

# Nuclear energy

Nuclear energy is the energy that binds nuclear particles such as protons and neutrons into the nucleus. This energy is very large and it can be released for the use of humans. Since the 1940s this energy has been used for peaceful purposes such as generation of electricity in nuclear power stations and also in the treatment and diagnosis of disease. It has also been used in war (eg. atomic bombs dropped on Japan in 1945) and in nuclear missile testing programs.



## Glossary

**Alpha particle**—radiation consisting of a positive particle composed of two protons and two neutrons

**Beta particle**—radiation consisting of a fast electron

**Gamma rays**—high energy electromagnetic rays

**Fission**—splitting of large nuclei into smaller nuclei by neutron bombardment with the release of energy

**Fusion**—joining of the nuclei of lightweight elements to form a heavier element with the release of energy

**Radioactivity**—emission of rays and/or particles due to the decay of an unstable nucleus



# Energy release from the nucleus

## Nuclear power

The nucleus of an atom is very small compared to the total volume of the atom. Most of the mass of the atom, however, is concentrated in this tiny space. The protons and neutrons are the particles that comprise the nucleus.

- Protons have a positive charge; neutrons have no charge.





- The protons and neutrons are bound strongly together by nuclear forces.
- In certain heavy atoms (such as uranium-235) some of this nuclear energy can be released by causing the nucleus to split into fragments. This process is called nuclear fission.
- Nuclear fission can be achieved by firing neutrons at the nucleus of a U-235 atom.



- As the nucleus splits into fragments, more neutrons are released that then cause other nuclei to split. This leads to a chain reaction and an explosion unless the process is controlled.
- In a nuclear power station the nuclear fission process is controlled so that no explosion can occur. The energy released by the fission process is used to generate electricity.



