The wave model

Waves moving on the surface of the ocean or a lake are interesting to observe. Surfers often use these waves for recreation or sport. There are also other types of waves. The concept of waves and wave motion is examined in this section.

Glossary

Longitudinal wave—a compression wave in which the particles of the medium oscillate to-and-fro along the axis of energy transfer

Mechanical wave—a wave form in which the particles of the medium oscillate in order to transmit the energy

Medium—the material space in which a wave travels

Sonar—acronym for sound navigation and ranging; a technique in which reflected sound waves are used to measure distance

Spectrum—a range of frequencies or wavelengths

Vibration—an oscillation or shaking motion (a to-and-fro movement)

Mechanical waves

Waves can be classified into two categories:

- **mechanical waves**—waves requiring a medium in which to move
- **electromagnetic waves**—waves not requiring a medium in which to move.

In this section we examine examples of mechanical waves.

Ocean waves

Ocean waves are mechanical waves, as the water surface is the medium that transmits the energy.

Ocean waves are formed by winds transferring kinetic energy to the surface of the water. This energy makes the water molecules **vibrate**. Some of this kinetic energy of vibration is transmitted to neighbouring water molecules, which also begin to move up and down.

- A **wave crest** begins to form where the particles move up relative to the normal undisturbed surface.
- When the particles move down, a **wave trough** is formed.

The crests and troughs move across the water surface because some of the energy of the vibrating water molecules is transferred away from the source of the original vibration.

We see the waves **travelling** across the water surface. They **carry energy** with them due to their motion.

Motion of particles in water waves

The waves on the water surface **carry energy but not matter away from the source.**

- The water particles move to-and-fro but **do not progress.**

If you watch a floating object in the ocean, it moves **up and down** as the wave passes by. The wave lifts it up and then it falls down as the wave passes. You can observe this using a cork floating in a bowl of water.

At the beach where **breaking waves** occur, the motion of the particles is different. Due to collisions of the vibrating water particles with the sand, the behaviour of the wave is altered and so there is some forward motion of the water particles. Surfboard riders use this phenomenon to ride breaking waves into the shore.

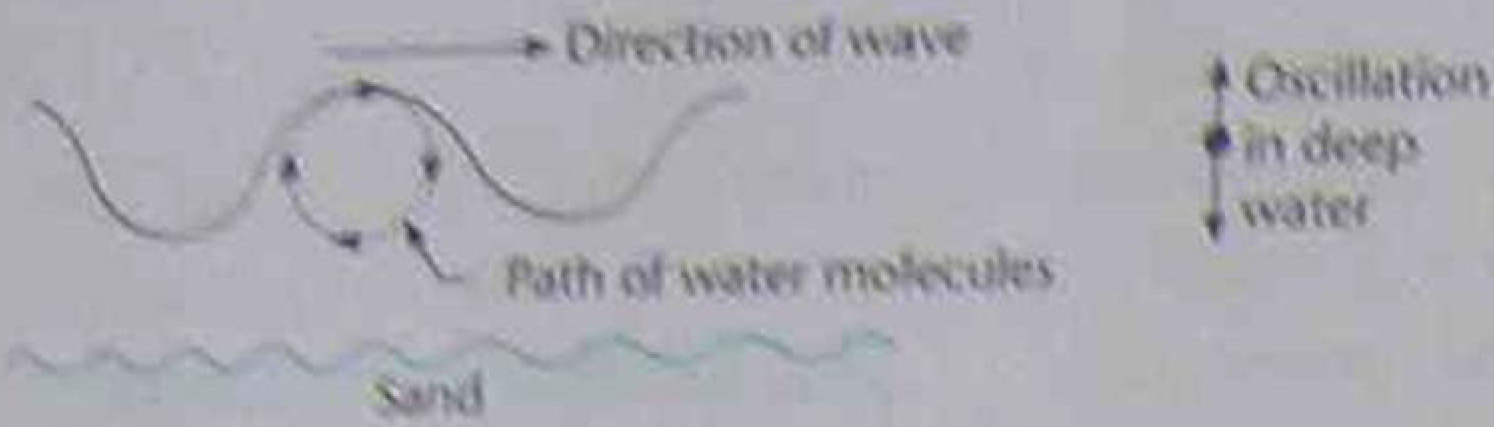

Figure 1.1 Motion of particles in a water wave near the shore

Sound waves

Sound is also an example of mechanical wave motion. Sound energy can travel through solids, liquids and gases.

