Second Series *April, 1926* *Vol. 27, No. 4*

THE

PHYSICAL REVIEW

HIGH FREQUENCY RAYS OF COSMIC ORIGIN
I. SOUNDING BALLOON OBSERVATIONS AT EXTREME ALTITUDES

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Abstract

Discharge rate of an electroscope at altitudes from 5 to 15.5 km.—Four specially designed instruments, each comprising a recording electroscope, thermometer and barometer and each weighing but 190 gr were sent up with sounding balloons from Kelly Field, Texas. Three were recovered and of these two had satisfactory records of their flight during which they reached altitudes of 11.2 and 15.5 km, respectively. A comparison of the recorded electroscope reading at the 5 km level during ascent with the reading at the same level during descent shows that the average discharge rate of the electroscopes while above the 5 km level was about three times their discharge rates at the surface of the earth, and corresponded to an average rate of production of ions of 46.2 ions per cc per sec. This is only 25 percent of the value to be expected from the observations of Hess and of Kolhörster and constitutes definite proof that there exists no penetrating radiation of cosmic origin having an absorption coefficient as large as 0.57 per meter of water.

IT was as early as 1903 that the Canadian physicists McLennan and Burton[1] and Rutherford and Cooke[2] noticed that the rate of leakage of an electric charge from an electroscope within an air-tight metal chamber could be reduced as much as 30 percent by enclosing the chamber within a completely encircling shield or box with walls several centimeters thick. This meant that the loss of charge of the enclosed electroscope was not due to causes inside the electroscope but must rather be due to some highly penetrating rays, like the gamma rays of radium, which could pass through metal walls as much as a centimeter thick and ionize the gas inside.

In view of this property of passing through relatively thick metal walls in measurable quantity, the radiation thus investigated was called the "penetrating radiation" of the atmosphere, and was at first quite naturally attributed to radioactive materials in the earth or air, and this is in fact the origin of the greater part of it. But in 1910 and 1911 it was found

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[1] McLennan and Burton, Phys. Rev. **16**, p. 184 (1903).

[2] Rutherford and Cooke, Phys. Rev. **16**, 183 (1903).

that it did not decrease as rapidly with altitude as it should upon this hypothesis. The first significant report upon this point was made by the Swiss physicist, Gockel,[3] who took an enclosed electroscope up in a balloon with him to a height of 4500 meters and reported that he found the "penetrating radiation" about as large at this altitude as at the earth's surface, and this despite the fact that according to Eve's[4] calculation it ought to have fallen to half its surface value in going up 250 feet.

In 1911, 1912, 1913, and 1914 two other European physicists, Hess[5] an Austrian, and Kolhörster,[6] a German, repeated these balloon-measurements of Gockel's, the latter going up to a height of 9 km, or 5.6 miles, and reported that they found this radiation decreasing a trifle for the first kilometer or so and then increasing until it reached a value at 9 km, according to Kolhörster's measurements, seven times as great as at the surface. This seemed to indicate that the penetrating rays came from outside the earth, and were therefore of some sort of cosmic origin. If so it was computed[7] that in order to fit the Hess and Kolhörster data, the rays had to have an absorption coefficient of .57 per meter of water and an ionizing power within a closed vessel sent to the top of our atmosphere of at least 500 ions per cc per sec., in place of the 10 or 12 ions found in ordinary electroscopes at the surface.

The following table gives a summary of all the Hess-Kolhörster data which in 1914 stimulated the interest of one of us in the problem and furnished the basis for the computations with the aid of which our sounding-balloon apparatus was designed. The earliest of these designs was made in 1915–16, but was not completed because the war put a stop

Table I

Hess

Altitude in Meters	Ions per cc per sec. in excess of ground value Instrument No. 1	Instrument No. 2
0 – 200	− 0.9	− 0.7
200 – 500	− 0.8	− 1.4
500 – 1000	− 0.7	− 1.5
1000 – 2000	− 0.4	+ 0.3
2000 – 3000	+ 1.0	+ 1.5
3000 – 4000	+ 3.5	+ 4.7
4000 – 5200	+18.1	+15.4

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[3] Gockel, Phys. Zeits. **11**, 280 (1910).

[4] Eve, Phil. Mag. **21**, 26 (1911).

