Section 9

PARTS LIST

SYMBOL	DESCRIPTION	SPECIFICATIONS	MANUFACTURER	MFGR PART NO.	NUCLEONIC STOCK NO.
N/A	Absorber, cylindrical, aluminum	Absorber, aluminum 2" dia x 6" long x 1/32" thick	Same as RDU-1F	RDU-1I	RDU-1I
N/A	Absorber, cylindrical cardboard	Absorber, lead 2" dia x6" long x 1/32" thick	Same as RDU-1F	RDU-1-J	RDU-1-J
N/A	Absorber, cylindrical, lead	Absorber, lead 2" dia x6" long x 1/32" thick	Same as RDU-1F	RDU-1K	RDU-1K
N/A	Radium Beta-Gamma Source	Radium Beta-Gamma Source	Same as RDU-1F	RDU-1E	RDU-1E
R30	V1B grid resistor	Resistor, fixed, composition, 1K, ½W, ±10%	Same as R1	Type EB	RDA69
TB7	Mounting Board for R30	Terminal Board	Cinch-Jones N.Y., N.Y.	51B	RDA70

PART II

Section 1

BACKGROUND

1. History of Radioactivity

The phenomenon of radioactivity was discovered accidentally in 1896 by Henry Becquerel who was experimenting with pitchblend, a uranium-containing ore. Its discovery resulted from the fortuitous blackening of some otherwise unexposed photographic plates and was caused by the penetrating radiations emitted by the natural occurring radioactive substances contained in the pitchblend. Shortly thereafter, Marie Curie working with her husband discovered radium, now perhaps the most famous radioactive substance. Since that time, over 40 naturally occurring radioactive substances have been found.

On Dec. 2, 1942 the first self-sustaining nuclear chain reaction was demonstrated in Chicago; this event marked the beginning of the atomic era. The atomic bomb, the hydrogen bomb, particle accelerators, and the nuclear pile or reactor, products of the atomic age, all produce artificial radioactive substances. Over 800 have been so produced.

The most important characteristic of these radioactive substances is their instability which results in their decay to more stable forms with an accompanying release of energy in the form of various types of radiation. The Geiger-Muller counter is a device which may be used to measure various qualities of this radiation including its intensity.

2. Radioactive Decay

The radioactive decay process is a property of certain types of atomic nuclei, and is independent of normal external environmental conditions.

The decay process is a statistical one, each radioactive nucleus of a particular species having only a definite probability of decaying within a given time and not a certainty of decaying in any finite time. The decay process is thus a random process. This randomness of the decay process means that during a given length of time the number of atoms of a particular species that decay, may vary due entirely to the statistical nature of the process. If during a time interval T, a certain number N of the atoms decay, this value N will differ from the expected value of N_e(based on the initial number of atoms present and the decay constant) by $0.6745\sqrt{N}$ fifty percent of the time or the rate N/T will vary from the expected rate by $0.6745\sqrt{N/T}$. Because such basic fluctuations exist, any interpretation of a measurement must include the statistics of the measurement for proper evaluation. However, although the process is random, there exists a certain average rate of decay for each type of radioactive substance, and this rate appears in the mathematical expression for the decay process as the decay constant. This law has the following form:

$$N = N_o e^{-\lambda \tau}$$

Where

N_o = the number of atoms of the particular species present initially.

N = the number of atoms of the same species present after τ time.

e = the base of the natural logarithms, a constant = 2.71828

λ = the decay constant for the particular species.

τ = time (in the same units as λ).

This law is called the exponential law of radioactive decay. The constant, λ, may be expressed in a different form called the half-life of the radioactive species. The relationship of these two quantities is:

$$\tau_{\frac{1}{2}} \text{ (half-life)} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

The half-life represents the amount of time required for N_o atoms to decay to $N_o/2$ atoms or for 1/2 of the original amount to decay.

3. Nuclear Radiations

The nuclear radiations resulting from radioactive decay are of several types; however, of particular interest are the most common forms, alpha, beta and gamma radiations.

Alpha radiation consists of double positively charged helium nuclei traveling at great speeds. They are emitted by certain types of radioactive substances such as uranium-238 and radium-226. This type of radiation is characterized by its great ionizing ability and short penetrating range. A typical alpha ray or particle has a range in air of only a few centimeters. This type of radiation has a definite maximum range in an absorbing medium.