- Sound waves in air are caused by **transfer of energy** from a vibrating source to the air molecules. For example, when a tuning fork is struck, the prongs vibrate and strike air molecules around them. The air particles also oscillate to-and-fro and energy radiates out from the source as a sound wave.

source as a sound wave.

- Sound waves are different to water waves in that the particles of the air vibrate to-and-fro **in the direction of energy transfer** rather than at right angles to the energy transfer, as in water waves.
- As a result the air particles alternately bunch up to form **compressions** and then spread out to form **rarefactions**.

The sound wave thus consists of regions of compression and rarefaction. When the sound wave reaches our eardrum it causes the drum to vibrate and energy is then transferred to the inner ear and finally the brain.

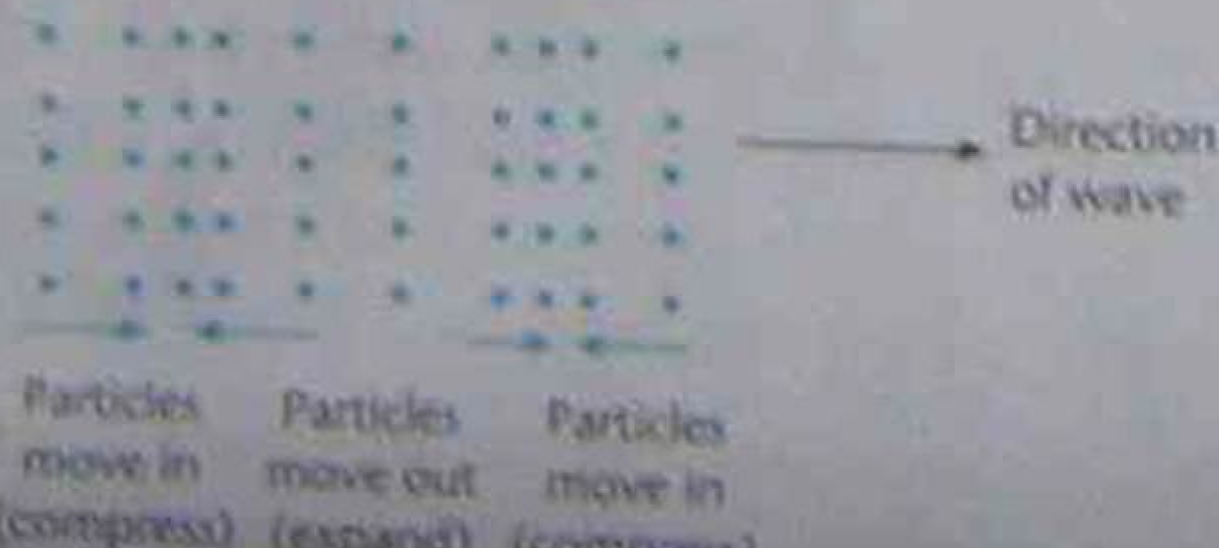

Figure 1.2 Motion of particles in a sound wave

Sound waves can be reflected from various surfaces. This property is used in a number of ways:

- **echo location**—animals such as dolphins and bats produce ultrasonic waves (~200 000 Hz) for navigation
- **sonar**—boats use ultrasonic waves to test water depth and detect schools of fish
- **medicine**—imaging of the fetus during pregnancy
- **seismic surveys**—using sound waves in Earth to determine its internal structure and to locate structures such as oil deposits.

Waves in strings and springs

Strings such as those in guitars and pianos can be made to vibrate by plucking or hitting them. As they vibrate, waves are formed in the string. Since the particles of the string vibrate at right angles to the string, the waves in the string disturb the air molecules around them, leading to the production of sound waves.

Mechanical waves can also be created in springs. If the spring is stretched and then one end is vibrated along the axis of the spring, then a series of compressions and rarefactions are observed to move down the spring from the source of the vibration. Vibrations can also be made at right angles to the spring axis, leading to travelling waves similar to water waves.