[5] Hess, Phys. Zeits. **12**, 998 (1911), and **13**, 1084 (1912).

[6] Kolhörster, Phys. Zeits. **14**, 1153 (1913), and Verh. d. Deut. Phys. Ges. (July 30, 1914).

[7] H. von Schweidler, Elster u Geitel Festschrift, p. 411, 1915.

Kolhörster

Flight 1		Flight 2		Flight 3		Flight 4	
Alt.	Ions	Alt.	Ions	Alt.	Ions	Alt.	Ions
310	− 1.2	500	− 2.0	1090	− 1.2	1000	− 1.5
760	− 1.3	600	− 1.4	2130	+ 2.1	2000	+ 1.2
1650	+ 0.8	1000	− 2.1	3550	+ 7.0	3000	+ 4.3
2110	+ 1.3	1400	− 1.7	4700	+14.5	4000	+ 9.3
2400	+ 3.1	1500	− 0.8	5600	+27.5	5000	+17.2
2600	+ 4.3	2400	+ 3.1	6200	+29.3	6000	+28.7
3000	+ 7.5	3300	+ 4.5			7000	+44.2
3400	+ 8.9	4000	+ 6.7			8000	+61.3
3500	+11.1					9000	+80.4

to further activity in this direction. Upon the cessation of the war about two years were spent in trying to have built the right kind of sounding-balloons. In the winter of 1921–22 with the aid of Mr. Julius Pearson we designed and had constructed in the Norman Bridge Laboratory of Physics four little recording electroscopes. These we took to Kelly Field near San Antonio, Texas, in the spring of 1922, for the purpose of attempting to get them as near as possible to the top of the atmosphere in order to obtain a crucial test as to whether there is such a cosmic radiation as the Hess-Kolhörster data seemed to require.

These electroscopes were made of steel 0.3 mm thick, and were designed to support an internal pressure of 10 atmospheres, our intention being to increase, if necessary, the rate of leak by using air at high pressure. Actually, however, the two successful flights were made at atmospheric pressure, since Kolhörster's data indicated that there existed a penetrating radiation of such intensity as completely to discharge the electroscope during the flight if the ten atmospheres pressure were used. In addition all the electroscopes carried photographic films and the necessary driving mechanism for obtaining a continuous record during the ascent and descent (1) of the divergence of the electroscope fibres, (2) of the temperature and (3) of the barometric pressure. The total weight of each with all its contents was but 190 grams, or about 7 ounces.

Plate 1a shows a photograph of one of these instruments ready for flight, and placed beside it a six-inch (15 cm) rule. Plate 1b shows the inner mechanism. The electroscope consists of two sputtered quartz fibres such as are used in a Wulf electroscope, the deflection of which was produced by charging with a 300 volt battery through the movable charging-rod *C*. To make them as free from temperature effects as possible, all the supports were of quartz and of the shape shown in Fig. 1.

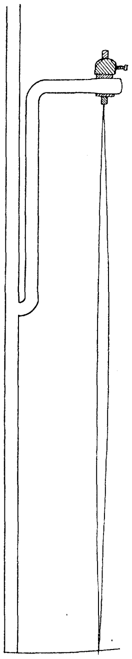


Fig. 1.

The lower spring was a single quartz fibre, having suitable elastic properties, rigidly attached at one end only. These supports are all inside the metal shield *M*, Plate 1b, provided to eliminate the effect of static charges on the quartz. A shadow image (diffraction pattern) of the fibres produced by the light from the sky passing through an exceedingly fine vertical slit S_1 carried by the slit holder shown at the left of the rule in Plate 1a fell upon the photographic film through a wide horizontal slit S_2 on the opposite side of the cylinder. The thermometer *T* was a small coil of duo-metal carrying a minute pointer *P* which moved up and down a vertical slit *N* behind which the photographic film was moving, the whole being illuminated by skylight entering through a fine horizontal slit *H* in the cap which fitted, light tight, over the thermometer and barometer chamber. The barometer *B* is a small, closed-arm manometer, the top of the liquid surface in one arm of which is also registered on the photographic film by skylight entering through *H*. The two circular films and the black paper separating them were fastened on the carrier *F* which was directly connected to the main spring of the small watch *W*.

