SOME PROPERTIES OF METALS UNDER THE INFLUENCE OF ALPHA RAYS.

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1. INTRODUCTION.

WHEN α-rays strike an insulated metal surface in a high vacuum the metal becomes positively charged. This charge is due to two chief causes—(*a*) the positive charge carried to it by the α-particles, (*b*) the negative charge carried away by the electrons emitted. The relative magnitude of these two effects has been investigated by Bumstead and the writer.[1] These emitted electrons are commonly known as δ-rays. The speeds of the δ-ray electrons have been studied by Bumstead,[2] who finds that they vary from very slow moving electrons to quite swift ones, more than 1,700 volts of retarding potential not being sufficient to stop them all. The number of these electrons emitted varies with the speed of the incident α-rays in a manner entirely analogous to the ionization of gases first investigated by Bragg. As the speed of the α-ray decreases the number of δ-electrons emitted increases up to a certain maximum and then rapidly falls off to zero.

The behavior of different metals under α-ray bombardment was also investigated[3] and the rather unexpected fact demonstrated that all the metals studied gave practically identical ionization curves. The actual charge received by any one metal was not the same as that received by another under similar conditions, but the shape of all the curves obtained was the same. This does not agree with the analogous case of gases where the particular gas studied gives a characteristic curve, the lower the atomic weight of the gas, the more pronounced the maximum or "knee" of the curve.

It was also observed in the course of these experiments that when a high vacuum has been newly made the total δ-ray current is considerably larger than after the vacuum has been maintained for some time. A progressive reduction amounting to as much as 30 per cent. has been noted for a period of two days after the application of liquid air. A similar result has been described by Pound.[4]

[1] Bumstead and McGougan, Am. Jour. Sci., XXXIV., Oct., 1912.

[2] Bumstead, Am. Jour. Sci., XXXVI., Aug., 1913.

[3] Bumstead and McGougan, *l. c.*

[4] Pound, Phil. Mag., 23, pp. 813–837, May, 1912.

The similarity in the behavior of different metals and the progressive reduction of the ionization current led to the supposition that the entire δ-ray effect is not a metallic ionization at all but is rather due to a film of gas adsorbed into the surface of the metal. This film could be reasonably supposed to be the same for all metals after exposure to the air and would naturally be reduced by a long continued vacuum.

An attempt was made[1] to remove this residual layer of gas by prolonged heating of a platinum strip in a high vacuum maintained by a Gaede pump. The result was a further diminution of the current by about 30 per cent. *but* the shape of the ionization curve still remained unaltered. A similar experiment by Campbell[2] indicated that after very prolonged heating the effect was entirely removed and the original condition of the metal could be restored only by exposing it again to the air. In a later experiment Pound[3] finds that a metal surface distilled in a vacuum lacks this effect entirely.

The need of further evidence on this question led the writer to the following experiments. In the first an attempt is made by scraping the surface of the metal while in a high vacuum to present a fresh clean surface of metal to the incident α-rays. In the second a similar result is sought for a surface of mercury by the method of overflow, thereby stretching the surface film and producing a new clean surface of mercury.

2. Description of Apparatus.

A brass vessel, Fig. 1, is connected to a Gaede pump, McLeod gauge and charcoal bulb. The cover consists of a heavy brass plate carefully ground to fit on the collar of the vessel and the joint is made tight with

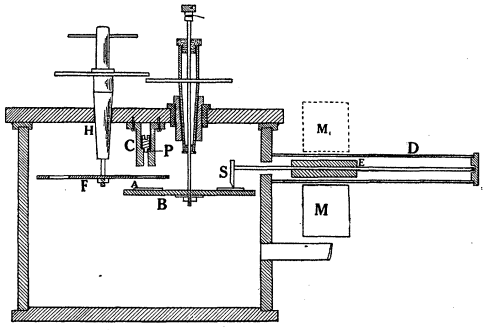

Fig. 1.

rubber stop-cock grease. A copper plug P, the lower surface of which is coated with polonium, is surrounded by a brass collar C which limits

[1] Bumstead and McGougan, *l. c.*

[2] Campbell, Phil. Mag., 28, 286–302, Aug., 1914.