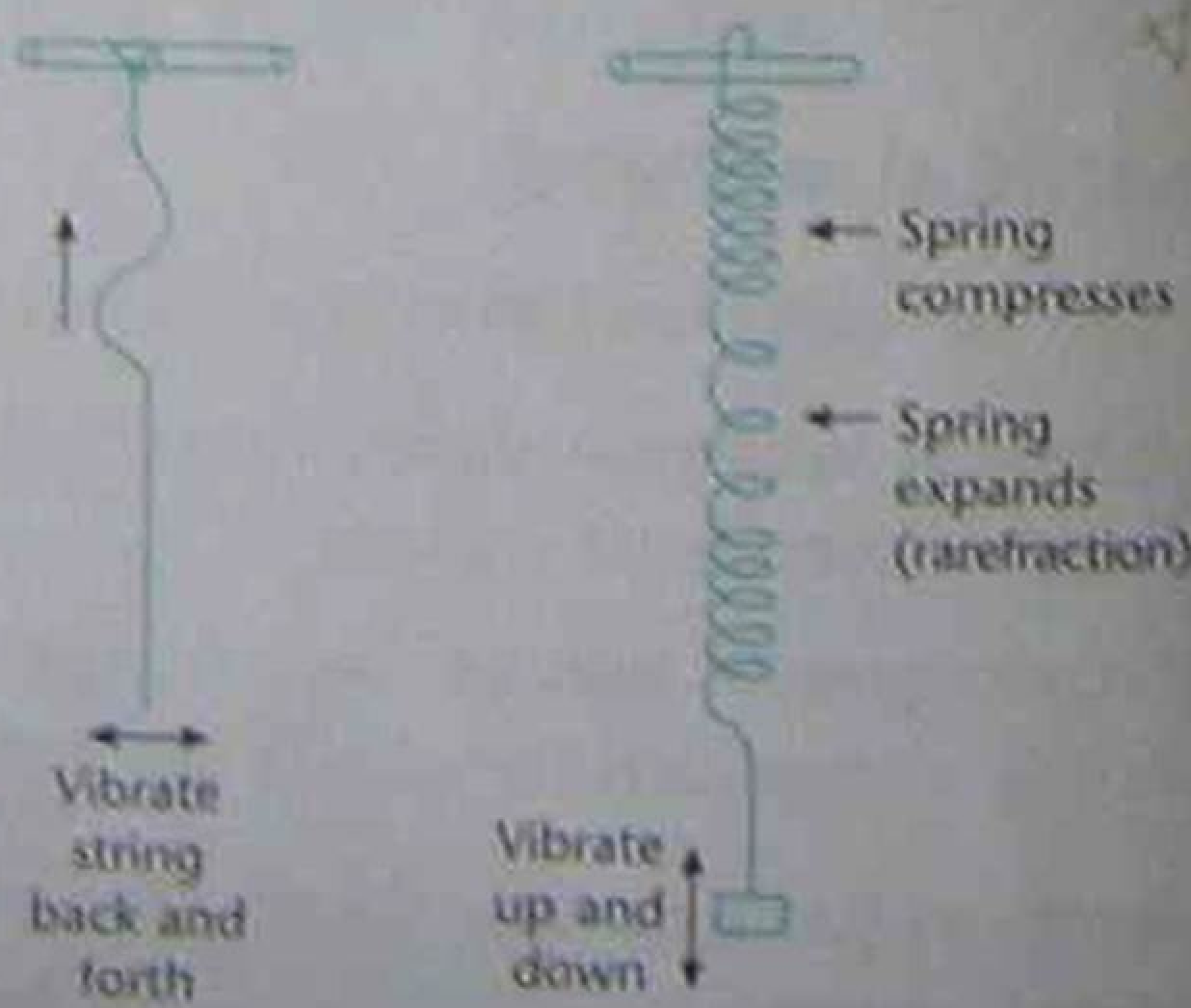

Figure 1.3 Waves in strings and springs

Transverse waves

Waves can be classified into two types:

- **transverse waves**—particles of the medium (or fields in electromagnetic waves) vibrate at right angles to the direction of wave motion
- **compression waves**—particles of the medium vibrate in the same direction as the wave motion. (These waves are also called longitudinal waves.)

A good example of a mechanical transverse wave is the wave in a vibrating string. Figure 1.4 shows how the particles in the string move as the wave moves along the string.

