THE FATIGUE OF METALS SUBJECTED TO THE ROENTGEN RADIATION.

A THESIS.

by

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The Fatigue of Metals Subjected to the Roentgen Radiation.

All metals and nearly all other substances give off a secondary radiation when exposed to the X-rays. This radiation consists principally, if not entirely, of a negative corpuscular discharge, very similar to the β -rays from radium. While there are numerous theories to account for this radiation, none is satisfactory.

The similarity of this radiation to that produced by ultra-violet light, leads to suspect some likeness in their behavior.

Hallwachs[1] has shown that the sensitiveness of metals to the ultra-violet rays, decreases after long exposure to them. Since its discovery this "photo-electric fatigue" has been investigated by many, and, in a general way, it may be said to be influenced by; the kind of metal, the state of the surface, the nature of the surrounding medium, and the character of the rays. But writers on this subject agree, neither in their experimental results, nor in their theories.

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1) Hallwachs , Sitzungsber. der Ges. der Wissensch. Zu Leipsig. lviii. 1906,p.341.

2) Ladenberg. Annal. der Phys. xii. 1903,p.558.

Ladenberg[2] attributes fatigue to oxidation and corrosion of the surface, but this theory is rejected by Hallwachs, who attributes the principal effect to ozone, which he supposes to have great absorbing power when in the gas layers on the surface of the metal. On the contrary it has been shown, that fatigue occurs in the absence of ozone, and in a vacuum. Sir William Ramsay and Spencer[3] believe secondary radiation to be due to disintegration of the atom.

Professor More, of the University of Cincinnati, while working in Cambridge in 1906-07, found that the secondary Roentgen radiation from metals suffered a fatigue analogous to that produced by ultra-violet light.

His results show that the radiations from old surfaces of iron, lead, nickle, and zinc, exposed in air, depend on the duration of the exposure, while the radiations from aluminum and copper are nearly constant.

Freshly polished surfaces of iron and lead show an initial rise in sensibility.

The effects in coal gas do not differ from those in air. An inert gas like hydrogen seems to reduce the fatigue, while the presence of ozone increases it, though not in any way comparable

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3) Ramsay and Spencer, Phil.Mag. xii. 1906, p.397.
4) More, Phil.Mag. xiii. 1907, p. 708.

to the extent noted by Hallwachs for the ultra-violet radiation.

In conclusion the writer states that his his results indicate that the fatigue is caused by "changes in the gas in or on the plates, rather than any change in the metals themselves".

Following the suggestion of Professor More this work has been carried on for the purpose of verifying his results and continuing the investigation, particular attention being given to the effect of oxidation on the behavior of the secondary radiation.

The first measurements of fatigue in this paper were made by the method described in the earlier paper by Professor More.

The Roentgen radiation is allowed to fall upon two similar plates and their secondary radiations measured and compared. If, then, one of these plates, which we shall call the "standard", be shielded from the primary radiation, and the other, known as the "trial" plate, be allowed to remain exposed for a length of time, a second comparison of the radiations may be expected to show any change in the sensitiveness of the "trial" plate, due to its prolonged exposure to the X-rays.

Two similar ionization chambers, twelve centimeters cube, were constructed of heavy sheet brass. A detailed cross-section of one of these chambers is shown in Figure I.

A is the charged electrode, consisting of an iron wire gauze, carried by three ebonite pillars, and having a connecting wire leading out through a sulphur insulator. The holder , B , carried the plate, C, to be tested and is supported by the brass rod, D , running out through the sulphur insulator, F , By means of a small gauge the distance between C and A could be nicely adjusted, and was kept at one centimeter in all the experiments. The test plates were uniformly four centimeters in diameter, and 0.3 cm. in thickness. A window, H , 4.5 cm. in diameter, admitted the X-rays through the side of the box opposite the plate. The X-rays entering the boxes were cut down, by lead diaphragms, to pencils which barely included the test plates, thus preventing secondary radiation from the back of the boxes.

In Figure II is shown the general arrangement of the apparatus.

The ionization chambers, 1 and 2, were set at an angle, and the X-ray bulb placed at the intersection of the normals to the centers of the test plates. Brass tubes in front of the ionization boxes carried the lead diaphragms, S , and shutters used for cutting off the rays, when required.

A difference of potential of 80 volts between plate and

gauze was found sufficient to produce saturation.

The switches, L , allowed either or both plates to be connected with the electroscope, M , or to earth, and also provided a means of earthing the electroscope.