Beta radiation consists of negatively charged electrons also traveling at high speeds. Substances such as phosphorus-32 and strontium-90 emit this type of radiation. Beta radiation has a smaller ionizing ability than alpha radiation but a much greater penetrating range. Typical beta rays may have ranges in air of many meters. As with alpha radiation, beta rays have definite maximum ranges.

Gamma radiation consists of very high energy electromagnetic radiation and is thus similar to radio waves, visible light, and x-rays.

It differs in being of much shorter wavelength (less than 1 Angstrom, 10^{-8} cm). Substances such as radium D (lead 210) and cobalt-60 emit such radiations. Gamma radiations has a still smaller ionizing ability than alpha or beta rays but a much greater penetrating power. This type of radiation does not exhibit a definite maximum range but obeys an exponential absorption law.

The ionizing ability and penetrating power of a given type of radiation are interrelated. The ionization process consists in the majority of the occurrences of the radiation knocking bound electrons free of their parent atoms; the result being free negative electrons and positively charged atoms called ions. This process also results in the loss of energy by the incident radiation; consequently, the greater the ionizing ability of the particular type of radiation the shorter its range must be. The collisions between the radiation and bound electron can result in a deflection or scattering of the radiation. This scattering depends on several factors including the type and energy of the radiation and the nature of the scattering medium.

If the radiation from a small source does not pass through an absorbing medium, i.e., if it passes through a vacuum, the radiation intensity becomes less the further one goes from the source. This is due to the fact that the source emits radiation in all directions, in a spherically symmetrical pattern, and thus, the radiation field spreads out as it leaves the source. The radiation intensity decreases due to this effect according to a $1/r^2$ law. This law may be expressed as follows:

$$I = \frac{I_o}{2}$$

where I_o = intensity at unit distance

I = intensity at distance r

r = distance

The mechanism behind this law may be understood through the following reasoning. Since there is no absorbing medium, the amount of radiation passing through any imaginary spherical surface centered at the source must be constant and equal to that emitted by the source. Since the surface area of a sphere equals $4\pi r^2$, the area of the spheres increase in proportion to the square of their radii. Therefore, the amount of radiation per unit area must decrease proportional to $1/r^2$ as indicated in the above law.

The two inferred methods of reducing radiation intensity, the use of absorbing material or shielding and the use of distance, are the two most effective and most commonly used for the protection of man from the damaging effects of nuclear radiations. In general, the damaging effects on man are associated with the ionizing effects which are involved in the mechanism of the radiation's absorption in matter and, in particular for man, his body tissue.

In general, alpha, beta, and gamma radiations occur in combination. For example, radium-226 emits alpha and gamma radiation. Other radioactive substances, for example those which are the products of the decay of radium, emit alpha, beta and gamma radiation. A radium source, thus, is a source of all three types of radiation. However, a single type of radiation can occur alone; phosphorus-32 and strontium-90 are so-called pure beta emitters, emitting only beta radiation. A third example, cobalt-60, is actually a beta and gamma emitter.

The beta radiation is of low energy and the gamma of relatively high energy, and thus, it is commonly used as a gamma ray source.

Section 2

EXPERIMENTS

1. G.M. COUNTER CHARACTERISTICS

a. G.M. Plateau

For proper operation of a Geiger-Muller counter (or G.M. counter), two particularly important properties of the system must be determined and employed. The first concerns the proper operating voltage for the G.M. tube. If the voltage is too low, none of the particles or rays traversing the tube will initiate an electrical discharge. As the voltage is increased, a point will be reached where occasionally a discharge sufficiently large will be detected; this is called the Geiger starting voltage. On further increasing the voltage, more and more discharges (or counts) will be observed until a region is reached where essentially each of the partic. or rays producing a free electron in the counter tube will yield a detectable discharge. This is the Geiger threshold voltage. A further increase in operating voltage will no longer result in any appreciable increase in the counting rate; this region is called the plateau. The correct operating voltage is in the center of this plateau. At some still higher voltage, the G.M. tube will break into a continuous or self-sustaining discharge which is injurious to the G.M. tube and prevents its use as a radiation detection device. From previous experimentation it is known that this region is not usually encountered within 150 volts above the threshold voltage; and consequently, it is considered a safe

practice never to permit the operating voltage to become greater than this voltage. Experiment #1 below concerns the determination of the counter plateau with this instrument.