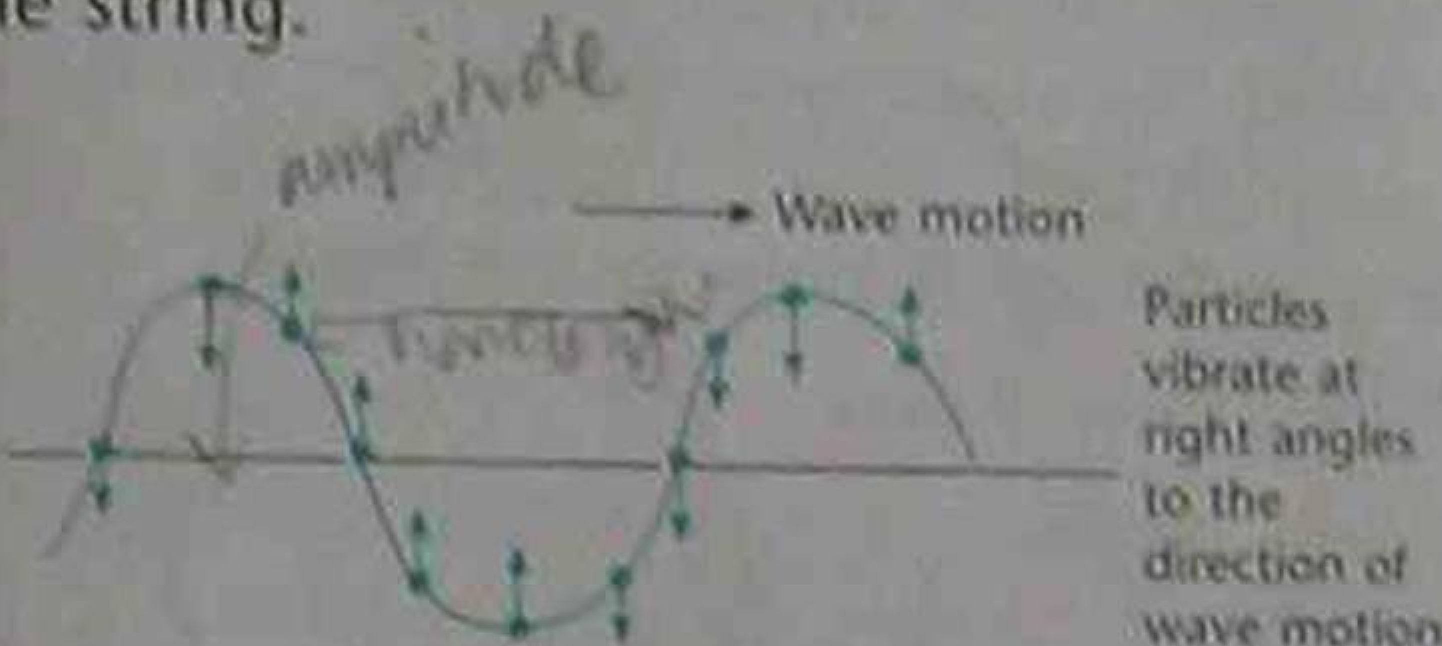

Figure 1.4 Motion of particles in a transverse wave

Some examples of transverse waves include:

- water waves
- visible light waves
- radio waves
- vibrating strings
- surface earthquake waves.

Mechanical transverse waves can only travel:

- **through solids**
- **over the surface of solids or liquids.**

Transverse waves can also be described in terms of a number of features:

- **wavelength** (λ)—the distance between two crests or two troughs (unit = metre)
- **amplitude** (A)—the height of a crest (or depth of a trough) measured from the midway point (central axis) (unit = metre)
- **frequency** (f)—the number of waves

passing a fixed point in 1 second
(unit = hertz, Hz)

- **period** (*T*)—the time for one complete wave to pass a fixed point
(unit = second, s)
- **velocity (speed)** (*v*)—the distance moved by a crest (or trough) in 1 second
(unit = metres per second, m/s).

Additional content—Mathematical extension:

The period (T) of a wave is the reciprocal of the frequency (f):

$$T = 1/f$$

The velocity of a wave is related to its wavelength and frequency via the **wave equation.**

Wave equation:

velocity = frequency × wavelength

$$v = f\lambda$$

transverse wave.