For the purpose of measuring the ionization currents an inclined Wilson electroscope was used, and the charged plate maintained at a potential of about two hundred volts.

All switches and connecting wires were enclosed in earthed metallic shields, and the X-ray tube and induction coil placed in a lead-sheathed box, to prevent static effects and leakage.

The radiation was taken to be directly proportional to the ionization current, and consequently inversely proportional to the time required for the gold-leaf of the electroscope to move over a definite number of divisions in the reading microscope.

From such measurements may be calculated the radiating power of the plate at any time, referred to its initial radiating power, which in the subsequent tables is taken as 100.

After working with the above method for some time, it became evident that, even with the most careful manipulation, irregularities in the action of the coil and bulb introduced considerable errors, and even in some cases masked the effects sought for.

If the radiation from both plates could be measured at the same time, and by the same instrument, the effect of the irregularities above noted would be nearly eliminated. A differential method was therefore devised, which accomplished practically this result, and which has proven to be very convenient in use and much more accurate than the method first described.

The same apparatus was used with the following changes and additions.

Thin perforated aluminium sheets were substituted for the iron wire gauzes in the ionization chambers, and the shielding diaphragms so arranged that the maximum quantity of radiation fell upon the plates without allowing any to pass the edge and strike the back of the box.

The substitutuon of aluminium for iron gauze allowed more radiation to strike the plate and reduced the disturbing effects of secondary radiation from the charged electrode, since the secondary radiation from aluminium is small, and, as will be shown later, constant. Secondary effects from this source will at least present a constant factor and will not tend to confuse the results.

In addition to the apparatus used before, a large variable air condenser was so arranged that it could be placed in parallel with the electroscope. The purpose of this condensor will be explained later.

Provision was also made for shifting the X-ray tube about a vertical axis.

Figure III. represents diagramatically the general arrangement of the new apparatus. The switches, N, were so arranged that the electrodes in the chambers 1 and 2 could be charged with electricity of like or unlike sign. The condenser was of about 350 C.G.S. electro-static units (calculated) capacity, and could be connected in parallel with the electroscope by means of the switch, R.

The observations are made in the following manner. The electrode in chamber 1 is charged positively and that in 2 negatively, to a potential sufficient to produce saturation. If the two plates are giving off the same amount of radiation the electroscope will then show no deflection. The plates however may not be equally sensitive to the primary radiation. In this case an equality of the secondary radiation may still be brought about, in general, by turning the X-ray tube about a vertical axis, until the inequality of the primary radiation falling on

