MECHANICS AND HEAT

The knowledge and understanding for this unit is given below.

Kinematics

1. Describe how to measure an average speed.
2. Carry out calculations involving distance, time and average speed.
3. Describe how to measure instantaneous speed.
4. Identify situations where average speed and instantaneous speed are different.
5. Describe what is meant by vector and scalar quantities.
6. State the difference between distance and displacement.
7. State the difference between speed and velocity.
8. Explain the terms ‘speed’, ‘velocity’ and ‘acceleration’.
9. State that acceleration is change in velocity in unit time.
10. Draw velocity - time graphs involving more than one constant acceleration.
11. Describe the motions represented by a velocity - time graph.
12. Calculate displacement and acceleration from velocity - time graphs involving more than one constant acceleration.
13. Carry out calculations involving the relationship between initial velocity, final velocity, time and uniform acceleration.

Dynamics

1. Describe the effects of forces in terms of their ability to change the shape, speed and direction of travel of an object.
2. Describe the use of a newton balance to measure force.
3. State that weight is a force and is the Earth’s pull on the object.
4. Distinguish between mass and weight.
5. State that weight per unit mass is the gravitational field strength.
6. Carry out calculations involving the relationship between weight, mass and gravitational field strength including situations where g is not equal to 10 N/kg.
7. State that the force of friction can oppose the motion of a body.
8. Describe and explain situations in which attempts are made to increase or decrease the force of friction.
9. State that force is a vector quantity.
10. State that forces which are equal in size but act in opposite directions on an object are called balanced forces and are equivalent to no force at all.
11. Explain the movement of objects in terms of Newton’s First Law.
12. Describe the qualitative of change of mass or of force on the acceleration of an object.
13. Define the newton.
14. Use free body diagrams to analyse the forces on an object.
15. State what is meant by the resultant of a number of forces.
16. Use a scale diagram, or otherwise, to find the magnitude and direction of the resultant of two forces acting at right angles to each other.
17. Carry out calculations using the relationship between acceleration, resultant force and mass and involving more than one force but in one dimension only.
18. Explain the equivalence of acceleration due to gravity and gravitational field strength.
19. Explain the curved path of a projectile in terms of the force of gravity.
20. Explain how projectile motion can be treated as two independent motions.
21. Solve numerical problems using the above method for an object projected horizontally.

(No knowledge of the equations of motion is expected.)

Momentum

1. State Newton’s Third Law.
2. Identify ‘Newton pairs’ in situations involving several forces.
3. State that momentum is the product of mass and velocity.
4. State that momentum is a vector quantity.
5. State that the law of conservation of linear momentum can be applied to the interaction of two objects moving in one direction, in the absence of net external forces.
6. Carry out calculations concerned with collisions in which all the objects move in the same direction and with one object initially at rest.
7. State that work done is a measure of the energy transferred.
8. Carry out calculations involving the relationship between work done, force and distance.
9. State the relationship between work done, power and time.
10. Carry out calculations using the above relationship.
11. Carry out calculations involving the relationship between change in gravitational potential energy, mass, gravitational field strength and change in height.
12. Carry out calculations involving the relationship between kinetic energy, mass and velocity.
13. Carry out calculations involving the relationship between efficiency and output power, output energy and input power, input energy.

Heat

1. State that the same mass of different materials needs different quantities of heat energy to change their temperature by one degree Celsius.
2. Carry out calculations involving specific heat capacity.
3. State that heat is gained or lost by a substance when its state is changed.
4. State that a change of state does not involve a change in temperature.
5. Carry out calculations involving specific latent heat.
6. Carry out calculations involving energy, work power and the principle of conservation of energy.

Units, prefixes and scientific notation

1. Use SI units of all quantities appearing in the aobve content statements.
2. Give answers to calculations to an appropriate number of significant figures.
3. Check answers to calculations.
4. Use prefixes (m, k, M).
5. Use scientific notation.

KINEMATICS

Speed, distance, time

Average Speed

Average speed is a measure of the distance travelled in a unit of time.
Average speed is calculated by using this formula:

$$\text{Average speed} \quad \boxed{\bar{v} = \frac{s}{t}} \quad \begin{matrix}\text{distance travelled}\\ \text{time taken}\end{matrix}$$

Units of speed

Speed can be measured in many different units.
Usually the unit is metres per second, m/s or m s^{-1}. This means the distance must be measured in metres and the time taken in seconds.

