Section 1: Radioactive Substances

What is radiation?

Radiation could refer to heat or light which has been emitted, but usually the term is used to refer to ionising radiation. If an atom or molecule gains or loses an electron and becomes charged it is known as an ion. Radiation which has sufficient energy to cause this, is known as ionising radiation. This can take various forms, either high energy electromagnetic waves like gamma radiation, or particles like alpha and beta radiation. Ionising radiation is emitted naturally from the nuclei of unstable atoms as they decay.

Suggested Film
- Radioactive Substances

Different materials will stop various types of radiation

Extension Question

Q1. How many different types of radiation are there?

There are three main types of radiation: alpha, beta and gamma.

Alpha particles are composed of two neutrons and two protons. Alpha particles are relatively large, slow moving and are positively charged. They have a short range and penetration depth. Alpha particles, which are emitted by unstable nuclei, can be absorbed by a sheet of paper or a few centimetres of air.

Beta particles are fast-moving electrons. They are emitted from the nucleus of an unstable atom when a neutron decays into a proton. They are small, fast-moving and negatively charged. Beta particles can be absorbed by a few centimetres in air or a few millimetres of aluminium.

Gamma rays are high energy electromagnetic radiation. They are very penetrating, and thick shielding is required to protect against gamma rays.

As well as these three types, there are other possible forms of radiation which can be emitted when some nuclei decay. Individual protons and neutrons can be emitted, as can positrons, the antiparticles of electrons. ‘Cluster decay’, where a combination of protons and neutrons heavier than an alpha particle is emitted, is also possible.
Extension Question

Q2. How is radioactivity measured?

There are several different ways to measure radiation. The activity of a sample is measured in becquerels; this measures the number of decays per second.

The activity is of limited use when considering the effect of the radiation. A better measure is the absorbed dose (measured in grays), which measures the energy deposited in each kilogram of material it passes through.

This does not give a good indication of the biological effect of the radiation, as this can depend on the type of the radiation and the energy of the individual particles. The absorbed dose is multiplied by a weighting factor, which depends on the type of radiation, to account for this. This gives a measure known as the equivalent dose, which is measured in sieverts.

The equivalent dose can also be adjusted to take into account the part of the body which has been affected. This measure is known as effective dose, and is also measured in sieverts.

Why do atoms decay?

Atoms consist of a nucleus of protons (which are positive) and neutrons (which are neutral) surrounded by a ‘cloud’ of electrons. The number of electrons and protons is equal, making the atom neutral overall. All the atoms in a particular element have the same numbers of protons in their nucleus. However, the number of neutrons may not be the same in every atom. Most elements have several isotopes, versions of the atom with different numbers of neutrons. Chemically, these will be almost indistinguishable, but the nuclei of some isotopes will be unstable.

Because of this the nucleus will decay, emitting radiation in the form of waves or particles, or even disintegrating. It should be remembered that as an isotope decays, the isotope which results may also be unstable and may also decay. This means that more than one isotope may be present in a sample and it may emit more than one type of radiation.

Extension Question

Q3. What is a half-life?

The time taken for half of the atoms in a sample to decay is known as the half-life and is a constant for a given material. As each atom decays it will emit radiation. Because there will be half as many atoms decaying after one half-life, the half-life can be determined by measuring the time taken for the activity of a sample to drop by half. If a particular isotope is stable it will have a very long half-life.
Section 2: Applications of Radiation

• What is nuclear fission?

When the nucleus of an atom breaks up into smaller parts, this is known as fission. With very large nuclei this can happen spontaneously, but fission can also be caused by striking the nucleus with a neutron.

Energy is released when a large nucleus splits. Although the energy released by one fission event is small, it is far larger than that released when an atom is involved in a chemical reaction. If enough atoms can be made to undergo fission at the same time, this process can be used in nuclear reactors to produce heat, which is then used to produce electricity, or can be exploited in nuclear weapons.

- Suggested Films
  - Nuclear Weapons
  - Nuclear Fission
  - Nuclear Fusion: The Hot and Cold Science

Extension Questions

Q4. What is nuclear fusion?

If two light nuclei combine and ‘fuse’ to form a heavier nucleus, energy can be released. This is difficult to achieve as atomic nuclei are positively charged and so repel each other. They have to be raised to very high temperatures for fusion to be achieved.

Stars like the Sun are powered by nuclear fusion reactions at their core. For decades, research has been conducted into the possibility of using nuclear fusion reactions to produce electricity in power stations, and fusion reactions are used in some nuclear weapons.