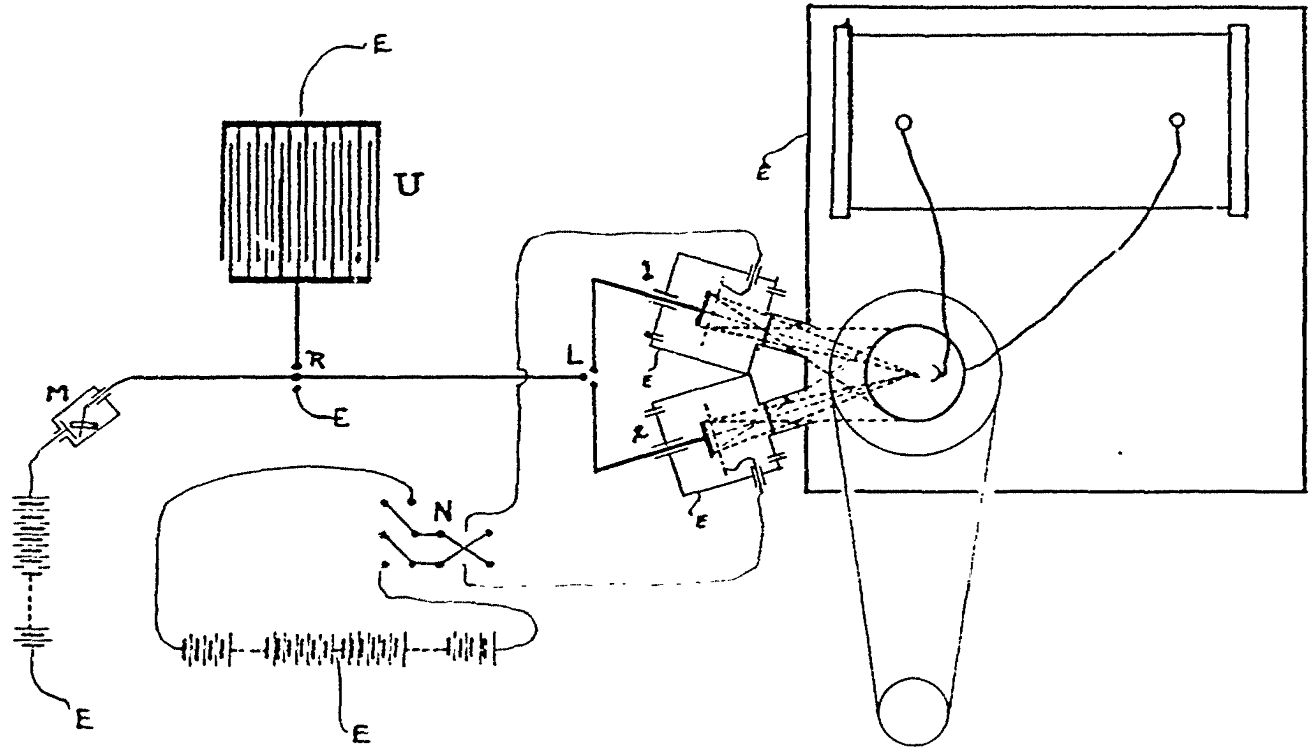


Figure III.

the two plates, compensates for the difference in their sensibilities, since the radiation is not uniformly distributed over the bulb.

Having obtained this balance in the radiation, the standard plate in 1 is shielded from the X-ray for a certain period, while the trial plate in 2 remains exposed to the rays. Now if any change in the sensitiveness of the trial plate takes place, then when the two plates are again connected to the electroscope, a deflection will be obtained, due to the current produced by the secondary radiation from the trial plate being either greater or less than that from the standard plate.

Let us denote the original conditions by

d_1 = current in box 1

d_2 = current in box 2

t_2 = time required for given deflection with box 1

t_2 = time required for given deflection with box 2

s_1 = sensitiveness of plate 1

s_2 = sensitiveness of plate 2

k_1 = radiation falling on plate 1

k_2 = radiation falling on plate 2

These quantities may be chosen in such units that we may write

$$c_1 = k_1 s_1 = 1/t_1 \dots\dots\dots\dots \quad (1)$$

$$c_2 = k_2 s_2 = 1/t_2 \dots\dots\dots\dots \quad (2)$$

Now after a certain length of time, during which the trial plate has been exposed, and the standard, shielded from the X-rays, any or all of these quantities may have changed and we may denote the new values by the same letters primed, so that we now have

$$c_1' = k_1' s_1' = 1/t_1' \dots\dots\dots\dots \quad (3)$$

$$c_2' = k_2' s_2' = 1/t_2' \dots\dots\dots\dots \quad (4)$$

From the second and fourth equations

$$s_2' = c_2' / k_2' = 1/k_2' t_2' \dots\dots\dots \quad (5)$$

$$s_2 = c_2 / k_2 = 1/k_2 t_2 \dots\dots\dots \quad (6)$$

$$\therefore \quad s_2' - s_2 = 1/k_2' t_2' - 1/k_2 t_2 \dots\dots \quad (7)$$

This is the expression for the absolute change in sensitiveness, but it unfortunately contains a quantity which we can not easily measure; the strength of the primary radiation. The proportional change in sensitiveness, however, may be obtained by dividing this quantity by s_2, giving,

$$\frac{s_2' - s_2}{s_2} = \left(\frac{1}{K_2' \cdot t_2'} - \frac{1}{K_2 t_2} \right) K_2 t_2$$

$$\frac{s_2' - s_2}{s_2} = \frac{K_2 t_2}{K_2' t_2'} - 1 \quad . . . . \quad (8)$$

By preliminary test it was found that, if the test plates are of the same material and have the same kind of surface, the balance once obtained is not disturbed by changes in the working of the coil or X-ray tube. We may therefore assume that the distribution of the rays about the tube does not vary with the condition of the tube nor the working of the coil, and we may write

$$\frac{k_1}{k_1'} = \frac{k_2}{k_2'} \quad . . . . \quad (9)$$

So that we have by substitution

$$\frac{s_2' - s_2}{s_2} = \frac{k_1 \cdot t_2}{k_1' \cdot t_2'} - 1 \quad . . . . \quad (10)$$

