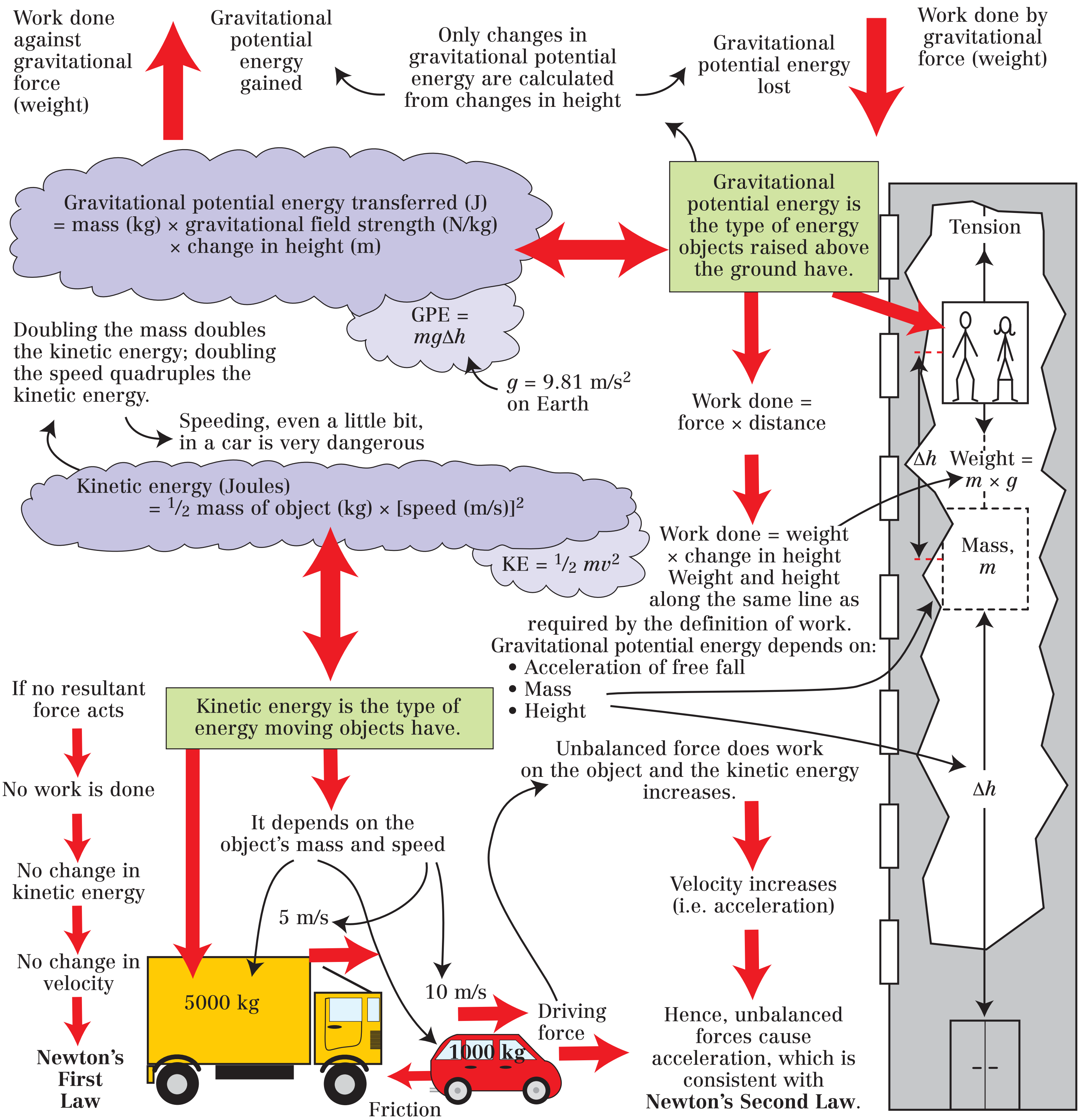
ENERGY Gravitational Potential Energy and Kinetic Energy



