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# LXIV. On the emission of negative corpuscles by the alkali metals

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hardly be established for sequences of less than ten thousand similar waves. Perhaps the only means of even roughly guessing at the time of optical relaxation is by the time-lag in such phenomena as fluorescence, which are connected in part with free internal vibrations excited in the elements o. the medium. Stated in the present form, the criterion that a Röntgen æther-pulse should be regularly refracted and dispersed into wave-trains, according to a process of which Lord Rayleigh's *rationale* has been paraphrased above, is that its duration should be long compared with the time of optical relaxation of the dispersing medium. In the hydrodynamic illustration the restriction does not arise, for the time of molecular relaxation is far beneath the period of any observable surface-waves.

To sum up, it now seems clear that Lord Rayleigh's application of the phenomena of a *maintained moving source* gives an adequate picture of the *modus operandi* of the dispersion of an incident aperiodic disturbance into regular wave-trains by refraction, for all types of disturbance that are slow compared with the period of natural molecular relaxation of the refracting medium,—provided, however, anomalous dispersion, which cannot be included unless a *quasi*-frictional term is *assumed* in the analysis, plays a part which is unimportant. But it is still held to be unlikely that æthereal pulses of the type of the Röntgen rays come as a rule within this limit. If this be so, white light, such as can be regularly dispersed by a prism, cannot consist of wholly irregular æthereal disturbance; each Fourier component, comprised within say the infinitesimal range of wave-length between $\lambda$ and $\lambda+\delta\lambda$, must have sequences of regularity in its amplitude, of duration comparable with the time of optical relaxation of the dispersing medium.

Cambridge, October 10, 1905.

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## LXIV. *On the Emission of Negative Corpuscles by the Alkali Metals.* *By* J. J. THOMSON, *M.A., F.R.S.**

IT is well known that the alkali metals when exposed to light give out negative corpuscles, even when the light is of very feeble intensity. Thus Elster and Geitel found that the light emitted by a piece of glass rod heated to a dull red heat was sufficient to make rubidium emit corpuscles. It has not, however, as far as I am aware, been noticed that

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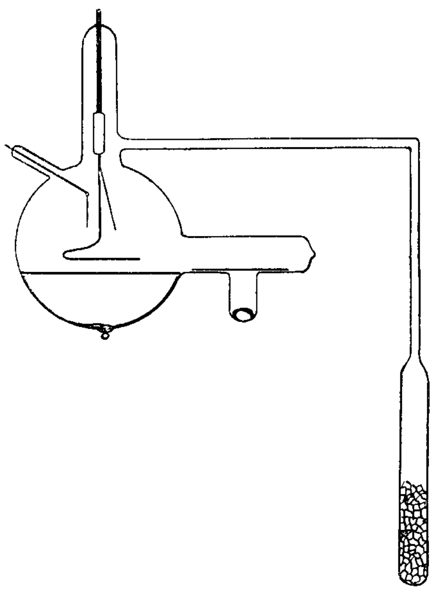
with these metals there is a small emission of corpuscles, even when all external light is excluded. The following experiments show, however, that rubidium and the liquid alloy of sodium and potassium give out corpuscles in the dark.

The experiments showing this were made as follows:—A gold-leaf electroscope with quartz insulation was enclosed in a glass vessel, which was exhausted to an exceedingly low

Fig. 1.



vacuum by means of charcoal cooled to a very low temperature by liquid air in the way discovered by Sir James Dewar. The rubidium or Na-K alloy was placed below the gold leaves of the electroscope, care being taken to have the surface of the metal as clean as possible; the metal was earthed by means of a wire fused through the glass. The vessel was placed inside a box made light-tight by means of felt, the tube containing the charcoal which protruded from the box was painted over with lamp-black. To measure the divergence of the leaves of the electroscope, these were momentarily illuminated by a faint light transmitted through a red glass window, the position of the leaves was deter-

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mined by a reading microscope passing through the side of the box; after a reading had been taken, shutters were put before the window and the eyepiece of the microscope covered with a cap. The readings only took a second or two, but even in that time the red light produced an appreciable leak in the electroscope; this part of the leak can, however, easily be separated from that taking place in the dark as the latter is proportional to the interval between two readings, while the former is independent of this interval.

To test the efficiency of the means taken to exclude the light, some of the experiments on the rate of leak were made in a photographic dark room, others with the case exposed to the light of the laboratory; the leak was the same in the two cases. Another proof of the exclusion of light is that a sensitive photographic plate placed in the case for 48 hours was not fogged.