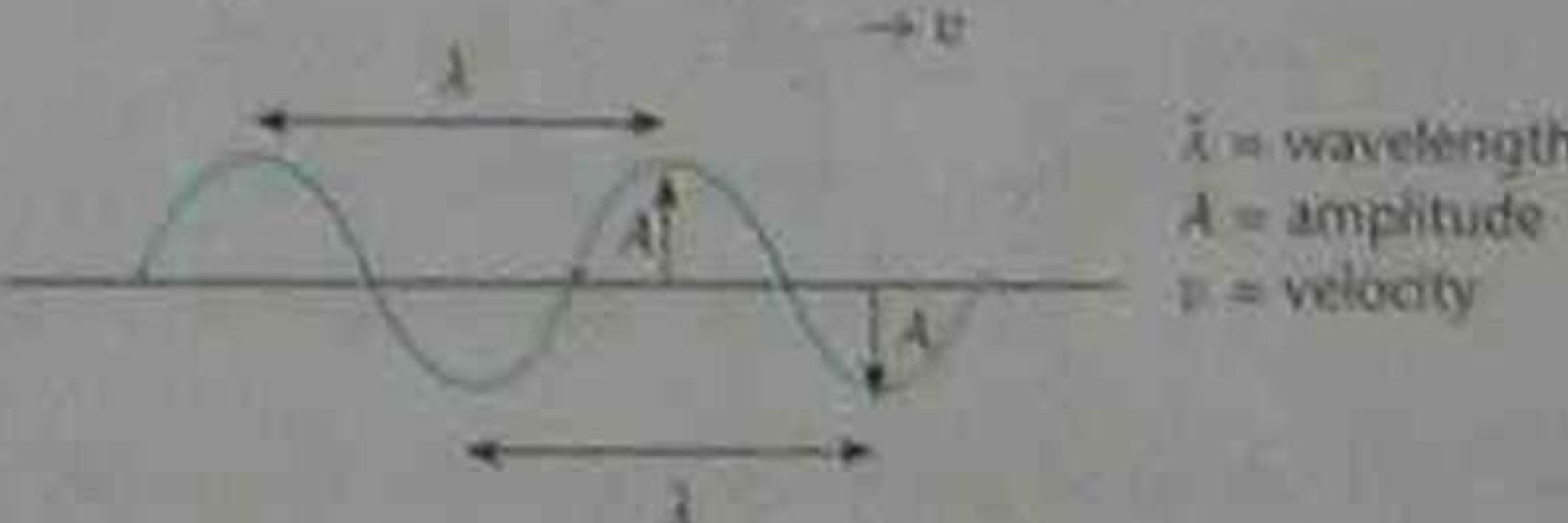

Figure 1.5 Features of a transverse wave

Compression waves

These waves are also called **longitudinal waves** as the vibration occurs along the axis of propagation of the energy.

Compression waves can travel through **all forms of matter**.

Examples of compression waves include:

- sound waves
- longitudinal spring oscillations
- some earthquake waves (inside Earth).

The features of a compression wave are the same as those of a transverse wave. Figure 1.6 illustrates the features of a compression wave.

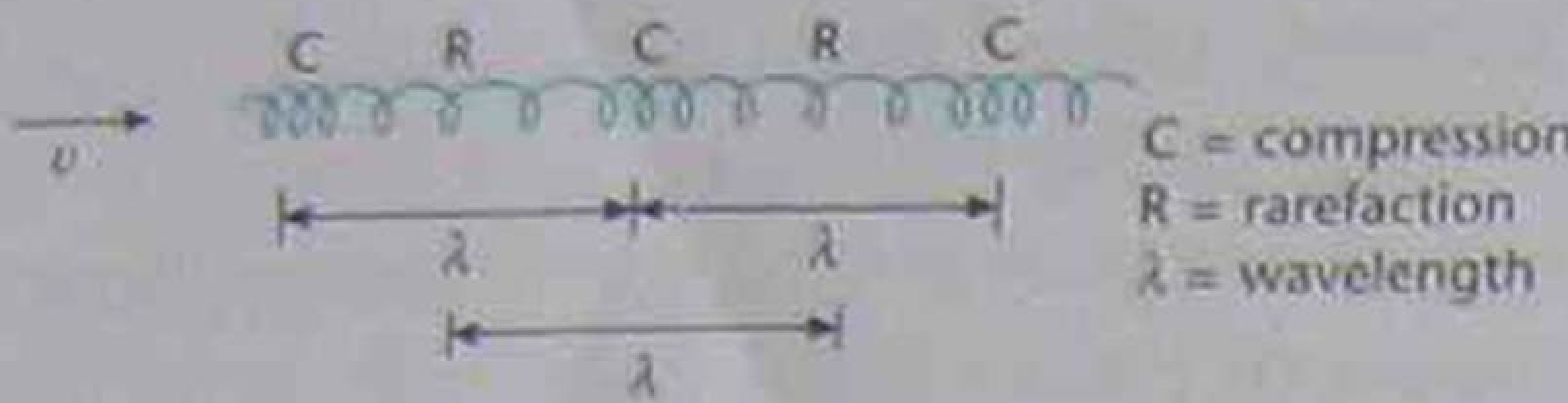

Figure 1.6 Features of a compression wave

Electromagnetic waves

Unlike a mechanical wave in which the particles in a medium are disturbed, electromagnetic rays **do not require a medium** for their propagation.