Questions

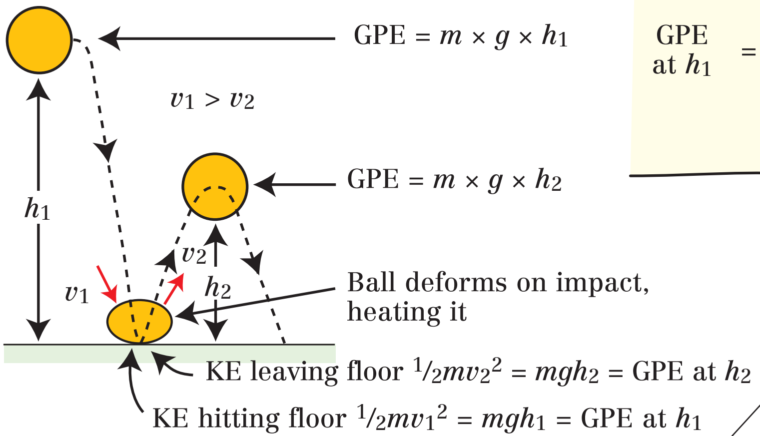
1. Make a list of five objects that change their gravitational potential energy.
2. Using the diagram above calculate the kinetic energy of the car and the lorry.
3. How fast would the car have to go to have the same kinetic energy as the lorry?
4. The mass of the lift and the passengers in the diagram is 200 kg. Each floor of the building is 5 m high.
   a. Show that the gravitational potential energy of the lift when on the eighth floor is about 80 000 J.
   b. How much gravitational potential energy would the lift have when on the third floor? If one passenger of mass 70 kg got out on the third floor, how much work would the motor have to do on the lift to raise it to the sixth floor?
   c. What is the gravitational potential energy of a 0.5 kg ball 3 m above the surface of the Moon where the gravitational field strength is about 1.6 N/kg?
5. A coin of mass 10 g is dropped from 276 m up the Eiffel tower.
   a. How much gravitational potential energy would it have to lose before it hits the ground?
   b. Assuming all the lost gravitational potential energy becomes kinetic energy, how fast would it be moving when it hit the ground?
   c. In reality, it would be moving a lot slower, why?

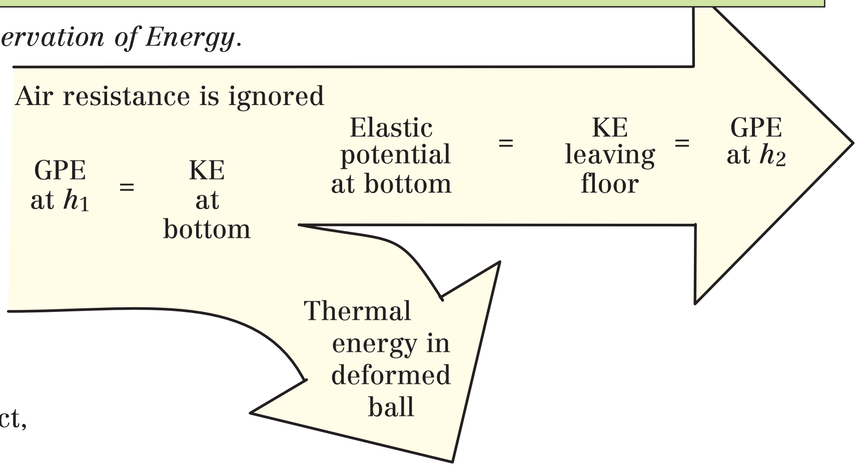
ENERGY Energy Calculations

GPE = gravitational potential energy KE = kinetic energy

All energy calculations use the *Principle of Conservation of Energy*.