When the leaves of the electroscope were charged with *positive* electricity there was, even in the dark always, a small leak of electricity from the leaves, while there was no perceptible leak when the leaves were *negatively* charged. The positive leak was entirely stopped by a transverse magnetic field: this proves that it is due to negative corpuscles emitted by the rubidium or the alloy of Na and K.

On some occasions the positive leak was abnormally large. This was traced to the presence in the tube containing the electroscope of minute quantities of hydrogen; it was found that this gas had an extraordinary influence on the emission of corpuscles from electropositive metals. To investigate this more fully, an arrangement was added to the glass vessel containing the electroscope, by which bubbles of hydrogen could be admitted from time to time into the vessel. The admission of a very small quantity of hydrogen produced temporarily a very large increase in the rate at which electricity escaped from the positively charged leaves of the electroscope, the rate of leak after the admission of the hydrogen being often ten times its previous value. The increase in the leak rapidly died away, and after about 20 minutes the leak resumed its original value; the admission of a fresh supply of hydrogen, however, sent it up again. The admission of small quantities of air or carbonic acid did not produce any appreciable increase in the leak. It would appear that while these electropositive metals are absorbing hydrogen, the rate of emission of negatively electrified particles is greatly increased.

The influence of hydrogen on the emission of corpuscles

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from a hot platinum wire has been observed by Dr. H. A. Wilson; the increase in this case is very much greater than that with cold alkali metals.

In a previous paper (Proc. Camb. Phil. Soc. xiii. p. 49) I showed that the radioactive substances radium and polonium emit when cold slowly-moving negatively electrified corpuscles. The experiments just described show that this property is also possessed to an appreciable extent by substances not usually regarded as radioactive. With more delicate apparatus than that used in these experiments it is probable that this property might be detected in all substances:—I tried in my apparatus, in addition to the alkali metals, lead, silver, and mercury, but could get no indication of the emission of corpuscles by these metals.

The alkali metals give out corpuscles when in the gaseous as well as in the solid state; this was proved in the following way. If the gaseous atoms of sodium give out negative corpuscles, the atoms themselves will be positively charged and so will be attracted by negatively electrified bodies: this was found to be the case. Sodium was heated in a highly exhausted flask, the cooler part of which contained two glass tubes down which ran wires. The wire in one tube was connected to the positive pole of a battery of small storage-cells giving a potential-difference of 600 volts, the wire down the other tube was connected with the negative pole of the same battery. When the bottom of the flask was heated, the sodium evaporated and condensed on the two tubes. When the wires down these tubes were disconnected from the battery, the deposit of sodium was pretty equally distributed between the tubes. When, however, the wires were connected with the battery, there was very little deposit on the tube connected with the positive pole, while the deposit on that connected with the negative pole was very dense. If the connexions with the battery were reversed, the sodium began to deposit on the tube which had previously been clean, while hardly any increase took place in the deposit on the other tube; showing that the effect was due to the electrical charges on the tubes, and not to any want of symmetry. In these experiments the tubes were not absolutely dark. This deposit of sodium on a negatively electrified surface may be compared with the flow of radium emanation to a negatively electrified wire.

The result at which we have arrived from the preceding experiments, that some substances emit many corpuscles, while others at the same temperature only emit few, if any,

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has important consequences when considered in relation with the Second Law of Thermodynamics. For, consider an enclosure at a constant temperature containing two substances in electrical connexion, one A giving at this temperature a copious supply of corpuscles, the other B few, if any: we see that we could utilize the stream of particles from A so as to do mechanical work. But since everything is at the same temperature, it follows from the Second Law of Thermodynamics that the energy required for this work cannot be derived from a lowering of the temperature of any part of this enclosure: it cannot come from thermal sources, but must come from some change in the state of the working substance, presumably from some diminution in the internal energy of the atoms of this substance. Investigations made with the object of seeing whether prolonged emission of corpuscles, such as might be produced by long-continued incandescence, produces any appreciable effect on the properties of the subject, might be expected to give interesting results. There are undoubtedly changes produced in a substance such as a piece of platinum wire by long-continued incandescence, but we do not know as yet whether these changes are such as indicate a change in the platinum atom, or whether they are merely physical, such, for example, as would result from the expulsion of gases absorbed by the wire. Again, many metals after the emission of corpuscles by exposure to ultra-violet light show "fatigue," *i. e.*, the rate of emission of corpuscles after long exposure becomes less than it was initially: this is usually ascribed to the formation or removal of films of gas or to a roughening of the surface; it is possible, however, that it may partly be due to some change in the metal itself. Investigations on these points would be of especial interest because, if the energy of the corpuscles does come from changes in the atomic energy, we have here a case in which this transmutation of energy can be started and influenced by external conditions, such as incandescence or the incidence of ultra-violet light or Röntgen rays.

