ON THE NATURE OF CERTAIN RADIATIONS FROM THE SULPHATE OF QUININE.

By Fanny Cook Gates.

IN studying the properties of certain substances known to become phosphorescent by a change in temperature, G. Le Bon found that when the sulphate of quinine is either heated or cooled through a high range of temperature, it becomes temporarily phosphorescent and possesses the power of discharging the leaves of an electroscope. He believed this effect to be due to chemical reaction, dehydration taking place when the quinine is heated above 100° C. and hydration upon cooling it again, and from this he argued that the radiations from radium and the other active minerals may be due to slight internal temperature changes and entirely explained by chemical reactions.

The ionization of the gas is the accompaniment of so many phenomena of totally different origin and character that before such a theory as M. Le Bon advances can be tenable to any degree, it must be proved that the radiations he describes possess other properties characteristic of those from the naturally radio-active substances, in addition to the property of causing the surrounding air to become a conductor of electricity. The experiments described in the following pages were undertaken for the purpose of determining the exact nature of the radiations emitted by the quinine sulphate under the conditions named, and of ascertaining to what extent they are similar to those given off from the radio-active substances.

The first tests were made with one gram of quinine sifted uniformly over a metal plate 20 cm. square. This was heated over a spirit lamp and then allowed to cool to the temperature of the room between parallel metal plates within a closed vessel. The plates were about 5 cm. apart and insulated. The lower one on which the quinine rested was joined to one terminal of a storage battery of 300 volts and the upper one to the electrometer, other connections being made in the usual manner. The strength of the current passing between the plates as indicated by the deflection of the electrometer was used as a measure of the rate of radiation from the quinine.

With the apparatus arranged as above described, it was found that after removing the quinine from the source of heat no deflection of the electrometer was at first produced, but that after about two minutes a slight current was noticed which increased slowly at first and then rose suddenly to a maximum at the end of about five minutes. It then rapidly decreased and the effect apparently ceased altogether after fifteen minutes. This variation of the radiation

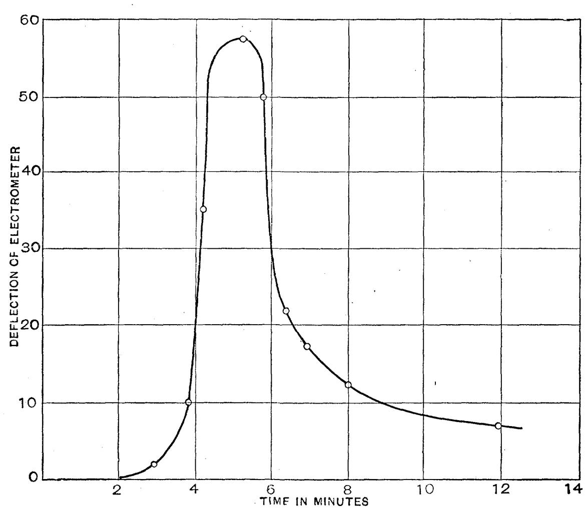

Fig. 1.

with time is shown in Fig. 1. On account of the rapid rate of change in current while passing through its maximum value, it was impossible to make accurate determinations near that point and the curve gives its value only approximately.

Upon reheating the same quinine and observing under apparently similar conditions, it was found that although curves of the same general type were obtained, the total radiation produced during successive tests varied greatly. This seemed to indicate either that repeated heatings of the quinine changed its power to emit rays or that slight differences in the temperature to which it was heated produced comparatively large changes in the resulting radiation. For this reason the spirit lamp was discarded and the quinine was heated to a definite temperature in a hot air bath. When allowed to cool from this temperature successive tests of the same substance gave curves of the same magnitude showing that the treatment had caused no inherent change in the quinine and that a slight variation in the temperature range produced a definite change in the resulting radiation.

Range and Rate of Cooling.

By the range of cooling, is meant the total number of degrees through which the quinine is cooled during a single test. The rate of cooling is the fall in temperature per second.

As has been stated, the ionization of the surrounding air is produced during the process of heating as well as that of cooling the quinine, but the experimental difficulties in obtaining accurate measurements of the radiation were so much greater in the former process than in the latter, that we have here confined our attention to the results obtained during cooling.