It was also found, by trial, that the sensitiveness of the standard plate varied but little with the intensity of the primary radiation, provided the tube remained soft. With this provision we may take

$$s_1 = s_1' \quad . . . . \quad (11)$$

and therefore from equations (1) and (3)

$$\frac{k_1}{k_1'} = \frac{t_1'}{t_1} \quad . . . . \quad (13)$$

Substituting this value in (10) we have

$$\frac{s_2' - s_2}{s_2} = \frac{t_1' t_2}{t_1 t_2'} - 1 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (13)$$

When the radiations from the two plates are balanced we have the condition

$$\left.\begin{array}{l} c_1 = c_2 \\ t_1 = t_2 \end{array}\right. \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (14)$$

equation (13) becoming

$$\frac{s_2' - s_2}{s_2} = \frac{t_1' - t_2'}{t_2'} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (15)$$

But the resultant current due to the two plates working oppositely to each other is

$$\begin{aligned} c_1' - c_2' &= 1/t_1' - 1/t_2' \\ &= \frac{t_2' - t_1'}{t_1' t_2'} = \frac{1}{t_d} \quad . \; . \; . \; . \; . \; . \; . \; (16) \end{aligned}$$

where t_d represents the time required for the gold-leaf to move through the given deflection when both plates are connected to the electroscope at the same time. From this it is evident that

$$\frac{s_2' - s_2}{s_2} = - \frac{t_1'}{t_d} \equiv - \text{fatigue} \quad . \; . \; . \; . \; (17)$$

where t_1' is the time required for the given deflection when plate 1 alone is radiating.

We have tacitly assumed all the foregoing equations to be simultaneous, a condition impossible in practice, since readings must necessarily be taken consecutively. The error thus introduced will be that due to variations in the sensibilities of the plates, caused by changes in the character of the rays. But it will be seen from equation (15) that proportional variations in the radiating powers will not effect the value of the result. This requirement of proportional variation may be fulfilled by having both plates of the same metal and their surfaces in the same condition.

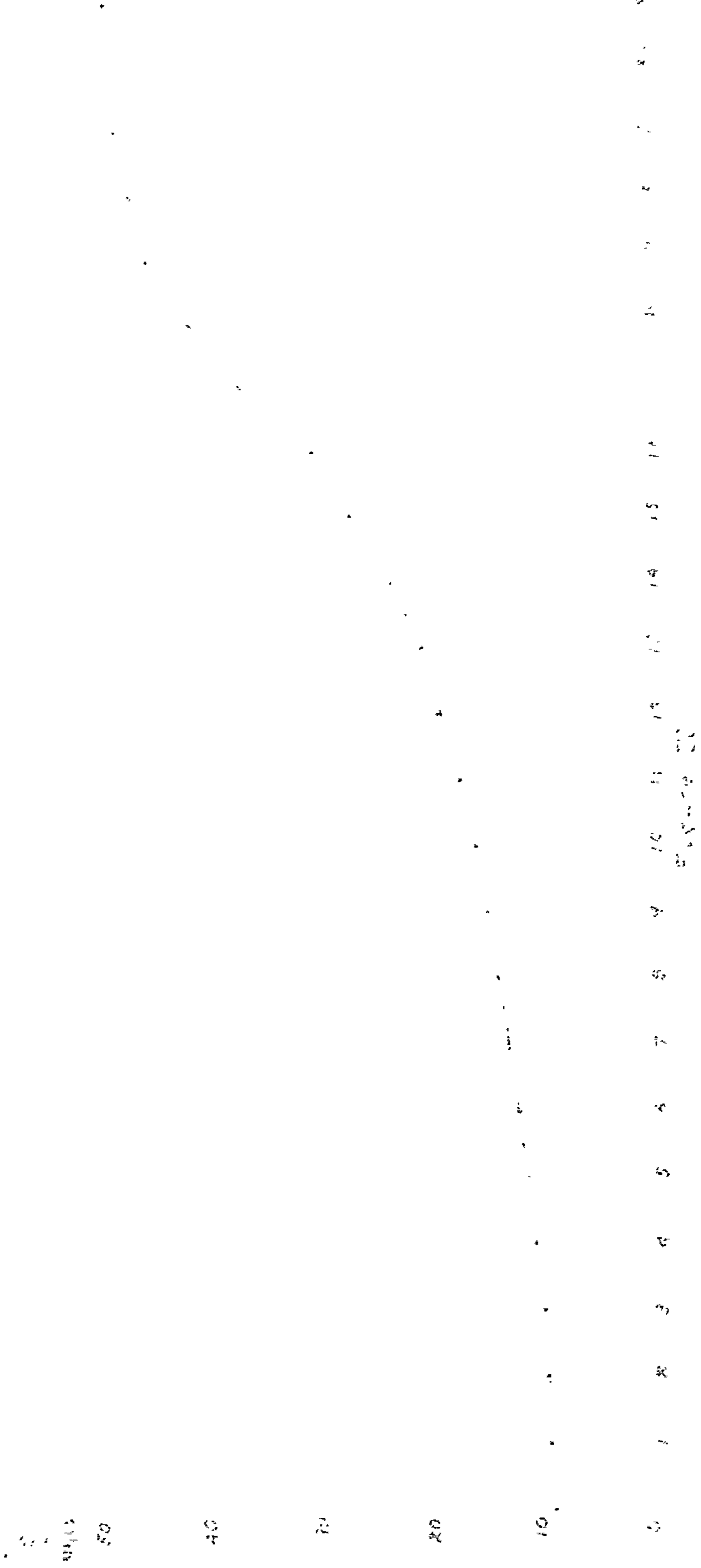
An instrument sufficiently sensitive to measure t_d would be entirely too sensitive for measuring t_1', since it is very small compared to t_d. To obviate this difficulty the condenser, U, is connected to the system, when measuring t_1', thereby reducing the rate at which its potential will rise. If Q denote the total capacity of the system and condenser, and q the capacity of the system exclusive of the condenser, then we have

