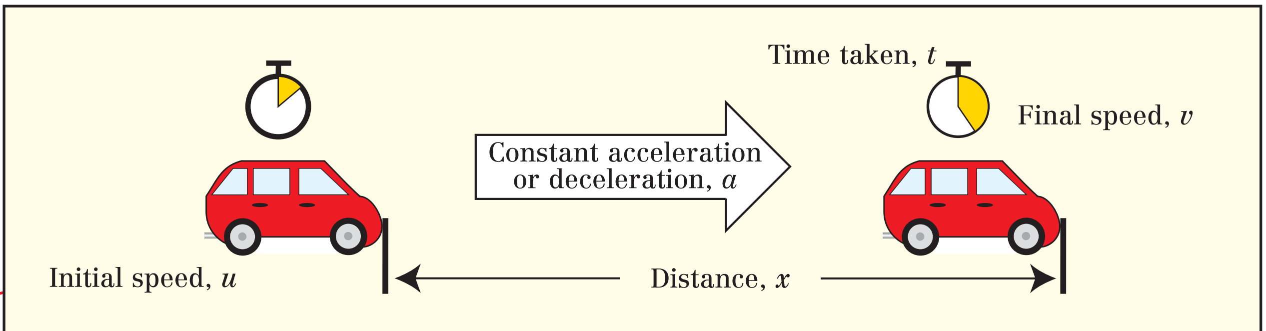
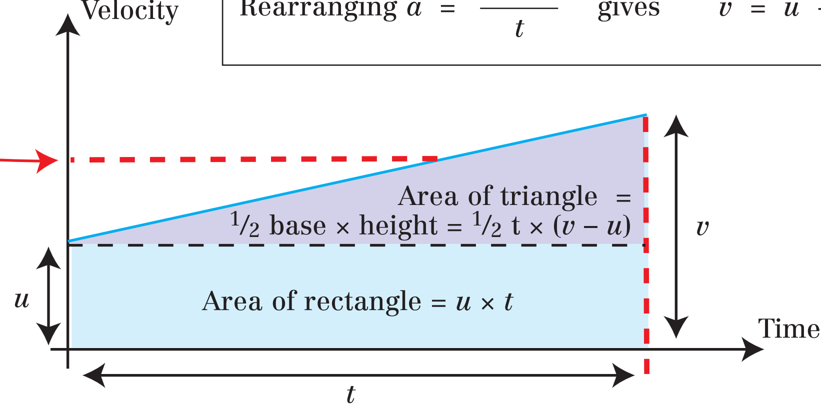


N.B. This motion could also be a falling object, or a rising one, like a rocket.

Gradient = acceleration = $\dfrac{\text{change in velocity}}{\text{time taken}} = \dfrac{(v-u)}{t}$

Rearranging $a = \dfrac{v-u}{t}$ gives $v = u + at$. **1**

Velocity–time graph for this motion



N.B.
average speed

$$= \frac{(v+u)}{2} = \frac{\text{total distance}}{\text{total time}} = \frac{x}{t}$$

So $\dfrac{(v+u)}{2} = \dfrac{x}{t}$ and therefore

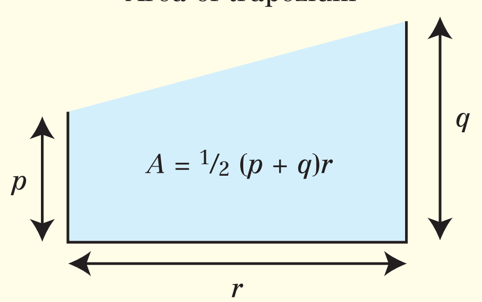
$x = \tfrac{1}{2}(v+u)t$

Total distance travelled = x = area under graph
$= u \times t + \tfrac{1}{2}\, t \times (v-u)$

From **1** : $(v-u) = at$ so $x = ut + \tfrac{1}{2}\, t\, (at)$

$\boxed{x = ut + \tfrac{1}{2}at^2}$ **2**

Area of trapezium



Alternatively, distance travelled = x = area under graph
= area of trapezium
$= \tfrac{1}{2}(u+v)\,t$

same result

But from **1** $t = \dfrac{(v-u)}{a}$

so $x = \tfrac{1}{2}(u+v) \times \dfrac{(v-u)}{a}$

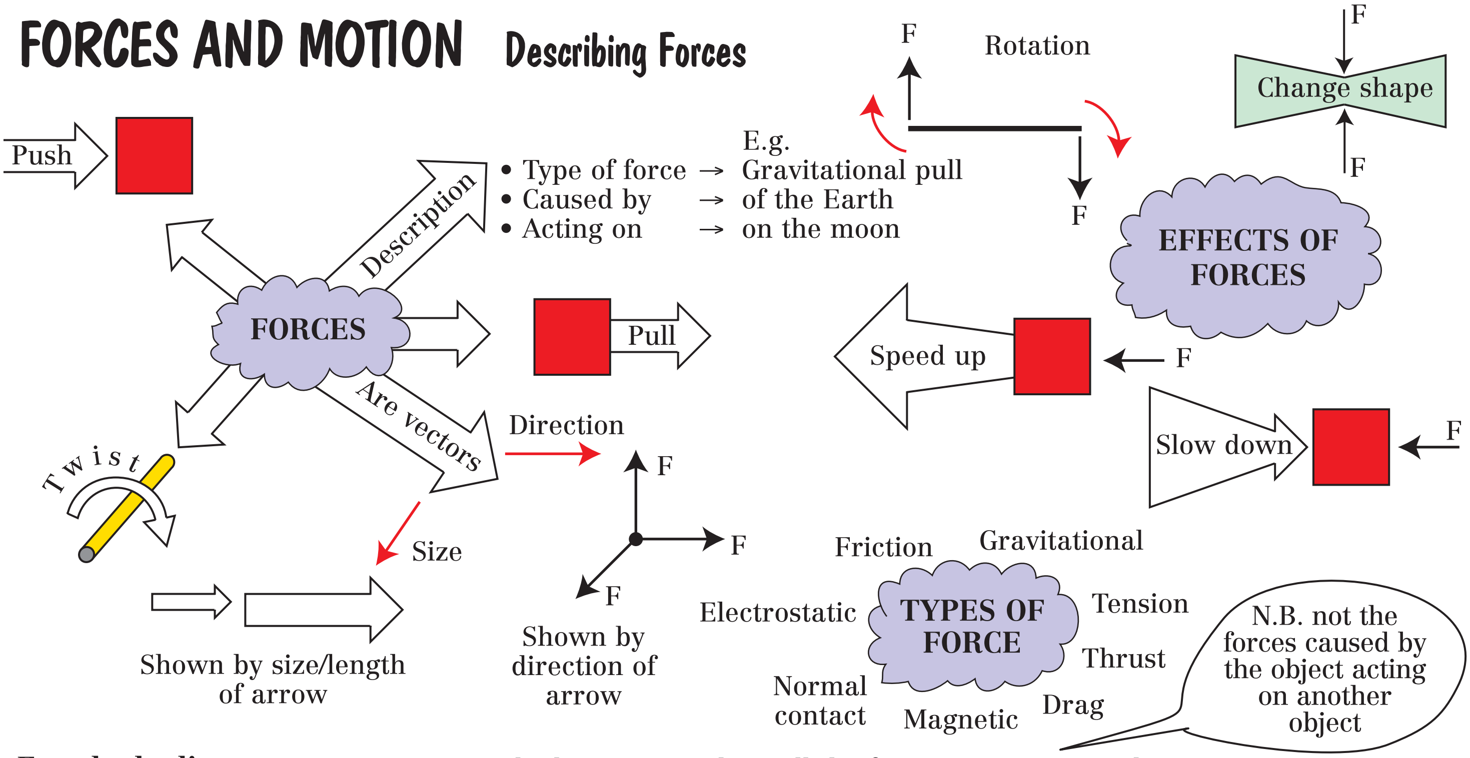
Rearranging $\boxed{v^2 = u^2 + 2ax}$ **3**

Questions

Show ALL your working.

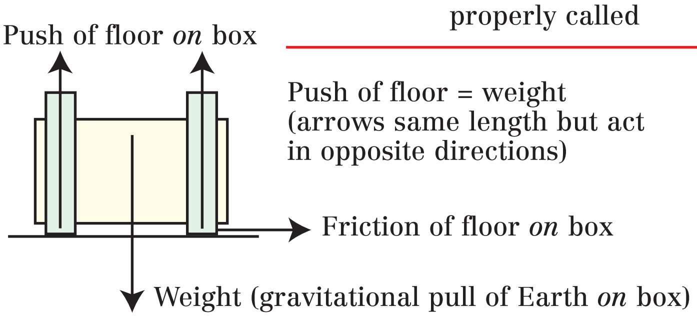
1. What quantities do the variables x, u, v, a, and t each represent?
2. Write a list of three equations which connect the variables x, u, v, a, and t.
3. A car accelerates from 10 m/s to 22 m/s in 5 s. Show that the acceleration is about 2.5 m/s^2.
4. Now show the car in (3) travelled 80 m during this acceleration:
   a. Using the formula $v^2 = u^2 + 2ax$.
   b. Using the formula $x = ut + \tfrac{1}{2}at^2$.
5. A ball falls from rest. After 4 s, it has fallen 78.4 m. Show that the acceleration due to gravity is 9.8 m/s^2.
6. Show that $x = \tfrac{1}{2}(u+v)(v-u)/a$ rearranges to $v^2 = u^2 + 2ax$.
7. A ball thrown straight up at 15 m/s, feels a downward acceleration of 9.8 m/s^2 due to the pull of the Earth on it. How high does the ball go before it starts to fall back?

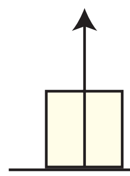
FORCES AND MOTION Describing Forces



Free body diagrams
E.g. Sliding box

Simple diagrams to show all the forces acting *on* an object.

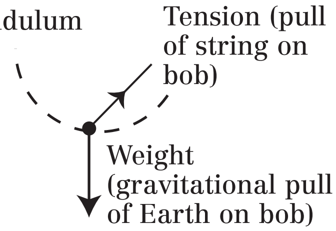




Push of one surface on another at right angles to the surface.
Due to atoms in each surface being slightly squashed together and pushing back

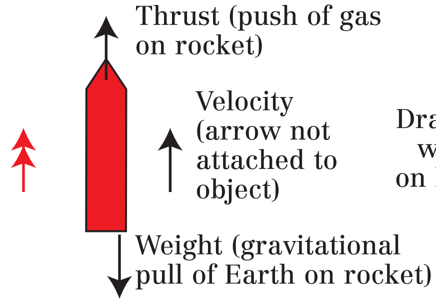
Weight – shorthand for 'the gravitational pull of a planet or moon (usually the Earth) on an object'

E.g. pendulum

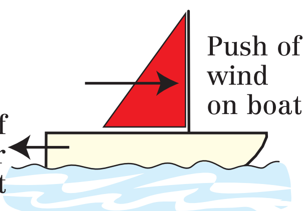


Resultant force – a single force that can replace all the forces acting on a body and have the same overall effect as all the individual forces acting together.
It is the sum of all the individual forces taking their directions into account.

