

RADIOACTIVITY

Some Practical Applications of the Geiger-Muller ratemeter are described by

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These simple experiments can be performed quite safely by any amateur interested in investigating the nature of radioactivity.

experiments



LAST month instructions were given for the construction of a simple Geiger-Muller ratemeter. In this article it is proposed to describe a series of basic experiments that will give the user of the ratemeter an introduction to the nature of radioactivity.

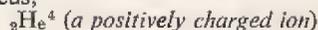
Before beginning, it would probably assist if a few basic facts concerning the atomic particles emitted in radioactivity were mentioned. There are many particles that are emitted or can be emitted by an atom under different conditions. Here we are only concerned with natural radioactivity and will only consider *alpha*, *beta* and *gamma* radiation.

ALPHA PARTICLES

Alpha particles have the following properties:

Cause fluorescence; blacken photographic emulsions; produce ionisation in gases. They are easily absorbed by matter; deflected by magnetic and electric fields; and are emitted with large velocities.

The alpha particle has been shown in fact to be a helium nucleus,



BETA PARTICLES

Beta particles have the following properties:

Cause fluorescence, though not as great as alpha particles; blacken photographic emulsions; cause ionisation, but to a lesser extent than alphas. They have much greater penetration than alphas; are deflected by magnetic and electric fields; and have extremely high velocities.

Beta particles, in fact, consist of electrons moving with extremely high velocities. *They carry a negative charge.*

GAMMA RAYS

Gamma rays were found to have the same properties as X-rays:

Unaffected by electric or magnetic fields; travel with the velocity of light; cause fluorescence; blacken photographic plates; cause a small amount of ionisation. They very easily penetrate matter; can be diffracted; cause interference; and can eject electrons from material.

The gamma rays are electromagnetic waves of shorter wavelength than X-rays. The wavelength of the rays emitted depends on the emitting material.

RANDOMNESS IN RADIOACTIVE DECAY

The randomness of radioactive decay is very easily demonstrated using the ratemeter and a radioactive source such as the luminous face of a clock or watch.

Set up the ratemeter with the luminous dial near to the G-M tube. It will be noted that the ratemeter needle does not give a constant reading but fluctuates to a certain extent, showing that the atoms of the source are not emitting at a constant rate, their emission being quite random.

INVERSE SQUARE LAW OF GAMMA RADIATION

Like light radiation, gamma radiation obeys the inverse square law. This states that the intensity of radiation observed is inversely proportional to the square of the distance from the source.

To verify this is simple, all that is needed is a gamma source and the ratemeter. A suitable gamma source

IMPORTANT NOTICE

R1 and R2 should be 2.7MΩ and not 2.7kΩ as given in last month's article—pages 30 and 32.

is radium shielded by thin aluminium sheet to stop the unwanted beta and alpha rays. A luminous clock or watch face can be used, but it is better to have a more concentrated source such as some of the luminous paint used by watchmakers. This paint can be purchased from a wholesaler in such goods, and is packaged in a small test tube (of the type known as semi-micro test tubes).

The method of testing the inverse square law is to take the count rate at varying distances from the source and to plot a graph of $1/\text{distance squared}$ against the count rate. (See Fig. 1.)

Alternatively, a logarithmic graph can be plotted of log distance against log count rate. Here the relationship is verified more exactly as the assumption of the inverse square law applying is not assumed but the power to which the distance has to be raised to satisfy the equation is arrived at from the graph. (See Fig. 2.)

A typical set of results will now be treated to give the graphs mentioned:

Distance	$\frac{1}{(\text{Distance})^2}$	Count Rate	Log Distance	Log Count Rate
2	0.25	100	0.3	2.0
3	0.1	45	0.48	1.65
4	0.063	25	0.6	1.4
5	0.04	15	0.7	1.178
6	0.03	10	0.78	1.0
7	0.02	8	0.85	0.9
8	0.0156	6	0.9	0.78

Mathematically, the inverse square law is expressed as

$$R = \frac{k}{d^2}$$

$$R = \text{Count rate}$$

$$d = \text{distance}$$

Taking logs,

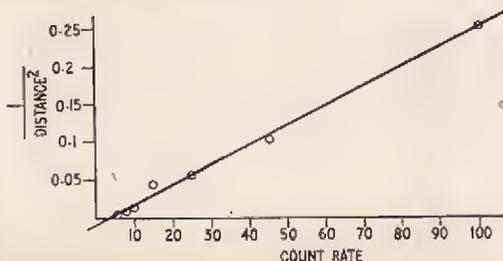
$$\log R = -2 \log d + \log k$$

Thus the power to which d must be raised can be obtained from the log graph as above (data for these graphs were from actual records using the ratemeter described last month).