$$\frac{s_2' - s_2}{s_2} = - \frac{T_1' \cdot q}{t_d \cdot Q} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (18)$$

where T_1' is the time required for the given deflection, when the condenser is connected and the standard plate in 1 alone is radiating.

The meaning of the minus sign is, that if the resultant deflection after the trial plate has changed its sensitiveness is in the same direction as the deflection produced by the standard plate alone, then the change in the trial plate has been a *decrease* in sensitiveness or a *positive* fatigue and vice versa. In practice, both t_d and T_1' were measured for deflections in the same direction and of equal magnitude, the polarity of the electrode in 1 being changed while measuring T_1', when a negative fatigue was encountered.

The variable air condenser consisted of nine stationary and eight sliding plates, each 17.6 cm. square, separated by air spaces of one centimeter each. The stationary plates were carried on sulphur pillars, and all corners carefully rounded so that the leakage from even so large a surface was negligible. The condenser was free from residual charge and all parts were nickel-plated and highly polished to prevent contact electro-motive forces. For convenience, the factor $\frac{q}{Q}$ was determined for various positions of the movable plates and the results plotted in a curve (Figure IV.), having for ordinates the values of $\frac{q}{Q}$, and for abscissae the linear distance which the movable plates were withdrawn from their position of maximum capacity. In nearly all cases the condenser was used at maximum capacity, which gave the value $\frac{q}{Q} = 0.088$. By withdrawing the movable plates this


0
10
20
30
40
50

ratio could be increased to $\frac{q}{Q} = 0.487$.

Table 1
Polished Metal Plates in Air.

Exposure	Aluminium	Copper	Zinc	Silver	Tin	Lead.	Iron
0 hrs.	100	100.	100	100	100	100	100
1 hr.	100	99.8	100	99.3	100	100	101
2 hrs.	100	100.	99.7	99.3	99.	—	101
3 hrs.	100	99.9	99.7	98.9	98.5	97.1	104
4 hrs.	—	—	99.4	—	98.1	—	102
5 hrs.	—	—	99.3	99.1	98.4	93.9	99.
6 hrs.	—	—	—	98.6	—	94.1	—
7 hrs	—	—	—	98.5	—	—	—

Table 2.

Iron and it's Oxides in Air.

Exposure	Freshly polished Iron	Magnetic Oxide Fe_3O_4		Ferric Oxide Fe_2O_3
0 hrs.	100.	100 Two Samples.		100
1 hr.	101.	99	101	101
2 hrs.	101.	101	—	101
3 hrs	104	99	101	101
4 hrs.	102	100	100	100
5 hrs.	99	—	—	100

Table 3

Copper and it's oxides in Air

Exposure.	Freshly polished Copper	Cuprous Oxide Cu_2O	Cupric Oxide CuO	
0	100	100	100 Two Samples.	
1	99.8	100	99	101
2	100.	100	99	101
3	99.9	100	100	99
4	100	—	101	101
5	—	—	100	99
6	—	—	100	101

Table 4.

Tin and it's Oxides in air.