Note: these notes will use the solidus for multiple units, e.g. m/s. However, you can use the negative index, e.g. m s^{-1}, if you prefer.

Measurement of average speed

To measure an average speed, you must:

- measure the **distance** travelled with a measuring tape or metre stick
- measure the **time** taken with a stop clock
- **calculate** the speed by dividing the distance by the time

Calculations involving distance, time and average speed

Note: care must be taken to use the correct units for time and distance.

Example
Calculate the average speed in metres per second of a runner who runs 1500 m in 5 minutes.

$s = 1500\ m$
$t = 5\ minutes = 5 \times 60\ seconds = 300\ s$

$$\bar{v} = \frac{s}{t} = \frac{1500}{300} = 5\ m/s$$

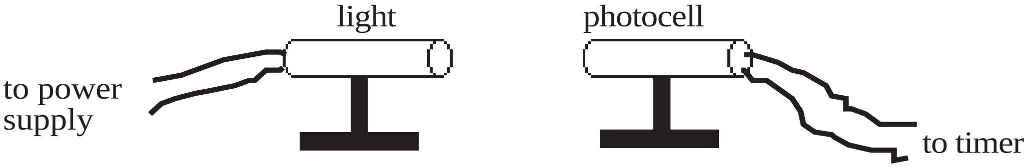
Instantaneous speed

The instantaneous speed of a vehicle at a given point can be measured by finding the average speed during a **very short time** as the vehicle passes that point.

Average speed and instantaneous speed are often very different e.g. the average speed of a runner during a race will be less than the instantaneous speed as the winning line is crossed.

Measuring instantaneous speeds

To measure instantaneous speeds, it is necessary to be able to measure **very** short times. With an ordinary stopclock, human reaction time introduces large errors. These can be avoided by using electronic timers. The most usual is a light gate**.**



A light gate consists of a light source aimed at a photocell. The photocell is connected to an electronic timer or computer.

The timer measures how long an object takes to pass through the light beam.

The distance travelled is the length of the object which passes through the beam.

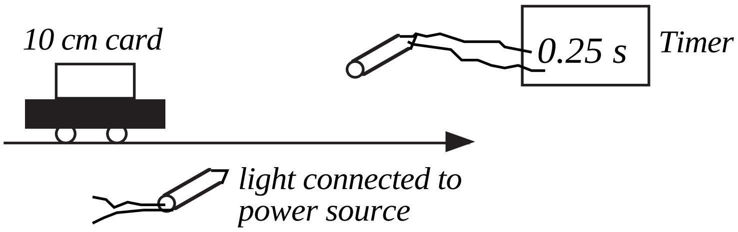
Often a card is attached so that the card passes through the beam. The length of the card is easy to measure.

The instantaneous speed as the vehicle passes through the light gate is then calculated using:

$$\boxed{\text{Speed of vehicle} = \frac{\text{length of card or vehicle}}{\text{time to cut beam}}}$$

Example

A vehicle moves through a light gate as shown in the diagram. Using the data from the diagram, calculate the instantaneous speed of the vehicle as it passes the light gate.



$$\text{speed} = \frac{\text{length of card}}{\text{time to cut beam}} = \frac{10}{0.25} = 40 \text{ cm/s} = 0.4 \text{ m/s}$$

Vectors and Scalars

Vector and Scalar quantities

Physical quantities can be divided into two groups:

- a **scalar** quantity is completely described by stating its **magnitude** (size).
- a **vector** quantity is completely described by stating its **magnitude** and **direction**.

Distance and Displacement

Distance is the total distance travelled, no matter in which direction.
Displacement is the length measured from the starting point to the finishing point in a straight line. Its direction must be stated.

Speed and Velocity

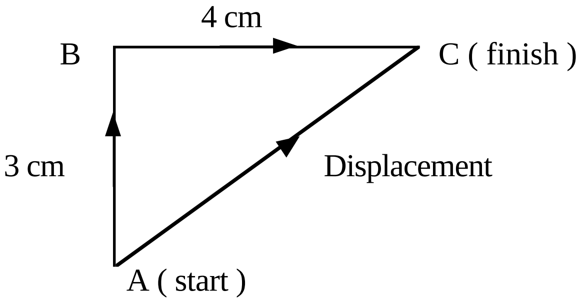
Speed and velocity are described by the equations below.

$$\boxed{\text{speed} = \frac{\text{distance}}{\text{time}}} \qquad \boxed{\text{velocity} = \frac{\text{displacement}}{\text{time}}}$$

Velocity is a vector quantity, but speed is scalar.
The direction of the velocity will be the same as the direction of the displacement.