Q5. How do nuclear weapons work?

Fission weapons use an uncontrolled chain reaction to release large amounts of energy. Fission can be induced by firing a neutron at a large nucleus. If the nucleus releases more than one neutron when it splits these can go on to induce fission in other nuclei. This rapidly results in a very large number of fission events and the release of a large amount of energy. Certain types of uranium and plutonium atoms are suitable for use in fission weapons.

Fusion weapons (sometimes called ‘hydrogen bombs’) can release far greater amounts of energy than fission weapons and so can be far more destructive. They use a combination of fission and fusion; a fission weapon is used to ignite fusion reactions which then release neutrons and cause further fission events.
Extension Question

Q6. How is the power of a nuclear weapon measured?

Even a relatively small nuclear weapon will be thousands of times more powerful than the most destructive conventional bombs. The destructive power (or explosive yield) of nuclear weapons is measured in kilotons or megatons. A kiloton is equivalent to the energy released by 1000 tons of TNT, a type of high explosive. A megaton is equivalent to the energy released by 1 million tons of TNT.

The first atomic weapons had yields of around 20 kilotons. The largest ever detonated, a hydrogen bomb, had a yield of around 50 megatons, although this could have been increased to 100 megatons if necessary.

How is radiation used in medicine?

Radiation has many uses in medicine. It can be used in radiotherapy to kill cancer cells and can also be used to produce images. Radioactive isotopes can be injected into the body; the radiation they emit can be detected and used to produce images of organs or monitor blood flow.

Extension Questions

Q7. How is radiation used in smoke alarms?

Many smoke detectors use americium 241, an alpha emitter. The alpha radiation emitted ionises the air in a small chamber, which allows a small current to pass between two electrodes. If smoke enters the smoke alarm it absorbs the alpha particles emitted by the radioactive source and the current no longer flows. This triggers an alarm.

Q8. How is radiation detected?

There are various ways to detect radiation. Photographic film is affected by radiation and so can be used in dosimeters. People who work with radiation often wear badges containing photographic film. The film from these is developed at regular intervals to check radiation exposure.

Geiger counters use a chamber filled with gas. When the gas is ionised by radiation it becomes conductive, a current is allowed to pass and a produces a ‘click’ on a loudspeaker. These events can be counted and used to measure the amount of radiation present.

Scintillation counters use materials, often crystals, which produce a flash of light each time radiation is present.

How does radioactive dating work?

It is possible to determine the age of rocks, sand or dead organic material through radioactive dating. There are several ways of doing this. By measuring the relative amount of the original radioactive isotope and the decay product (or ‘daughter’ product) it is possible to estimate the length of time since the isotope was included in the sample.

Carbon dating relies on the fact that nitrogen atoms in the atmosphere are converted to carbon 14 atoms by cosmic rays. As carbon 14 decays into nitrogen 14 over time the amount in the atmosphere at any time is approximately constant.
Living creatures contain carbon and after they die the proportion of carbon 14, which is present in their body, decreases over time as it decays. Hence, the proportion of carbon 14 to carbon 12 (which does not decay) decreases, and by measuring this ratio it is possible to estimate the time that has passed since the organism died.

Luminescence dating does not measure the ratio of isotopes, but instead involves exposing a sample to heat or light and measuring the small amounts of light which are emitted; this is proportional to the total amount of radiation which has been received by the sample. If the dose rate from the sample’s environment is known it is possible to calculate the age of the sample.

### Section 3: Effects of Radiation

**Who was Marie Curie?**

Marie Curie was a Polish scientist who, along with her husband Pierre Curie, did extensive work on radioactivity. Together they discovered two new elements: polonium, named after Poland, and radium. In 1903, the Curies, along with Henri Becquerel, were awarded the Nobel prize for physics. Although Pierre Curie died in 1906, in 1911 Marie Curie became the first person to win two Nobel prizes when she won the Nobel prize for chemistry.

Marie and Pierre’s daughter, Irène, also worked on radioactivity, and in 1935 won the Nobel prize for chemistry, along with her husband, Frédéric.

**How can exposure to radiation be reduced?**

Exposure to radiation can be reduced by ensuring that an adequate distance is kept from the source, by minimising the time of exposure, and by using shielding.

Even using forceps, instead of handling a source, can increase the distance from the source sufficiently to significantly reduce the dose received.