Two series of tests were made in which the temperature range was made to vary. In the first set the upper temperature was changed for each test while the lower one was kept always the same. In the second set the upper temperature was kept constant, and the effect noted by cooling the quinine from this temperature to different lower ones. This was accomplished by placing the parallel plates, between which the ionization took place, inside an air-bath the temperature of which could be regulated. These observations made it possible not only to test the effect of increasing the range and the rate of cooling, but to compare the effects produced by equal falls in different parts of the scale, and thus to determine where the maximum radiation is produced.

From the first set of observations, about 180° C. was found to be the highest temperature to which the quinine could be heated without permanent chemical change, and no appreciable radiation was observed unless the quinine was heated above 70° C. A comparison of the currents observed at the end of four different temperature ranges, each having the same lower limit is given in the following table. The current is here measured in an arbitrary unit of the order of 10^{-13} amperes and in each case the current at the end of five minutes after heating is approximately the maximum current for that test.

Upper Temperature.	Lower Temperature.	Range.	Current After 5 Minutes.	Current After 10 Minutes.
180° C.	18° C.	162°	75	20
165	18	147	50	16
100	18	82	20	11
75	18	57	10	7.5

From the second series of experiments due to changing the lower temperature of each cooling, a normal fall from 180° C. to 50° C. was found to produce but little effect, but when the lower limit was

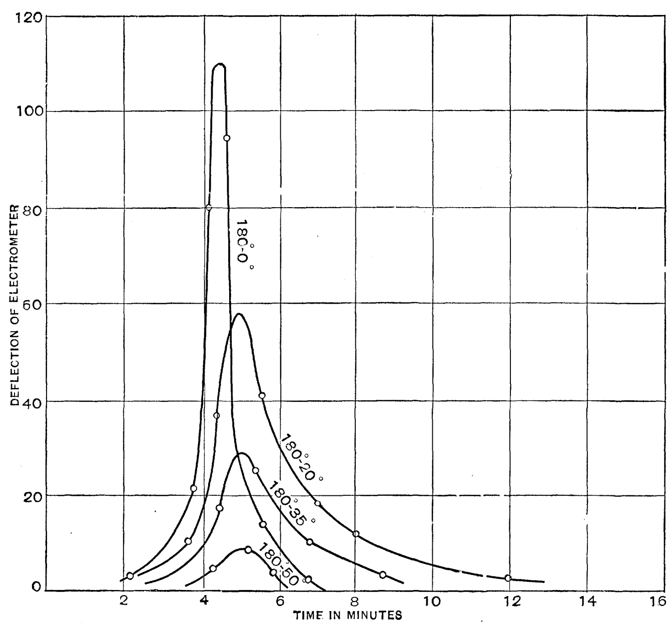

Fig. 2.

below 40° an increase in the range produced a rapid increase in the current. The total quantity of electricity discharged by the rays however did not increase when the lower temperature was below 18° or 20°. Thereafter an increased rate of radiation due to an increased rate of cooling was counterbalanced by a decrease in the time during which the radiation continued. The curves shown in Fig. 2 illustrate this. When cooled to 0°, the maximum current was nearly twice as great as when cooled to 20°, but the effect lasted only half as long. A similar but more marked effect was observed when the testing plates were placed over a vessel containing liquid air. In this case the current rose almost immediately to a high maximum value, but the effect apparently ceased within three minutes. Thus it would seem that *the total radiation is not increased by an increase in range when the lower limit is below 20°.*

The fact that an increase in the range from 180° to a point below

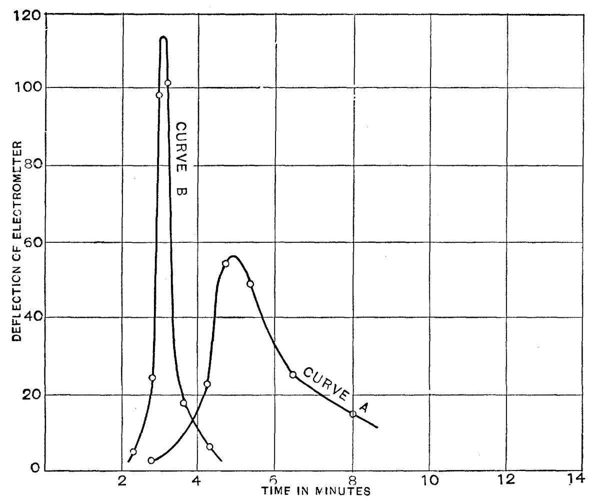

Fig. 3.