Example
A woman walks 3 km due North and then 4 km due East. She takes two hours.
a) Find the distance she has walked and her displacement.
b) Calculate her average speed and velocity.

We will represent her walk by drawing a diagram to scale. Scale 1cm = 1 km



a) *The distance she has travelled is 3 km + 4 km = 7 km*

Her displacement is from A to C. This can be measured on the diagram as 5 cm, then converted using the scale to 5 km.
The angle BAC is measured to find the direction of her final displacement. It is 53°
Displacement = 5 km at a bearing of (053).

b) $$\textit{average speed} = \frac{\textit{distance travelled}}{\textit{time taken}} = \frac{7}{2} = 3.5\ \textit{km/h}$$

$$\textit{average velocity} = \frac{\textit{displacement}}{\textit{time taken}} = \frac{5}{2} = 2.5\ \textit{km/h at a bearing of (053)}$$

Acceleration

Most vehicles do not travel at the same speed all the time. If they speed up, they are said to accelerate. If they slow down, they decelerate. Acceleration describes **how quickly** velocity changes.
Acceleration is a **vector** quantity. However, only the acceleration of vehicles travelling in straight lines will be considered.

Acceleration is the change in velocity in unit time.

$$\boxed{\textbf{acceleration} = \frac{\textbf{change in velocity}}{\textbf{time taken}}}$$

Units of Acceleration

The units of acceleration are the units of velocity divided by the units of time (seconds).
If the velocity is in m/s, acceleration is in m/s^2 (metres per second squared).
An acceleration of 2 m/s^2 means that every second, the velocity increases by 2 m/s.

Formula for Acceleration

$$\boxed{a = \frac{v - u}{t}}$$

a = acceleration in m/s^2
u = initial velocity in m/s
v = final velocity in m/s
t = time taken in s

Note: If a vehicle is slowing down, the final velocity will be smaller than the initial velocity, and so the acceleration will be negative.
A negative acceleration is a deceleration.

The equation for acceleration can be rearranged to give an alternative version.

$$\boxed{v = u + at}$$

Example
A car is moving at 15 m/s, when it starts to accelerate at 2 m/s^2 . What will be its speed after accelerating at this rate for 4 seconds?

$u = 15$ m/s
$a = 2$ m/s^2
$t = 4$ s

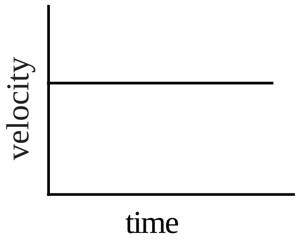
$v = u + at$
$= 15 + (2 \times 4)$
$= 23$

The car will reach a speed of 23 m/s

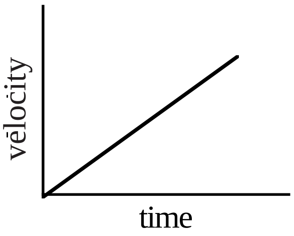
Velocity-time graphs

A velocity-time graph is a useful way to describe the motion of a vehicle.
Time is always plotted along the x-axis, and velocity is plotted along the y-axis.

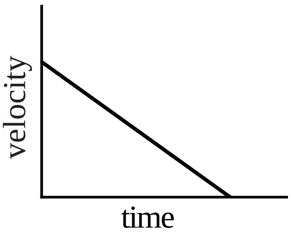
The **shape** of the graph indicates whether the vehicle is accelerating, decelerating or moving at a constant velocity.



constant velocity



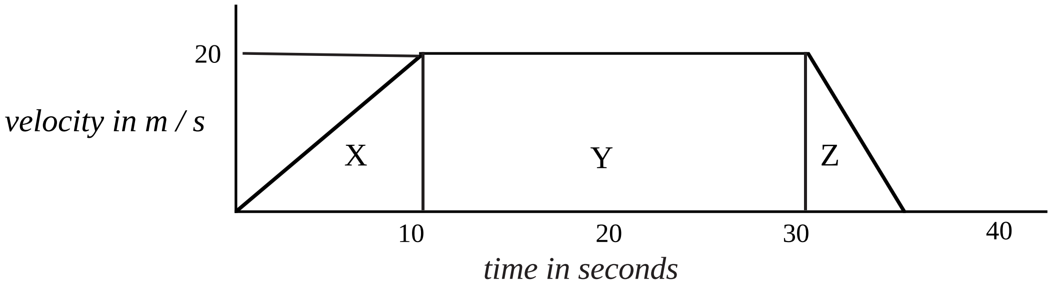
increasing velocity
= acceleration



decreasing speed
= deceleration

The **slope** (or gradient) of the line on a velocity-time graph indicates the acceleration.
While the slope is steady, the acceleration is constant. If the line gets steeper, the acceleration (or deceleration) gets greater.
Acceleration can be calculated using data from the graph and the formula.
The **area** vertically below a section of the graph is equal to the displacement during that time.