[3] Pound, Phil. Mag., 30, pp. 491–502, Oct., 1915.

the cone of rays so that they fall entirely on the disc of metal A under investigation. Six such discs about 2 cm. in diameter are soldered to the upper surface of the brass disc B which is supported by a brass rod insulted with amber and connected to a sensitive electroscope of the Hankel type, which was designed by Bumstead and has been described by him.[1] The earthed guard tube which surrounds this rod is made in two parts, an inner cone-shaped tube being ground to fit in an outer supporting tube insulated from the cover with ebonite.

Thus the disc B can be rotated from the outside while the vacuum is maintained and the different metals such as A brought under the influence of the α-rays. A tube D attached to the side of the vessel contains the handle of a hoe-shaped steel scraper S. The handle is pivoted at its outer end. A cylinder of soft iron E surrounds it and fits loosely in the tube. An electromagnet M acting on this soft iron produces a considerable pressure between the scraper and the metal to be studied; or in the position M_1 the magnet may be used to hold the scraper free from the metal. For simplicity in the diagram the scraper is shown as if its handle were in the same plane as the rod carrying the disc B. In reality the scraper handle lies in a plane parallel to this but displaced toward the observer about 4 cm. so that the scraper S lies in a plane perpendicular to the paper and passing through the rod which supports B. Hence when B is rotated the scraper will drag across the surface of the metal discs and by rotating B back and forth while properly manipulating M a thorough scraping may be effected. By this means quite appreciable chips of metal were removed especially from lead. The scraping was observed through plate glass windows in the vessel not shown in the diagram.

A second conical bearing H carries the brass disc F in which eight holes about 2 cm. in diameter are cut. These holes are covered with aluminum foil from the same supply used in the former experiment, viz., a heavy foil 3.2×10^{-4} cm. in thickness having a retarding effect on α-rays equivalent to 0.58 cm. of air; and a thin foil 0.64×10^{-4} cm. in thickness or one fifth the thickness of the heavy. Several combinations of the heavy and thin foils are used on the different holes varying from one thin to six heavy, the latter practically stopping all the α-rays. By rotating these different foils into the path of the α-ray beam eight points on the Bragg curve can be obtained in a fairly short time. The different metals on the disc B can be investigated under exactly similar conditions; and any metal can be scraped in vacuo and the Bragg curve obtained while the surface is fresh.

[1] Am. Jour. Sci., XXXII., 405, Dec., 1911.

In order to insure that all the δ-rays excited by the incident α-rays leave the electrode, a positive potential of 40 volts is applied to the vessel. The electrode is connected to the electroscope through a key and potentiometer arrangement so that the leaf can be grounded, insulated or charged to any desired potential. Thus the volt-sensitiveness of the leaf can be measured after each reading. During this experiment a sensitiveness in the neighborhood of 30 divisions in the microscope per 0.2 volt was maintained.

3. RESULTS OF EXPERIMENT I.

The effect of the scraping is shown on the accompanying curves for lead and gold. These two gave the most consistent results in the several trials made. Curve *I*, Fig. 2, shows the Bragg curve for lead which has not been scraped. Curve *II* was obtained in an exactly similar manner immediately after scraping. Curve *III* was taken about three

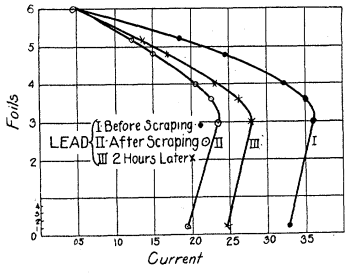

Fig. 2.