20° increased the rate of radiation at the expense of the time it continued would be entirely explained by the increased rate of cooling, providing the rate of radiation is solely determined by the rate of cooling during a given change. Direct experiments were therefore made in which the cooling was hastened by blowing dry dust-free air between the parallel electrodes as soon as the quinine was in place. In Fig. 3, Curve A shows the rate of radiation under normal cooling, while B is the curve when the cooling was hastened in the manner described, the range being the same. The similarity of the latter curve with that in Fig. 2 caused by the 180°–0°

range is striking and strongly indicates that *an increase in the rate of cooling increases the rate of radiation but does not change the total radiation during a single cooling.*

Consistent with these results were those obtained by using very thin layers of quinine. One fifth of a gram scattered over a given area was found to give as large a maximum current as that derived from one gram over the same space, but the radiation continued for a correspondingly shorter time. This is entirely explained by the more rapid cooling of the thin than of the thick layer. When heated on a thick metal plate the effect was less than when a thin plate was used, presumably because it retained the heat and retarded the cooling. Plates of different metals of uniform thickness gave no appreciable difference in the radiation. Similar but more marked results were obtained by saturating the air of the testing vessel with water-vapor, and also by spraying the quinine itself with water. In both cases the decay of the radiation was hastened.

The above results were all obtained with an air space between electrodes of about two inches and a potential difference of 300 volts. By attaching the upper plate to an insulated screw of known pitch it was possible to vary the distance between the plates as much as desired. Before this question of the absorption in air could be satisfactorily investigated it was necessary to determine the effect produced by increasing the P.D. between the electrodes.

Effect of Voltage. Saturation Curve.

One of the chief characteristics of the radiations from the active

Voltage.	Current After 10 Minutes.				
	First Test.	Second.	Third.	Average.	Ratio.
900	32.0	33.5	32.8	32.8	100
600	23.5	23.9	24.0	23.8	72
300	13.0	13.7	13.4	13.4	41
Voltage.	**Current After 5 Minutes.**				
900	21.5	21.5	23.5	22.2	100
600	15.5	15.7	17.0	16.1	72
300	8.5	9.2	9.5	9.1	41

elements is that after a certain strength of electric field is attained a further increase in the potential difference will not increase the ionization current; that is, a saturation current is obtained which cannot be increased with voltage.

The effect of voltage on the radiations from quinine sulphate was found to be very different, as will be seen from the tabulated results obtained from three coolings of the same quinine, during which the potential difference was each time varied. These results on a current voltage diagram (Fig. 4) give no indication of a saturation value to the current, although the strength of the field is about

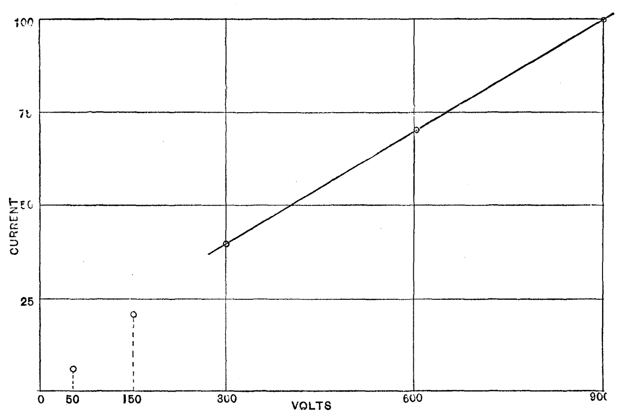

Fig. 4.

twenty times as great as that sufficient to produce saturation for radium radiations under similar conditions.

Observations were made with various widths of air space, but although the plates were brought to within 2 mm. of each other, no indication of saturation was obtained for a P.D. as great as 900 volts. An attempt was also made to determine whether with low voltages, the current might not vary as the square of the P.D. but no definite results could be obtained. With 150 and 50 volts respectively the values found for the current when expressed in ratio as above were 21 and 5 (see Fig. 4).

Absorption by Air and other Substances.

Since no saturation current could be obtained it was impossible to secure a value of the coefficient of absorption in air, but by varying the width of the air space and keeping a constant potential difference between the plates, results were obtained which were a marked contrast to those produced with the uranium, thorium and radium radiations.