E.g. Bouncing ball

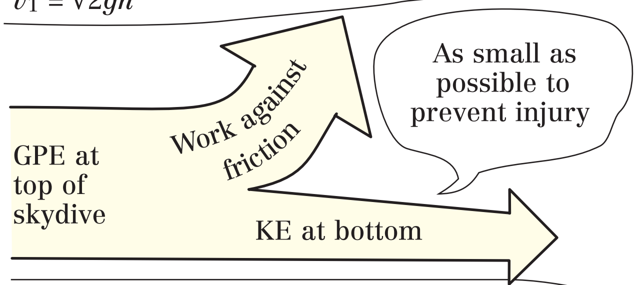




Conservation of energy
GPE at top of bounce = KE at bottom of bounce

$mg\Delta h = {}^1/_2 m v_1^2$

$v_1 = \sqrt{2gh}$



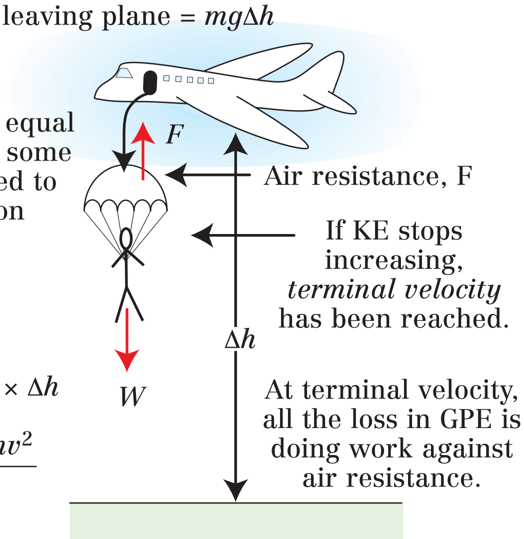
GPE on leaving plane = $mg\Delta h$

GPE at top is not equal to KE at bottom as some GPE was transferred to work against friction (air resistance).

GPE = KE + work against friction

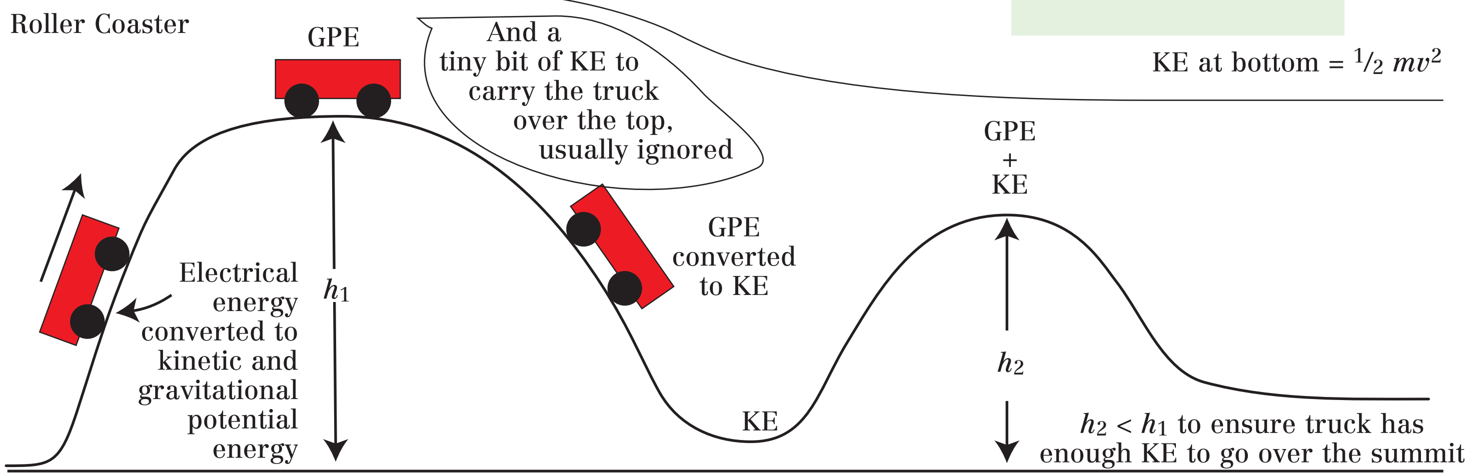
$mg\Delta h = {}^1/_2 m v^2 + F \times \Delta h$

$$F = \frac{mg\Delta h - {}^1/_2 m v^2}{\Delta h}$$



KE at bottom = $^1/_2\, mv^2$

Roller Coaster



Time to reach top of track
= GPE gain / power of motor = mgh_1 / power
The time will be greater than this as some electrical energy is converted to KE and does work against friction.

KE here = loss of GPE from top
$^1/_2 mv^2 = mgh_1$
$v = \sqrt{2gh_1}$

This is an overestimate as the truck did work against friction.

Questions Take $g = 9.8\text{m/s}^2$.