Experiment #1:

First, make certain that the high voltage adjustment is turned fully counter-clockwise. Then, turn the unit on and allow it to warm up for several minutes. While the unit is warming up, place one of the radium sources approximately 1 inch from the side of the G.M. tube. The source label should face the tube and the beta shield should be closed. With the selector switch in the "high voltage check" position, increase the voltage slowly until the unit begins to record counts as observed on the indicating light or heard over the speaker. (Caution: Never allow the voltage to go over 1000 volts. If the unit does not begin counting before this voltage it is not functioning properly).

Record the voltage at which counting began; it is the counter starting voltage.

Next increase the operating voltage in 20-volt steps until 1000 volts is reached. After each 20-volt step, record the voltage. Place the selector switch in the X1 position. Allow the indicating meter to settle down to a steady reading by waiting eight seconds and record the counting rate. Plot the results on graph paper to determine the nature of the plateau curve. In general, a G.M. plateau for a halogen-quenched type of geiger tube such as is supplied with this equipment shows some increase in observed counting rate with increase in operating voltage; calculate what this increase actually is from the above data in terms of percent increase per 100 volts increase in operating voltage. A G.M. tube such as is supplied with this equipment may yield values varying from 5 to 20% increase per 100 volts. Select an operating voltage for the instrument which is near the center of the plateau region. This operating voltage should always be employed when using the particular instrument for which it was determined. If a new G.M. tube is put in the instrument or if the tube has not been used for a considerable time, an operating voltage should be determined.

b. Resolving Time

The second important property of a G.M. counter is its resolving time. Due to the nature of the G.M. discharge, during and shortly after a discharge the tube cannot be stimulated to yield a second discharge. This is because the positive ions, which were created during the first discharge, and ultimately aided in the quench of that discharge, remain and thus quench the second discharge before it actually begins. If sufficient time is allowed, however, these positive ions, under the influence of the high voltage, drift to the outer electrode and are neutralized. The time that elapses before a second discharge of full magnitude can appear corresponds to the resolving time of the counter. Experiment #2 concerns the experimental measurement of the counter resolving time.

Experiment #2

Place the counter in operation using the operating voltage determined in experiment #1 and put the selector on the X10 position. Place the two radium sources on a firm support in front of the G.M. tube; the calibration mounting board may be used for this purpose. The G.M. tube shield should be open, and the white faces of the sources should be facing the tube.

Adjust the relative position of the G.M. tube and the sources so that the counter is measuring from 10,000 to 15,000 cpm (1000 to 1500 on X10 scale.) Mark the location of the two sources so that they may be individually removed and replaced in exactly the same place and position as initially. Determine the measured count rate for each individual source in its particular position. The sum of the measured count rates of the individual sources should be greater than that measured for the two together. From the value of these three measurements, an approximation of the resolving time of the G.M. counter can be obtained through the following formula:

$$T_R = \frac{R_1 + R_2 - R_{1+2} - R_b}{R_{1+2}^2 - R_1^2 - R_2^2}$$

Where T_R = the resolving time in minutes

R_1 = the measured count rate of source number 1 in cpm

R_2 = the measured count rate of source number 2 in cpm

R_{1+2} = the measured count rate of sources number 1 and number 2 together in cpm.

R_b = the measured count rate in cpm in the absence of both sources (i.e., the background count rate)

Calculate the resolving time of your instrument using the above obtained data and this formula.

Once the resolving time of the instrument is known, each measurement can be corrected for errors due to this so-called coincidence loss using the following formula:

$$R^* = \frac{R}{1 - RT_R}$$

where R^* = the corrected rate in cpm.

R = the measured count rate in cpm.

T_R = the resolving time in minutes.

Usually the resolving time is on the order of several hundred microseconds (one microsecond is one millionth of a second), and consequently, the measured count rate must be several thousand cpm for the correction to be significant. However, the correction is proportional to the square of the measured count rate; and thus, it increases rapidly at the higher count rates.

Questions on Experiments #1 and #2

(1) Before turning on the instrument, what adjustment should be made?

(2) What would be the percentage correction for a measured rate of 15,000 cpm if the resolving time were 200 microseconds? What would this correction be in terms of percentage correction per 1000 cpm of measured rate?

(3) Would the plateau change shape if it were determined at a count rate of 10,000-15,000 cpm instead of 1000 to 1500 cpm? Why?