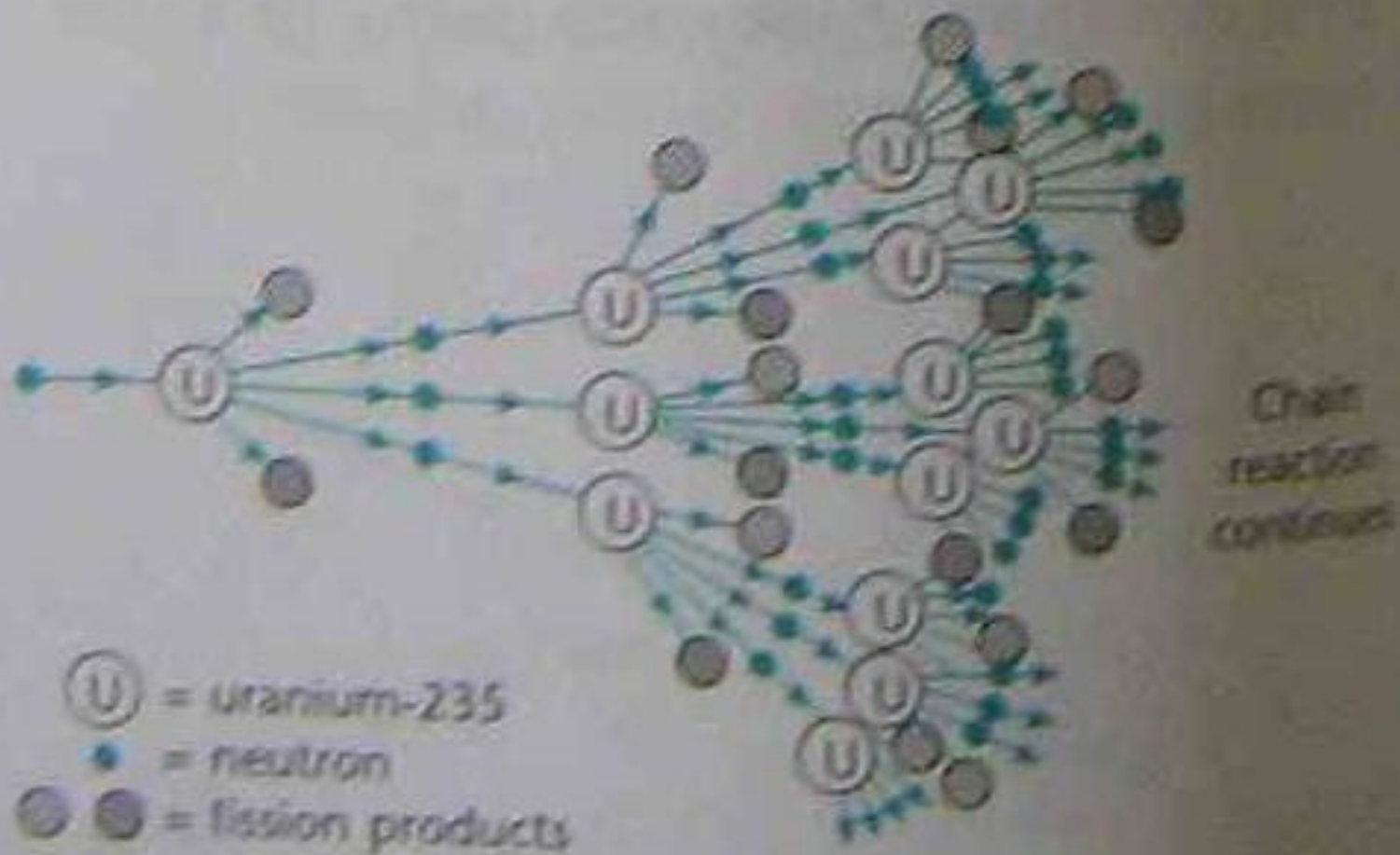


Figure 1.49 Nuclear fission of uranium-235 and the chain reaction



## **Energy from nuclear fusion**

Energy is also released from the Sun and other stars by nuclear processes called nuclear fusion.

- Nuclear fusion involves the joining (fusing) together of the nuclei of lightweight atoms such as hydrogen.
- In the Sun and other stars the hydrogen nuclei fuse to form helium with the release of vast amounts of energy.





- About 20% of the electricity produced in the world is generated in nuclear power plants. Australia does not have any nuclear power plants. Our only nuclear reactor is a small research reactor at Lucas Heights in Sydney. This facility also provides radioisotopes for industry and medicine.
- One kilogram of uranium can release as much energy on fission as that released by the combustion of 2300 tonnes of coal.





release of vast amounts of energy.

- On Earth, hydrogen bombs have been developed using the principle of hydrogen fusion. Such bombs release more energy than uranium fission bombs.
- Scientists have not yet succeeded in developing controlled nuclear fusion. The huge pressure and temperatures required to initiate and sustain controlled fusion have still not been achieved, despite many years of research.





Key  $\oplus$  = proton  
 $\bullet$  = neutron  
 $\gamma$  = gamma ray  
 $e^+$  = positron

Figure 1.50 Nuclear fusion of hydrogen



## Unstable nuclei

Many heavy atoms such as uranium have unstable nuclei. The nuclear forces are not strong enough to prevent the escape of nuclear particles or the release of radiant energy.

- Atoms are radioactive if their nuclei spontaneously emit particles or high energy electromagnetic radiation. This spontaneous emission of radiation is known as nuclear decay.
- There are three common types of radiation emitted from radioactive atoms.



1. Alpha particles—these positive particles consist of 2 protons and 2 neutrons (ie. a helium nucleus).
2. Beta particles—these negative particles are fast moving electrons that have formed by the breakdown (decay) of a neutron into a proton.
3. Gamma rays—these are high energy electromagnetic rays released from a nucleus as it sheds excess energy.





energy.

- The different types of radiation have different abilities to penetrate matter. This is important because exposure to excessive radiation can cause disease and death in living things. The radiation can cause disruption to DNA. This disruption often leads to cancer.



1. Alpha particles can travel through only several centimetres of air. They are absorbed by paper and thin metal foils.
2. Beta particles are more penetrating and can travel up to several metres in air before losing their energy. Aluminium sheeting (~3 mm) will absorb beta particles.
3. Gamma radiation is highly penetrating. It can travel thousands of metres through air and requires thick concrete (~1 m) or lead shields



