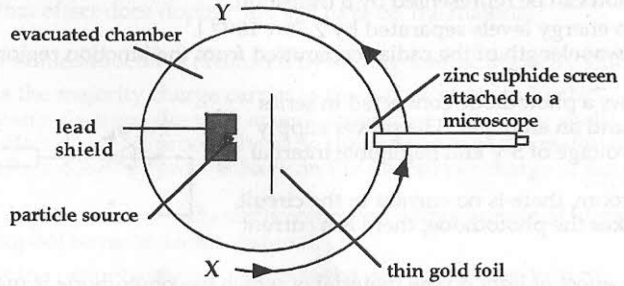
Radioactivity

Exercise 10.1 Rutherford's Experiment

1. In Rutherford's famous experiment to investigate the structure of the atom, a beam of radiation is directed at a thin gold foil target as shown.



a) i) State the type of radiation used.
   ii) Describe what the experimenters observed as the microscope was moved from X to Y.
   iii) Explain how the results of the experiment suggest that the mass of the atom is concentrated at its centre (the nucleus).

b) Geiger and Marsden carried out the experiment and also investigated the effect of using elements other than gold.
By imagining the passage of a single particle near to the nucleus of an atom with an atomic number less than gold, suggest how the deflection might compare with a particle passing at the same distance from the nucleus of a gold atom.
Explain your answer.

2. Describe briefly, with the aid of a diagram, the model of the atom which Rutherford proposed on the basis of the experiment described in question 1.

3. Decide whether or not each of the following are valid conclusions resulting from Rutherford's particle scattering experiment.

a) The nucleus of an atom contains only neutrons and protons.
b) The mass of the proton is nearly equal to that of the neutron.
c) The nucleus of an atom is very much smaller than the atom itself.
d) Alpha particles are helium nuclei.
e) There are large spaces between the atoms in a gold foil.
f) The nucleus has a very high density.
g) The nucleus contains uncharged particles called neutrons.
h) The nucleus has a positive charge.
i) The alpha particles are absorbed, changing the atomic number of the metal.

Exercise 10.2 Alpha, Beta and Gamma

(A copy of the Periodic Table is required for the questions in this exercise.)

1. A radioactive source is known to emit two types of radiation.
Describe, with the aid of a diagram, an experiment on the absorption of radiation which would allow you to determine which radiations are emitted.

2. A radioactive source emits radiation which is reduced to one third of its intensity when a sheet of notepaper is placed in front of the source, and is reduced almost to zero when sheet of aluminium, 1 cm thick, is placed between the source and the counter.
What types of radiation are emitted?

3. A radioactive source gives a high count rate when a Geiger-Muller detector is placed near it. The count rate drops appreciably when a sheet of paper is placed between the source and the detector. A sheet of lead, a few millimetres thick, in place of the paper causes no further appreciable drop but a sheet of lead, several centimetres thick, does cause a further drop in the count rate.

a) What two types of radiation are emitted?
Explain your answer.
b) Why is there a very small count-rate, even with the lead screen in position?

4. A uranium atom has the symbol $^{238}_{92}U$.

a) How many protons are in the nucleus?
b) How many neutrons are in the nucleus?
c) How many electrons are in the neutral atom?

5. The two isotopes of chlorine have relative atomic masses of 35 and 37.

a) What is meant by isotopes?
b) Explain why the relative atomic mass of chlorine is quoted as 35.5.

6. a) What is meant by the term 'ionisation'?
b) Which radiation, alpha, beta or gamma, produces the most ionisation?

7. Decide whether each of the following statements concerning gamma rays is true or false.

a) They can ionise air.
b) They can be deflected by electric fields.
c) They can be deflected by magnetic fields.
d) When a gamma ray is emitted, the nucleus changes into a different isotope.

8. a) Describe the structure of
   i) an alpha particle,
   ii) a beta particle.
b) What is a gamma ray?

9. For each of the following emissions, give the structure of the final daughter product.

a) An atom of the radioactive isotope $^{234}_{91}Pa$ emits a beta particle.
b) The nuclide $^{220}_{86}Rn$ emits an alpha particle.
c) The radioisotope $^{237}_{93}Np$ emits an alpha particle.
d) The radioactive nucleus $^{238}_{94}Pu$ emits a gamma ray.