Possible Additional Experiments

(1) Determine the plateau at high count rates and compare with that at low count rates.

(2) Determine the resolving time for different operating voltages below 920 volts.

(3) Correct the count rates observed in 1 above with coincidence corrections determined in 2 above and compare with the plateau obtained at lower count rates.

Answers to Questions on Experiments #1 and #2

(1) The high voltage adjustment should always be turned fully counter-clockwise to insure that an accidental turning of the knob during transportation or a variation in line voltage does not result in too high a voltage being applied to the G.M. tube.

(2) Substituting in the given equation:

$$T_R = \frac{200}{1{,}000{,}000} \times \frac{1}{60} = 0.0000033 \text{ min}$$

$$R^* = \frac{15{,}000}{1 - 15{,}000 \times 0.0000033} = \frac{15{,}000}{1 - 0.0495} = \frac{15{,}000}{0.95}$$

$$R^* = 1.053 \times 15{,}000 = 15{,}800 \text{ cpm}$$

Therefore the percentage correction is 5.3%. The percentage correction per 1000 cpm of measured count rate would be:

$$\frac{5.3}{15} = 0.35\% \text{ per } 1000 \text{ cpm}$$

It is common to convert this resolving time correction to a percentage correction per 1000 cpm as above. This can be justified by the following approximation:

$$R^* = \frac{R}{1 - RT_R} \cong R(1+RT_R)$$

This formula shows that the correction is proportional to the measured rate. It has been found that this coincidence correction is easily handled in this fashion.

(3) Yes; since increased voltage makes the positive ions drift to the outer electrode faster, the resolving time decreases with increasing operating voltage causing the coincidence correction to become less at the higher voltages; and thus, the measured count rate must increase. The resulting plateau tends to become steeper at the higher voltages. The plateau is, consequently, determined at the lower count rate so that its true shape may be determined.

2. Statistics of The Radioactive Decay Process

As already discussed, the decay process is a random process. Although nothing can be said about any individual observed count, very definite things can be said concerning averages of large numbers of observed counts. If a large number of counts, N, are expected in a given time interval, T, the actual number observed, n, will have the following probability distribution:

$$P(n) = \frac{1}{\sqrt{2\pi N}} e^{-\frac{(N-n)^2}{2N}}$$ (for N greater than approximately 100)

P(n) is the probability of observing n counts when N is expected. The number, N, expected is presumably known or can be precisely determined from the amount of the radioactive substance, its decay constant, and the sensitivity of the detecting system. This formula can be expanded, and it will be found that the probability is 0.5 that n will be within the interval from $N-0.6745\sqrt{N}$ to $N+0.6745\sqrt{N}$. and that the probability is 0.95 that n will be within the interval from $N-1.96\sqrt{N}$ and $N+1.96\sqrt{N}$. If N is not known, n can be used as a satisfactory estimate of N with the following change in interpretation. If n counts are observed the probability is 0.5 that the interval $n-0.6745\sqrt{n}$ to $n+0.6745\sqrt{n}$ includes the true or expected number, N, and the probability is 0.95 that the interval $n-1.96\sqrt{n}$ to $n+1.96\sqrt{n}$ includes the true or expected number, N. It should be noted that the greater the certainty of the inclusion of the expected number within the interval the wider that interval becomes, and the greater n is the smaller this interval becomes. Experiment #3 concerns the demonstration of these statistical properties.

Experiment #3

Turn the Radioactivity Demonstrator on and adjust it to its proper operating voltage after allowing it to warm up. Remove all sources from the vicinity of the instrument and adjust the speaker volume so that it is easily heard. Under such conditions, the background radiation intensity, which is due to cosmic rays and radioactivity in the local

area, should be near 50 cpm, and it should be possible to count them by ear as individual pulses. While watching the clock, count, listening by ear, the number of counts which occur during several 30-second intervals. For each interval, calculate the number of counts that the above formula predicts for a 0.5 probability (the $n-0.6745\sqrt{n}$ to $n+0.6745\sqrt{n}$ interval.) Compare the observed fluctuation from interval to interval with those calculated.