E.g. rocket

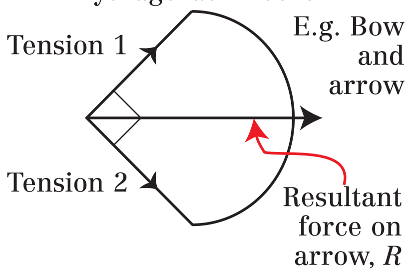


Parallel forces – add



Resultant = push of wind on boat – drag of water on boat

Perpendicular forces – Pythagoras Theorem

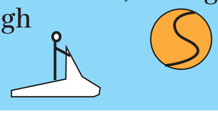


R^2 = (tension $1)^2$ + (tension $2)^2$

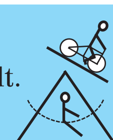
Shows opposite direction

Questions

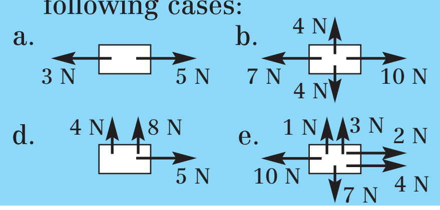
1. List three effects forces can have.
2. Explain what the term 'resultant force' means.
3. To describe a force fully, what three pieces of information should be recorded?
4. Copy and add arrows to these diagrams to show all the forces (and their directions) acting on:
   a. A netball flying through the air.
   b. A jet ski.



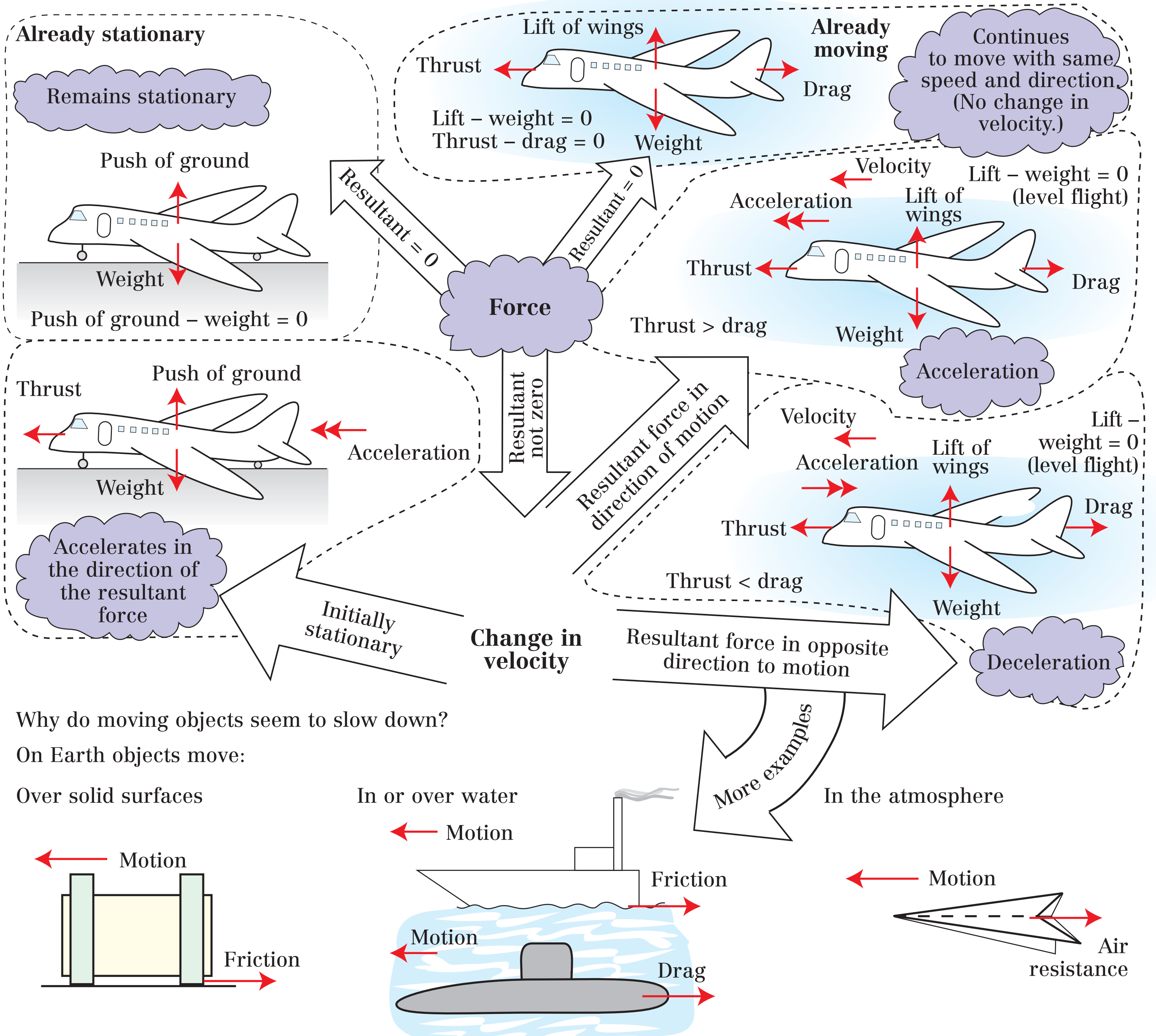
   c. A cyclist freewheeling down a hill.
   d. A child on a swing pushed by an adult.



5. Calculate the resultant force in the following cases:



FORCES AND MOTION Balanced Forces – Newton's First Law



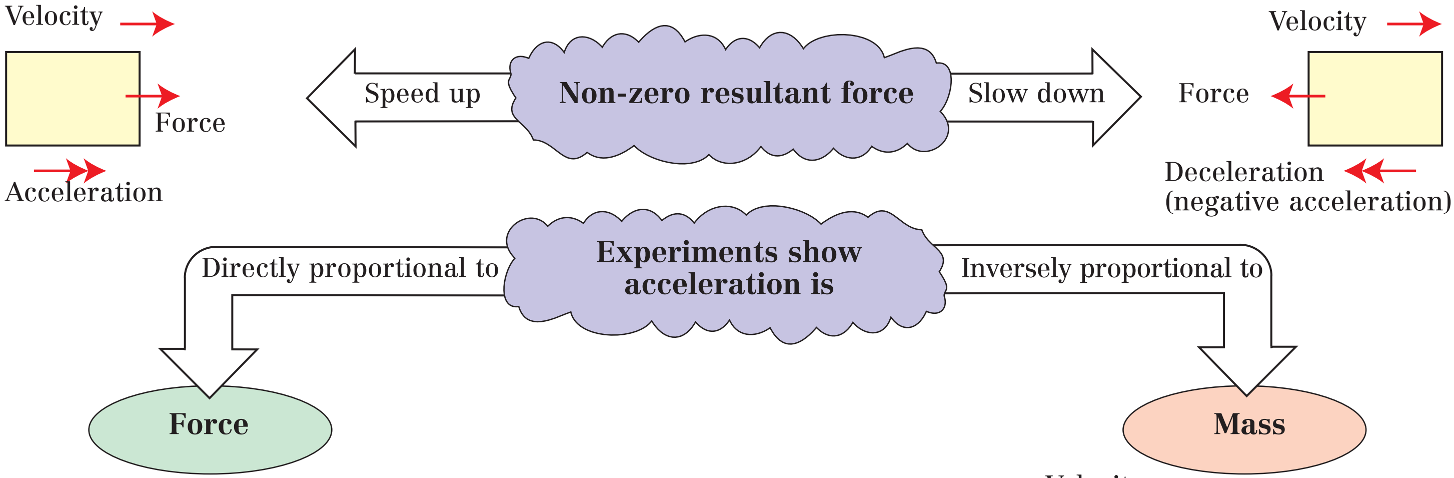
In all cases, resistive forces act to oppose motion. Therefore, unless a force is applied to balance the resistive force the object will slow down. In space, there are no resistive forces and objects will move at constant speed in a straight line unless another force acts.

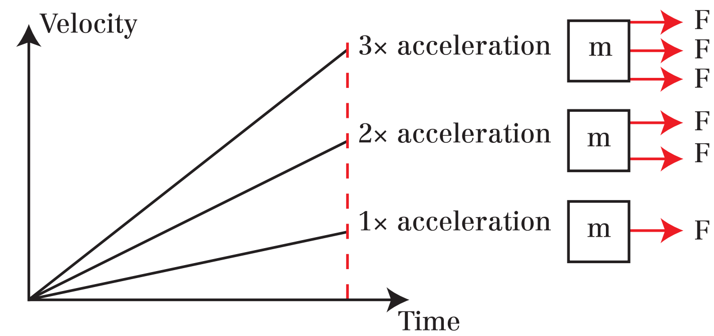
Newton's First Law of Motion:
- If the resultant force acting on a body is zero, it will remain at rest or continue to move at the same speed in the same direction.
- If the resultant force acting on a body is not zero, it will accelerate in the direction of the resultant force.

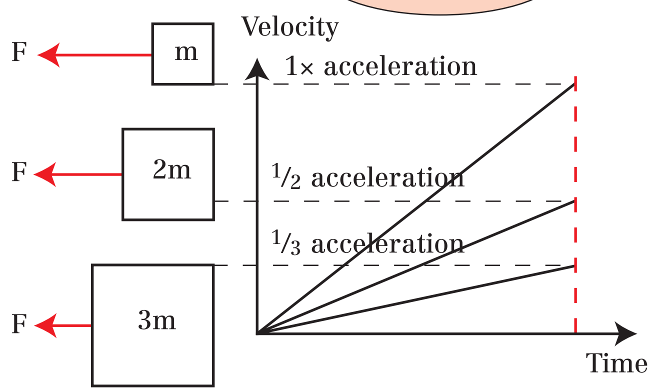
Questions

1. In which of the following situations is the resultant force zero? Explain how you decided.
   a. A snooker ball resting on a snooker table.
   b. A car accelerating away from traffic lights.
   c. A ball rolling along level ground and slowing down.
   d. A skier travelling down a piste at constant speed.
   e. A toy train travelling round a circular track at constant speed.
2. A lift and its passengers have a weight of 5000 N. Is the tension in the cable supporting the lift:
   i. Greater than 5000 N, ii. Less than 5000 N, iii. Exactly 5000 N when:
   a. The lift is stationary?
   b. Accelerating upwards?
   c. Travelling upwards at a constant speed?
   d. Decelerating whilst still travelling upwards?
   e. Accelerating downwards?
   f. Travelling downwards at constant velocity?
   g. Decelerating while still travelling downward?
3. Explain why all objects moving on Earth will eventually come to rest unless another force is applied?

FORCES AND MOTION Unbalanced Forces – Newton's Second Law



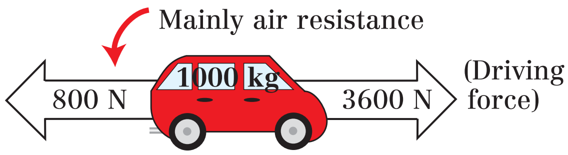




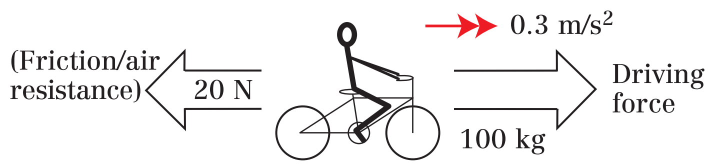
We *define* the Newton as the force needed to accelerate a 1 kg mass at 1 m/s^2. Therefore, we can write:

Force (N) = mass (kg) × acceleration (m/s^2). **Newton's Second Law**

E.g.



Resultant force = 2800 N
Acceleration = force/mass = 2800 N/1000 kg = 2.8 m/s^2.