1. At the start of a squash game, a 44 g ball is struck by a racquet and hits the wall at 10 m/s.
   a. Show its KE is about 2 J.
   b. The ball rebounds at 8 m/s. Calculate the loss in KE.
   c. Where, and into what form, has this energy been transferred?
2. An acrobatics aircraft of mass 1000 kg is stationary on a runway. Its take off speed is 150 m/s.
   a. Show that the KE of the aircraft at take off is about 11×10^6 J
   b. The maximum thrust of the engines is 20 000 N. Show the aircraft travels over 500 m along the runway before it lifts off.
   c. Give two reasons why the runway will actually need to be considerably longer.
   d. The aircraft climbs to a height of 1000 m. Show it gains about 10×10^6 J.
   e. If the aircraft takes 5 minutes to reach this height, show the minimum power of the engine must be about 33 kW.
   f. Why must this be the minimum power?
   g. The aircraft then flies level at 200 m/s. What is its KE now?
   h. The pilot cuts the engine and goes into a vertical dive as part of the display. When the plane has dived 500 m what is the maximum KE the plane could have gained?
   i. Hence, what is the maximum speed the plane could now be travelling at?
   j. In reality, it will be travelling slower, why?

ENERGY Efficiency and the Dissipation of Energy

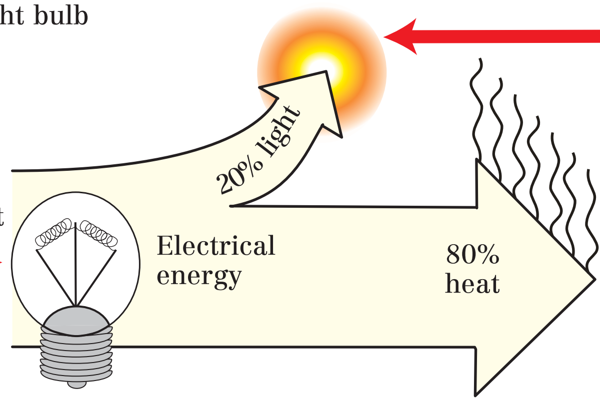
If energy is conserved, why do we talk about ‘wasting energy’?

Usually when energy is transferred only a proportion of the energy is converted to a useful form, the remainder is converted to other less useful forms of energy, often heat.

E.g. Light bulb

Useful – the type of energy we want from a light bulb.

20% efficient



This energy is not useful – light bulbs are not designed to be heaters. We say this energy has been ‘wasted’.

We say that this energy, that is not useful, is ‘wasted’.

compare

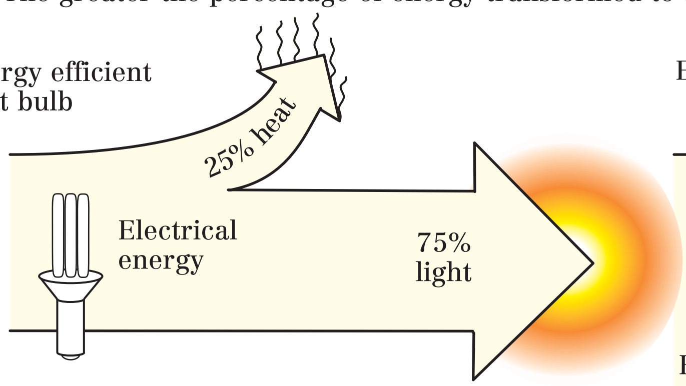
The proportion of the total energy transferred that is useful is called the *efficiency* of the system.

Efficiency (%) = useful energy output (J) / total energy input (J) × 100%

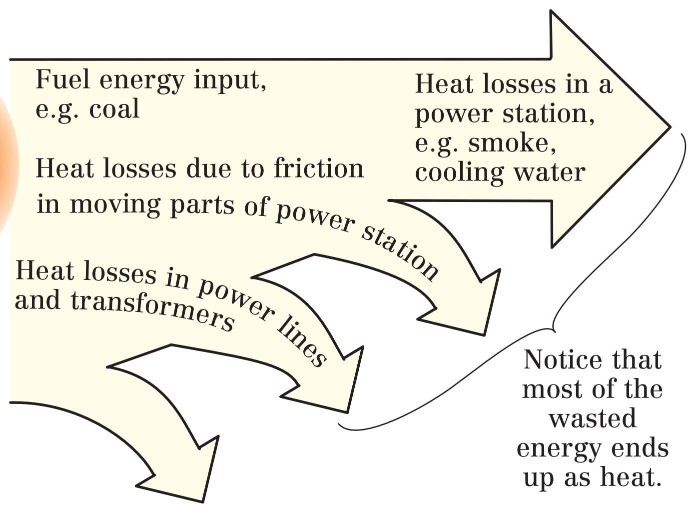
The greater the percentage of energy transformed to a useful form, the more efficient the device.

