brass guard cylinder C with a sliding sleeve T to hold the soapstone light shield S in place. The heating filament F was made of 10-mil tungsten wire. The cathode plates N were cut from 5-mil nickel sheet in the form of Fig. 1(c), and the protruding strips were folded around the filament wire as shown in Fig. 1(d).

To measure the temperature of the cathode, 5-mil tungsten and nickel wires were spot-welded to the bottom center of the cathode and fastened to the thermocouple leads L . The use of a nickel-tungsten thermocouple enabled the cathode itself to act as one thermocouple metal.

CALIBRATION OF THE MICROSCOPE

In the form of Dushman's equation used for experimental data, $\log_e J_{th} + 2 \log_e 1/T = \log_e A_0 - b_0(1/T)$,⁶ the current strength must be expressed as a natural logarithm. Fortunately, the relation between photographic density and $\log_e J_{th}$ results in a curve similar to the characteristic curve for photographic film.

Pictures of the fluorescent screen were taken with a 35-mm camera supplied with an auxiliary lens to give an object distance of 8.5 cm. To maintain accurate exposure times, a sector disk driven by a synchronous motor was used. The

⁶ Saul Dushman, Rev. Mod. Phys. 2, 383 (1930).

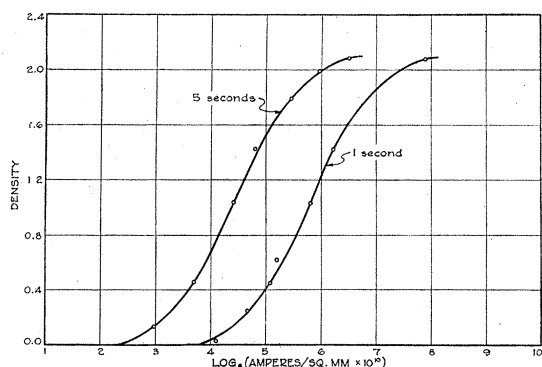


FIG. 2. Calibration curves for the electron microscope—photographic density vs. electron current density.

time intervals chosen were one and five seconds, as this choice provided two calibration curves which overlapped and increased the useful range of the method. The exposures were made at $f : 4.5$ on du Pont Micropan, and the film was developed under standard conditions.

An electron "gun" system was substituted in the cathode position to provide a uniform calibration spot on the screen, while a galvanometer placed in the cathode lead of the microscope measured the current represented by the beam.

In the calibration curves of Fig. 2 the $\log_e J_{th}$ is in amperes/sq. mm at the photographic film. That is, the photographic density is a function of the current arriving at the screen divided by the area of the image on the photographic film surface. To obtain $\log_e J_{th}$ at the cathode, the \log_e of the area magnification between the photographic film and the cathode must be added to the abscissa.

PREPARATION OF THE CATHODE SURFACES

The emitting material was ground with water in a small mortar to form a suspension which

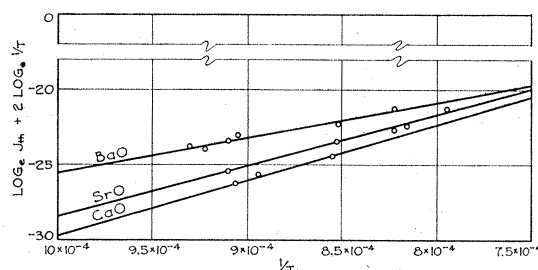


FIG. 3. Logarithmic temperature—emission curves for BaO, SrO, and CaO.

could be applied to the cathode in the form of a liquid drop. The concentration was controlled by the amount of material and water placed in the mortar and was adjusted until the material would form a coating of approximately 5 mg per sq. cm. For comparison measurements, the materials were placed on the cathode in the above manner with a dividing space between adjacent spots of less than 0.5 mm. This arrangement insured the same base temperature at the boundaries.

EXPERIMENTAL PROCEDURE

Oxides were reduced from other compounds by subsequent heating in the microscope. When the pressure reached 10^{-3} mm the cathode temperature was raised to 950°C for an hour to decompose the material and heat the cathode assembly. Then the anode voltage was applied and the current drawn for another hour after which the cathode was cooled to the desired temperature and observations made. The cathode was then removed from the tube and measurements made to determine the magnification.

THE TEMPERATURE CORRECTION

A correction to the thermocouple temperature was made to account for the temperature

TABLE I. Comparison of emission from barium compounds.