Resultant force = mass × acceleration
= 100 kg × 0.3 m/s^2
= 30 N
Resultant force = driving force – 20 N
Driving force = 50 N

What is mass?

The reluctance of the object to accelerate when a force is applied (its inertia).

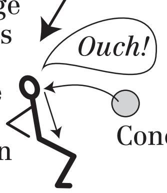
Means 'resistance to change' (in this case its velocity).

A measure of the amount of material in an object.

Never varies from place to place.

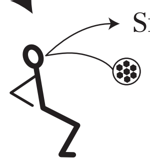
Large mass

Large force for small acceleration



Small mass

Small force gives large acceleration.



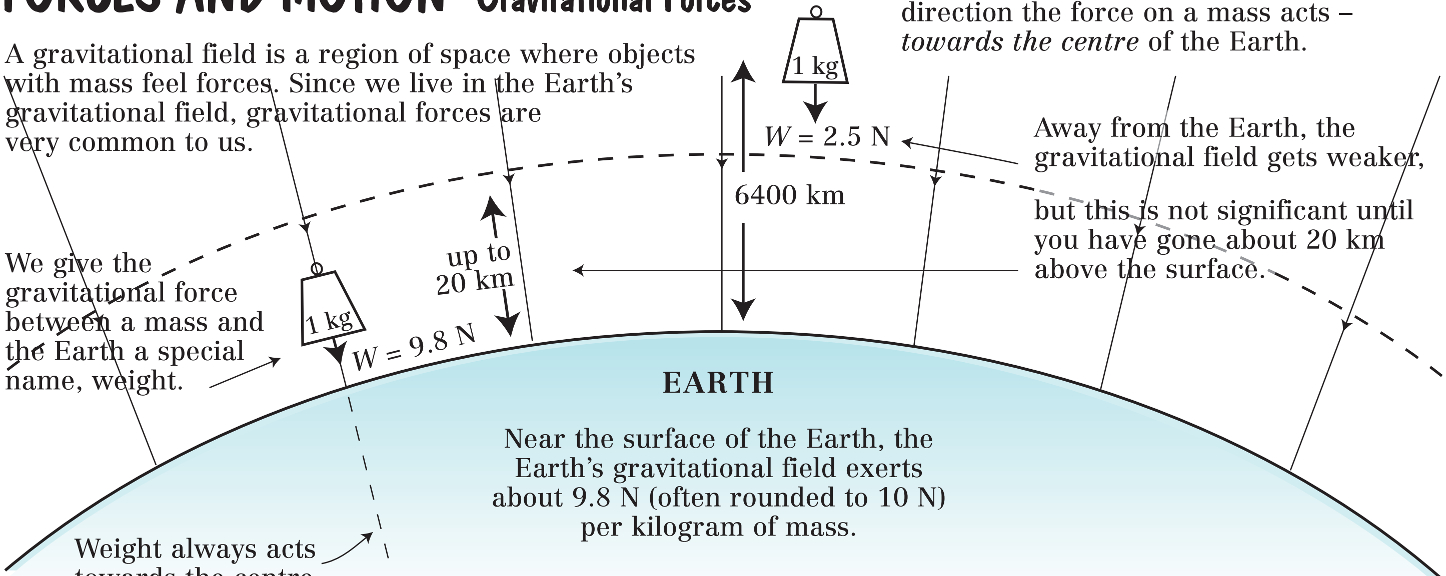
Questions

1. Calculate:
   a. The force needed to accelerate a 70 kg sprinter at 6 m/s^2.
   b. The acceleration of a 10 g bullet with 2060 N explosive force in a gun barrel.
   c. The mass of a ship accelerating at 0.09 m/s^2 with a resultant thrust of 6 400 000 N from the propellers.
2. An underground tube train has mass of 160 000 kg and can produce a maximum driving force of 912 000 N.
   a. When accelerating in the tunnel using the maximum driving force show the acceleration should be 5.7 m/s^2.
   b. In reality, the acceleration is only 4.2 m/s^2. Hence show the resistive forces on the train are 240 000 N.
3. Explain why towing a caravan reduces the maximum acceleration of a car (two reasons).
4. A football made of concrete would be weightless in deep space. However, it would not be a good idea for an astronaut to head it. Why not?

FORCES AND MOTION Gravitational Forces

A gravitational field is a region of space where objects with mass feel forces. Since we live in the Earth's gravitational field, gravitational forces are very common to us.

Invisible gravitational field – lines show direction the force on a mass acts – *towards the centre* of the Earth.



Away from the Earth, the gravitational field gets weaker, but this is not significant until you have gone about 20 km above the surface.

We give the gravitational force between a mass and the Earth a special name, weight.

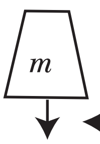
Near the surface of the Earth, the Earth's gravitational field exerts about 9.8 N (often rounded to 10 N) per kilogram of mass.

Weight always acts towards the centre of the Earth.

Gravitational field strength g, defined as the force per kilogram of mass placed at the point of interest.

The force per kilogram of mass is a good way of measuring the strength of the Earth's gravitational field.

Weight (N) = mass (kg) × gravitational field strength (N/kg).



$W = mg$

If an object is in free fall, the only force on it is weight (difficult in practice because of air resistance).

Applying Newton's second law

Resultant force = mass × acceleration

Then acceleration (m/s^2) = weight (N) / mass (kg).

10 m/s^2

Hence, acceleration due to free fall is equivalent to gravitational field strength.

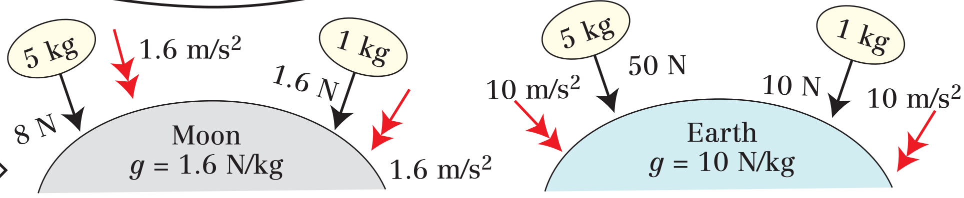
However, this is also the definition of gravitational field strength.

g = 10 N/kg

All masses fall with an acceleration of about 10 m/s^2 (providing there are no resistive forces).

You can think of this as the weight increasing to compensate for the increased mass so all objects fall at the same rate, independent of their mass.

The mass of an object is the same everywhere. The weight depends on the gravitational field strength.



Questions

1. Near the surface of the Earth, what are the values of:
   a. The acceleration due to free fall?
   b. The gravitational field strength?
2. What are the weights on the Earth of:
   a. A book of mass 2 kg?
   b. An apple of mass 100 g?
   c. A girl of mass 60 kg?
   d. A blade of grass of mass 0.1 g?
3. What would the masses and weights of the above objects be on the moon? (Gravitational field strength on the moon = 1.6 N/kg).
4. 6400 km above the surface of the Earth a 1 kg mass has a weight of 2.5 N. What is the gravitational field strength here? If the mass was dropped, and started falling towards the centre of the Earth, what would its initial acceleration be?
5. Write a few sentences to explain the difference between mass and weight.

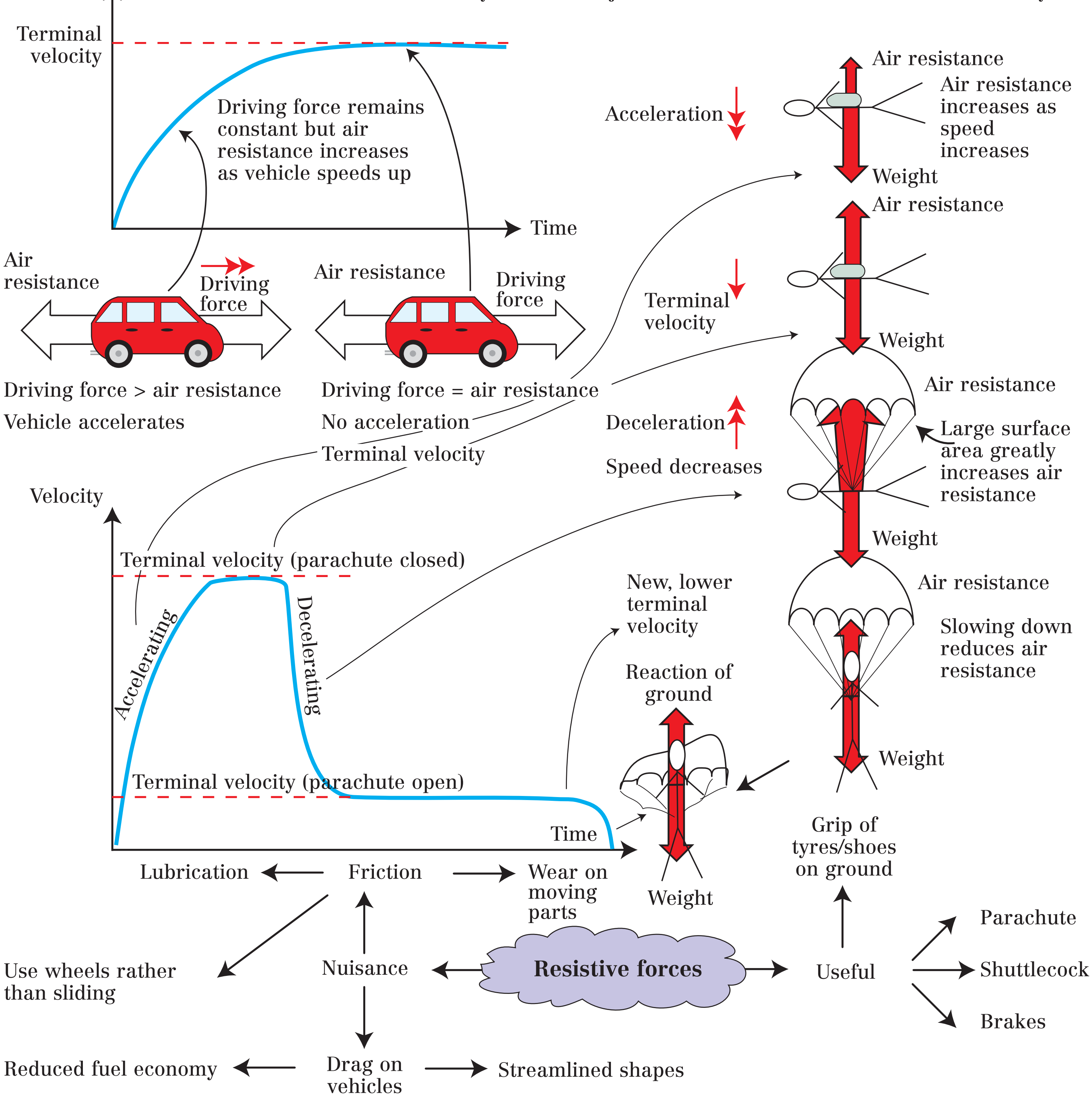
FORCES AND MOTION

Terminal Velocity

Terminal velocity occurs when the accelerating and resistive force on an object are balanced.

Key ideas:

- Drag/resistive forces on objects increase with increasing speed for objects moving through a fluid, e.g. air or water.
- When accelerating and resistive forces are balanced, Newton's First Law says that the object will continue to travel at constant velocity.