Energy efficient light bulb

75% efficient



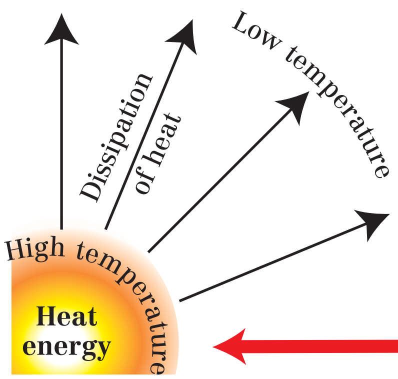
E.g. Power generation



Useful electricity

Notice that most of the wasted energy ends up as heat.

Heat energy naturally spreads out into the environment.



Most energy that spreads out into the environment is relatively cool and therefore not useful.

Thermal energy can be efficiently transferred if it has a high temperature. } Useful

Questions

1. An electric motor on a crane raises 50 kg of bricks 10 m. If the energy supplied to the motor was 16 000 J show that the motor is about 30% efficient.
2. A rollercoaster has 250 000 J of GPE at the top of the first hill. At the bottom of the first hill, the coaster has 220 000 J of KE. Where did the rest of the energy go, and what is the overall efficiency of the GPE to KE conversion?
3. A ball of mass 30 g falls from 1.5 m and rebounds to 0.8 m. Show that the efficiency of the energy transformation is about 50%. Why do you not need to know the mass of the ball?
4. A car engine is about 20% efficient at converting chemical energy in petrol. If a car of mass 1000 kg has to climb a hill 50 m high, how much chemical energy will be required? Why in reality would substantially more chemical energy be needed than the value you calculated?
5. A filament light bulb produces a lot of waste heat. Explain why this waste heat energy cannot be put to other uses very easily.
6. What are the main sources of energy wastage in:
   a. A vacuum cleaner?
   b. A motor car?

TRANSFER OF ENERGY

WAVES

Describing Waves

WAVES

All waves transfer energy from one place to another, without transferring any matter.

A wave is a periodic disturbance of a medium.

Speed = distance travelled by a wave crest or compression in one second.

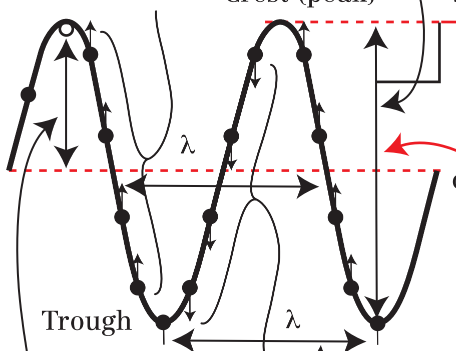
The direction of wave motion is defined as the direction energy is transferred.

The medium is the material that is disturbed as the wave passes through it.

Two types

Transverse waves

Particles of the medium oscillate about fixed positions at right angles to the direction of wave travel.



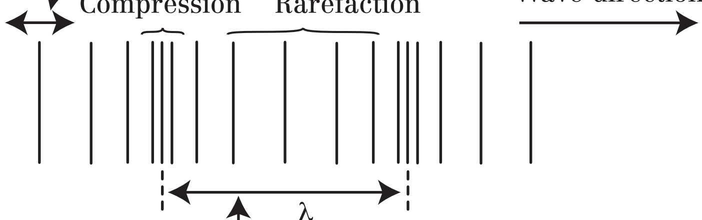
Amplitude – distance between a crest or trough and the *undisturbed position*.

Examples transverse:

- Surface water waves
- Light
- Plucked guitar string

Longitudinal waves

The particles of the medium oscillate about fixed positions along the same line as the wave energy travels.

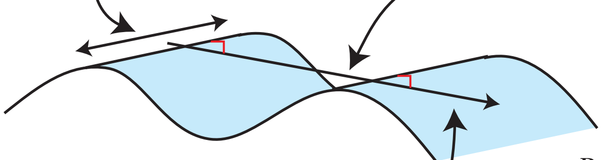


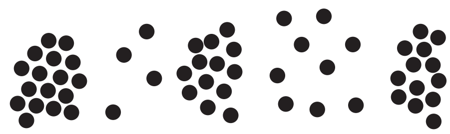
Wavelength (λ) – distance between the same point on two adjacent disturbances. Measured in metres.