It can be seen that the power to which the distance had to be raised was not determined exactly as 2, but consideration of the errors involved in the experiment (mainly in taking the reading from the ratemeter) shows the result to be within the range of experimental error.

Fig. 2 (right). A logarithmic graph of log distance against log count rate

Fig. 1 (below). This graph shows $1/\text{distance squared}$ plotted against count rate



This may seem to be a high error, but the ratemeter was not designed to give extremely high accuracy, and it must be remembered that the needle of the meter flickers to some extent all the time, presenting a difficulty in determining exactly what the reading should be. Each experimenter will have his own idea of where the arithmetic mean of the flickerings lie.

HALF LIFE AND ITS DETERMINATION

In radioactivity the decay of a substance is exponential, it never being completely annihilated, hence to talk of its total active period is impossible; so the time taken for *half* the specimen to decay away by radioactivity is taken as a measure of its term of existence, this being called the *half life*.

Treating this mathematically, suppose a given sample of radioactive compound contains N radioactive atoms at some time t , and the probability that each of these will decay in any one second is represented by a constant a (the decay constant).

Then the average number of atoms dN that decay in a time dt is given by,

$$dN = -aNdt$$

Integrating this over a time $t = 0$ to $t = t$

$$\int_{N_0}^N \frac{dN}{N} = a \int_{t=0}^{t=t} dt$$

hence,

$$N = N_0 e^{-at}$$

Where N_0 is the number of atoms present at time $t = 0$. The ratio N to N_0 is the fraction of radioactive atoms remaining unchanged after a time t .

The decay constant, a , is the fraction of the total number of atoms that decay in unit time (provided unit time is small enough). The units of the decay constant are reciprocal time, it usually being expressed as reciprocal seconds. Its value is constant and specific for a given nucleus.

Practically, this decay constant is not used, but half life, mentioned above.

At a time $t = \frac{1}{2}t_0$, the number of atoms remaining, N , equals $\frac{1}{2}N_0$. Substituting in the integral formula,

$$\frac{1}{2} = e^{-a \frac{1}{2}t_0}$$

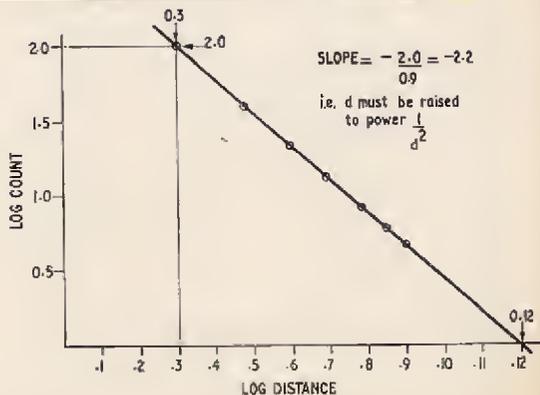
or

$$\log e^{-\frac{1}{2}} = -a \frac{1}{2}t_0$$

(t_0 is the half life)

then,

$$t_0 = \frac{\log e^{-2}}{a}$$



The actual rate of decay of a specimen is equivalent to the rate of emission of photons or particles, since each atom gives rise to a particle and/or a photon of radiation. This rate of emission is therefore the same as the absolute rate of decay, represented by,

$$-\frac{dN}{dt}$$

It is very difficult, however, to detect and record every single particle emitted from a radioactive mass, although it is possible to measure a constant fraction of that decay. This distinguishes between the count rate registered on the G-M ratemeter and the true rate of decay. The relationship between the two can be given as follows,

$$C = K\left(\frac{-dN}{dt}\right)$$

Where K represents the overall efficiency of the detection.

The numerical value C may replace the true rate of decay in the integrated decay equation.

$$C = C_0 e^{-at}$$

Hence,

$$\log_{10} C = -0.4343at + \log_{10} C_0$$

The logarithm of the measured count rate, C, plotted against the time, yields a straight line graph of slope $0.4343a$, from which a and hence $t_{1/2}$ can be found. In practice it is easier to plot count rate on semi-logarithmic graph paper against the time, and read off $t_{1/2}$ directly. (See Fig. 3.)