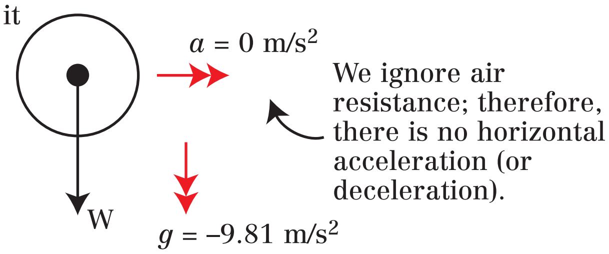
Questions

1. What happens to the size of the drag force experienced by an object moving through a fluid (e.g. air or water) as it speeds up?
2. What force attracts all objects towards the centre of the Earth?
3. Why does a car need to keep its engine running to travel at constant velocity?
4. A hot air balloon of weight 6000 N is released from its mooring ropes.
   a. The upward force from the hot air rising is 6330 N. Show the initial acceleration is about 0.5 m/s^2.
   b. This acceleration gradually decreases as the balloon rises until it is travelling at a constant velocity. Explain why.
   c. A mass of 100 kg is thrown overboard. What will happen to the balloon now?
   d. Sketch a velocity–time graph for the whole journey of the balloon as described in parts a–c.
5. Explain why the following are likely to increase the petrol consumption of a car:
   a. Towing a caravan.
   b. Adding a roof rack
   c. Driving very fast.

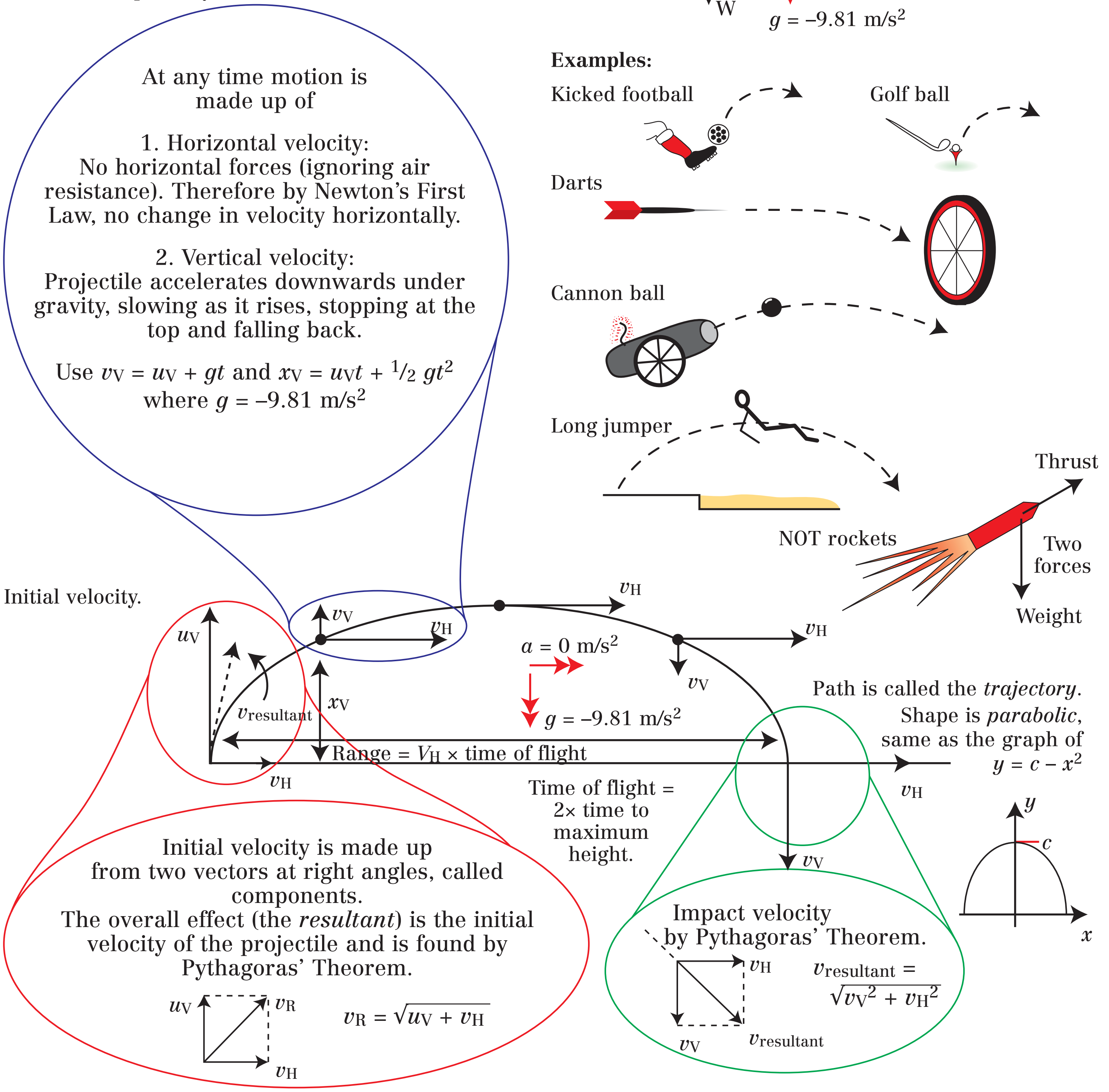
FORCES AND MOTION

Projectiles

A true projectile only has one force, weight, acting on it when it is in flight.



The secret is to consider the velocity of the projectile to be made up of horizontal and vertical velocities, which can be considered separately.

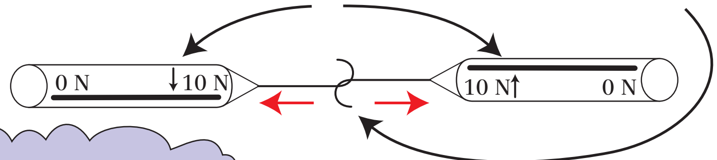


Questions

1. In an ideal world how many forces act on a projectile, and what are they?
2. State the value of the vertical acceleration of a projectile.
3. Explain why the horizontal acceleration of a projectile is zero. What assumption has to be made?
4. Explain why a firework rocket cannot be analysed as a projectile with the methods shown here.
5. A ball is kicked so it has a velocity of 15.59 m/s horizontally and 9.0 m/s vertically.
   a. Show that the resultant velocity of the ball has a magnitude of 18.0 m/s.
   b. Show that the ball takes 0.92 s to reach its maximum height above the ground.
   c. For how long in total is the ball in the air and how far along the ground will it travel?
   d. Show the maximum height the ball reaches is 4.1 m.
   e. What will the magnitude of its resultant velocity be when it hits the ground? Hint: no calculation needed.

FORCES AND MOTION Newton's Third Law

Whenever an object experiences a force it always exerts an equal . . . . . and . . . . . opposite force on the object causing the force.



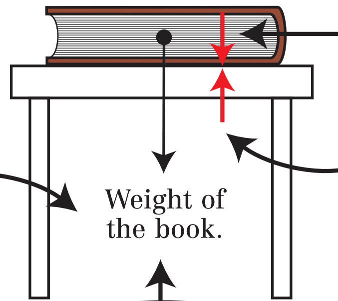
These pairs of forces are called Third Law pairs.

Always have the same *size*.

Always the same *type* of force.

Always act on different bodies (compare with Newton's First Law where we are only interested in the force acting on the body in question).

Always act in *opposite directions*.



Push of the book downwards on the table.

Equal

Push upward of the table on the book.

The reaction of the table on the book.

Gravitational pull downwards of Earth on the book.

Weight of the book.

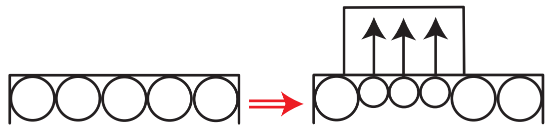
Equal

Gravitational pull upwards of book on Earth.

Normal contact forces.

Third law pairs follow this format:

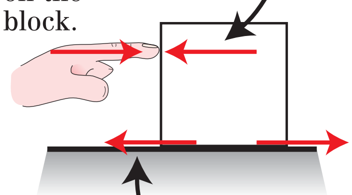
Force F of A on B in one direction =
Force F of B on A in the other direction



Molecules in the surface are pushed slightly closer together and push back. This is often called the *reaction* of a surface.

Push of the hand on the block.

Push of the block on the hand.



Frictional push of the block on the surface.

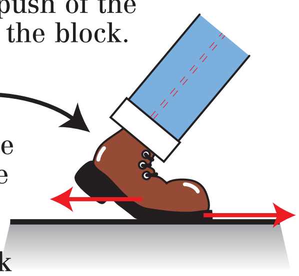
Frictional push of the surface on the block.

Examples

Push of the rocket on gas downwards (out of the rocket).

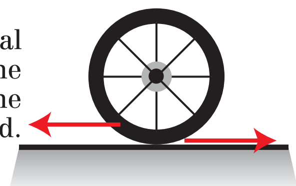
Push of gas on the rocket upwards (propelling the rocket upwards).

Frictional push of the foot on the ground (pushes Earth back slightly).



Frictional push of the ground on the foot (pushes foot forward – this is the force that propels us forward).

Frictional push of the tyre on the ground.



Frictional push of the ground on the tyre (pushes car forwards).

If the ground is icy, both these forces are very small and we cannot walk or drive forwards.

Questions

1. Explain what is meant by the term 'normal contact force'.
2. A jet engine in an aircraft exerts 200 000 N on the exhaust gases. What force do the gases exert on the aircraft?
3. Describe the force that forms a Third Law pair with the following. In each case, draw a diagram to illustrate the two forces:
   a. The push east of the wind on a sail.
   b. The push left of a bowstring on an arrow.
   c. The frictional push south of a train wheel on a rail.
   d. The normal contact force downwards of a plate on a table.
   e. The attraction right of the north magnetic pole of a bar magnet on a south magnetic pole of a different magnet.
4. Why are the following not Third Law pairs? (There may be more than one reason for each.)
   a. The weight of a mug sitting on a table; the normal contact force of the tabletop on the mug.
   b. The weight of the passengers in a lift car; the upward tension in the lift cable.
   c. The weight of a pool ball on a table; the horizontal push of the cue on the ball.
   d. The attraction between the north and south magnetic poles of the same bar magnet.
5. Explain why it is very difficult (and dangerous) to ride a bicycle across a sheet of ice.

Momentum and Force (Newton's Laws revisited)

Momentum helps to describe how moving objects will behave.

Momentum (kgm/s) = mass (kg) × velocity (m/s)

Momentum is a vector. It has size and direction (the direction of the velocity).

Newton's Second Law

Resultant force = mass × acceleration

$F = m \times a$

acceleration = change in velocity/time taken

$a = (v - u)/t$

Resultant force = mass × change in velocity / time taken

$F = m\,(v - u)\,/\,t$

Rearranging

$F\Delta t = mv - mu$

Impulse (Ns)

Change in momentum (kgm/s)

Hence, an alternative version of Newton's Second Law

If a resultant force acts on a body free to move a change in momentum occurs equal to the product of the force and the time for which it acts.

Initial velocity, u

Force, F

Mass, m

Time, Δt

Final velocity, v

$F\Delta t = mv - mu$

Also consider

Zero resultant force → No change in momentum → No change in velocity → Stationary? → Stays stationary

Newton's First Law

Already moving? → Continues to move at a steady speed in a straight line.

A | B

$F_{\text{A on B}}$ | $F_{\text{B on A}}$

Newton's Third Law

As $F_{\text{A on B}} = -F_{\text{B on A}}$ and objects must be in contact for the same time, Δt,

$F\Delta t = mv - mu$

$F\Delta t$ = change in momentum.

then $(F_{\text{A on B}})\,\Delta t = -\,(F_{\text{B on A}})\,\Delta t$

Gain of momentum by B

Loss of momentum by A

Equal

Momentum transferred from A to B

Momentum is conserved

Consistent with the idea that when two objects collide they exert equal and opposite forces on each other.