The electronic circuitry of the demonstrator ratemeter circuit averages over a period of time of approximately two seconds. This means that electronically the number of counts observed during this period is effectively divided by the time interval and displayed on the meter. Place a source in such a position that a count rate of several thousand cpm are observed. Calculate the size of the predicted fluctuations from a 0.5 probability. In this case the value of n equals the count rate observed in cpm divided by 30, and the predicted fluctuations are $\pm 0.6745\sqrt{n}$ multiplied by 30. Compare the observed and calculated values. The observed count rate should be outside of the calculated interval approximately 1/2 of the time. Calculate and compare for a 0.95 probability; under these conditions the observed value should be outside of the calculated region only 1/20 of the time.

Note that the larger the observed count rate the larger the effective value of n becomes. Note also that although the relative magnitude of the fluctuations decreases, their absolute value increases. This sort of effect makes it difficult to observe small relative changes. Using two of the radium sources, place one so that a count rate of approximately 250 cpm is observed. Remove this source and note the decrease in observed count rate. Next place the second source so that a count rate of 10,000 cpm is observed. Place the first source back in its original position and note the exact observed count rate due to both sources. Is it easily possible to detect the presence of the first source when the second one is present? Compare the calculated and observed fluctuations of the second source with the measured intensity due to the first source.

Questions on Experiment #3

(1) If one sums all the counts observed during all the 30-second intervals, what is the size of the predicted interval of uncertainty of 0.5 probability?

(2) If one has an instrument with a fixed time constant such as this one, how can he obtain a more precise measure of a particular observed radiation intensity?

(3) If one wished to observe small changes in radiation intensity with greater precision, how would one change the experimental conditions?

Possible Additional Experiments

(1) Count the number of counts due to background radiation for periods other than 30 seconds, such as ten seconds and two minutes. Compare the observed and predicted fluctuations.

(2) Determine the time constant of the instrument by removing a source producing a high observed radiation intensity very quickly. The time constant is equal to the time it

takes for the indicated intensity to drop approximately 2/3 of the way to its ultimate value with the source removed or 1/2 of the time it takes it to drop 8/9 of the way to its ultimate value.

(3) For small values of N and n the probability distribution is better represented by the following formula:

$$P(n) = \frac{N^n e^{-n}}{n!}$$

Where n! n(n-1) (n-2).... 1, and the other symbols are as above. Calculate the differences between the two formulae for several values of N less than 10 and n less than 20. Determine which formula best represents the observed data by counting the number of counts due to background radiation over short periods of time such as five seconds.

Answers to Questions on Experiment #3

(1) If you add all counts together the new value of n is this sum. In calculating the interval of uncertainty this value of n is used in the formula; the size of the interval is not the sum of the intervals calculated for each individual 30-second period.

(2) Since the instrument has a given time constant over which it averages, if one records the indicated radiation intensity at periods separated by several times the instrument time constant, essentially independent measurements will be obtained. One may, consequently, record the exact indicated intensity at arbitrary instances of time which are separated by at least 10 seconds and average the results, thus obtaining a more precise value. In general, one does not record the exact indicated intensity at an arbitrary

instant of time, but one tends to mentally average the variations thus obtaining a more precise value unconsciously; however, the mind tends to exhibit prejudices while electronic circuitry usually does not.

(3) Three improvements should be made. First, any radiation sources which are not of interest should be removed from the vicinity, thus reducing the absolute value of the undesired statistical fluctuations. Second, an instrument of longer time constant should be employed, thus effectively increasing the number of observed counts, n. Third, the detector should be placed as close to the source as possible to detect as many of the particles or rays from the source of interest as possible, thus reducing the relative statistical fluctuations and permitting the detection of smaller relative changes in intensity due to the source of interest.

3. The Propagation, Absorption and Scattering of Radiation

As discussed in the technical background section, the radiation intensity due to a physically small source, considered a "point source", can be reduced by two basic means. First, the further one goes from the source the lower is the radiation intensity due to that source. Second, the more matter that is placed between the source and the point of interest the lower is the radiation intensity. However, since both beta and gamma radiation are easily scattered and thus are not always propagated in straight lines, surrounding matter can cause the radiation intensity to be greater than would be observed without this surrounding matter. Consequently, the nature of these effects and their interrelations are of interest. Experiments #4, #5, and #6 concern these effects.

a. The $1/r^2$ Propagation Law:

Free from the effects of absorption and scattering, these nuclear radiations obey a $1/r^2$ propagation law as described in the technical background section. Measurements performed in air while making use of the wooden calibration board supplied yield results which indicate the satisfactory reduction of the effects of absorption and scattering. Experiment #4 is such an experiment.