Frequency is the number of waves per second produced by the source that pass through a given point in the medium. Measured in waves per second or Hertz, Hz.

Examples longitudinal:

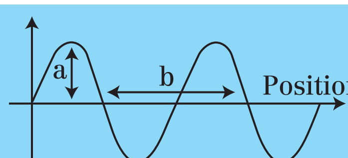
- Sound

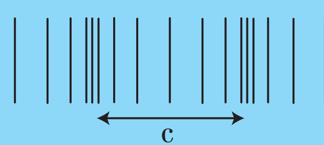




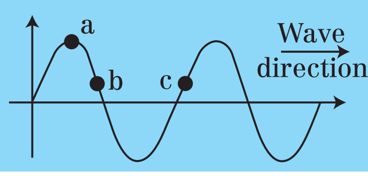
Questions

1. Identify the measurements a, b and c in the following diagrams:





2. Write a sentence to define each of the following terms:
   a. Wavelength.
   b. Frequency.
   c. Amplitude.
2. Give one similarity and one difference between a longitudinal and transverse wave and give an example of each.
3. For each of particles a, b, and c in the diagram decide if the particle is moving up, moving down, or is momentarily stationary.



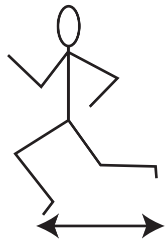
WAVES Wave Speed

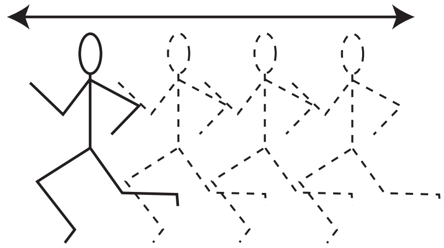
The speed of a wave is given by the equation

Wave speed (m/s) = frequency (Hz) × wavelength (m).

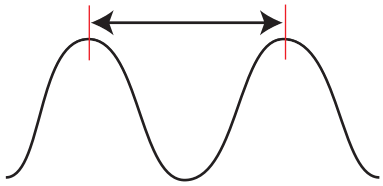
Here is how to see why

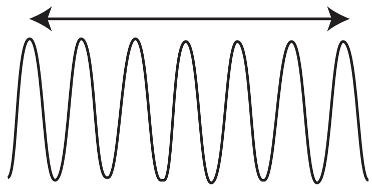
Walking speed (m/s) = stride length (m) × no of steps per second





Wave speed (m/s) = wavelength (m) × no of waves per second (frequency)

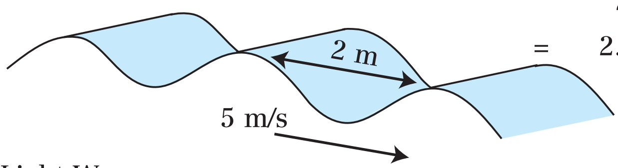




Examples

Water Wave:

$$\text{frequency} = \frac{\text{speed}}{\text{wavelength}} = \frac{5 \text{ m/s}}{2 \text{ m}} = 2.5 \text{ Hz}$$



Light Wave:

Speed of light $= 3 \times 10^8$ m/s

frequency $= 5 \times 10^{14}$ Hz,

$$\text{wavelength} = \frac{\text{speed}}{\text{frequency}} = \frac{3 \times 10^8 \text{ m/s}}{5 \times 10^{14} \text{ Hz}} = 6 \times 10^{-7} \text{ m}$$

Common speeds:

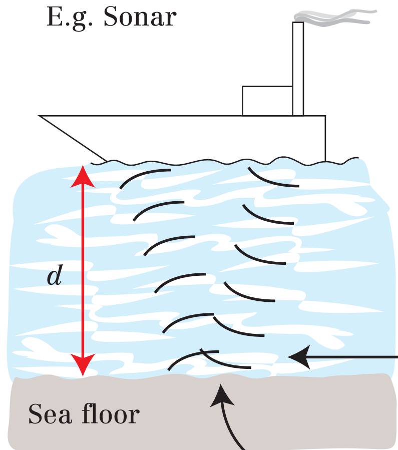
Speed of light = 3×10^8 m/s (300 000 000 m/s)

Speed of sound ≈ 340 m/s (in air at room temperature)

Wave speeds can also be calculated by

$$\text{Wave speed (m/s)} = \frac{\text{distance travelled (m)}}{\text{time taken (s)}}$$

E.g. Sonar



N.B. Remember time is the out and back time.