Questions

1. What units do we use to measure momentum and impulse (2 answers)?
2. Calculate the momentum of:
   a. A 55 kg girl running at 7 m/s north.
   b. A 20 000 kg aircraft flying at 150 m/s south.
   c. A 20 g snail moving at 0.01 m/s east.
3. What is the connection between force and change in momentum?
4. What is the change in momentum in the following cases:
   a. A 5 N force acting for 10 s?
   b. A 500 N force acting for 0.01 s?
5. What force is required to:
   a. Accelerate a 70 kg athlete from 0 to 9 m/s in 2 s?
   b. Accelerate a 1000 kg car from rest to 26.7 m/s in 5 s?
   c. Stop a 10 g bullet travelling at 400 m/s in 0.001 s?
6. What would be the effect on the force needed to change momentum if the time the force acts for is increased?
7. A 2564 kg space probe is to be accelerated from 7.7 km/s to 11.0 km/s. If it has a rocket motor that can produce 400 N of thrust, for how long would it need to burn assuming that no resistive forces act? Why might this not be practical? How else might the space probe gain sufficient momentum (see p113 for ideas)?

FORCES AND MOTION Momentum Conservation and Collisions

Law of Conservation of Momentum:

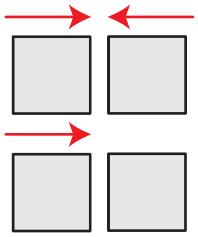
Momentum cannot be created or destroyed but can be transferred from one object to another when they interact.

There are no exceptions to this. It is applied to analyse interactions between objects, which can be classified as:

Velocities

Up and **right** are taken as **positive.**

Down and **left** are taken as **negative.**



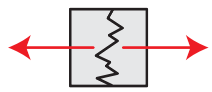
Or

Objects initially moving towards each other

Collisions

or

Objects originally stationary and move apart

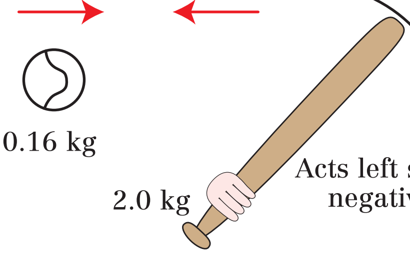


Explosions

1. Momentum before collision

Add up all the individual momenta taking care over their directions.

30 m/s 20 m/s



0.16 kg

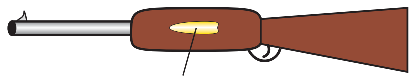
2.0 kg

Acts left so negative

$m_1u_1 + m_2u_2 =$
$0.16\text{ kg} \times 30\text{ m/s} + 2\text{ kg} \times (-20\text{ m/s})$
$= -35.2\text{ kgm/s}$

Overall momentum acts to the left.

3 kg rifle



0.01 kg bullet

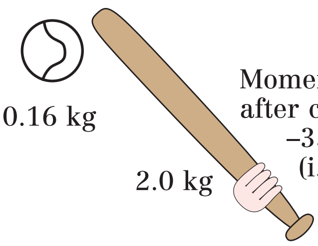
Momentum = 0 kgm/s

Initial momentum is always *zero* for an explosion.

2. By momentum conservation: momentum before = momentum after

Again take care over the direction of the velocities, are they positive or negative?

v m/s 13.76 m/s

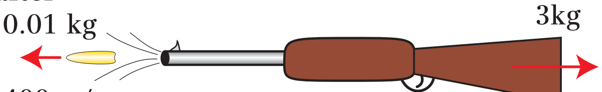


0.16 kg

2.0 kg

Momentum after collision = −35.2 kgm/s (i.e. to the left)

0.01 kg 3kg



400 m/s

v

Momentum after explosion = 0 kgm/s (rifle and bullet move off in opposite directions)

Acts left so negative

3. Equate momentum before and after to find unknown masses or velocities.

Do not worry about the direction of an unknown velocity. The maths will tell you whether it is positive or negative, and therefore its direction.

Momentum after = $m_1v_1 + m_2v_2$

$35.2\text{ gm/s} = 0.16\text{ kg} \times v + 2\text{ kg} \times (-13.76\text{ m/s})$

$v = -48$ m/s

Negative sign tells us the ball travels to the left (as expected).

Momentum after = $m_1v_1 + m_2v_2$

$0\text{ kgm/s} = 0.01\text{ kg} \times (-400\text{ m/s}) + 3\text{ kg} \times v$

$v = +1.33$ m/s

Positive tells us the rifle recoils to the right (as expected).

4. The force involved depends on the size of the change of momentum and the time it is exerted for.

Use $F\Delta t = mv - mu$

If time of collision = 0.02 s the force on the ball

$F \times 0.02\text{ s} = 0.16\text{ kg} \times (-48\text{ m/s}) - (0.16\text{ kg} \times 30\text{ m/s})$

$F = -624$ N (i.e. to the left)

If time of explosion = 0.002 s then the force on the bullet

$F \times 0.002\text{ s} = 0.01\text{ kg} \times -400\text{ m/s} - (0.01\text{ kg} \times 0)$

$F = -2000$ N (i.e. to the left)

FORCES AND MOTION Momentum Conservation and Collisions (continued)

The calculation of the force exerted on the bullet and the ball would work equally well if the force on the bat or the rifle were calculated. The size of the force would be the same, but in the opposite direction according to Newton's Third Law. Again using $F\Delta t = mv - mu$.

Force of ball on bat

$F \times 0.02\text{ s} = 2\text{ kg} \times (-13.76\text{ m/s}) - 2\text{ kg}\ (-20\text{m/s})$

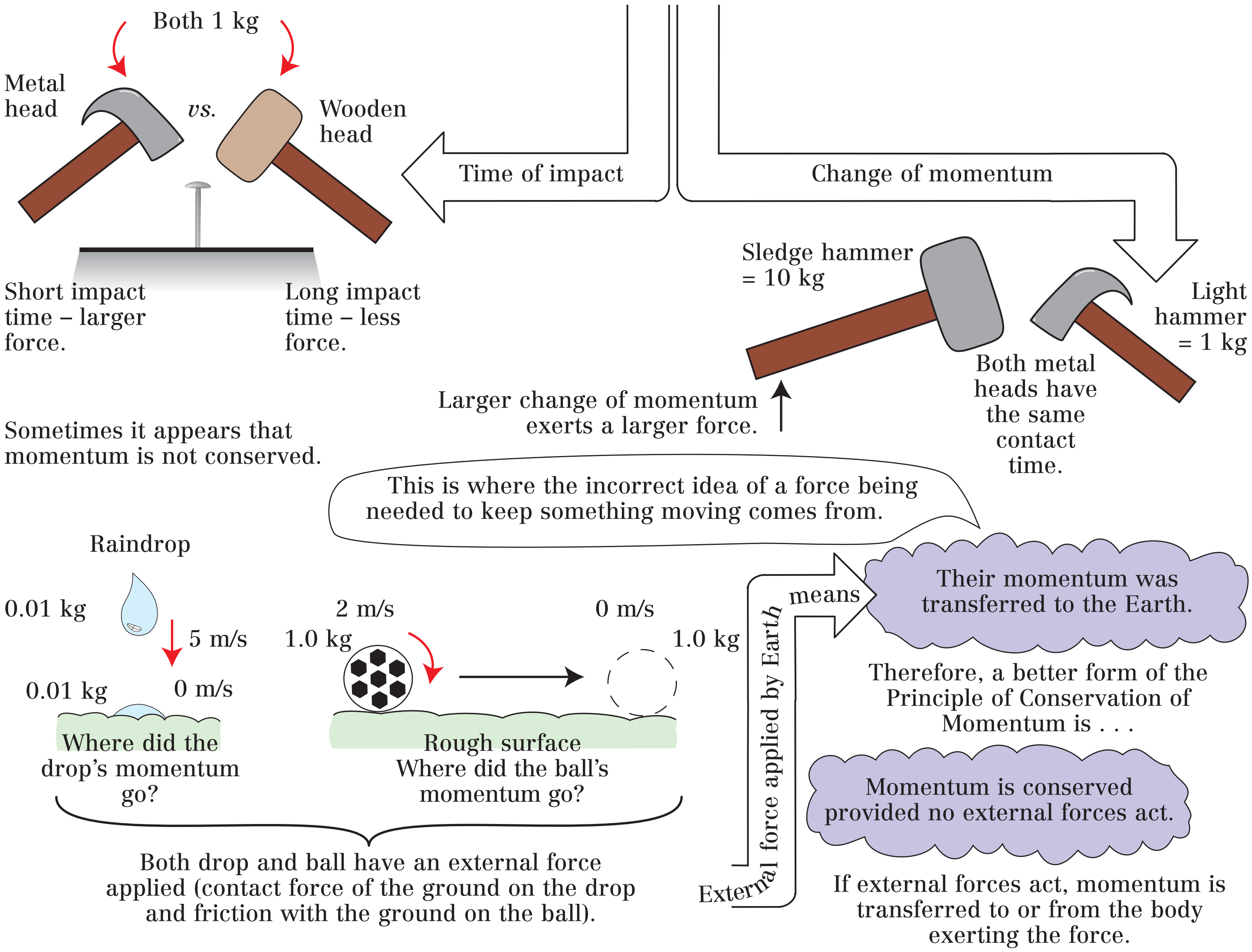
$F = 624$ N (positive, to the right).

Force of bullet on gun

$F \times 0.002\text{ s} = (3\text{ kg} \times 1.33\text{ m/s}) - (3\text{ kg} \times 0\text{ m/s})$

$F = 2000$ N (positive, to the right).