MATERIAL	T°K	RATIO	J MA/CM ²	MATERIAL	T°K	RATIO	J MA/CM ²
SrCO ₃	1000	1.0	0.35	Ba(NO ₃) ₂	1100	5.1	36.0
SrCO ₃	1100	1.0	7.0	BaS	1000	1.8	0.63
SrCO ₃	1200	1.0	86.0	BaS	1100	1.3	9.1
BaCO ₃	1000	16.0	5.6	BaSO ₄	1100	1.2	8.4
BaCO ₃	1100	7.4	52.0	BaMnO ₄	1100	0.08	0.56
BaC ₂ O ₄	1100	8.9	63.0	BaCl ₂	1100	0.13	0.91
Ba(NO ₂) ₂	1100	5.4	38.0				

gradient through the emitting material. This correction was obtained by equating the heat conducted by the material to the heat emitted by radiation as described by Blewett.⁷ The average thickness of the emitting material applied by the method described was found to be 0.0033 cm which gives a temperature difference of approximately 7°C. It was therefore assumed that the thermocouple recorded a temperature 7°C greater than the temperature of the emitting surface. Heat loss along the thermocouple wire seemed negligible since the nickel cathode constituted one element of the couple and the tungsten wire was surrounded by the cathode for a considerable distance beyond the junction.

THE MICROPHOTOMETER

A microphotometer with an optical system patterned after that of Lange⁸ was used to measure the photographic densities. Instead of the usual slit used in spectrographic work a round spot of light was focused on the film. The diameter of this spot was made small enough to include a uniform density area and the average density computed from a number of readings by the expression

$$D_M = \log_{10} \sum_{i=1}^n \frac{I_0/I_i}{n}$$

where I_0/I_i is the ratio of incident to transmitted light in the microphotometer.

CURVES FOR DUSHMAN'S EQUATION

The logarithmic temperature-emission curves for BaO, SrO, and CaO are shown in Fig. 3. In plotting these curves, a comparison run of BaO and SrO was made, and then a comparison run of SrO and CaO. It was found that the SrO curve of the second run was shifted a distance of 2.5 units above the SrO curve of the first run. The correction was then applied to the SrO-CaO run in order to bring it in accordance with the BaO-SrO run. This indicated that there is some difference between cathodes, but that a comparison of two materials on the same cathode gives consistent results.

⁷ J. P. Blewett, *J. App. Phys.* **10**, 670 (1939).

⁸ B. Lange, *Zeits. f. tech. Physik* **13**, 600 (1932).

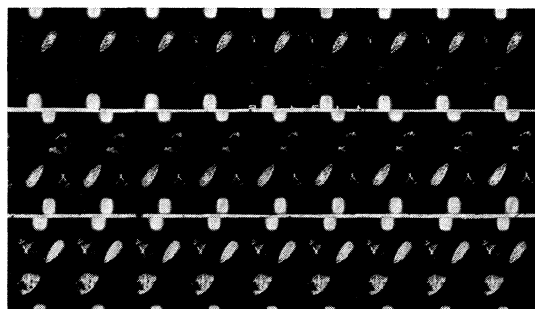


FIG. 4. Motion picture of emission growth.

COMPARISON OF BARIUM COMPOUNDS

Since the emission of other barium compounds is lower than that of BaO, SrO (reduced from the carbonate) was used as a standard material for comparison. The filament current was adjusted until the cathode temperature became steady at 1100°K and then a picture was recorded. Another was taken at 1000°K but in many cases the emission was not sufficient to make an exposure.

The data obtained are recorded in Table I. The first column gives the compounds as applied to the cathode. The third column gives the ratio of the emission of the unknown to that of the SrCO₃. The last column gives a value for the current in milliamperes/sq. cm based on an average value obtained for all the data collected on SrCO₃.

MOTION PICTURE RECORDS AND SAMPLE PHOTOGRAPHS

Figure 4 is a series of motion picture frames showing the growth of emission across the surface of a barium oxide cathode. In this case the temperature was held below 1000°K so that the growth proceeded slowly enough to make a



FIG. 5. Fluorescent electron images. (Magnification 36× linear.)

record. It will be noticed that the emission starts from the periphery of the spot and grows inward. Probably the higher temperature of the region adjacent to the nickel plate promoted activation more rapidly than the cooler central portions insulated from the plate by the oxide beneath. The current through the oxide then raised the temperature and caused the emission to spread toward the center. This explanation is the same as that outlined by Myers⁹ to account for the hot spots in the emission surfaces.