Exposure	Freshly polished Tin	Tin Surface two weeks old	"Tin Oxide"	Stannic Oxide SnO_2
0 hrs.	100	100	100	100
1 hr.	100	—	100.	100
2 hrs.	99	100	100	100
3 hrs.	98.5	—	100	100
4 hrs.	98.1	98.2	100	100
5 hrs.	98.4	97.8.	100	100.

Table 5

Zinc and Zinc Oxide in Air.

Exposure	Freshly polished Zinc	Zinc Oxide. Thick Layer	Zinc Oxide Thin Layer.
0 hrs.	100	100	100
1 hrs	100	100	100.7
2 hrs.	99.7	100	100.2
3 hrs.	99.7	100	99.5
4 hrs.	99.4.	—	100.3
5 hrs.	99.3	—	100.7
6 hrs.	—	—	99.8.

Table 6

Silver Surfaces in Air.

Exposure	Freshly polished Silver.	Tarnish-ed Silver.
0 hr.	100	100
1 hr.	99.3	100.
2 hrs.	99.3	100.
3 hrs.	98.9	100.
4 hrs.	—	100.
5 hrs.	99.1	100.

METALS AND OXIDES IN AIR.

In Table 1 are given the length of exposures and the corresponding values of the radiation from freshly polished surfaces of aluminium, copper, zinc, tin, silver, lead and iron, exposed in air. The surfaces of the metals in these experiments were polished on the finest grade of crocus cloth obtainable and were tested as soon as they became cool, after polishing. The surfaces thus obtained, while not of mirror brightness in the case of the softer metals, were clean, and quite smooth and uniform.

Iron alone shows an increase in radiation, reaching a maximum in three hours. Silver, lead, and tin do not show this initial rise, the silver beginning to fatigue during the first hour,and the tin and lead not until the second. Aluminium and copper show no change in radiation and zinc but little.

In Tables 2, 3 and 4 are given the results obtained with oxidized surfaces of the same metals, the radiation from the polished metals also being given for the purposes of comparison.

The coating of magnetic oxide was prepared by heating the polished iron plate to a temperature of about 700° C, a thin even bluish black coating being thus obtained. The irregularity shown for this, and the ferric oxide in Table 2, is probably due to experimental errors involved in the first method, ~~and~~ used for these determinations. The magnetic oxide may be said to show no decisive change during a four hour exposure.

The ferric oxide coating was obtained by covering the plate with dilute hydrochloric acid, forming on the surface chloride of iron and the ferric hydroxide, eventually formed by the addition of a few drops of ammonia, was allowed to dry. The plate was then set away for a week to allow further oxidation, after which the ammonium chloride was expelled by heating the plate. The well-rusted surface thus obtained also shows no decisive change in five hours exposure.

It will be noticed that the change in sensibility exhibited by the polished metal is not shown by either oxide. Both of these oxides are quite stable in air, while, of course, the metal itself is very liable to rust.

Table 3 shows the behavior of the two oxides of copper.

The cuprous oxide was formed by gently heating the polished copper plate, care being taken that the temperature did not become sufficiently high to convert it all into cupric oxide. Such a coating will, at best, probably contain a considerable quantity of cupric oxide.

The cupric oxide was formed by heating the plate to dull redness in an alcohol (sulphur-free) flame. Neither of these oxides shows any fatigue in air.

These three surfaces are stable in air, and none shows variation in radiating power beyond that of experimental error.

The results of tests on two oxides of tin are given in Table 4.

The coating called "tin oxide" is of undetermined composition, but it is probably a lower oxide, or a mixture of oxides, containing less oxygen than the stannic oxide. It was formed by heating a polished tin plate to a temperature of 170° C. for several hours, and appeared as an olive to yellowish tarnish on the surface of the metal. As might be expected from its method of formation, this surface appears to be quite stable in air at ordinary temperatures, and undergoes no further change.

The stannic oxide was prepared by igniting the nitrate formed on the surface of the metal by coating it with nitric acid.

Neither oxide showed any fatigue and the surface of the polished metal allowed to age in the air for two weeks did not behave differently from the freshly polished surface.

A thin coating of a stable oxide has completely stopped the fatigue experienced by the fresh surface of the metal not thus protected.

Table 5 shows the radiations from zinc, a thick, and a thin layer, of the oxide, ZnO.

The thick layer of the oxide was formed by igniting the nitrate, as with tin. The thin layer was the result of slow oxidation in air, allowed to proceed for a year and a half.

