

On the Radioactivity of the Rocks of the Kolar Gold Fields
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The Kolar Gold Fields are situated on the Mysore plateau in latitude 13° N, and 50 miles East of Bangalore. The present workings extend along a line about 5 miles long, running North and South, and several of them are carried down for 4000 feet, the greatest vertical depth reached so far being about 3,600 feet. The "country rock", in which the quartz lies, consists of schists, and is apparently of a very uniform nature throughout the workings. Consequently, it was thought that it might be interesting to carry out some estimations of radium with a view to determining whether its distribution in this homogeneous rock was uniform.

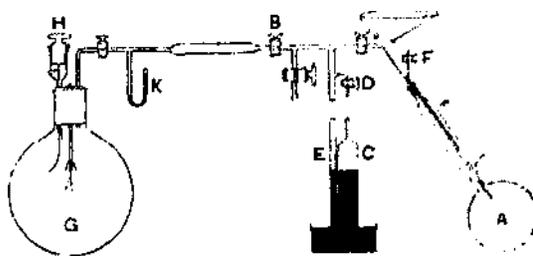
A few estimations of the radium in some of the other rocks from the same locality have also been made for the sake of comparison.

The following is an account of the method used and of the results obtained.

Experimental.

The method used for the estimation of radium was a modification of Joly's fusion method. (Phil. Mag. 1911—22, p. 134). It is, perhaps, not quite capable of general application, but it proved very efficacious for all the rocks dealt with in the present investigation. The method consists in the fusion of the rocks with potassium hydroxide under reduced pressure, and the results obtained appear to show that by this means the radium emanation is liberated just as completely as at the higher temperatures necessitated by fusion with alkaline carbonates. A thick copper flask, A, of about 300 c. c. capacity with a long neck, upon which was soldered an outer tube forming a water jacket, was used to effect the decomposition. 10 grams of the rock, powdered so as to pass through a 120-mesh sieve, were mixed with a 2 grams of anhydrous sodium carbonate, and introduced into the flask, and 50 grams of stick potassium hydroxide was added. The last was not fused to remove water previous to use as it has been shown that vigorous ebullition assists in the liberation of the emanation. The flask was then connected to the rest of the apparatus by a rubber stopper, and the whole apparatus was

evacuated by means of a Fluess pump to a pressure of about 1 cm., as shown by the small manometer, K. The tap, B, was then closed, and the flask and its contents was heated with a large Teclu burner for 15 minutes, a very rapid stream of water



being passed through the condenser surrounding the neck. A certain amount of gas was usually liberated, and in the earlier experiments the pressure sometimes rose to such an extent; that the cork was blown out of the flask. To avoid this, a safety valve was devised. A tube, E, slightly greater in length than the barometric height, was attached to the apparatus, and bent round under the wider tube, C, which was about 50 c. c. in capacity. If the pressure rose much above that of the atmosphere, gas escaped into C. The gas liberated was, on one occasion, pumped off, and was found to be almost perfectly pure hydrogen.

After heating, the copper flask was cooled in water, and the pressure fell sufficiently to cause C to fill with mercury when the tap D was opened. The taps leading to the electroscope, G, were then very cautiously opened and the gas washed out of the flask and drying tubes which contained, respectively, calcium chloride, fused potassium hydroxide, and phosphoric anhydride, by opening the tap, F, which was connected to a tube leading nearly to the bottom of the flask. The electroscope itself was similar to those used by Joly, but about twice as sensitive. The moving leaf was of aluminium about 30 x 2 mm., and a small piece of quartz fibre, attached to the end and illuminated from the side, made it possible to take readings to the tenth part of a scale division with ease. The insulation was a quartz tube with a sulphur rod shaded by black paper on the end. Charging was* effected by means of a wire movable through an air-tight ground glass joint, H. A potential of 300 volts from a battery was used, and the wire was always replaced in the same position and earthed after charging. The whole was contained in a 500 cc. glass flask, silvered on the inside, except for two small areas, and earthed.

The quartz fibre was observed through a small microscope with a scale in the eyepiece. The constant was determined, roughly at first, by weighing out 5 milligrams of Joachimsthal pitchblende, which was mixed with a little rock and fused in the usual way. As this quantity was found to be much too large, 10 milligrams were accurately weighed, well digested with nitric acid, and the solution made up to 100 cc. 1 cc. of this solution was taken and evaporated to dryness in a small glass capsule. After 3 weeks, the residue was fused with 25 grains of potassium hydroxide, and the resulting leak determined. Two similar determinations were made at intervals of 8 months with different portions of pitchblende, and in the second case twice the quantity was taken.