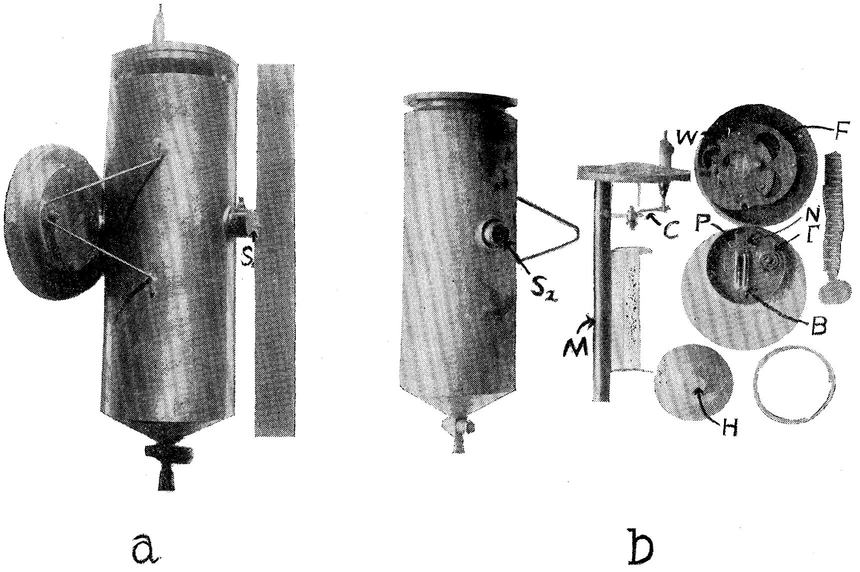


Plate 1. a. The complete recording instrument ready for flight. A 6-inch (15 cm) rule is shown beside it for comparison.
b. The inner mechanism.

Each of these electroscopes was carried up by two balloons eighteen inches across when deflated and weighing about 300 grams apiece. These balloons were specially made from our specifications by the Sterling

Rubber Company of Guelph, Canada. They were inflated with hydrogen to a buoyancy of 550 grams each (diameter about 95 cm) and rose at a rate of 130 meters per minute when carrying between them a total load of 220 grams (electroscope, cord, directions for return and so forth).

The rates of ascent were measured by the two-theodolite method, Lieutenant McNeal was especially sent from Washington to Kelly Field by Major William R. Blair of the U. S. Signal Corps to assist us in these experiments by making these two-theodolite altitude measurements.

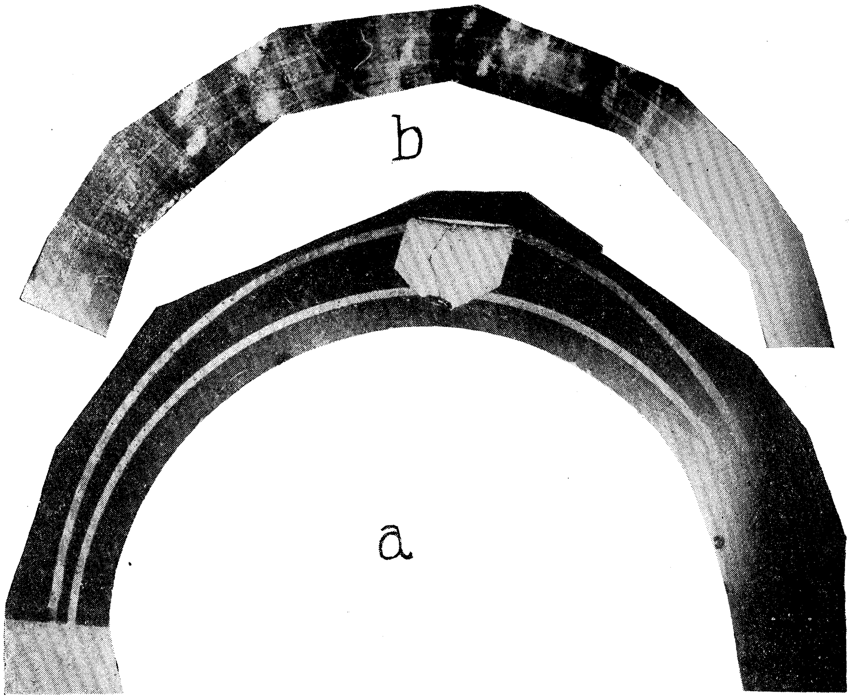


Plate 2. a. Reproduction of the photographic film giving the temperature record of the 15.5 km flight.

b. Reproduction of the photographic film giving the divergence of the electroscope fibers during the 15.5 km flight.