- Electromagnetic waves involve the propagation of **oscillating electric and magnetic fields.**
- Electromagnetic waves are **transverse waves** (Figure 1.7).
- Electromagnetic waves move at their highest velocity ($v = 3 \times 10^8$ m/s, the speed of light) in a vacuum. They travel

slightly more slowly through matter (eg. air, glass).

Electromagnetic spectrum

Electromagnetic waves vary in their frequencies and wavelength even though their velocities are the same in a vaccum. The collection of different frequency waves is called the **electromagnetic spectrum**. Figure 1.8 and Table 1.1 illustrate the components of the electromagnetic spectrum.

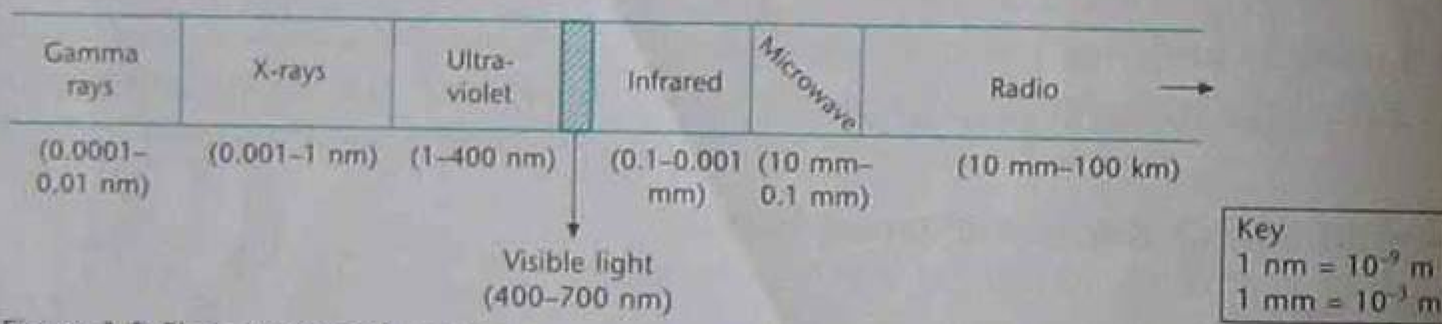

Figure 1.8 Electromagnetic spectrum

Table 1.1 Features of the electromagnetic spectrum

Table 1.1 Features of the electromagnetic spectrum

Band name	Wavelength band (approximate)	Sources of waves	Uses of waves
Radio/TV	100 km–10 mm	radio/TV transmitters	radio/TV communication, radio astronomy
Microwave	10 mm–0.1 mm	radar transmitters microwave ovens	satellite communication, cooking food
Infrared	0.1 mm–0.001 mm	electric radiators	heating rooms, medical heat treatments, night vision systems
Visible light	400 nm–700 nm	stars, electric lamps	human vision, photosynthesis, photography astronomy
Ultraviolet	400 nm–1 nm	UV lamps, stars	UV astronomy, sterilisation
X-rays	1 nm–0.001 nm	X-ray tubes, black holes	medical radiography (diagnosis and treatment), flaws in structural materials, X-ray astronomy
Gamma rays	0.01 nm–0.0001 nm	radioactive minerals	sterilisation, killing cancer cells

(1 nm = 1 nanometre = 1×10^{-9} m)

Newton's laws of motion

The English scientist Isaac Newton (1642–1727) developed the laws of motion as well as theories of gravitation and light. He ranks as one of the world's greatest scientists. His laws of motion explain the effects of forces acting on bodies at rest or in motion.

acting on bodies at rest or in motion.

Glossary

Acceleration—a type of motion in which the speed continues to increase (unit = m/s^2)

Deceleration—a type of motion in which the speed continues to decrease (unit = m/s^2)

Force—a push, pull or twist that changes the motion or shape of an object on which it acts (unit = newton, N)

Friction—a force that opposes motion when surfaces move over each other

Mass—the amount of matter in a body (unit = kg, g)

Velocity—a measure of speed in a fixed direction (unit = m/s)

Weight—a force acting on a body due to gravity (unit = newton, N)