The irregularities of the figures for the thin layer are probably due to experimental error since but one of the surfaces was obtainable and a fresh surface of the metal had to be used for a standard. As had been pointed out, this may cause some [illegible]or. No decisive change in radiation is shown by either surface. This oxide is quite stable in air.

The radiation from a freshly polished silver plate, and one covered with a dark tarnish, aacquired by a month exposure to the air in the laboratory, are given in Table 6. These results show a slight fatigue for the polished silver and none whatever for the tarnished surface.

Whatever may have been the nature of this tarnish, the fact of its formation indicates that it was a more stable surface, chemically, than the pure silver. The slight fatigue shown by the fresh metal is stopped by this protecting tarnish.

While four out of the five metals tested exhibit variation in radiating power, of the eleven oxidized surfaces formed on these metals, <u>none shows fatigue</u>.

If oxidation does effect the secondary radiation, we might expect an increased effect if an oxidizing atmosphere, such as ozone, be used in place of air.

Table 7.

Copper and it's Oxides in Ozone.

Exposure.	Freshly polished Copper.	Cuprous Oxide Cu_2O.	Cupric Oxide CuO.
0 hr.	100	100	100.
1 hr.	96.3	97.	97.8
2 hrs.	93.3	93.5	97.3
3 hrs.	91.±	—	96.5
4 hrs.	—	—	95.4
5 hrs.	—	—	95.9
7 hrs	—	—	93.4.

Table 8.

Iron and it's Oxides in Ozone.

Exposure	Freshly polished Iron	Magnetic Oxide Fe_3O_4.	Ferric Oxide Fe_2O_3
0 hrs.	100.	100	100
$\frac{1}{2}$ to $\frac{1}{3}$ hr.	98.6	97.3	100
1 hr.	96.1	94.1	100
2 hrs.	94.6	91.±	100
3 hrs.	94.1	90.4	100.

Table 9.
Tin and it's Oxides in Ozone.

Exposure	Freshly polished Tin	"Tin Oxide"	Stannic Oxide SnO_2
0 hrs	100	100	100
½ hr.	—	99.1	—
1 hr.	100	—	—
2 hrs.	100	97.9	100
3. hrs.	98.4	97.3	100
4 hrs.	99.2	95.6	100.
5 hrs.	96.8	94.2	—
6 hrs.	94.1	—	—

Table 10.
Zinc and Zinc Oxide in Ozone.

Exposure	Freshly polished Zinc	Zinc Oxide ZnO
0 hrs	100	100.
½ hr.	98.2	—
1 hr.	96.6	100.
2 hrs.	95.2	100.
3 hrs	—	100.

Table 11.

Silver and Lead in Ozone.

Exposure	Freshly polished Silver.	Freshly polished Lead.
0 hrs.	100	100
$\frac{1}{3}$ to $\frac{1}{2}$ hr	98.8	98.6
1 hr.	97.7	97.7
2 hrs.	97.5	95.1
3 hrs.	98.1	93.1
4 hrs.	97.5	——
5 hrs.	97.0	——
6 hrs.	96.9.	——

METALS AND OXIDES IN OZONE.

The results so far obtained for some of the metals and their oxides when exposed in ozone are given in Tables 7, 8, 9, 10 and 11.

Table 7 shows the fatigue of copper, cuprous oxide, and cupric oxide, and it will be observed that the fatigue decreases as the oxidation increases. The fatigue occasioned in the freshly polished copper and cuprous oxide in two hours, requires about three and one-half times as long to be produced in the higher oxide.

These plates on examination after exposure showed decided changes in the character of the surface. The polished copper had become dull and had taken on the appearance of old copper surface exposed to air for some time. The cuprous oxide had changed from a reddish brown to about the same appearance as the copper had after exposure. The cupric oxide, originally black, became dark reddish brown after 7.25 hrs. in ozone.

The radiations from iron, magnetic oxide and ferric oxide surfaces are given in Table 8, but show in this case the opposite effect, with the lower oxide, that it fatigues about three times as rapidly as the freshly polished surface. Both the iron and magnetic oxide surfaces showed that further oxidation had taken place; the polished metal had become dull and the blue-black magnetic oxide had taken on a reddish brown cast. It is probable that the film of higher oxide, formed by the ozone on the magnetic oxide surface, was much thicker than that on the iron, which may account for the greater fatigue. The ferric oxide showed no fatigue nor was its appearance changed by the exposure.