The purpose of sending up two balloons with each instrument is not merely to gain additional buoyancy but to enable one of them to bring the instrument safely to earth after the other has burst and also to serve, after the return to earth, to attract attention and increase the likelihood of the return of the instrument to the sender as per instructions attached to it.

We succeeded in making four flights and had three instruments returned, two of which had reached the altitudes of 11.2 and 15.5 kilometers respectively. They were returned from distances about eighty miles away from the starting point.

Plate 2a is a reproduction of the photographic film giving the temperature record of the 15.5 kilometer flight. The film was driven at the rate of 48° to the hour, the total time of flight as shown by this film was three hours and eleven minutes. This was accurately determined by plotting as in Fig. 2 the slopes of the time-temperature curve going up and coming down. The point of intersection of these two slopes gives the exact time at which one of the balloons burst and the descent began. The temperature at this time was in this case $-60°C$, as measured by the divergence of the two traces, a divergence read with a microscope and accurately calibrated by preceding laboratory tests down to $-77°C$. The horizontal edge on the left side of the blackened portion of the film gives the instant at which the driving mechanism was started just before the beginning of the flight. In this particular flight the apparatus reached the earth just after sunset and for this reason the thermometer record vanishes before the temperature has quite returned to the initial value, but the rate of descent is altogether uniform so that no uncertainty is thereby introduced into the time of flight. The time of ascent was in this case 115 minutes and that of descent 76, the total being 191 minutes. The

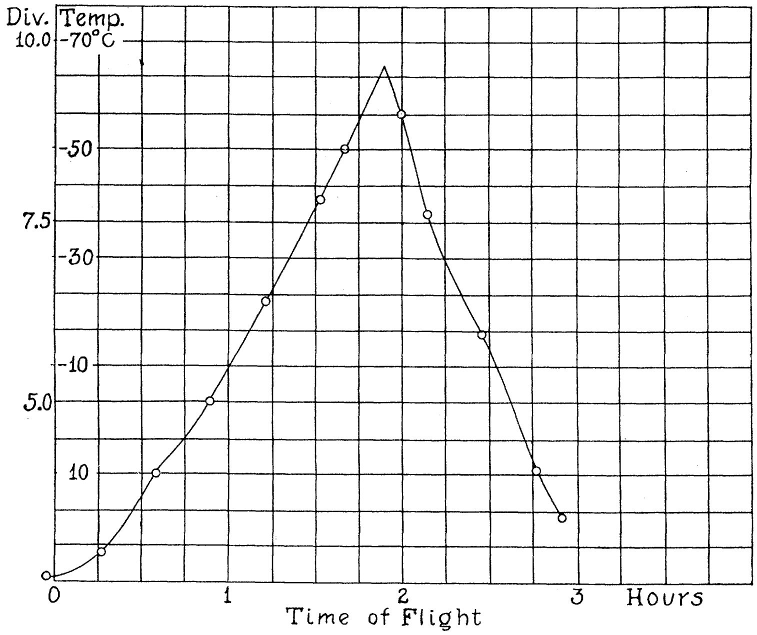


Fig. 2. The time-temperature curve for one flight.

relative times of ascent and descent are determined accurately from the ratio of the slopes of the ascending and descending portions of the temperature curve.

Plate 2b is a reproduction of the photographic record of the divergence of the electroscope fibres during the three hours and eleven minutes of this flight. It will be seen that the two lines representing the shadows of the fibres on the film lend themselves very well to accurate microscopic measurement. Indeed, there was a very sharp diffraction edge on each side of each line which made the setting particularly exact. On account of the fact that we were interested only in discharge rates at high altitudes we used for our computation of these discharge rates the initial measurements of the deflection of the fibres when the instrument had reached an altitude of 5 kilometers on the ascent, and final measurements of the fibre-deflection when it had reached again the same altitude of 5 kilometers on the descent. Since the temperature of the instrument is the same at a given altitude while going up as while coming down, our discharge rates are thus made entirely independent of the influence of temperature upon the elastic properties of the fibres and supports—a matter that we have found to be of greatest importance.