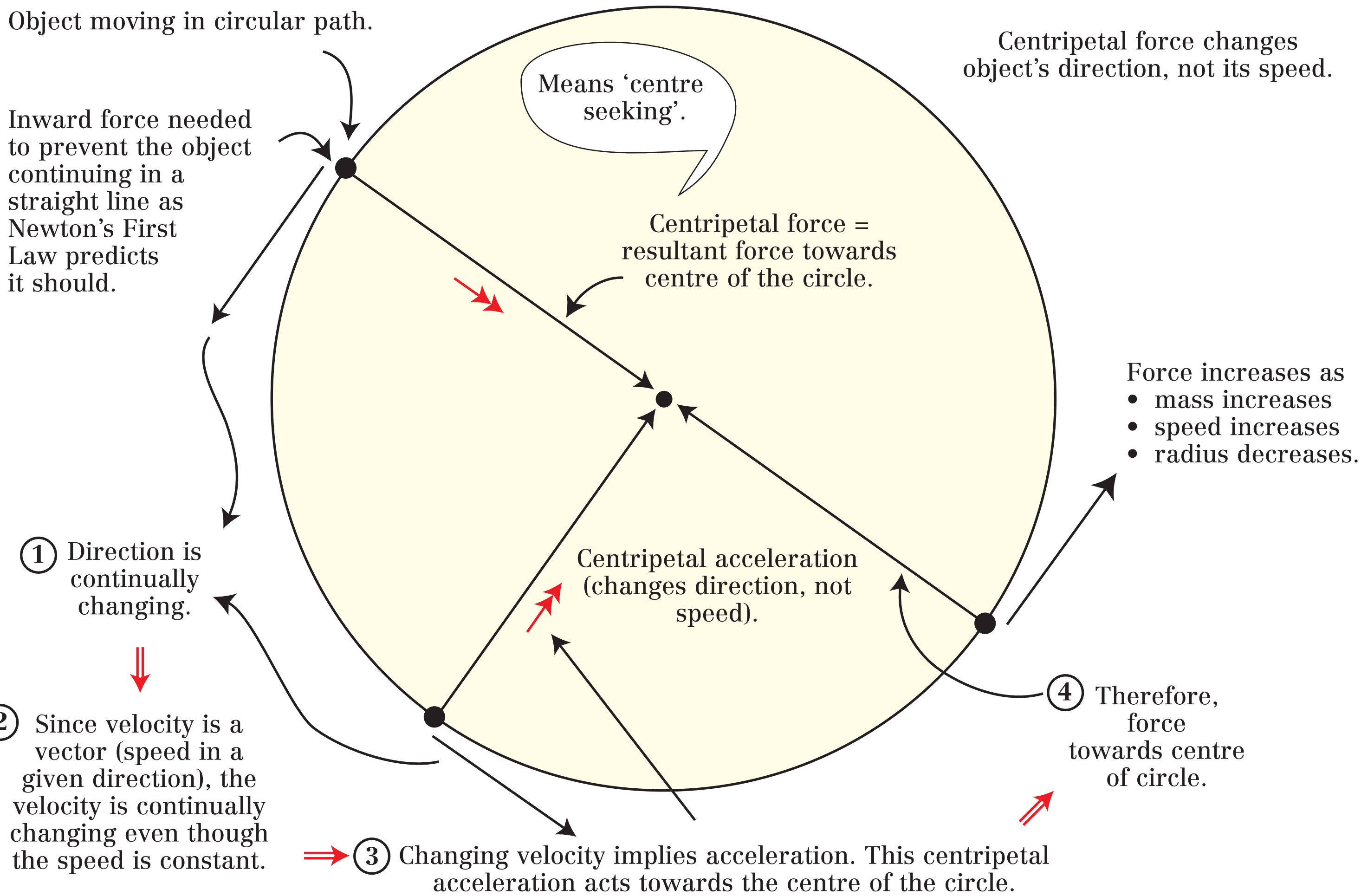
These calculations show that the force involved depends on.



Questions

1. When a raindrop hits the ground where does its momentum go?
2. Why do boxers wear padded gloves?
3. A squash ball is hit against a wall and bounces off. An equal mass of plasticine is thrown at the same wall with the same speed as the ball, but it sticks on impact. Which exerts the larger force on the wall and why?
4. A golfer swings a 0.2 kg club at 45 m/s. It hits a stationary golf ball of mass 45 g, which leaves the tee at 65 m/s.
   a. What was the momentum of the club before the collision?
   b. What was the momentum of the ball after the collision?
   c. Hence, show that the club's velocity is about 30 m/s after the collision.
   d. If the club is in contact with the ball for 0.001 s, what is the average force the club exerts on the ball?
5. A 1.5 kg air rifle fires a 1 g pellet at 150 m/s. What is the recoil velocity of the rifle? Show that the force exerted by the rifle on the pellet is about 70 N if the time for the pellet to be fired is 0.0021 s.
6. Assume that the average mass of a human being is 50 kg. If all 5.5×10^9 humans on Earth stood shoulder to shoulder in one place, and jumped upward at 1 m/s with what velocity would the Earth, mass 6×10^{24} kg recoil?
7. Two friends are ice-skating. One friend with mass 70 kg is travelling at 4 m/s. The other of mass 60 kg travelling at 6 m/s skates up behind the first and grabs hold of them. With what speed will the two friends continue to move while holding onto each other?

FORCES AND MOTION Motion in Circles and Centripetal Forces



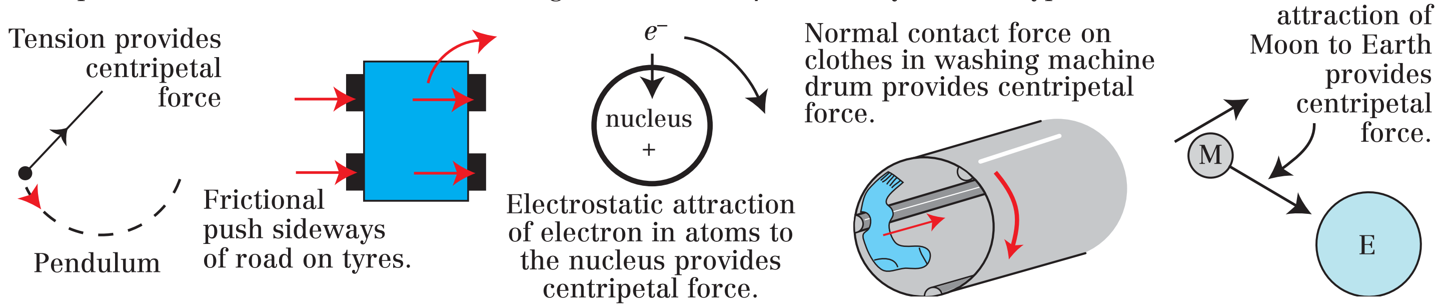
Centripetal acceleration (m/s^2) = $\dfrac{[\text{velocity (m/s)}]^2}{\text{radius (m)}}$

$a = v^2/r$

Centripetal force = mass (kg) × acceleration (m/s^2)

$F = mv^2/r$ = $\dfrac{\text{mass (kg)} \times [\text{velocity (m/s)}]^2}{\text{radius (m)}}$

Centripetal force is not a force in its own right – it must be *provided* by another type of force.



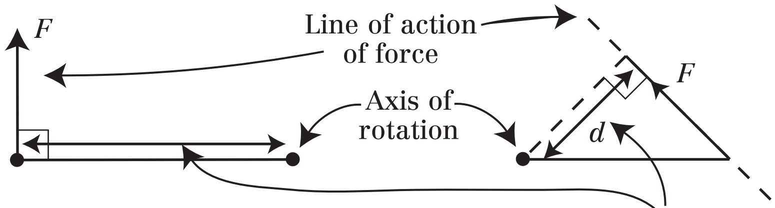
Questions

1. What force provides the centripetal force in each of these cases?
   a. The Earth moving in orbit around the Sun.
   b. Running around a sharp bend.
   c. A child on a swing.
2. Explain how a passenger on a roundabout at a funfair can be moving at constant speed around the circle and yet accelerating. In what direction is the acceleration?
3. What is the centripetal acceleration of, and force on, the following:
   a. A wet sweater of mass 1 kg, spinning in a washing machine drum of radius 35 cm, moving at 30 m/s.
   b. A snowboarder of mass 70 kg travelling round a half pipe of radius 6 m at 5 m/s.
4. The Earth has a mass of 6×10^{24} kg. Its orbit radius is 1.5×10^{11} m and the gravitational attraction to the Sun is 3.6×10^{22} N.
   a. Show that the circumference of the Earth's orbit is about 9.5×10^{11} m.
   b. Show that the Earth's speed around the Sun is about 30 000 m/s.
   c. Therefore, show that the time to orbit the Sun is about 3×10^{7} s.
   d. Show that this is about 365 days.
5. On a very fast rotating ride at a funfair, your friend says that they feel a force trying to throw them sideways out of the ride. How would you convince your friend that actually they are experiencing a force pushing *inwards*? You should refer to Newton's First and Third Laws in your explanation.

FORCES AND MOTION

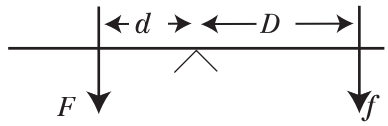
Moments and Stability

A moment (or torque) is the turning effect of a force.



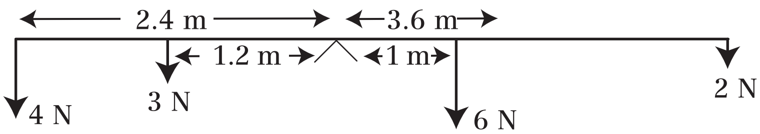
Moment (Nm) = Force (N) × perpendicular distance from line of action of the force to the axis of rotation (m).

A body will not rotate if there is no resultant moment.



Anticlockwise moment $F \times d$ = Clockwise moment $f \times D$

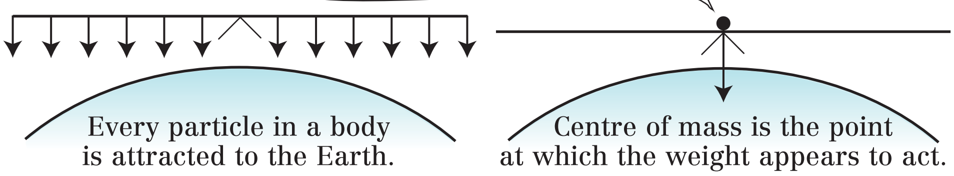
Sum of anticlockwise moments = sum of clockwise moments when in equilibrium.



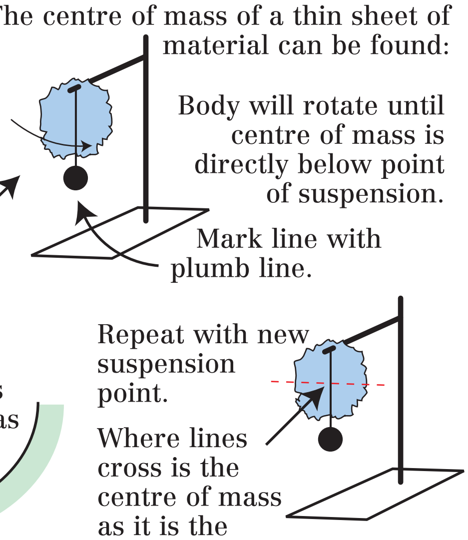
(4 N × 2.4 m) = (3 N × 1.2 m) = (6 N × 1 m) + (2 N × 3.6 m)
13.2 Nm = 13.2 Nm

Centre of mass:

You could think of the mass behaving as if it were all concentrated here.



The centre of mass of a thin sheet of material can be found:



Body will rotate until centre of mass is directly below point of suspension.

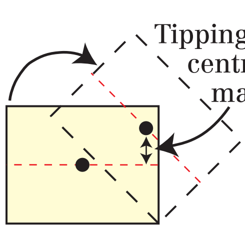
Mark line with plumb line.

Repeat with new suspension point.

Where lines cross is the centre of mass as it is the only point that is on all the lines.

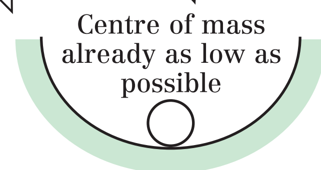
To be stable a body must keep its centre of gravity as low as possible. Therefore factors that affect stability are:

- Mass distribution.
- Shape.



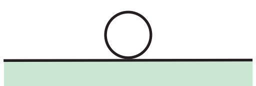
Tipping raises centre of mass

Stable equilibrium



Equilibrium

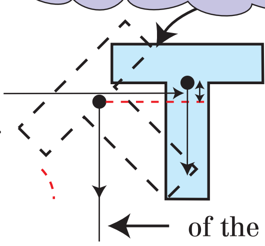
Neutral equilibrium

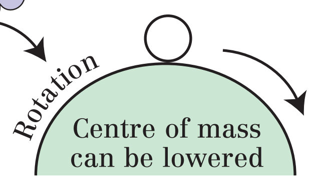


Rotation neither raises, nor lowers, the centre of mass.

Unstable equilibrium

Tipping will lower the centre of mass.