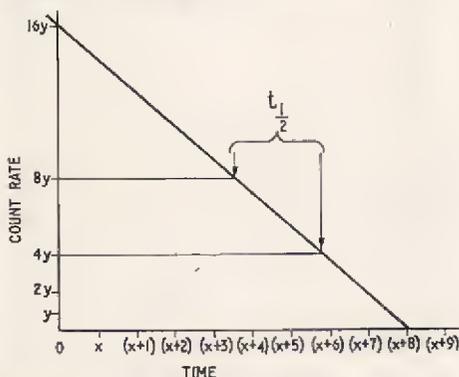


Fig. 3. Count rate plotted against time on a semi-logarithmic graph

It can be seen from the above description and the graph, that to obtain a value for the half life of a substance, a graph from which the slope can be easily determined or from which the half life is directly obtainable, is essential. This means that this method can only be employed for the determination of the half lives of substances in which that period is practicably short (say, up to one year). Thus the substances that the amateur normally deals with (uranium and radium mainly) whose half lives are extremely long (1,000 years at least) cannot easily be treated in this manner to obtain values for the half life period.

For the determination of the long half lives a special technique is employed. Here the rate of decay and the number of atoms present in the specimen are determined separately, these together with knowledge of the Avogadro number for the specimen (the number of molecules in one gram molecule of a substance). The value of the Avogadro number is 6.02×10^{23} molecules per mole. In the actual determination of the half life the quantities required are the decay rate,

the weight of substance under examination (accurately in grams), the gram molecular weight (from tables), and the Avogadro number.

It must be remembered that the count rate recorded by the ratemeter is not the decay rate but a fraction of it, and before any determinations of half lives can be undertaken this relationship must be established.

A SIMPLE PIECE OF APPARATUS

It will be of great use if the following simple piece of apparatus is constructed and used when determining half lives. It consists of a short length of wood with mounts for the G-M tube and the source holder. No dimensions have been given as these depend on the size of G-M tube available. The tube is mounted through holes drilled in blocks of wood which are mounted in the positions shown in Fig. 4.

Once the relationship between count rate and decay rate has been determined for the apparatus it can easily be used for future determinations of half lives. The relationship can be determined in two ways: by consideration of the geometry of the arrangement and by experiment, assuming the half life of a substance.

Considering the geometry of the system, the source can be considered as a point source as the quantities used by the amateur are small. Referring to Fig. 5, the following measurements must be made:

1. The distance from the centre of the source to the G-M tube—"d".
2. The width of the G-M tube—"a".

Hence from the geometry of the figure,

$$\tan A = \frac{a}{d}$$

hence A can be found in degrees.

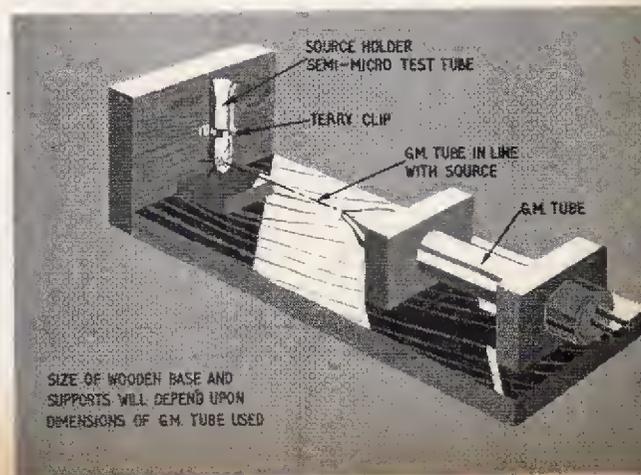
The constant relating count rate to decay rate is then $360/A$, assuming that the specimen radiates equally in all directions.

Having determined the constant for the apparatus it can now be used to find half lives. The method is as follows.

The first consideration is the fraction of radioactive material in the specimen under examination. Consider a radioactive element, M, existing in a compound, MX, which is under examination. The fraction of M present is then the ratio of M to M + X. A practical examination will now be given. In the compound radium chloride, the fraction of radium present is found as follows

$$\begin{aligned} \text{Molecular weight of Ra Cl}_2 &= 226 + (35.5)2 \\ &= 297 \end{aligned}$$

Fig. 4. Simple apparatus for half life experiments



Therefore the fraction of radium present is

$$\frac{226}{297} = 0.761$$

A weighed specimen of the substance under examination is then taken and the weight of radioactive material present is found. The count rate observed from the specimen in the above apparatus is noted. The half life is then found as follows.