Thick lead or concrete is often used in shielding, although care must be taken when shielding against beta particles. The use of high density material can result in the particles being stopped too quickly, which can result in them emitting X-rays or gamma rays. For this reason, aluminium or Perspex are often used to shield against beta radiation.

**Extension Question**

Q9. Why is radon gas dangerous?

Radon is produced when uranium or thorium in rocks undergoes radioactive decay. As radon is a gas it can seep up through the ground and it is possible for it to accumulate in houses, leading to the occupants experiencing an increased exposure to radiation. It is thought that the inhalation of radon is the cause of many lung cancers.

**Suggested Films**

- Reducing Radiation Risk
- FactPack: Background Radiation
Extension Question

Q10. How are alpha particles dangerous?

Although alpha particles are stopped by a few centimetres of air and are unable to penetrate skin, they can be extremely dangerous if an alpha emitter is ingested or inhaled. In this case, the alpha particles would be entirely absorbed within the body, causing significant damage.

In 2006 in London, the ex-KGB agent Alexander Litvinenko was poisoned with polonium 210, an alpha emitter. He died three weeks later.

What is nuclear waste?

One of the disadvantages of nuclear power is that nuclear reactors produce radioactive waste. For example, when nuclear fission occurs and an atomic nucleus splits, the two smaller nuclei which result are likely to be unstable and highly radioactive.

The safe storage and disposal of nuclear waste can be difficult. Highly radioactive waste is often stored on site at nuclear power stations to allow its activity to decrease before it is prepared for deep burial.

Extension Question

Q11. What happened at Chernobyl?

In April 1986 there was an accident at the Chernobyl power plant in the Ukraine. While an experiment was being conducted on the reactor, a sudden increase in power output occurred. This vapourised water used to cool the reactor, causing a steam explosion. A second explosion caused a fire in the reactor core, which led to the graphite in the reactor igniting. The reactor core burned for two weeks, resulting in the release of huge amounts of radioactive material, which was carried as far as western Europe.

The long-term effects of the Chernobyl accident on human health are controversial. The number of cancer deaths caused by radiation exposure following the accident is difficult to determine, but it has been estimated that approximately 4000 additional cancer deaths will occur in Russia, the Ukraine and Belarus due to the accident.

The accident resulted in the release of several different types of radioactive material, including a large amount of radioactive iodine 131. As iodine is absorbed by the thyroid gland and concentrated there, this resulted in an increase in the number of thyroid cancers in the affected areas.
## Radioactive Substances

### Basic

**What is usually used to detect ionisation?**
- A – a Geiger counter
- B – a thermometer
- C – a microphone
- D – a seismometer

**Which of these is NOT one of the three main types of nuclear radiation?**
- A – alpha
- B – beta
- C – gamma
- D – infrared

**Which of these can only travel a short distance through air?**
- A – alpha particles
- B – neutrons
- C – X-rays
- D – infrared

**Which of these is a form of electromagnetic radiation?**
- A – neutrons
- B – alpha particles
- C – gamma rays
- D – beta particles

### Advanced

**What is radioactivity?**
- A – the nuclear decay of unstable elements
- B – the release of energy due to the breaking of bonds between atoms
- C – the emission of infrared by hot objects
- D – the tendency of some substances to react with oxygen in the air

**When do atoms emit excess energy or mass?**
- A – when they are travelling at high speed
- B – when they are unstable
- C – when they absorb light
- D – when they are at high temperatures

**What is an alpha particle composed of?**
- A – a fast-moving electron
- B – two protons and two neutrons
- C – one proton and one neutron
- D – a neutron

**Which of these is a form of particulate radiation?**
- A – beta radiation
- B – gamma rays
- C – ultraviolet
- D – infrared
Radioactive Substances

**Basic**

• What is required to shield against gamma rays?
  
  A – a sheet of paper
  B – a centimetre of Perspex
  C – several centimetres of air
  D – several metres of concrete

**Advanced**

• What is the thinnest material which will stop beta radiation?
  