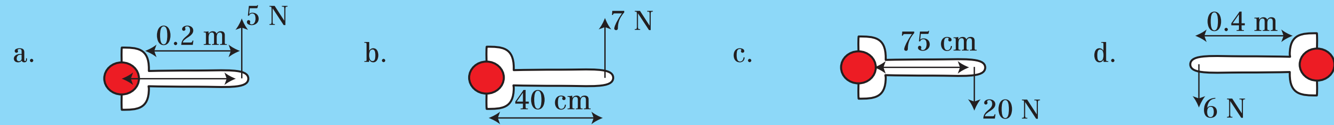




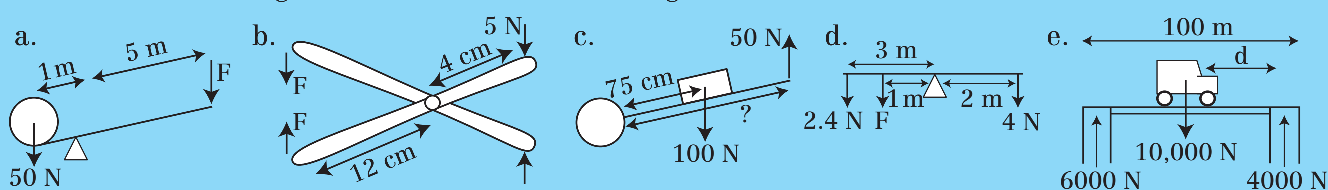
Object topples if the line of action of the weight is outside the base of the body.

Questions

1. What is the moment in each of the diagrams below?



2. If the forces in question 1 acted at 60° to the spanner rather than 90° would the moment be greater, the same as, or less than that calculated in question 1? Explain.
3. What are the missing forces or distances in the diagrams below?

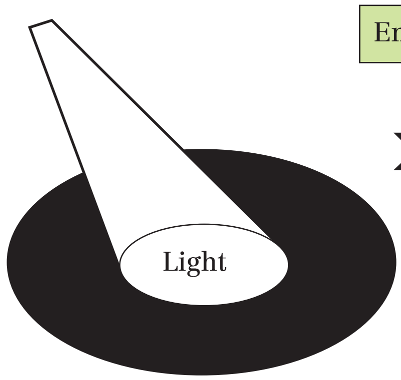


4. A letter P is cut from thin cardboard. Explain how to locate its centre of mass.
5. The following letters are cut from a thick plank of wood. W, P, O, I, H, L, U. If stood upright in their normal positions, which are in stable equilibrium, which unstable, and which neutral? Which letter would you expect to be easiest to topple and why?

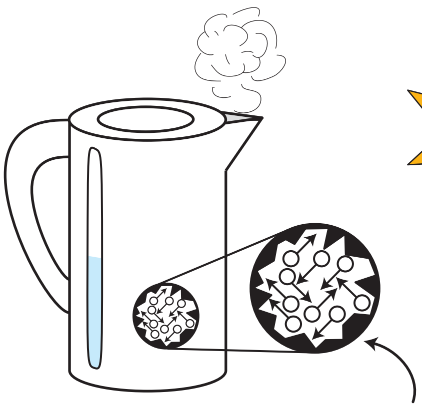
ENERGY Types of Energy and Energy Transfers

Energy is the ability to make something useful happen.

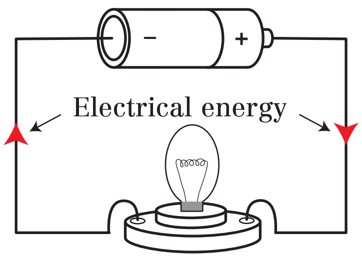
Energy comes in a number of different types:

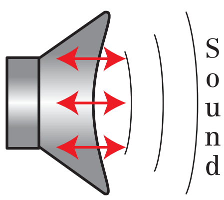


Kinetic – energy an object has due to its motion.

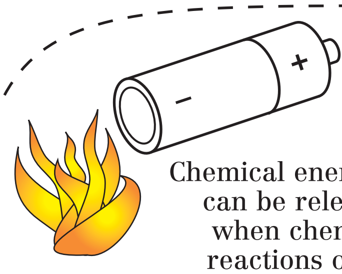


Heat (or thermal) – a measure of the total kinetic energy of the particles making up a material.

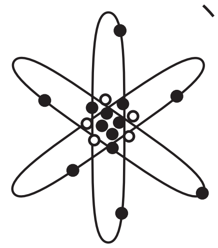




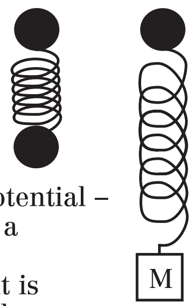
These types are easily stored.



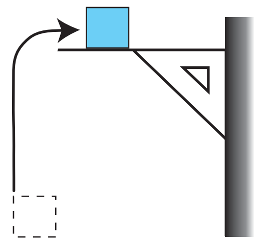
Chemical energy – can be released when chemical reactions occur (including burning of fuels and the reactions of chemicals in batteries).



Nuclear energy – stored in the nucleus of atoms and can be released in nuclear reactions.



Elastic potential – stored in a material because it is stretched or compressed. It is released when the object returns to its natural shape and size.



Gravitational potential energy – stored by objects raised up above the Earth's surface. It is released if the object falls towards the Earth.

Whenever something useful happens, energy is transferred.

Energy transfers can be shown on simple diagrams.

Transducer: A device that converts one form of energy into another.

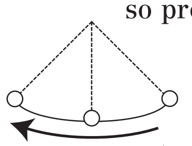
Input energy → Output energy 1, Output energy 2

Many transducers have a number of output energies. Sometimes we ignore some of these if they are insignificant.

E.g. Candle
Chemical energy (in wax) → Heat, Light } (In flame)

E.g. Electric motor
Electrical energy (in wires) → Kinetic energy, Heat energy, Sound energy (very small so probably ignored)

Some transfers are cyclical
E.g. pendulum



Gravitational potential ⇄ Kinetic ⇄ Gravitational potential

Questions

1. Nuclear energy is stored in the nucleus of atoms. Make a list of the other types of energy that can be stored giving an example of each.
2. What is a transducer? Make a list of five transducers that might be found in a home and the main energy change in each case.
3. Draw an energy transfer diagrams for the following showing the main energy transfers in each case:
   a. Electric filament light bulb.
   b. Solar cell.
   c. Electric kettle.
   d. Loudspeaker.
   e. Mobile 'phone 'charger'.
   f. Clockwork alarm clock.
   g. Playground swing.
   h. Bungee jumper.
   i. Petrol engine.
   j. Microphone.
4. What provides the energy input for the human body? List all types of energy that the body can transfer the energy input into.

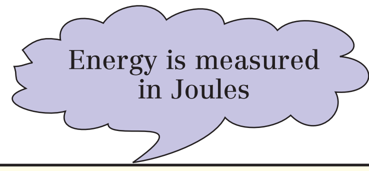
ENERGY Energy Conservation

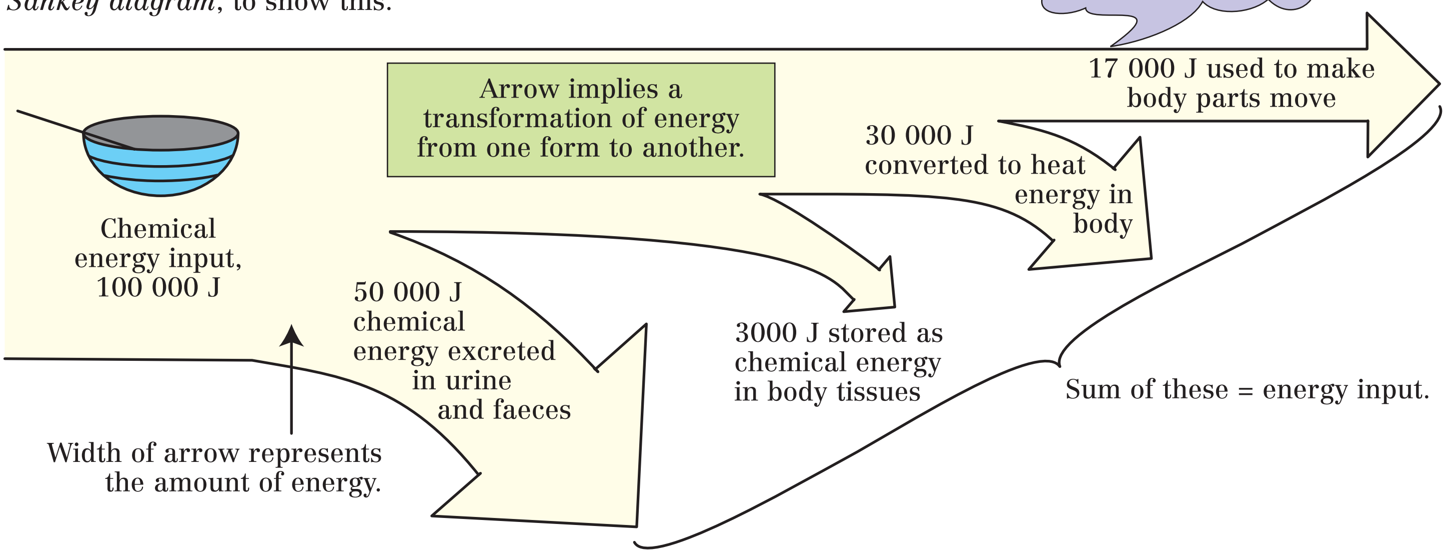
Probably the most important idea in Physics is the Principle of Conservation of Energy, which states:

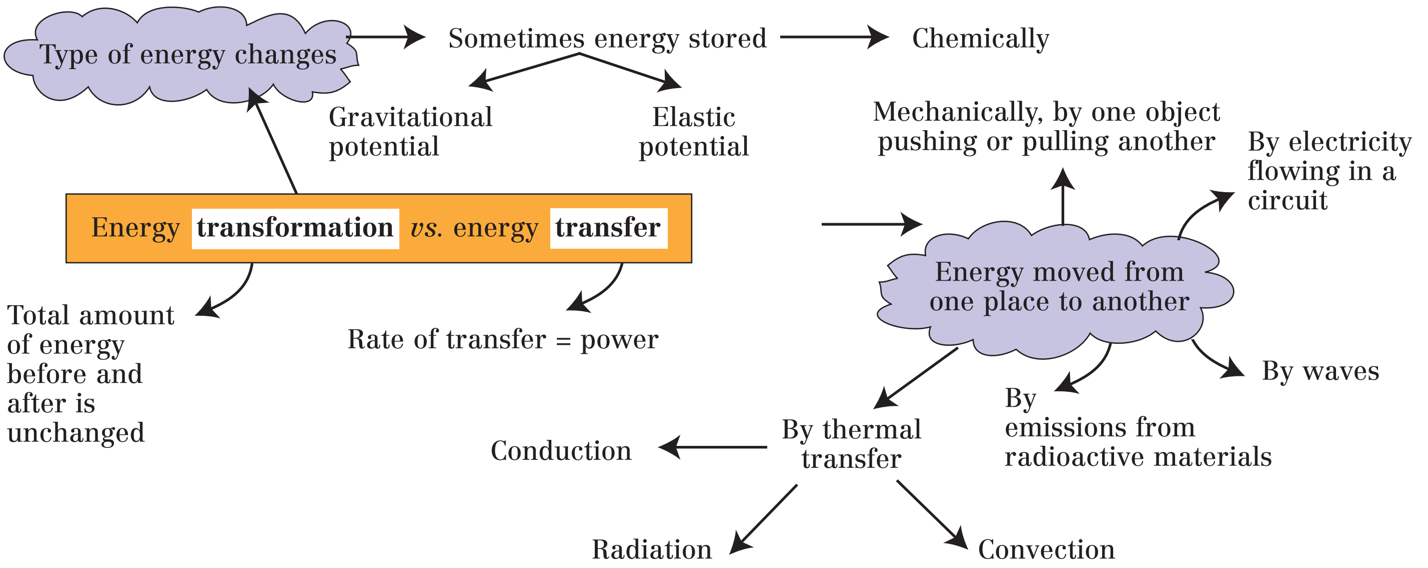
> Energy cannot be created or destroyed. It can only be transformed from one form to another form.