Let the count rate be C, the constant of the apparatus be $360/A$, the weight of specimen taken W, the fraction of radioactive material present $1/f$, and the Avogadro number L. Let the molecular weight of the specimen be M. Then,

$$\text{Weight of radioactive substance present} = \frac{W}{f}$$

$$\text{True decay rate} = \frac{360C}{A}$$

Number of atoms present in the radioactive specimen

$$= \frac{W \times L}{f \times M}$$

The decay constant "a" therefore equals,

$$a = \frac{360CfM}{AWL}$$

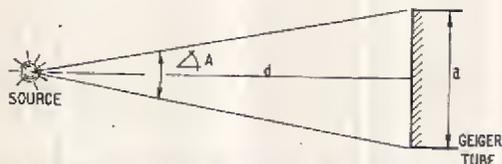


Fig. 5. Critical measurements in half life experiment set-up

A PRACTICAL EXAMPLE

A practical example from the author's own records will now be given.

Source to tube distance = 10cm
 Weight of radium taken = 5×10^{-6} grammes
 Diameter of G-M tube = 2cm
 Count rate = 570/sec

$$\text{Angle of acceptance} = \tan^{-1} \frac{2}{10} = 11.3^\circ$$

therefore,

$$\text{Decay rate} = \frac{570 \times 360}{11.3} = 18,150 \text{ counts/sec.}$$

Hence,

$$a = \frac{18,150 \times 226 \text{ (M.W. of radium)}}{6.02 \times 10^{23} \times 5 \times 10^{-6}}$$

(the weight of radium taken was 5×10^{-6} grammes)

Hence,

$$t_{\frac{1}{2}} = \frac{\log_e 2 \times 6.02 \times 10^{23} \times 5 \times 10^{-6}}{18,150 \times 226 \times 60 \times 60 \times 24 \times 365} \text{ years} = 1,600 \text{ years (true value 1,595 years).}$$

ASSAY OF ORES

The above determinations of the half lives of radioactive substances, while useful as an exercise, is not of much use to the amateur as the half lives of all the radioactive substances have been determined to a far greater degree of accuracy by professionals. The

use of the above method, however, does enable the amateur to assay radioactive ores. The process is as follows.

Having determined the radioactive compound present by chemical analysis, a weighed sample of the ore is treated as in the above experiment. The half life and molecular weight of the specimen are taken from tables, leaving the weight of radioactive material present the only unknown factor.

Having determined this, the assay of the ore can be expressed as a percentage or as content of radioactive material per ton. To clarify this an example will be given.

Weight of uranium ore taken = 100 grammes
 Molecular weight of uranium = 235
 Avogadro number = 6.02×10^{23}
 Rate count = 1,470 counts/sec.
 Half life of uranium = 7.1×10^8 years
 Constant for apparatus = $\frac{360}{11.3}$

$$t_{\frac{1}{2}} = \frac{\log_e 2 LW}{RM} \text{ (symbols as before, R = decay rate)}$$

Hence weight of radioactive material present is,

$$W = \frac{t_{\frac{1}{2}} RM}{\log_e 2L} = \frac{7.1 \times 10^8 \times 60 \times 60 \times 24 \times 365 \times 235 \times 1,470 \times 360}{11.3 \times 6.02 \times 10^{23}} = 0.593 \text{ grammes.}$$

Hence, assay of material is 0.593 per cent of uranium 235.

EXAMINATION OF RAIN WATER

Readers will no doubt remember the consternation that was caused a few years ago by the discovery of radioactive iodine (I_{131}) in milk. The half life of this isotope is eight days so its presence can be easily detected by the first of the two methods described for determination of half lives. The iodine entered the milk via rain which fell on the pastures of cattle. The concentration of the isotope in the rain would be very small.

Investigation of radioactive material in rain first necessitates the concentration of the rain water. For this a special kettle reserved for the purpose should be used. About a gallon of rain water is collected. The kettle is filled with this water and boiled almost to dryness; it is then refilled and the process repeated until all the rain water collected has been concentrated (a gallon is the minimum for usable results).

The concentrate should be of the order of 50 to 100cc. This is then transferred to a conical flask of 250cc capacity where final concentration is carried out. The final volume should occupy about a half of one of the semi-micro test tubes.

The radioactivity of the specimen is observed over a period of time and a graph of count rate against time is plotted. One reading a day at the same time each day will be sufficient. If the graph adopts an exponential form, the half life of the radioactive material present can be found. Since the half life is peculiar to a particular nucleus, the substance present can be identified.

The specimen of rain water for concentration must be concentrated as soon as possible after it has fallen.

The above article by no means exhausts the possibilities of the use of the ratemeter, but it is hoped that it will serve as an introduction to radioactivity enabling the individual to devise his own experiments and lines of research. ★