10. Part of a radioactive decay chain is shown.

$$^{238}_{92}U \xrightarrow{x} {}^{234}_{90}Th \xrightarrow{y} {}^{234}_{91}Pa \xrightarrow{z} {}^{234}_{92}U$$

Identify the particles emitted at stages x, y and z.

11. A decay series starting with thorium, $^{232}_{90}Th$, involves the emission in turn of alpha, beta, beta, gamma and alpha radiation.
Identify the final product.

12. What **three** particles must be emitted to change $^{238}_{92}U$ into $^{234}_{92}U$?

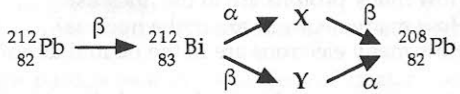
13. A radioactive element of atomic number Z and mass number A emits an alpha particle followed by a gamma ray.
What is the atomic number and the mass number of the new element formed?

14. The diagram shows a series of radioactive changes in which nucleus W forms nucleus X which then forms Y and finally Z.

$$W \xrightarrow{\alpha} X \xrightarrow{\beta} Y \xrightarrow{\gamma} Z$$

a) What is the total change in mass number?
b) What is the total change in nuclear charge?

15. Part of a radioactive decay series of lead-212 is shown.
Give the element symbols with atomic number and mass number for each nuclide X and Y.



16. The unstable isotope of iodine, $^{139}_{53}I$, is a possible fission product in a nuclear reactor.
It decays in **four** stages, emitting a beta particle each time.
a) Identify the nuclide formed as the stable end product, after the four stages.
b) The emitted beta particles carry away some energy as kinetic energy and at the same time energy is radiated from the nucleus in another form.
What name is given to this other form of radiation?

17. The last two stages in a radioactive decay series are shown. A bismuth nucleus decays by beta decay into polonium which then emits an alpha particle to form lead.
Which numbers are represented by **P**, **Q**, **R** and **S**?

$$^{P}_{Q}Bi \xrightarrow{\beta} {}^{R}_{S}Po \xrightarrow{\alpha} {}^{208}_{82}Pb$$

18. Part of a radioactive decay series is:

$$^{235}_{92}U \xrightarrow{x} {}^{231}_{90}Th \xrightarrow{y} {}^{231}_{91}Pa \xrightarrow{z} {}^{227}_{89}Ac \ldots\ldots\ldots\ldots {}^{207}_{82}Pb$$

a) Name the types of radiation x, y and z .
b) How many alpha and beta particles are emitted in the missing part of the series, between actinium-227 and lead-207?
c) Explain why the series as given does not necessarily give a complete picture of the radiations emitted by each radioactive nucleus.

Exercise 10.3 Absorbed Dose and Equivalent Dose

1. A patients's thyroid gland is to receive a radiation dose of 500 Gy from a source, so that 15 J of energy is absorbed by the gland.
Calculate the mass of the thyroid gland.

2. A stream of neutrons, of radiation weighting factor 10, produces a equivalent dose of 5 mSv in a biological specimen.
Calculate the absorbed dose.

3 a) State the typical equivalent dose rate, in millisieverts per year, due to background radiation.
b) Give **three** sources of background radiation.

4. Guidelines state that workers in the nuclear industry should not exceed 50 mSv in any year. Readings on monitors show that a particular area near Chernobyl will provide an absorbed dose rate of 1 mGy h^{-1} of gamma radiation, 200 μGy h^{-1} of thermal neutrons and 40 μGy h^{-1} of fast neutrons.
a) Explain the meaning of 'absorbed dose'.
b) Give **one** method of monitoring the absorbed dose that a worker experiences.
c) State the relationship between equivalent dose and absorbed dose.
d) Using the W_R values given below, calculate how many days in a year a worker can be employed in this area if the worker is exposed to this environment for five hours per day.

Radiation	W_R value
γ-rays	1
thermal neutrons	3
fast neutrons	10

5. In investigating the effect of different types of radiation on the human body, the data shown was obtained for one particular type of body tissue.