  A – a sheet of paper
  B – a centimetre of Perspex
  C – several centimetres of lead
  D – several metres of concrete
### Radioactive Half-Life

#### Basic

**• What happens in radioactive decay?**
- A – the nucleus of an atom changes, emitting radiation
- B – the nucleus of an atom breaks apart
- C – molecules break up into individual atoms
- D – atoms absorb light

**• Why doesn’t ruthenium 99 emit radiation?**
- A – it is stable
- B – its nucleus is too heavy
- C – it is too unstable
- D – its half-life is very short

**• When is a sample of molybdenum 99 safe to handle?**
- A – it is always safe to handle as the radiation emitted has very low energy
- B – it will never be safe to handle as it will always be radioactive
- C – after six months as no molybdenum is left to emit radiation
- D – it is always safe to handle as molybdenum 99 is stable

**• Which of these statements about half-lives is true?**
- A – half-lives vary from fractions of a second to millions of years
- B – the half-life of an element can vary
- C – the more unstable a substance, the longer its half-life
- D – the half-life is the time taken for a substance to become completely safe

#### Advanced

**• What is meant by a ‘decay chain’?**
- A – a set of substances which each emit a different type of radiation
- B – it is another name for half-life
- C – the sequence of atoms produced by a series of radioactive decays
- D – the list of radioactive isotopes of a particular element

**• What kind of radiation does molybdenum 99 emit?**
- A – alpha
- B – beta
- C – gamma
- D – X-rays

**• What is the half-life of molybdenum 99?**
- A – 6 months
- B – 20 days
- C – 3 days
- D – 20 minutes

**• If a substance has a half-life of 4 days how much will be left after 8 days?**
- A – 94%
- B – 50%
- C – 25%
- D – 0%
Reducing Radiation Risk

Basic

• Which of these statements is NOT true?
  A – radiation can be used in the treatment of cancer
  B – radioactive substances can be used in nuclear power stations
  C – radiation is harmless to humans
  D – radiation will ‘fog’ photographic film

• What can be used to detect radiation?
  A – a Geiger counter
  B – a thermometer
  C – a microphone
  D – a seismometer

• Which of these is NOT a precaution used when handling radioactive material?
  A – wearing protective clothing
  B – marking materials with the radiation warning symbol
  C – the use of shielding such as lead or Perspex
  D – monitoring to ensure radiation levels are always zero

• Why are machines sometimes used to handle radioactive sources?
  A – machines are more accurate
  B – this increases the distance between the sources and the workers
  C – machines work far more quickly
  D – machines can be shielded to protect against radiation

Advanced

• What is a Geiger-Müller tube used for?
  A – to make substances emit radiation
  B – to absorb radiation
  C – to store radioactive substances
  D – to detect radiation

• What kind of gas is found inside a Geiger-Müller tube?
  A – hydrogen
  B – an inert gas like argon
  C – oxygen
  D – nitrogen

• Why do workers in nuclear plants wear film badges?
  A – the badge will reduce their radiation dose
  B – the badge will click if radiation is detected
  C – the film can be checked monthly and used to monitor their radiation dose
  D – the badge will change colour as soon as radiation is detected

• Why do radiation detectors ‘click’ when not near radioactive sources?
  A – they are detecting natural background radiation
  B – due to contamination caused by nuclear power stations
  C – they are responding to electrical interference
  D – the clicks are used to show the equipment is working

10
**Radioactive Substances**

### Basic

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is usually used to detect ionisation?</td>
<td>A – a Geiger counter, B – a thermometer, C – a microphone, D – a seismometer</td>
</tr>
<tr>
<td>Which of these is NOT one of the three main types of nuclear radiation?</td>
<td>A – alpha, B – beta, C – gamma, D – infrared</td>
</tr>
<tr>
<td>Which of these can only travel a short distance through air?</td>
<td>A – alpha particles, B – neutrons, C – X-rays, D – infrared</td>
</tr>
<tr>
<td>Which of these is a form of electromagnetic radiation?</td>
<td>A – neutrons, B – alpha particles, C – gamma rays, D – beta particles</td>
</tr>
</tbody>
</table>

### Advanced

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is radioactivity?</td>
<td>A – the nuclear decay of unstable elements, B – the release of energy due to the breaking of bonds between atoms, C – the emission of infrared by hot objects, D – the tendency of some substances to react with oxygen in the air</td>
</tr>
<tr>
<td>When do atoms emit excess energy or mass?</td>
<td>A – when they are travelling at high speed, B – when they are unstable, C – when they absorb light, D – when they are at high temperatures</td>
</tr>
<tr>
<td>What is an alpha particle composed of?</td>
<td>A – a fast-moving electron, B – two protons and two neutrons, C – one proton and one neutron, D – a neutron</td>
</tr>
<tr>
<td>Which of these is a form of particulate radiation?</td>
<td>A – beta radiation, B – gamma rays, C – ultraviolet, D – infrared</td>
</tr>
</tbody>
</table>
## Radioactive Substances

### Basic

• What is required to shield against gamma rays?