Fig. 3 contains the graphical representation of all of the electroscope readings as well as the time-altitude determinations, abscissas being time in hours and the scale of ordinates to the right, altitude in kilometers, while the scale of ordinates to the left represents fibre-deflections. The straight sloping lines meeting at the top represent the constant rates of ascent and of descent, the first of which are obtained from direct theodolite measurements.

The line G at the top sloping gently downward is the rate of discharge in scale divisions while the instrument was at the surface. This discharge rate is very accurate since it was taken over a discharge period of twenty-four hours. It will be seen that the straight line F connecting the two groups of points representing measurements at the two 5 kilometer altitudes has a slope corresponding to a mean discharge rate three times that found at the earth's surface. *This shows quite unambiguously, in agreement with the findings of Gockel, Hess, and Kolhörster, that the discharge rates at high altitudes are larger than those found at the surface.* Quantitatively, however, there is complete disagreement between the Hess-Kolhörster data and our own, the total loss of charge of our electroscope in the two hours spent between the altitudes of 5 km and 15.5 km having been but about 25 percent of that computed from the Hess-Kolhörster curve which is represented by the curved line K of Fig. 3. The data plotted in Fig. 3 also shows very beautifully that, despite the extraordinary precautions herein taken to make an electroscope whose readings would be independent of temperature, there was nevertheless a marked temperature effect. Thus Fig. 3 shows that the apparent deflection reaches a minimum when the temperature is a minimum and then rises again as the instrument warms up in the descent. *Our results are entirely free from these temperature effects since our initial and final readings are taken under the same temperature conditions.*

The mean rate of discharge in the ascent from 5 km to 15.5 km and the descent again to 5 km of this electroscope was 46.2 ions per cc per sec. The average rate of discharge of the same electroscope at the surface was 15.4 ions per cc per sec., so that the mean rate of discharge at these very high altitudes here attained was but three times the surface rate, in contrast with the sevenfold rate shown by the data in Table 1 at the lower altitude of 9 km.