Radiation	Absorbed dose rate	Radiation weighting factor
gamma rays	100 μGy h^{-1}	1
fast neutrons	400 μGy h^{-1}	10
alpha particles	50 μGy h^{-1}	20

a) Use the data in the table to show which radiation is likely to be the most harmful to this tissue.
b) The maximum permitted equivalent dose for this tissue is 5 mSv.
Calculate the time the tissue can be exposed to fast neutrons without exceeding this limit.
c) A sample of this tissue has a mass of 25 g.
How much energy will it absorb from fast neutrons in 2 hours?

6. A radium-226 source emits alpha, beta and gamma radiation with radiation weighting factors of 10, 1.3 and 1 respectively. The source is is stored in a steel cabinet and the absorbed dose rate 1 m from the cabinet is 0.0410 μGy h^{-1}.
   a) i) Which radiation will **not** penetrate the walls of the steel cabinet?
   ii) Find the annual equivalent dose for someone working 1 m from the cabinet for 6 hours per day, 200 days per year.
   iii) State whether this exceeds the annual permitted dose for a member of the public.
   b) The worker considers this equivalent dose to be too high. State **two** ways in which it could be reduced.
   c) The biological effect of radiation striking a body depends on the energy absorbed by the body. State the **three** factors on which the energy absorbed by the body depends.

7. The workers in the factory assembling a smoke detector will experience an absorbed dose of 1.2×10^{-8} Gy for each detector assembled. The radiation weighting factor of this radiation is 20.
   Show by calculation whether or not a worker assembling 15 000 detectors in a year will exceed the permissible limit of 5.0 mSv per year.

8. A nuclear medicine laboratory contains a small radioactive source in a sealed container. The following information is displayed on the label.

   Radionuclide: ^{131}I
   Date: 7 th June 1999 (12 noon)
   Activity: 300 MBq
   Half life: 8 days
   Radiation emitted: gamma (radiation weighting factor 1)
   Equivalent dose rate at a distance of 1 m: 16 μSv h^{-1}

   a) When the source has the activity stated on the label, how many nuclei decay in 1 minute?
   b) A technician needs to work at a distance of 1 m from a freshly prepared source. For what period of time can the technician work at this distance so that the absorbed dose does not exceed 50 μGy?

9. In a sample of radioactive material 6×10^5 nuclei decay in a time interval of 1 minute.
   a) Calculate the activity of the sample.
   b) If each decay provides 2.5×10^{-16} J of energy to a tissue of mass 25 g, calculate the absorbed dose in 1 minute.
   c) If the radiation weighting factor of the radiation is 1.7, calculate the equivalent dose.

Exercise 10.4 Half Life

1. The activity of a radioactive source falls to one eighth of its original value in 24 minutes.
   What is the half life of this radioactive source?

2. A radioactive isotope has a half life of 20 minutes. A particular sample of this isotope gives a count rate of 3200 per second at 2 o'clock on a certain afternoon.
   At what time later that day is the count rate 200 per second?

3. In a half life experiment, the following readings were obtained.

Time	Corrected count rate
0 s	320 counts per second
40 s	160 counts per second

   What is the corrected count rate 160 s from the start of the experiment?

4. A radioactive element has a half life of 20 minutes.
   If we could study the decay of **one particular atom** of this material, what can we say about when this atom will decay?

5. In order to trace the line of a water pipe buried about 0.5 m below the surface of a field, an engineer proposes to add a radioactive isotope to the water. A Geiger-Muller detector will show an increase in count rate when held directly above the pipe.
   a) State whether the isotope should emit alpha, beta or gamma radiation.
   b) State whether the isotope should have a half life of a few minutes, a few hours or a few years.

6. The half life of radioactive sample is 8 days. The sample is held in front of a Geiger-Muller detector which gives a corrected count rate of 120 per minute. A second corrected count of 120 is taken 24 days later.
   For how many minutes would this second count have lasted?

7. Two radioactive substances are mixed together. Initially the count rate from each substance is 320 counts per minute, giving a total count rate of 640 counts per minute. The half lifes of the substances are 1 hour and 2 hours.
   What is the combined count rate after 4 hours, in counts per minute?