- A – a sheet of paper
- B – a centimetre of Perspex
- C – several centimetres of air
- D – several metres of concrete

### Advanced

• What is the thinnest material which will stop beta radiation?

- A – a sheet of paper
- B – a centimetre of Perspex
- C – several centimetres of lead
- D – several metres of concrete
Radioactive Half-Life

**Basic**

• What happens in radioactive decay?
  
  A – the nucleus of an atom changes, emitting radiation
  
  B – the nucleus of an atom breaks apart
  
  C – molecules break up into individual atoms
  
  D – atoms absorb light

• Why doesn’t ruthenium 99 emit radiation?
  
  A – it is stable
  
  B – its nucleus is too heavy
  
  C – it is too unstable
  
  D – its half-life is very short

• When is a sample of molybdenum 99 safe to handle?
  
  A – it is always safe to handle as the radiation emitted has very low energy
  
  B – it will never be safe to handle as it will always be radioactive
  
  C – after six months as no molybdenum is left to emit radiation
  
  D – it is always safe to handle as molybdenum 99 is stable

• Which of these statements about half-lives is true?
  
  A – half-lives vary from fractions of a second to millions of years
  
  B – the half-life of an element can vary
  
  C – the more unstable a substance, the longer its half-life
  
  D – the half-life is the time taken for a substance to become completely safe

**Advanced**

• What is meant by a ‘decay chain’?
  
  A – a set of substances which each emit a different type of radiation
  
  B – it is another name for half-life
  
  C – the sequence of atoms produced by a series of radioactive decays
  
  D – the list of radioactive isotopes of a particular element

• What kind of radiation does molybdenum 99 emit?
  
  A – alpha
  
  B – beta
  
  C – gamma
  
  D – X-rays

• What is the half-life of molybdenum 99?
  
  A – 6 months
  
  B – 20 days
  
  C – 3 days
  
  D – 20 minutes

• If a substance has a half-life of 4 days how much will be left after 8 days?
  
  A – 94%
  
  B – 50%
  
  C – 25%
  
  D – 0%
Reducing Radiation Risk

Basic

- Which of these statements is NOT true?
  A – radiation can be used in the treatment of cancer
  B – radioactive substances can be used in nuclear power stations
  C – radiation is harmless to humans
  D – radiation will ‘fog’ photographic film

- What can be used to detect radiation?
  A – a Geiger counter
  B – a thermometer
  C – a microphone
  D – a seismometer

- Which of these is NOT a precaution used when handling radioactive material?
  A – wearing protective clothing
  B – marking materials with the radiation warning symbol
  C – the use of shielding such as lead or Perspex
  D – monitoring to ensure radiation levels are always zero

Advanced

- What is a Geiger-Müller tube used for?
  A – to make substances emit radiation
  B – to absorb radiation
  C – to store radioactive substances
  D – to detect radiation

- What kind of gas is found inside a Geiger-Müller tube?
  A – hydrogen
  B – an inert gas like argon
  C – oxygen
  D – nitrogen

- Why do workers in nuclear plants wear film badges?
  A – the badge will reduce their radiation dose
  B – the badge will click if radiation is detected
  C – the film can be checked monthly and used to monitor their radiation dose
  D – the badge will change colour as soon as radiation is detected

- Why do radiation detectors ‘click’ when not near radioactive sources?
  A – they are detecting natural background radiation
  B – due to contamination caused by nuclear power stations
  C – they are responding to electrical interference
  D – the clicks are used to show the equipment is working

- Which of these is NOT true?
  A – radiation can be used in the treatment of cancer
  B – radioactive substances can be used in nuclear power stations
  C – radiation is harmless to humans
  D – radiation will ‘fog’ photographic film

- What can be used to detect radiation?
  A – a Geiger counter
  B – a thermometer
  C – a microphone
  D – a seismometer

- Which of these is NOT a precaution used when handling radioactive material?
  A – wearing protective clothing
  B – marking materials with the radiation warning symbol
  C – the use of shielding such as lead or Perspex
  D – monitoring to ensure radiation levels are always zero

- Why are machines sometimes used to handle radioactive sources?
  A – machines are more accurate
  B – this increases the distance between the sources and the workers
  C – machines work far more quickly
  D – machines can be shielded to protect against radiation