Prints of the negatives used in comparing emission are shown in Fig. 5. In each picture SrO is the compound on the right, while the compounds on the left are (A) BaO, (B) Ba(NO₂)₂, (C) BaS.

⁹ L. M. Myers, *Electron Optics, Theoretical and Practical* (Chapman and Hall Ltd., London, 1939), p. 435.

DISCUSSION

The points used to plot the curves of Fig. 3 were obtained from several runs. Since they do not lie above or below the curves a distance of more than 0.25 unit along the ordinate, the error in current density, on a comparative basis, was not greater than the antilog 0.25 or a factor of 1.3.

The absolute values of the current densities appear to be low when compared with the literature.^{10,11} This indicates that the absolute measurement of current density by this method is not as reliable as the comparative measurement.

The authors wish to express their appreciation to Dr. P. H. Carr for his suggestions throughout the course of the work.

¹⁰ Saul Dushman, *Rev. Mod. Phys.* **2**, 381 (1930).

¹¹ H. J. Spinner, *Ann. d. Physik* **75**, 609 (1924).

Motion of the Earth's Fluid Core: A Geophysical Problem

D. R. INGLIS

The Johns Hopkins University, Baltimore, Maryland

(Received October 30, 1940)

The earth's core may be assumed to have a very low viscosity, such as is characteristic of molten metals. The angular acceleration of the earth is sufficiently large, and the radius of the core is sufficiently great, to raise the question whether the rotation of the central part of the core lags appreciably behind the rotation of the solid mantle. The angular acceleration of the mantle, which is known astronomically, consists of a gradual deceleration and a more pronounced change of direction of the angular velocity, the 27,000-year precession. These two aspects are discussed separately. Three types of force might accelerate the core, viscous force in laminar flow, resistance caused by turbulent flow, and the force of induction associated with the earth's magnetic field. The viscous force is so weak that the interior would be practically unaccelerated if the flow were laminar, and the magnetic induction is

expected to be weak enough to permit a large lag between the rotation of the mantle and interior of the core. But the core is so large that the flow should be turbulent. Reasonable assumptions on the nature of the flow in this case, based on empirical data on turbulence near a flat boundary, are used to estimate the lag. It is concluded that the axis of rotation of the interior of the core may be expected to lag behind the axis of the mantle in the precession by an angle of the order of magnitude of a few degrees. Apart from the superposed eddies, points rather near the surface of the core would then move relative to the mantle around horizontal closed paths, approximately a hundred kilometers across, with a period of a day. This would cause a diurnal variation of the earth's magnetism much larger than observed if it were not for the shielding of metallic layers above the core.

INTRODUCTION

THE fact that transverse seismic waves are apparently not transmitted through the core of the earth^{1a} indicates that the matter

¹ B. Gutenberg, Editor, *Internal Constitution of the Earth* (McGraw-Hill, 1939), (a) Gutenberg, p. 347 and verbal report, Macelwane, p. 277; (b) Jeffries, p. 13.

within the core is almost certainly fluid. The transmission of the longitudinal waves shows² that the viscosity is not greater than that of pitch at room temperature, 2×10^{10} g cm sec.⁻¹. The viscosity is, however, probably very much

² H. Jeffreys, *M. N. R. A. S., Geophys. Supp.* **1**, 412 (1926).

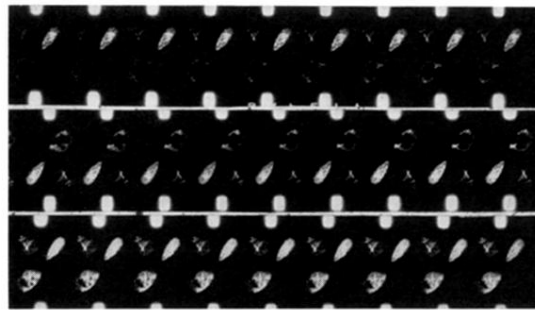


FIG. 4. Motion picture of emission growth.

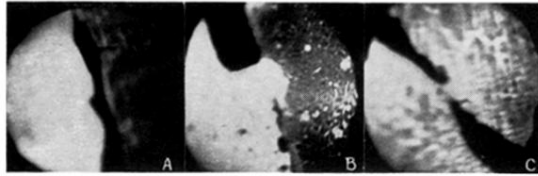


FIG. 5. Fluorescent electron images.
(Magnification $36\times$ linear.)