Example
The graph describes the motion of a car during 35 seconds.
a) What was the initial acceleration of the car?
b) What was the deceleration?
c) How far did the car travel in the 35 seconds?



a) *initial acceleration lasts from 0 - 10 s:* $u = 0$, $v = 20$ m/s, $t = 10$ s

$$a = \frac{v-u}{t} = \frac{20-0}{10} = 2 \text{ m/s}^2$$

b) *deceleration was from 30 -35 s:* $u = 20$ m/s, $v = 0$, $t = 5$ s

$$a = \frac{v-u}{t} = \frac{0-20}{5} = -4 \text{ m/s}^2$$

c) *distance travelled = area under graph:*
divide into sections of rectangles and triangles: X + Y + Z: use scale for sizes
area X = $\frac{1}{2}$ base × height = $\frac{1}{2} \times 10 \times 20$ = 100 m
area Y = length × breadth = 20×20 = 400 m
area Z = $\frac{1}{2}$ base × height = $\frac{1}{2} \times 5 \times 20$ = 50 m
Total area = 550 m so: distance travelled = 550 m

DYNAMICS

Forces

Effects of forces

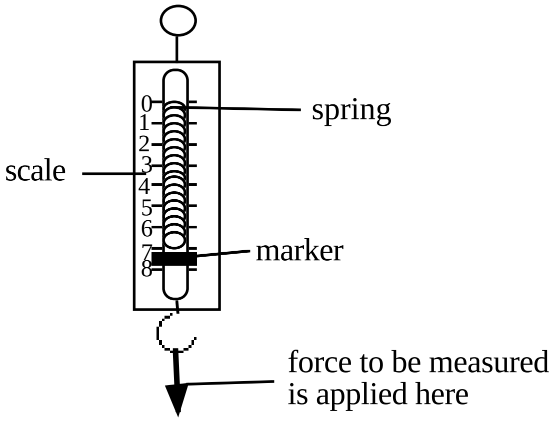
Forces can only be detected by their effects.

They can change:
- the shape of an object (stretch it, squeeze it etc)
- the speed of an object
- the direction of movement of an object

Measurement of Forces

Forces are measured in units called **newtons** (N). (see later for definition)

Forces can be measured with a newton balance. This instrument depends on the effect of a force on the shape (length) of a spring.



A newton balance has a spring inside. The force to be measured is applied to the hook which is attached to the spring. The force causes the spring to stretch. The greater the force, the greater the stretch of the spring and the further the marker moves across the scale.

Mass and Weight

Weight is a force caused by gravity acting on an object's mass. On Earth, it measures the pull of the Earth on the object. It is measured in **newtons**.

Weight always acts vertically downwards. Its size does not just depend on the mass of the object, but on the strength of gravity at that place.

Mass measures the amount of matter in an object. It is measured in **kilograms** (kg).

The value of mass does not change from place to place.

The strength of gravity in a particular place is called **the gravitational field strength.** This tells you the weight of 1 kilogram. Its symbol is **g** and its unit is **N/kg.**

On Earth, g = 10 N/kg.

Mass and weight are connected by the following formula:-

weight in N

$$\boxed{\mathbf{W = mg}}$$

gravitational field strength in N/kg

mass in kg

Example

a) What is the weight of a 50 kg girl on Earth?

b) What would she weigh on the moon where the gravitational field strength is 1.6 N/kg?

a) $W = mg = 50 \times 10 = 500\ N$

b) $W = mg = 50 \times 1.6 = 80\ N$

The Force of Friction

Friction is a **resistive** force, which opposes the motion of an object. This means that it acts in the **opposite** direction to motion. Friction acts between any two surfaces in contact. When one surface moves over another, the force of friction acts between the surfaces and the size of the force depends on the surfaces, e.g. a rough surface will give a lot of friction.

Air friction is usually called **air resistance**. It depends mainly on two factors:

- the shape and size of the object
- the speed of the moving object.