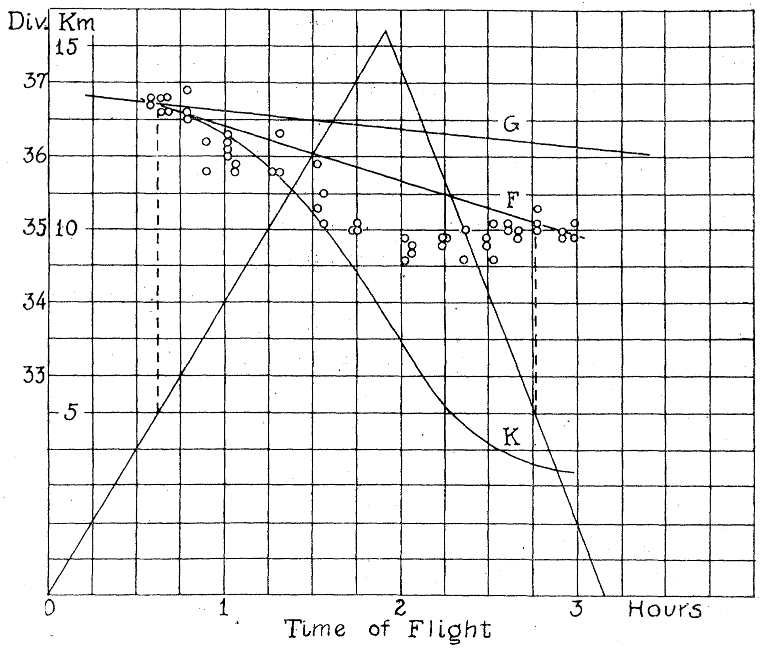


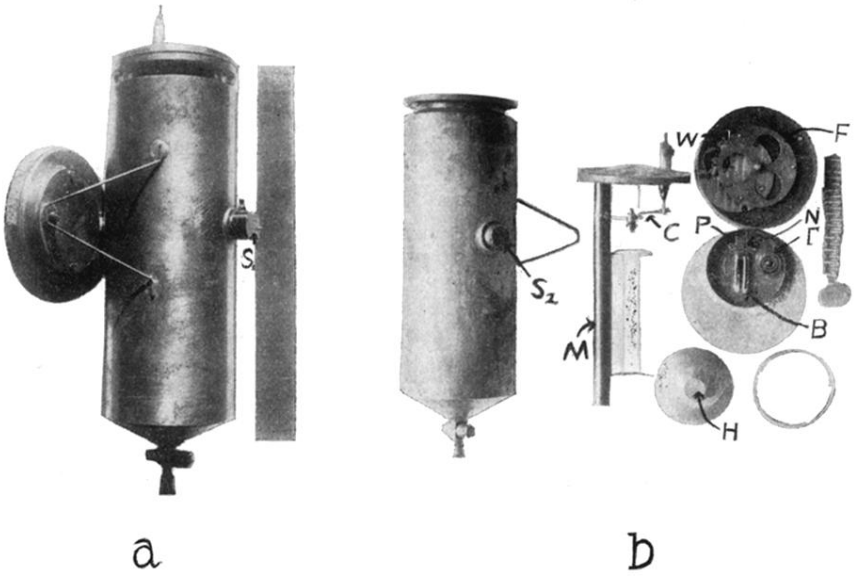
Fig. 3. Electroscope readings and altitude determinations as functions of the time.

Another flight which reached an altitude of 11.4 km also yielded a total loss of charge not more than 25 percent of that found by the European observers, though some temperature changes rendered its evidence much less reliable than that of the 15.5 km flight.

The results then of the whole Kelly Field work constitute definite proof that there exists no radiation of cosmic origin having such characteristics as we had assumed. They show that the ionization increased much less rapidly with altitude than would be the case if it were due to rays from outside the earth having an absorption coefficient of .57 per meter of water.

Taken in conjunction, however, with experiments on absorption coefficients to be reported in the succeeding articles II and III—experiments which present unambiguous evidence for the existence of a cosmic radiation of extraordinary penetrating power, μ calculated as above being as low as .18 per meter of water, these experiments at very high altitudes have important bearings upon the distribution in wave-length of these hard rays as they enter the atmosphere.

NORMAN BRIDGE LABORATORY OF PHYSICS,
CALIFORNIA INSTITUTE OF TECHNOLOGY,
PASADENA, CALIFORNIA,
December 24, 1925.



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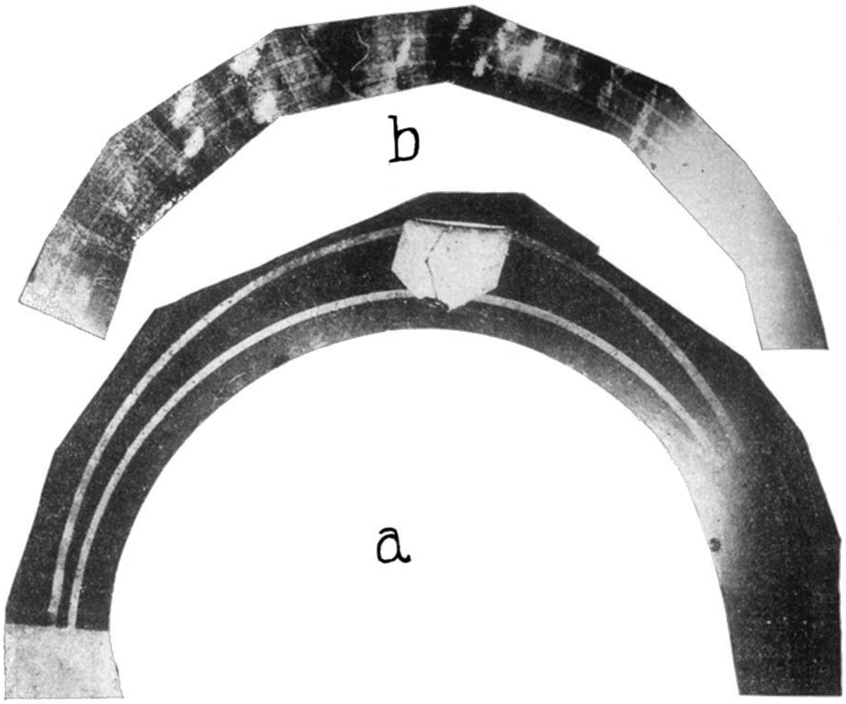

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