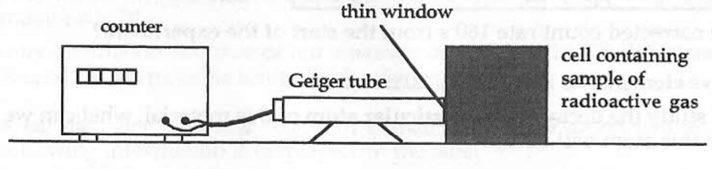
8. A radioactive source contains two materials. One material decays by the emission of alpha particles with a half life of 4 days, while the other material emits beta particle and has a half life of 3 days.
   The initial corrected count rate is 176 s^{-1} but this becomes 80 s^{-1} when a piece of tissue paper is placed between the source and the detector.
   What will be the corrected count rate (without the tissue paper present) after 12 days?

9. A counter measures the activity of a sample of radioactive element. The following results were obtained.

Time/s	0	30	60	90	120	150	180	210	240
Count rate per second	56	41	29	23	17	13	10	7	6

a) Draw a graph of count rate against time.
b) From the graph determine the background count rate.
c) From the graph determine the half life of the sample.
d) Explain why a background count rate of about 20 counts per second would have made it difficult to determine accurately the half life of this sample.

10. The sketch shows the apparatus used to determine the half life of a radioactive gas which is a member of the thorium decay series.



The counter is switched on for 10 s in every half minute and reset before the next reading is taken. The activity due to background radiation is 90 counts per minute. The results are recorded in the table below.

Time/s	0-10	30-40	60-70	90-100	120-130	150-160	180-190
Total count in 10 s	199	141	103	75	56	43	33

a) Use the results to plot a graph of corrected count rate in counts per second against time in seconds.
b) Use the graph to find the half life of the gas, explaining clearly how you arrived at your answer.

11. It has been calculated that it takes 4.5×10^9 years for half the uranium in a rock sample to disintegrate radioactively and turn into lead. The metals uranium and lead are contained in a particular rock sample. Of the atoms present in the metallic content, 30% are uranium and 70% are lead.

By drawing a graph of mass of uranium present or otherwise, estimate the age of the rock, assuming that 50% of the atoms in the original metallic content were uranium.

Exercise 10.5 Half-value Thickness

1. Sheets of lead of different thicknesses are placed between a radioactive source emitting only gamma radiation and a Geiger-Muller detector connected to a counter.

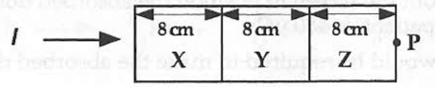
   Sketch a graph to show the variation of count rate with the thickness of lead.

2. Describe an experiment to show how the intensity of gamma radiation, transmitted through a lead absorber, varies with the thickness of the lead.
   List all the apparatus used and which measurements have to be made.

3. The half-value thickness for a particular material is 7 mm. A block of this material of thickness 3.5 cm is inserted between a radioactive source and some human tissue.

   What fraction of the original radiation passes through the block and reaches the human tissue?

4. Three materials X, Y and Z are used as gamma ray absorbers. They have half-value thicknesses of 2 cm, 4 cm and 8 cm respectively. Gamma rays of intensity *I* strike the left side of a 'sandwich' composed of X, Y and Z as shown.



   Calculate the irradiance at P as a fraction of *I*.

5. A detector placed near a source of gamma rays records a count rate of 480 counts per second. A slab of material of thickness 3 cm is then placed between the source and the detector. The half-value thickness of the material is 1 cm and the half life of the source is 1 day.

   After 1 day, what is the count rate recorded by the detector?

6. A worker in a nuclear fuel reprocessing plant is protected from gamma radiation by a screen as he sits at his work station. The absorbed dose rate at the work station is 40 $\mu Gy\ h^{-1}$ of gamma radiation. The half-value thickness of the screen material is 8 mm.

   What extra thickness of screen material would be needed to reduce the absorbed dose rate at the work station to 5 $\mu Gy\ h^{-1}$?

7. A source produces a equivalent dose rate of 32 $\mu Sv\ h^{-1}$ at a distance of 1 m. Lead shielding with a half-value thickness of 3.3 mm is used to reduce the equivalent dose rate.

   a) Draw a graph to show how the equivalent dose rate at a distance of 1 m varies with the thickness of lead shielding.
   b) Use your graph to estimate the thickness of shielding required to reduce the level to 2.5 $\mu Sv\ h^{-1}$.