Experiment #4:

Place the G.M. tube in the clip provided for it on the wooden calibration board. Open the beta shield, center the open window over the groove, and face the open window towards the board. Turn the unit on and adjust the operating voltage to the proper value. Place one of the radium sources on the board and record the radiation intensity when the source is placed at various distances from 1 to 24 inches from the G.M. tube.

Substitute the values in the $1/r^2$ law formula below:

$$I = \frac{I_o}{R^2}$$

where I = radiation intensity at the distance r

I_o = radiation intensity at unit distance

r = distance

Calculate the value of I_o for each distance. The value of I_o should be constant, independent of the distance; is it constant? Plot the results of observed radiation intensity versus distance on graph paper. Select a value of I_o that is constant for several different distances, and observe whether

Questions on Experiment #4:

(1) Variations from the $1/r^2$ propagation law will be observed at the very small and very large distances. In both cases, the observed radiation intensity will be too small. Explain the cause for these deviations.

(2) At extremely large distances, the variation from the $1/r^2$ propagation law will deviate in the positive directions, too large a radiation intensity will be observed. Explain a cause for this deviation.

(3) If one doubles the distance from a particular "point source", what will be the factor of reduction in radiation intensity due to that source?

(4) The quantity of radiation one can be exposed to with safety is directly proportional to both the intensity and the time of the exposure. If one can remain five feet from a particular "point source" for one hour, how long may one remain at a distance of twenty feet?

(5) If a person can work a distance of ten feet from a "point source" for eight hours a day, and five days a week, year round, how much of the time can he safely work a distance of twenty feet from the source?

Answers To Questions On Experiment #4:

(1) In the case of the extremely short distances, the radiation detector (the G.M. tube) and the source cannot be considered points. There is thus no clearly defined distance from the source to the detector. In general, one measures from the front of the source to the center of the G.M. tube; consequently, at short distances the extreme ends of the G.M. tube are significantly further from the source than the measured distance. The result is thus a lower measured radiation intensity.

In the case of the great distances, the effect of the intervening air is the cause of the variation. It was required that the effects of absorption be eliminated to demonstrate the propagation law. However, although air is not a dense absorbing medium, at sufficiently great distances the less penetrating beta particles from the radium source are absorbed. The result is a lower observed radiation intensity.

(2) At extremely great distances the effect of background radiation becomes important. No matter where measurements are performed, one always observes a relatively constant level of background radiation. This radiation

is from local radioactive materials present in the earth and most building materials and from cosmic rays which strike the earth from outer space. When one attempts to observe radiation intensities below this background intensity, one actually observes the now predominant background radiation intensity.

(3) Using the given formula, let I_1 be the radiation intensity at distance r and I_2 be the intensity at distance 2r. I_o will be the same for both situations.

Substituting into the formula:

$$I_1 = \frac{I_o}{r^2} \quad , \quad I_2 = \frac{I_o}{(2r)^2} = \frac{I_o}{4r^2}$$

Therefore:

$$\frac{I_2}{I_1} = \frac{I_o/4r^2}{I_o/4^2} = 1/4$$

Consequently, the intensity will be reduced by a factor of 1/4.

(4) As in Question #3:

$$\frac{I_2}{I_1} = \frac{I_o/20^2}{I_o/5^2} = \frac{25}{400} = 1/8$$

thus, since the intensity is reduced to 1/8, the time may be increased to eight hours.

(5) Since the distance is doubled (from 10 to 20 feet), the radiation intensity is reduced to 1/4 of its former value. The worker was allowed formerly eight hours times five days, or forty hours a week at ten feet from the source; consequently, he may now work four times forty hours or one hundred and sixty hours a week at a distance of twenty feet. Since a week contains one hundred and sixty-eight hours, he may work essentially 100% of the time at twenty feet or further from the source.

Possible Additional Experiments:

(1) Since part of the variation at great distance was due to beta ray absorption in the air, one may close the beta shutter and perform the experiment without the beta radiation.

(2) The results may be plotted on log-log graph paper; the result should be a straight line.

(5) The coincidence correction determined in experiment #2 may be employed to correct the measured radiation intensity observed when the source was close to the detector. This correction should help to correct for some of the variations from the theoretical propagation law observed at these distances.

b. The Absorption of Radiation:

The absorption of radiation depends not only on the amount of absorbing material, but also on the composition of the material, and the type and energy of the radiation. Experiment #5 concerns these effects.