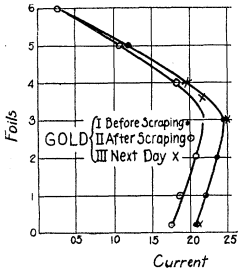

Fig. 3.

hours later. A similar set for gold is shown in Fig. 3, except that Curve *III* was taken next day and it so closely agrees with Curve *I* that it has not been drawn separately.

Scraping in vacuo lessened the δ-ray emission of all the metals studied. The most marked decrease was in the case of lead where a maximum reduction of 37 per cent. was obtained. Gold was reduced 10 to 15 per cent., platinum 6 per cent. and aluminum 16 per cent. However, the shape of the new curve was almost identical with that of the old and the percentage reduction at each point was reasonably constant. Curve *III* shows that this reduction is only temporary and a complete recovery has taken place within a day with the metal still enclosed in a liquid air vacuum. On several occasions the metal surface was re-scraped after taking a series of observations. The δ-ray current after this second scraping was not appreciably different from that preceding. A certain maximum reduction seems possible by this method but not a complete removal of the effect. On the other hand if a metal was re-scraped after

the complete recovery has taken place a reduction practically equal to that obtained on the first scraping was produced.

A few readings were taken with this apparatus to compare the δ-ray current from different metals under exactly similar conditions, none having been recently scraped. Quite a wide variation in values was obtained ranging from 18 to 27 divisions on the microscope scale with one thick foil interposed in the α-ray beam. In order of increasing δ-ray current the metals stood, lead, copper, silver, gold, platinum, aluminum. The shape of the curves obtained for the various metals agreed within the limits of accuracy of the measurements thus substantiating the previous investigation of this point.

The result of this experiment seems to support the theory that the δ-ray current is due to adsorbed gas which is present in the metal and which is more densely collected on the surface. Scraping removes some of this gas with the surface of the metal and so reduces the δ-ray emission. However, in time a new layer forms on the surface, either diffusing outward from the interior of the metal or condensing from the remaining gas within the chamber.

4. EXPERIMENT II.

In the second experiment the electrode is replaced by a cup of mercury, the surface of which is exposed to the α-rays. The cover of the chamber used in the previous experiment was again utilized, the polonium plug, the disc with holes covered by aluminum foil and the conical bearing which carried the electrode being retained. But the brass plate B (Fig. 1) was replaced by a sheet of platinum B (Fig. 4). A glass air-pump receiver lined with an iron gauze of about 1 mm. opening took the place of the brass vessel. This receiver is placed on a heavy iron plate provided with levelling screws and accurately ground to fit the lower face of the vessel. Through the base plate three iron tubes open into the chamber. The central one carries a conical iron cup A fitting as a collar near its upper end. Through a plug inserted in the top of this tube there is a minute hole. The level of this opening is set just below the level of the top of the cup. The upper part of this tube is insulated from the lower by a ring of amber D. It is connected by a rubber hose with a mercury reservoir which can be raised and lowered. By this

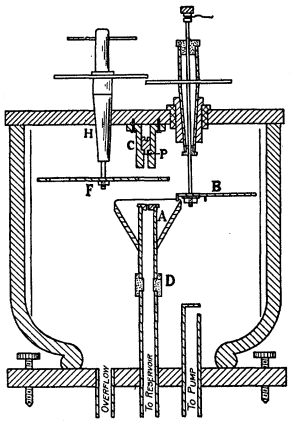

Fig. 4.

means mercury can be made to flow into A until it overflows. Uniform overflowing on all sides is made possible by adjustment of the levelling screws. On lowering the reservoir, the mercury column drops in the tube below the amber section D and thus an insulated cup of mercury is exposed to the α-rays. When the hole in the top of this tube is quite small and near the surface of the mercury in A there will be no dripping back into the tube when the reservoir is lowered. This condition was realized with a hole approximately 0.2 mm. in diameter. A contact point on the platinum strip B may be turned into such a position that it touches the convex mercury surface and thus the conditions of the previous experiment are reproduced with mercury in place of the metals previously studied. The platinum strip B can itself be rotated into the path of the α-rays, thus giving a check on the results and making possible the direct comparison of mercury with other metals. A second contact point is provided so that in the latter position the insulated mercury cup is in electrical contact with the platinum strip and thus the capacity of the whole system remains unaltered. The remaining tubes through the base plate lead, one to a McLeod gauge, charcoal bulb and pump; the other through a tube of barometric height to an overflow vessel. The base plate, cover and gauge lining are all charged to the usual positive potential of 40 volts.