These two experiments gave the quantity of radium which produced a leak of 1 scale division per hour as 0.310×10^{-12} grams and 0.315×10^{-12} grams respectively*. The pitchblende was found to contain 60% of uranium and it was assumed that the amount of radium in equilibrium with 1 gram of uranium was 3.15×10^{-12} grams. (Pirret and Soddy. Phil. Mag. VI. 1911. 21. 652.)

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The natural leak was fairly constant- It varied from 5.5 to 6.2 scale divisions per hour and was determined at frequent intervals.

The materials used for fusion appeared to be fairly free from radioactive matter. Blank experiments showed that a correction of about 1 scale division per hour for 50 grams was all that was necessary.

It was found at once that the quantity of radium in the rocks under examination was very minute, and in order to be quite sure that this was not due to faults in the method, or in the apparatus, a number of experiments were carried out.

No increase in the leak was observed if the heating was continued for more than 15 minutes. The resulting melt nearly all went into solution on treatment with water and hydrochloric acid in succession. To be certain, however, that the emanation had been expelled, these solutions, which were quite clear, were kept for three weeks and then boiled under reduced pressure, and the gas introduced into the apparatus, following the original method of Soddy (Roy. Soc. Proc. A. 1905, 76, p. 88). The small insoluble residue was also brought into solution by fusion with carbonates and the solutions added to the others. Only a very

* Another preliminary experiment with a different leaf gave 0.275×10^{-12} gms.

slight increase in the natural leak was ever observed, although a control experiment, with a solution to which 1 cc. of the uranium nitrate solution, previously mentioned, had been added, showed that this method was not at fault, even though the results were lower than those obtained by the other method.

Although other observers have shown that very little emanation is given up by a mineral on reducing the pressure of air in the vessel containing it, an experiment was carried out in order to test this, in which only the electroscope was evacuated. No abnormal result was obtained. The method of sweeping out the gas from the copper flask was also found to remove at least 95% of the emanation; and as all determinations were carried out in exactly the same way, no error should arise from this cause.

In all normal cases, electroscope readings were taken every half hour, for about 3 hours, starting about $1\frac{1}{2}$ hours after admission of the gas, and the rates of leak were reduced to their maximum value by means of the curve given by Satterly (Phil. Mag. 1910, 20, p. 2.)

The decay curve, after three to four hours, corresponded approximately with that of radium emanation, although an accurate determination was difficult owing to the extremely small quantities of gas.

After a considerable number of determinations had been made, an important source of error was discovered owing to one specimen of rock giving rise to a leak which was less than the normal leak of the electroscope. This was found to be due to the presence of a large quantity of hydrogen in the evolved gas. As the available data on ionisation in hydrogen are very meagre, some experiments were carried out to determine the magnitude of the effect. It was found that the natural leak in hydrogen was 70 scale divisions an hour, while in air it was 6.0. Also in an experiment with uranium nitrate similar to the others, but in which the apparatus was filled with hydrogen instead of air, a leak of 36.5 scale divisions per hour was observed, while the same weight of the salt produced a leak of 133.5 scale divisions per hour in air.

From these data, assuming that the rate of leak is a linear function of the quantity of hydrogen (a doubtful assumption) it may be calculated that if 100 cc. of hydrogen are introduced into an electroscope of 500 cc. capacity, a leak of 15 divisions per hour would be reduced to $12 \cdot 7$ and one of 10 to $8 \cdot 4$. With a natural leak of 6 it will be seen that the error in the later case is nearly 100 per cent.

As the actual leaks increase in magnitude the relative error **decreases**, but becomes by no means negligible.

In consequence of this, all the experiments which had been carried out were repeated, a red hot tube of copper oxide being inserted between the copper flask and the first tap. The effects of this were very satisfactory, as the pressure never rose above half an atmosphere during the fusion, and after cooling the flask, it was rarely 30 mm. more than the initial pressure. Even if this were due entirely to hydrogen which was not absorbed in its subsequent passage over the copper oxide, the amount (10 cc.) would be insufficient to influence the results.