Table 9, giving the results for tin, the "tin oxide" before described, and stannic oxide, shows again a more rapid fatigue for the lower oxide than for the pure metal, and no change whatever for the stannic oxide. An inspection of the polished metal and the "tin oxide" surfaces, after the test, showed the formation of stannic oxide by the ozone, the film formed on the "tin oxide" being appreciably thicker than that on the tin. The stannic oxide surface showed no change in appearance.

The fatigue of tin seems to have the peculiarity of being slow in starting under any conditions, not appearing until the third hour in ozone, while other metals experience from one to four per cent. fatigue during the first hour of exposure in this gas.

The fatigues for the fresh surface of zinc and for a surface covered with a layer of zinc oxide, when exposed in ozone, are given in Table 10.

The radiations from the freshly polished surface diminishes rapidly, while that from the zinc oxide surface remains constant.

The results for fresh surfaces of lead and silver exposed in ozone are given in Table 11.

By comparison of Table 11 and Table 9 with Table 1, it will be noted that the fatigue for lead, silver, and tin, progresses at about twice the rate in ozone that it does in air. Comparison of Tables 10 and 1 show that zinc fatigues about fifteen times as fast in ozone as in air.

These surfaces after exposure all showed evidence of oxidation, the lead especially being very badly tarnished.

Lastly, a few experiments were tried to determine the radiating powers of these oxidized surfaces compared to the polished metal, and the results for copper and iron and their oxides are given below.

Cu	100	Fe	100
Cu O	95	Fe O	94
Cu O	92	Fe O	84

The cuprous oxide and ferro-ferric oxide films were very thin, perhaps not over a few wave lengths of light in thickness and yet their effect on the secondary radiation is very marked. The same qualitative relations hold for the tin oxide surfaces used and in fact it may be said, that in every case in our experience the radiation decreases as oxidation progresses.

During the course of the experiments, a tin and a silver plate accidentally became amalgamated, and I was surprised to note that these mercury-coated surfaces gave much more radiation than the pure metals. Quantitative measurements of this increase in sensitiveness have not yet been made.

The six freshly polished metals and three lower oxides tested all showed fatigue when exposed in ozone. Of the five highest oxides tried, but one showed any fatigue and that relatively small.

The fatigue suffered by cupric oxide was probably due to the further oxidation of sub-layers of the lower oxide which we might expect to be present. The change in appearance of the surface indicates some chemical reaction or physical change, which might produce a change in the radiating power.

SUMMARY OF RESULTS.

Freshly polished surfaces of lead, tin, silver, and iron show fatigue, while those of aluminium, copper, and zinc experience little or no change in their secondary radiation.

None of the oxidized surfaces shows any fatigue in air.

All the metals tried gave fatigue in ozone with accompanying change in appearance of the surface, due to oxidation.

All the lower oxides tested, fatigue in ozone.

None of the highest oxides, with the expeption of cupric oxide, shows any change in sensitiveness.

The radiating power of a surface decreases as oxidation progresses.

The results obtained by Professor More have been confirmed with the exception of those for freshly polished lead, and for unpolished zinc, in air, although in either case it would be difficult to say whether or not the surfaces of the plates were in the same condition in the two experiments.

CONCLUSION.

It appears from these results that there is a close relation between the behavior of the surface when exposed to X-rays and its "chemical stability".

The theory that fatigue is due to great absorptive power of ozone, when absorbed or adsorbed by the metal, is evidently not applicable to this case; since it does not account for the absence of fatigue from a chemically stable surface.

The results are also against disintegration theories, for particularly in the ozone experiments there were just as many atoms to disintegrate after oxidation as before, in fact a number of oxygen atoms had been added. If a density law of absorption holds, the oxides would probably have less absorbing power than the metal itself, and the decrease in radiation can not be accounted for by assuming increased absorption of the radiation coming from the body of the metal. This limits the secondary radiation mainly to a surface effect.

The explanation of fatigue upon a basis of chemical stability would lead us to expect that the more stable a surface the less the fatigue. This order is followed, without exception, in the results given.

The simple hypothesis of the fatigue depending upon oxidation or at least primarily on chemical change of the surface, serves to explain these results while their explanation on other grounds is less apparent.

In conclusion, I wish to extend to Professor More my most sincere thanks and appreciation, for his suggestions and direction of this work.

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"Fatigue of Metals Excited by the Roentgen Rays"
(Phys. Rev. Vol. XXVIII, no. 2, CLV, 1909, p. 148.)

"On the Absorption of Short Electric Waves by Air at Different Pressures"
(Phys. Rev. Vol. XXVI, no.2. CXLIII, 1908, p. 196.)