As has already been stated all observable effect from the quinine ceased within fifteen minutes of the time of heating when the distance between the plates was 5 cm. When the width of the air space was reduced to one half of this value the value of the maximum current was approximately doubled, and the electrometer deflection was easily observed for thirty or forty minutes. When the electrodes were only 3 mm. apart the effect was clearly observed for over two hours. The actual numerical values obtained from observations with a P.D. of 900 volts are shown in the following table:

Distance in Centimeters Between Electrodes.	Current After 10 Minutes.	Current After 20 Minutes.
5.0	1.6	1.0
2.5	7.4	4.5
1.2	14.0	10.5
.3	32.0	20.0

With the electrodes 3 mm. apart and with a potential difference of 900 volts between them, a sheet of aluminum foil only .003 mm. thick was found to cut out all effect and the radiations were also found to be unable to penetrate a thin sheet of paper. This offers perhaps the most striking contrast between the two types of radiations since the most easily absorbed rays from radio-active substances will penetrate several layers of aluminum foil with comparatively little loss in intensity.

Both quartz and glass plates 2 mm. thick were placed over the quinine in turn and although no deflection of the electrometer was produced these results can carry no evidence one way or the other since the conditions prevented a sufficiently rapid rate of cooling.

Direction of the Electric Field.

One of the most unexpected and suggestive phenomena connected with the radiations under discussion is that caused by changing the direction of the electric field. When the plate on which the quinine rested was joined to the positive pole of the battery, the resulting ionization was invariably greater than when joined to the negative pole. This effect was more marked when the plates were far apart, but even when the space between the electrodes was only 3 mm., the ratio of the current obtained by joining the lower plate to the positive pole of a 600-volt battery to that obtained by joining it to the negative pole was 1.2. This ratio for other distances is shown in the following table:

Distances in Centimeters Between Electrodes.	Ratio.
.3	1.20
1.2	1.48
2.5	1.64
3.7	1.93
7.5	2.53

This marked effect indicates that the radiations may possibly be produced by ultra-violet light. The current voltage curves are very similar to those obtained when ultra-violet light falls on a charged surface, except that here both positive and negative ions are present. The difficulty in obtaining saturation may be due to the fact that the ionization takes place very close to the surface of the quinine and the ions consequently rapidly diffuse to its surface and cannot be removed without a very intense field. The difference in the positive and negative currents is probably due to a difference in the size of the positive and negative ions, the positive ions traveling faster than the negative ones. A difference in their size could be explained by the condensation of vapor around them in the same way as the ions in flame gases increase in size when the gases cool. The whole effect appears to be due to some type of radiation which is easily absorbed in the gas and since the electrical effects are accompanied by marked phosphorescence it seems possible to suppose that the ionization may be caused by very short waves of ultra-violet light such as Lenard has shown to be active in ionizing the gas.

Optical Effect.

Mention has been made of the phosphorescence accompanying this phenomenon. The quinine when heated in a dark room was observed to glow for about fifteen minutes while cooling. The light given off was bluish white in color but was of insufficient intensity to admit of optical measurement.

SUMMARY.

In conclusion let us contrast those properties found to be most characteristic of the quinine radiations with those obtained under similiar conditions from radio-active bodies.

1. The quinine radiations are only apparent when accompanied by a great temperature change. The rate of ionization varies during this change and in a short time the effect ceases altogether. The rate of discharge of electricity between plates exposed to the radiations from the active elements, however, is incapable of alteration by any change in temperature, and so far as is known these radiations suffer no alteration with time.

2. By increasing the strength of the electric field it is impossible to secure a maximum ionization current from quinine radiations while a comparatively weak electric field is sufficient to produce a saturation current due to the radiations from radium and the other active elements.

3. The quinine radiations are certainly largely absorbed by at least two or three mm. of air and may be absorbed by a much shorter distance, while the least penetrating radiations from the active elements will pass through several cm. of air without great loss in intensity.

4. The quinine radiations are completely absorbed by a very thin sheet of aluminum which does not cut out the rays of uranium, radium and thorium.

5. The rate of ionization due to radium radiations is independent of the direction of the field, whereas that from quinine radiations undergoes a marked change upon reversing the direction of the field.

These conclusions show very clearly that there is no evidence for believing that the ionization from quinine radiations is due to the spontaneous projection of charged masses from the atom as in the case of radio-active bodies, but to molecular actions which are influenced by temperature.

While M. Le Bon is therefore undoubtedly correct in his assertion as to the nature of the cause of the quinine radiations, these experiments show no justification whatever for attributing the radiations from radium and the other active bodies to a similar cause, but on the contrary testify to a fundamental difference in production.

I desire to express my deep obligation to Professor Rutherford for his kind interest and direction during the course of these experiments.

MacDonald Physics Building,
McGill University, June, 1903.