Distance, d = speed × $^1/_2$ time for sound to return

Sound wave

Reflects off sea floor

Questions

1. Calculate the speed of the following waves:
   a. A water wave of wavelength 1 m and frequency 2 Hz.
   b. A water wave of wavelength 3 m and frequency 0.4 Hz.
2. Rearrange the formula wave speed = frequency × wavelength to read:
   a. wavelength = _____. b. frequency = ______.
3. Calculate the frequency of a sound wave of speed 340 m/s and wavelength:
   a. 2 m. b. 0.4 m.
4. Calculate the wavelength of a light wave of speed 300 000 000 m/s and frequency:
   a. 4.62×10^{14} Hz. b. 8.10×10^{14} Hz.
5. Calculate the speed of the following waves. Why might we say that all of these waves belong to the same family?
   a. Wavelength 10 m, frequency = 3×10^7 Hz.
   b. Wavelength 4×10^{-3} m, frequency 7.5×10^{10} Hz.
   c. Wavelength 6×10^{-10} m, frequency 5×10^{17} Hz.
6. In the sonar example above, the echo takes 0.3 s to return from the sea floor. If the sea is 225 m deep, show that the speed of sound in seawater is about 1500 m/s.
7. A radar station sends out radiowaves of wavelength 50 cm and frequency 6×10^8 Hz. They reflect off an aircraft and return in 4.7×10^{-5} s. Show that the aircraft is about 7 km from the radar transmitter.

WAVES Electromagnetic Waves

Electromagnetic waves, like all waves transfer energy. They also have the following properties in common.

Electromagnetic waves

- Will travel across empty space. They do not need a medium (solid, liquid, or gas) to travel, unlike sound waves.
- They all travel at the speed of light (300 000 000 m/s) in a vacuum.
- As the speed is fixed, as wavelength increases frequency decreases and *vice versa*.
- They can all be reflected, refracted, diffracted, and interfere.
- They obey the wave speed equation:
  Wave speed (m/s) = frequency (Hz) × wavelength (m).
- The electromagnetic spectrum of increasing frequency and decreasing wavelength is broken up into blocks and given names. These group the wavelengths that are produced in similar ways.

Notice that ultraviolet, X-rays, and gamma rays wavelengths overlap but they are named according to their source.

	Radiowaves	Microwaves	Infrared (IR)	Visible light	Ultraviolet (UV)	X-rays	Gamma Rays
	I N C R E A S I N G F R E Q U E N C Y →						
Frequency range (Hz)	3×10^9	3×10^{11}	4.3×10^{14}	7.5×10^{14}	3×10^{17}	3×10^{20}	
	← I N C R E A S I N G W A V E L E N G T H						
Wavelength range	10 cm	1 mm	7×10^{-7} m	4×10^{-7} m	UV 1×10^{-9} m	X-rays 1×10^{-12} m	γ-rays
Sources	Radio transmitters (electrons accelerating up and down metal aerials)	Microwave transmitters (Klystron or magnetron tube)	Any hot object →	Very hot, luminous objects → Light emitting diodes	Extremely hot gases, e.g. the Sun, UV lamps	X-ray tubes	Nuclei of radio-active atoms
Detectors	Aerials	Microwave receiver (aerial)	← (special) Photographic film → ; ← Charge coupled device – used in digital cameras and camcorders → ; Thermistor	Light dependent resistor	Fluorescent materials	← GM tube →	
	I N C R E A S I N G E N E R G Y →						

Detectors: Things which produce an observable response to the radiation they absorb.

Notice that light is just one of this family of radiations and that the visible spectrum, red–violet, can be extended on both sides.

Questions

1. State three properties all electromagnetic waves have in common.
2. Calculate the wavelength of electromagnetic waves of the following frequencies:
   a. 5×10^9 Hz. b. 5×10^{14} Hz. c. 5×10^{15} Hz.
   d. What part of the electromagnetic spectrum does each of these waves come from?
2. Calculate the frequencies of electromagnetic waves of the following wavelengths:
   a. 1 m. b. 1×10^{-5} m. c. 5×10^{-8} m.
   d. What part of the electromagnetic spectrum does each of these waves come from?
3. List the electromagnetic spectrum in order of increasing energy.
4. Which has the longest wavelength, red or blue light? List the colours of the visible spectrum in order of increasing frequency.