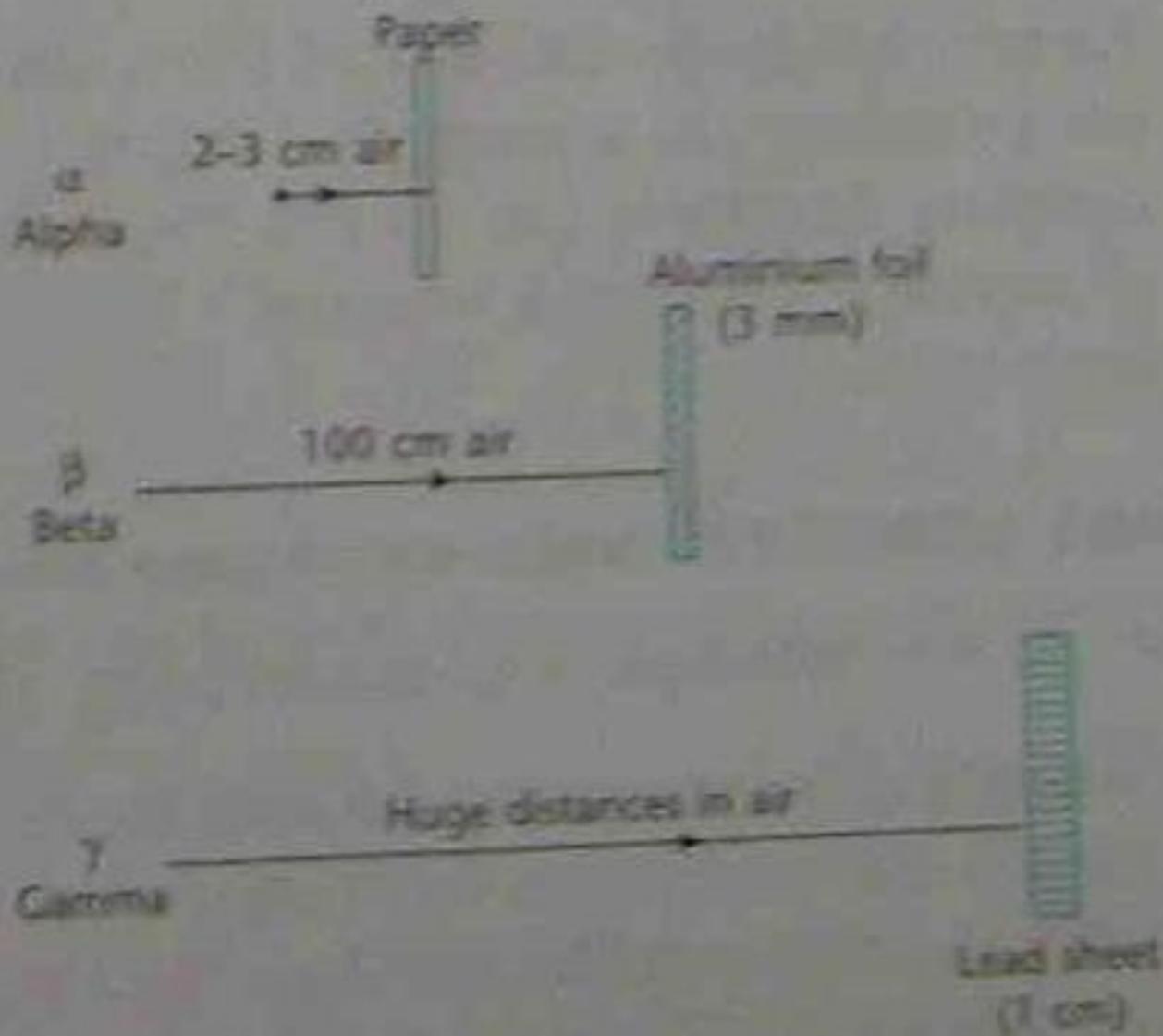


Figure 1.51 Types of radiation and their penetrating ability

(~1 cm) to contain it. It is highly dangerous to living cells.

## **Social and environmental issues**

There are social and environmental advantages and disadvantages of using uranium as a fuel instead of chemical fuels such as coal and oil. Both types of fuel are non-renewable.





## Advantages

- Large amounts of energy can be generated from small amounts of nuclear fuel. This makes nuclear fuel useful in powering nuclear submarines and some ships. It is also useful in countries that do not have coal and oil reserves.
- Unlike coal and oil combustion, few toxic gases and no greenhouse gases are released into the atmosphere by nuclear power stations.