On this view, the energy of the corpuscle emitted is not derived directly from the work done on the corpuscles by the electric field which exists in the Röntgen rays or in the light. The rays act as detonators, causing some of the atoms on which they fall to explode, and the energy of the corpuscle is derived from the energy liberated by this explosion.

In the case of radium and other radioactive substances we have probably also the transformation of internal atomic energy into the kinetic energy of corpuscles and $\alpha$ particles, but in this case, as far as is known, the transformation is quite uninfluenced by external physical conditions, and is thus beyond our control. If, however, the view we have been considering above is correct, the tapping of the internal atomic energy by corpuscular streams is to some extent under our control and can be brought about by elevation of temperature or by ultra-violet light.

Since the emission of corpuscles goes on to some extent at all temperatures, and since inside a body the energy of these corpuscles would ultimately be transformed into heat energy, there is probably a continual transformation of internal atomic energy into heat: this would cause the interior of a mass of metal to be hotter than the surface, the increase in the inside temperature depending on the amount of energy transformed, on the size of the body, and on its thermal conductivity.

If the body is a sphere of radius $a$, of uniform composition, we can easily show that $\theta$, the difference between the temperature of the surface and that at the centre, is given by the equation

$$\theta = \frac{qa^2}{6k},$$

where $q$ is the amount of energy transformed into heat per cubic centimetre per second, $k$ the thermal conductivity of the substance.

For bodies comparable in size with the earth, a very small amount of transformation of internal atomic energy into heat would produce very large differences of temperature between the centre and the surface. Thus, if the conductivity of the sphere were ·01, which is about three times that of granite at the temperature of the earth's surface, there would be a difference of 3000° C. between the centre and surface of a sphere the size of the earth if $q = 45 \times 10^{-17}$, *i. e.*, if the atomic energy transformed into heat per c.c. in 100 million years were less than that required to raise the temperature of 1·5 gramme of water 1° C. If the corpuscles were emitted with a kinetic energy corresponding to that which would be acquired by the fall of their electric charge through two volts, the emission by an atom of a corpuscle once in a thousand million years on an average would be far more than sufficient to produce the required transformation of energy. The temperature difference between the centre and the surface being proportional

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to the radius of the sphere, leads us to expect that with bodies of the size we could manipulate in the laboratory the differences of temperature would be exceedingly small unless the emission of corpuscles was very copious. It would, however, be interesting to test whether the inside of a block of lime which, as Wehnelt has shown, at high temperatures emits large quantities of corpuscles, is at such temperatures appreciably hotter than the outside.

If there is a continual transformation of the internal energy of the atoms into other forms of energy when the atom is emitting corpuscles, we should expect that the internal energy of an atom would vary with the treatment it had received; that it would have been more diminished if the atom had been maintained for long periods in a state of incandescence than if it had been kept cool; we should thus expect the internal energy of an atom of an element in the sun to differ from that of the same atom on the earth: if this is so, then this variation in the internal atomic energy must be without effect on some of the properties of the atom. Thus, for example, spectrum analysis shows that the periods of vibration of an atom in the sun do not differ appreciably from those of the same element on the earth; we have indeed at present no evidence of the existence of any difference in the properties of atoms of the same element. We can, however, easily conceive an atom constructed in such a way that before the internal energy had diminished sufficiently to appreciably alter many of its properties, the atom would become unstable and explode, breaking up into atoms of elements of a different kind. Suppose, for example, that the atom consists of a number of corpuscles arranged in layers on the surfaces of concentric shells, and that the loss of internal energy by the atom is mainly due to the loss of kinetic energy by those corpuscles in the outer layer, this will hardly affect the times of vibrations of the corpuscles inside, while the outer layers may lose such a large amount of energy that their configuration becomes unstable, and the corpuscles in the outer layers rearrange themselves: in doing this, such a large amount of kinetic energy may be liberated that the atom explodes and breaks up into atoms of different kinds. Thus, in a case of this kind we should have the atom losing internal energy and yet as long as it remained intact the great majority of its periods of vibration would be unaltered, and the atom would explode before the change in its internal energy was sufficient to appreciably affect the great majority of its properties.

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