This means that the total energy input into a process is the same as the total energy output.

We can use a more sophisticated energy transfer diagram, called a *Sankey diagram*, to show this.







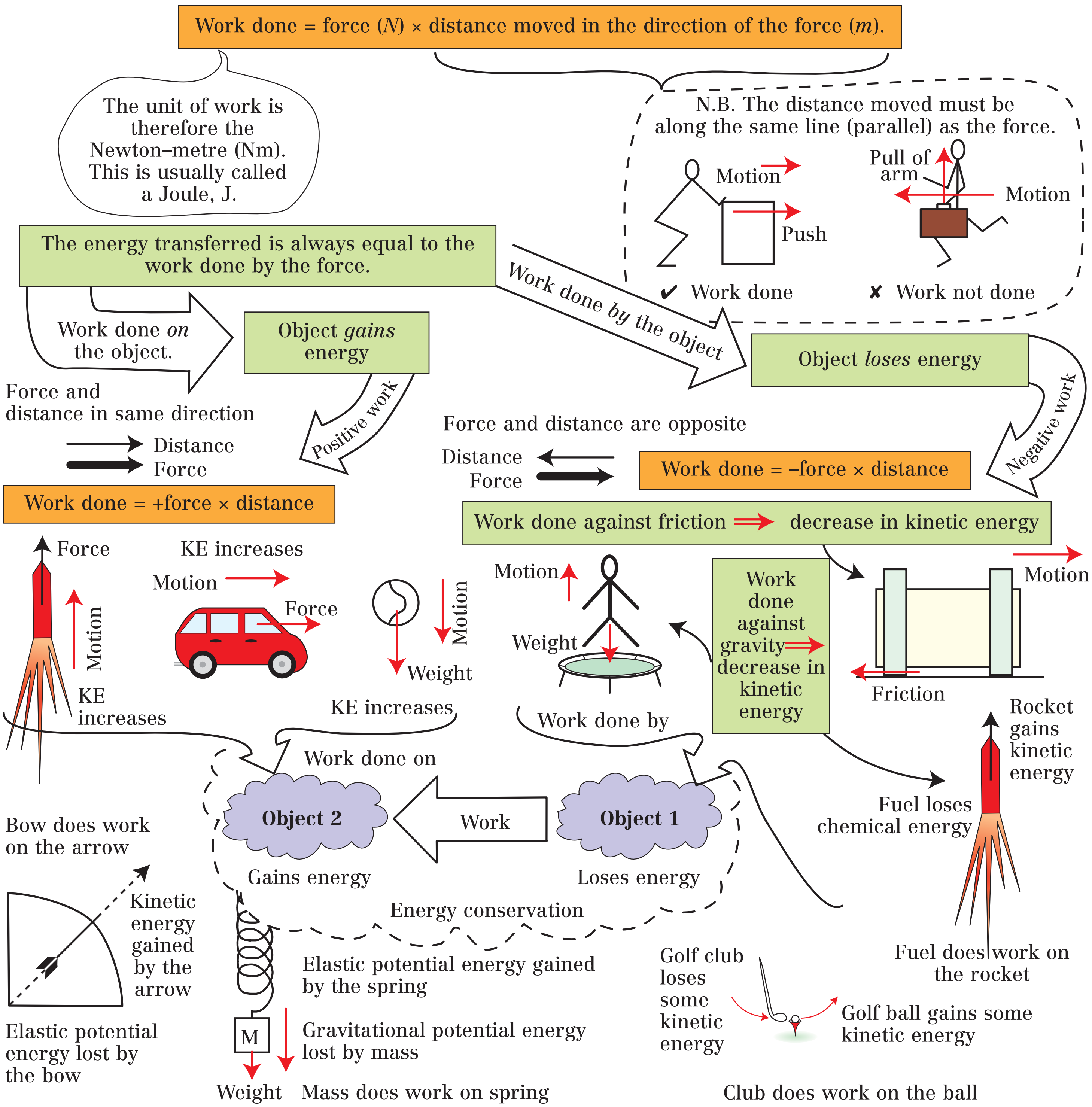
> The majority of the rest of this book explores this in more detail.

Questions

1. State the Principle of Conservation of Energy.
2. What units is energy measured in?
3. Explain the difference between energy transformations and energy transfers. Suggest four ways energy can be transferred.
4. A TV set uses 25 J of energy each second. If 15 J of energy is converted to light and 2 J is converted to sound, how much energy is converted to heat, assuming this is the only other form of energy produced?
5. The motor in a toy train produces 1 J of heat energy and 2 J of kinetic energy every second. What must have been the minimum electrical energy input per second? If the train runs uphill and the electrical energy input stays the same, what would happen to its speed?
6. Use the following data to draw a Sankey diagram for each device:
   a. Candle (chemical energy in wax becomes heat energy 80% and light 20%).
   b. Food mixer (electrical energy supplied becomes 50% heat energy in the motor, 40% kinetic energy of the blades, and 10% sound energy).
   c. Jet aircraft (chemical energy in fuel becomes 10% kinetic energy, 20% gravitational potential energy, and 70% heat).

ENERGY Work Done and Energy Transfer

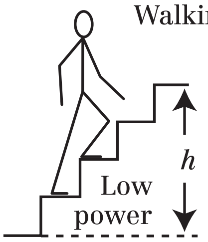
Whenever something useful happens, energy must be transferred but how can we measure energy? The only way to measure energy directly is by considering the idea of *work done*.



Questions

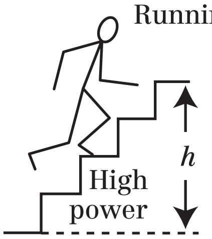
1. Copy and complete:
   'Work is done when a ? moves an object. It depends on the size of the ? measured in ? and the ? the object moves measured in ?. Whenever work is done, an equal amount of ? is transferred. The unit of energy is the ?. Work is calculated by the formula: work = ? × distance moved in the ? of the ?.'
2. I push a heavy box 2 m along a rough floor against a frictional force of 20 N. How much work do I do? Where has the energy come from for me to do this work?
3. A parachute exerts a resistive force of 700 N. If I fall 500 m, how much work does the parachute do?
4. A firework rocket produces a constant thrust of 10 N.
   a. The rocket climbs to 150 m high before the fuel is used up. How much work did the chemical energy in the fuel do?
   b. Explain why the chemical energy stored in the fuel would need to be much greater than the work calculated in (a).
   c. The weight of the empty rocket and stick is 2.5 N. How much work has been done against gravity to reach this height?
   d. The answers to parts (a) and (c) are not the same, explain why.

ENERGY Power



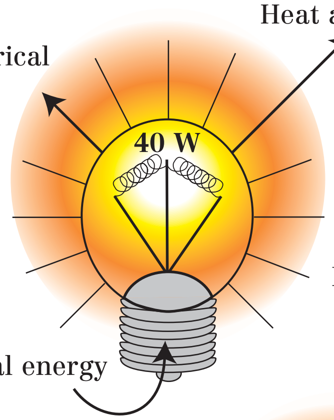
Slow gain in gravitational potential energy.

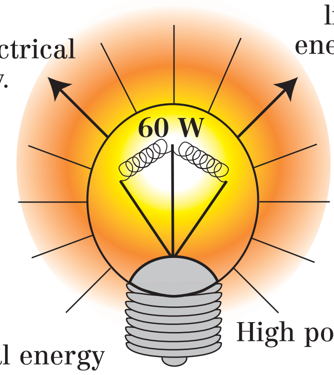
Low rate of doing work.



Rapid rate of doing work.

Rapid gain in gravitational potential energy.





Power is the number of Joules transferred each second.

The unit of power is the Joule per second, called the Watt, W.

Power is the rate of energy conversion between forms.

$$\text{Power (W)} = \frac{\text{energy transferred (J)}}{\text{time taken (s).}}$$

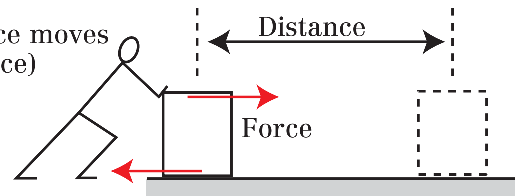
'Rate' means how quickly something happens.

Energy transferred = work done, so

$$\text{Power (W)} = \frac{\text{work done (J)}}{\text{time taken (s).}}$$

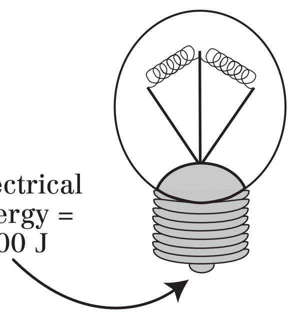
Calculating power. Non-mechanical:
- Find out total (heat, light, electrical) energy transferred
- Find out how long the energy transfer took
- Use the formula above

Mechanical:
(i.e. where a force moves through a distance)



- Calculate the work done = force (N) × distance (m)
- Find out how long the work took to be done
- Use the formula above

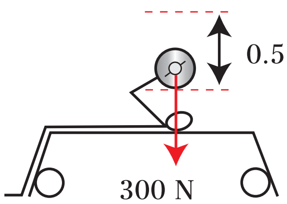
Electrical energy = 1200 J



$$\text{Power} = \frac{\text{energy transferred}}{\text{time taken}} = 1200\text{ J}/20\text{ s} = 60\text{ W}$$

Bulb is switched on for 20 s.

Compare these: imagine how tired you would get if you personally had to do all the work necessary to generate all the electrical power your house uses.



Work done = 300 N × 0.5 m
= 150 J per lift

Total work done = 20 × 150 J
= 3000 J

$$\text{Power} = \frac{\text{work done}}{\text{time taken}} = \frac{3000\text{ J}}{60\text{ s}} = 50\text{ W}$$

Questions

1. A kettle converts 62,000 J of electrical energy into heat energy in 50 s. Show its power output is about 1,200 W.
2. A car travels at constant velocity by exerting a force of 1,025 N on the road. It travels 500 m in 17 s. Show that its power output is about 30 kW.
3. The power to three electrical devices is as follows: energy efficient light bulb, 16 W; the equivalent filament bulb, 60 W; a TV on standby, 1.5 W.
   a. How many more Joules of electrical energy does the filament bulb use in one hour compared to the energy efficient bulb?
   b. Which uses more energy, a TV on standby for 24 hours or the energy efficient bulb on for 1.5 hours?
4. When I bring my shopping home, I carry two bags, each weighing 50 N up two flights of stairs, each of total vertical height 3.2 m. I have a weight of 700 N.
   a. How much work do I do on the shopping?
   b. How much work do I do to raise my body up the two flights of stairs?
   c. If it takes me 30 s to climb all the stairs, show that my power output is about 170 W.