Experiment #5:

Using the same arrangement as used in Experiment #4, place the source at a distance such that 10,000-15,000 cpm are observed. Place in succession 1, 2, 3, etc. of the twenty cardboard absorbers between the G.M. tube and the source and record the observed radiation intensity after the addition of each absorber. Perform the similar measurements for the fourteen aluminum absorbers and the ten lead absorbers. Plot the three sets of data on three pieces of graph paper. Note the change in the curve after the addition of the 14th and/or 15th cardboard absorbers. A similar change should be observed for the aluminum and lead absorbers.

Questions on Experiment #5

(1) What is the cause of the change in the shape of the absorption curve after the 14th and/or 15th cardboard absorber?

(2) From the recorded data, how many lead absorbers are required to absorb all of the beta radiation?

(3) How many lead absorbers are required to reduce the gamma radiation intensity to 1/2 its initial intensity?

(4) Why are dense materials such as lead used for shielding instead of equal weights of lighter materials?

Answers

(1) As in experiment #4, this effect is due to the absorption of the beta radiation. As the amount of absorbing material between the source and detector is increased, the beta radiation is reduced much faster than the gamma radiation; consequently after a sufficiently great thickness of absorber has been added, the beta radiation is reduced to zero and only the remaining gamma radiation is observed. Since the gamma radiation has an absorption law different than the beta radiation, the shape of the absorption curve changes.

(2) Essentially all the beta radiation should be absorbed in a single lead absorber.

(3) Approximately 10 lead absorbers should be required.

(4) Dense materials such as lead permit the construction of more compact absorbers. However, in some situations where large areas such as a room or a building must be protected, materials such as iron and concrete are ultimately more economical.

Possible Additional Experiments:

Plot the data for all types of absorbers on semi-log graph paper. The radiation intensity should be plotted on the log axis, and the number of absorbers on the linear axis. The semi-log graph paper permits a better representation of the data.

c. The Scattering Of Radiation:

The scattering of nuclear radiation requires the interaction of the primary radiation with the scattering medium and the subsequent continuation of the radiation in a different direction. Since the interaction is a process of energy absorption, many primary particles or rays do not result in a scattered particle or ray which can trigger the G.M. tube; when large amounts of radioactive materials are involved, the net effect may be very important.

Experiment #6

Employing the set-up used in experiment #4, place a radium source at or near the end of the G.M. tube with the white source face facing away from the G.M. tube. Observe and record the radiation intensity due to the radiation source. Next place one cardboard absorber, then one aluminum, and then one lead each separately one inch in front of the source. The source should be between the absorber and the tube. Observe and record the increased radiation intensity. Next, place all of the cardboard, aluminum, and lead absorbers separately in front of the source and G.M. tube as was done with one absorber. Note any increased scattering with the thicker scattering medium. Next, place one lead absorber in front of the source and G.M. tube and note the radiation intensity, and then in succession place 1, 2, 3, and 4 cardboard absorbers between the lead absorber, and the G.M. tube and source. Note the decreased scattering of radiation. To observe increased scattering tape the source to the end of the G.M. tube probe so that they may as one unit be placed within the cardboard, aluminum and lead tubes provided. Note the increased scattering due to the shape of the scattering medium.

Questions on Experiment #6

(1) What material produces the greatest amount of scattering?

(2) Does the scattering depend greatly on the thickness of the scattering medium?

(3) Sometimes lead shielding for counters is lined with aluminum. Why?

Answers to Questions For Experiment #6

(1) The lead absorber yields the greatest amount of scattered radiation. It is found that the higher the average atomic number of the material (a property of the individual elements) the greater the scattering.

(2) In this experiment, the main part of the scattering radiation was due to the beta radiation. Since beta rays are relatively easily absorbed, a scattering medium greater in thickness than 1/2 that required to absorb all all the beta rays will have the same effect as a thicker absorber. Consequently, one or two lead absorbers have the same effect as all ten lead absorbers.

(3) The aluminum lining is used to minimize the effect of scattered radiation within the shielding.

Possible Additional Experiments

(1) Create a beam of beta rays by placing a source behind a hole (approximately 1" in diameter) in a lead absorber. Study the beam and determine whether it travels in straight lines and is reflected (or scattered) as with light.