It was found best to keep the electroscope continuously charged; consequently at the end of each day's readings it was evacuated to a pressure of about 10 mm., and if the rock which had been examined had contained more than the usual excessively small quantity of radium, air was again admitted, and pumped out. At this pressure the leak was only 0.3 divisions per hour, and consequently the fibre would remain on the scale for a long period. Immediately after the electroscope had been filled with fresh emanation, it was charged to a higher potential, so that the pointer reached a spot about 15 divisions off the scale, and no readings were taken for at least an hour (except in the case of large leaks). The reason for this was that the leaf fell very rapidly at first if charged up directly from zero potential owing to some "soaking in" effect of uncertain duration.

The sensitiveness of the electroscope remained practically constant over the whole scale, as might be expected from the potential to which it was charged (—300 volts), but the final values were as far as possible deduced from readings over the same part of the scale owing to a slight variation in parts, which was evidently due to rigidity of the leaf.

Mr. H. M. A. Cooke of Kolar very kindly supplied us with large specimens of "country rock" selected at varying depths from each of the chief mines. These were roughly crushed in order to obtain fair samples.

The following table shows the amount of radium per gram of rock in units of 10^{-4} gm.

The depths from which the samples were taken are only approximate and are measured along the incline of the shaft.

The actual vertical depths are usually considerably less, for instance, 4,000 feet on the incline in the Mysore mine is only 2,664 ft. below the surface. As however the shafts follow the direction of the strata, a comparison made in this way is probably preferable to one made at equal vertical depths.

The names of the Mines are given as they occur geographically, Balaghat being the most northerly.

TABLE I.

Name of mines	Depth in feet			
	1000	2000	3000	4000
Balaghat	21	14	21	
Nundydroog	17		14	...
Ooregum	18	17		21
Champion	...	24	18	14
Mysore	34	21	23	96

It will at once be seen from the above that there is no obvious relationship between the radium content and the position of the rock, and in fact, with two exceptions, the numbers are almost the same within the limit of experimental error. Thus, it appears that the distribution of radium is uniform.

With regard to the high value found for the deepest sample from the Mysore mine, a second experiment showed the figure to be correct; but it was found on subsequent examination that the rock was of quite a different character to the others, being probably of later formation.

A few other samples of rock, the geological history of which was known to some extent, were kindly presented to us by Dr. Smeeth of the Mysore Geological Department, and the radium content was determined. As these rocks were of a different character to those previously dealt with, the melt was in all cases treated with water and hydrochloric acid, and any residue was weighed to see if the decomposition had been sufficiently complete.

TABLE II.

Rock	Radium content 10^{-12}
1. Ooregam, 2000, altered	0.18
2. Schist, subsequently altered	0.82
3. Very auriferous quartz	1.28
4. Quartz of same age as (8), much less gold	1.34
5. Schist, late formation	1.44
6. Quartz containing tourmaline, of same age as (5)	6.90

The first of these samples was picked out from the piece of rock which was used for the determination given in table I. It differed considerably from the rest of the rock, and it was thought that the radium content of the two portions might not be the same. As may be seen, however, the two were almost identical. Samples 2, 3 and 4 were of approximately the same age, and related, geologically, to the deepest sample from the Mysore mine. A comparison of 3 and 4 seems to show that the quantity of radium does not vary greatly with the gold content. The comparatively large amount of radium in sample 6 did not appear to be due to the tourmaline, as a determination made on a small quantity of the latter gave no abnormally high result.

One sample of water from a large spring at the bottom of the Balaghat mine was also examined, both by boiling some of the water, and by fusing the residue from over two litres after it had stood for three weeks. Radium was present in such small quantity that it was practically undetectable.

It is interesting to note that these rocks, which are probably some of the oldest known, contain so little radium. In fact the quantity appears to be equal to the smallest quantity hitherto estimated in any rock. Also, as may be seen from table II, there appears to be some slight tendency of the radium content of the rocks of this locality to increase as their age diminishes but the number of experiments is not sufficient to show that this is definitely the case. Dr. Smeeth has promised to secure & number of additional specimens, and any results obtained will be published in due course.

In connection with the small radium content of these rocks it is worthy of note that the temperature gradient in the Kolar mines is quite abnormally small, and is hoped that a communication on this subject may be made at some future date.