In the first form in which this apparatus was made the upper section of the central tube was of quartz, itself serving as an insulator. However it was found that the frictional charge given to the quartz by the flowing mercury was so great, and took so long to leak off, that any other effects due to the fresh surface were completely masked. This charge was investigated with the polonium plug removed. Even with the iron tube a slight disturbance of this kind was found but it disappeared very rapidly.

In order to prevent contamination of the polonium by the mercury vapor within the chamber a thin coating of gelatine was placed over the end of the plug before putting it in place in its collar. This film decreases slightly the range of the α-rays and so affects the shape of the δ-ray curve. However as it is the effect produced by overflowing the surface that is sought, this decreased range will make no difference in this case.

Repeated trials with this apparatus failed to show that the overflowing of the mercury surface made any difference on the emission of δ-rays. The readings taken before and after overflowing did not differ more than the usual experimental variations. Curves were obtained for both mercury and platinum. The total δ-ray emission for mercury was always about 10 per cent. less than for platinum but the curves agreed

in shape very closely, thereby verifying previous demonstrations of this fact.

The result of this experiment shows that while a mercury surface emits δ-rays like any other metal surface, it is impossible to change that emission by providing a new layer of molecules on the surface by the method of overflow. The surface gas film even if removed by overflowing almost instantly re-forms. Whether the molecules which constitute this layer are provided from the interior of the metal with the fresh mercury molecules or are deposited on the surface from the residual gas in the chamber is a matter of question. It is difficult to see why such a deposit should be made so quickly when in the analogous case of solid metals a day was required for a complete recovery. On the other hand, if these gas molecules are provided from the interior and are entangled among the mercury molecules it is evident that they could easily form a film over the surface in an exceedingly short time. In the case of solids one would expect a much slower diffusion of internal gas to the surface. This might explain the slow recovery in that case.

5. SUMMARY.

1. The δ-ray current from a metal under bombardment by α-rays in a high vacuum is reduced by scraping the surface of the metal with a steel scraper while the vacuum is maintained. The reduction effected in these experiments varied from 6 per cent. for platinum to 37 per cent. for lead.

2. The reduction of the δ-ray emission is not permanent, a recovery was observed a short time after scraping and a complete restoration took place in one day.

3. The δ-ray emission from a mercury surface is not affected by overflowing the surface. The emission from mercury is practically the same as from other metals, all the curves having the same shape.

4. The evidence presented in these experiments supports the belief that the δ-ray effect in metals is due to a gas film on the surface. In the case of mercury it seems more likely that this film is formed from molecules of gas contained within the liquid. The scraping experiment provides no criterion for judging whether the film on solids is provided by a "soaking out" of gas from the interior or by a slow deposition of the residual gas in the chamber. The reduction and subsequent recovery of the δ-ray effect shows that the film is partly removed and renewed from somewhere. The interior origin seems in accord with Pound's results on surfaces distilled in vacuo. There would be little opportunity for such a surface to have gas molecules entangled within it while it could

have a deposited layer the same as any other surface. The reduction of δ-ray activity by heating and by continued low pressure show that the surface film under these circumstances loses gas molecules to its surroundings which are not replaced from the residual gas.

In conclusion I wish to express my thanks to Professor Bumstead for continued interest and inspiration in this series of experiments and to Professor Boltwood for kindly providing the polonium which made these investigations possible.

Sloane Laboratory,
Yale University,
September, 1917.