## Disadvantages

- Nuclear power plants produce highly radioactive waste products that must be stored safely in secure storage sites for thousands of years. The waste must not contaminate the biosphere.
- Nuclear power plants present a radiation problem when they reach the end of their useful lives. Methods need to be devised for safe storage of dismantled plants.
- Transportation of nuclear fuel from one site or country to another is a major concern. Accidents can lead to the escape of radioactive material into the environment.



# Gravitational force

Isaac Newton developed a theory to explain the gravitational attraction between various objects of different mass. He was able to extend his gravitational theory to explain the motion of the planets in our solar system. The force of gravity is an example of a field force. A gravity field exists around





of a field force. A gravity field exists around all bodies. The more massive the body the stronger is the gravity field around it. The Sun is a very massive body and its gravitational field is very strong.

Astronomical objects such as comets or planets become trapped in the Sun's gravitational field and orbit it. Earth is much less massive than the Sun. Therefore, the gravitational field of Earth is weaker than the Sun's gravity field.





The strength of the gravitational field around any astronomical body decreases with distance from the centre of the body. Given sufficient speed, space probes can eventually escape Earth's gravity field. As they move out into deep space away from the Sun they will eventually escape the Sun's gravitational attraction well beyond the orbit of Pluto.



## Glossary

**Gravitational acceleration**—the acceleration experienced by a mass in a gravitational field

**Mass**—the amount of matter in a body

**Weight**—the force of gravity acting on a mass



## Mass and weight

The mass of a body is the amount of matter present in the body. Mass is measured in units such as kilograms, gram or tonnes. The mass of an unknown body can be measured using a beam balance. By comparing it to bodies of known mass, the mass of the unknown is determined.

The weight of a body is different to



The **weight** of a body is different to its mass. Weight is a **force** experienced by a body when placed in a gravitational field. Weight is measured in units such as newtons (N). The weight of a body on Earth's surface is measured using spring balances called **newton meters**.

The mass of a body is always constant but its weight varies according to the strength of the gravity field. Thus a 10 kg body weighs more on Earth than on Mars as the gravity on Mars is much less than on Earth.





**Additional content—Mathematical extension:**

The weight ( $W$ ) of a body of mass ( $m$ ) in a gravitational field ( $g$ ) is determined by the equation:

$$W = mg$$

**Example**

**Q** Calculate the weight of a 50 kg mass on the Moon's surface where the gravitational acceleration is  $1.6 \text{ m/s}^2$ .

**A**  $m = 50 \text{ kg}$

$$g = 1.6 \text{ m/s}^2$$

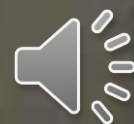
$$W = mg = (50)(1.6) = 80 \text{ N.}$$



## Gravitational acceleration

The strength of the gravity field of a planet can be measured in terms of the **gravitational acceleration ( $g$ )**. The larger the planet or astronomical object the greater is the gravitational acceleration at its surface.

Table 1.7 gives some values of  $g$  at the surface of various planets. The value of  $g$



the surface depends on the mass of the planet as well as its radius (ie. distance from the centre of mass).

Table 1.7 Gravitational acceleration at the surface of various planets

Planet	Mass (relative to Earth = 1)	Radius (relative to Earth = 1)	Gravitational acceleration ( $g$ ) ( $\text{m/s}^2$ )
Earth	1	1	9.8
Mars	0.11	0.53	3.8
Jupiter	318	11	25.8
Saturn	95	9	11.5



## Gravity and altitude

The strength of gravity decreases with altitude above the surface of a planet. In the case of Earth the surface gravity is  $9.8 \text{ m/s}^2$ . At 500 km from the surface the gravitational acceleration is  $8.4 \text{ m/s}^2$ . Table 1.8 shows the decrease in gravity with altitude above Earth's surface. At an altitude of 380 000 km, which corresponds to the orbit of the Moon, the gravitational acceleration due to Earth has dropped to  $0.003 \text{ m/s}^2$ . Although this is small it is sufficient to trap the Moon in Earth's gravitational field.





Table 1.8 Gravitational acceleration and altitude above Earth's surface

Altitude (km)	Gravitational acceleration ( $g$ ) ( $\text{m/s}^2$ )
0	9.8
100	9.5
500	8.4
1000	7.3