Air resistance **increases** as the speed of movement increases.

Increasing and Decreasing Friction

Where friction is making movement difficult, friction should be reduced.

This can be achieved by:

- lubricating the surfaces with oil or grease
- separating the surfaces with air, e.g. a hovercraft
- making the surfaces roll instead of slide, e.g. use ball bearings
- streamlining to reduce air friction.

Where friction is used to slow an object down, it should be increased.

This can be achieved by:

- choosing surfaces which cause high friction e.g. sections of road before traffic lights have higher friction than normal roads
- increasing surface area and choosing shape to increase air friction, e.g. parachute.

Forces are Vectors

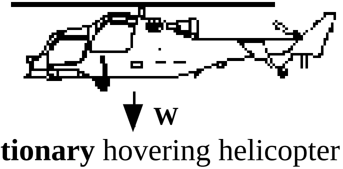
A force is a vector quantity because to describe it properly requires a direction as well as size. Two forces which are equal in size but which act in opposite directions are called **balanced** forces. Balanced forces have the same effect as **no force** at all.

Newton's First Law

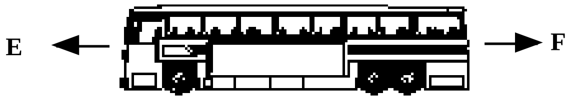
When the forces on an object are balanced (or when there are no forces at all), then neither the speed nor direction of movement will change.

Balanced forces mean **constant velocity** or the object is stationary.

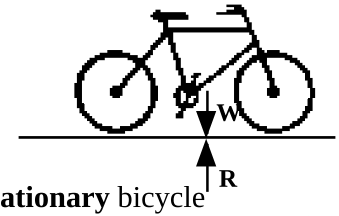
Examples of balanced forces



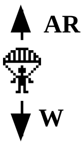
Stationary hovering helicopter
Weight down = **L**ift up



Bus moving at **steady speed**
Engine force forward = **F**riction forces backwards



Stationary bicycle
Weight down = **R**eaction of road up



Parachutist drifting down at **steady speed** (terminal velocity)
Weight down = **A**ir **R**esistance up

Newton's Second Law of Motion

This law deals with the situation when there is an **unbalanced** force acting on an object. The velocity cannot remain constant, and the acceleration produced will depend on the mass of the object and the value of the unbalanced force.
As the unbalanced force acting on an object increases, the acceleration increases also.
As the accelerated mass increases, the acceleration decreases for a given force.

The **newton** is defined as the force which makes a mass of 1 kg accelerate at 1 m/s^2.

These facts can be summarised in an equation:

$$\boxed{\mathbf{F = ma}}$$

unbalanced force in N
acceleration in m/s^2
mass in kg

Example
A car of mass 1000 kg has an unbalnced force of 1600 N acting on it.
What will be its acceleration?

$m = 1000\ kg$
$F = 600\ kg$

$$a = \frac{F}{m} = \frac{1600}{1000} = 1.6\ m/s^2$$

Resultant Forces

When several forces act on one object, they can be replaced by one force which has the same effect. This single force is called the **resultant** or **unbalanced** force.

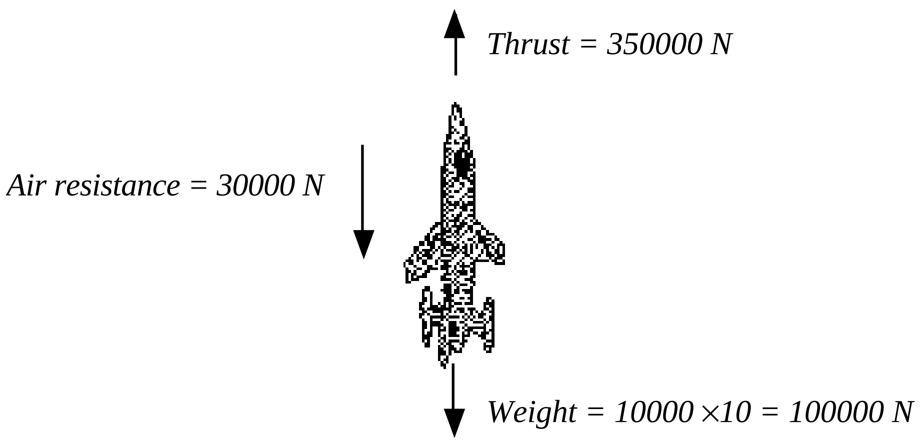
Combining forces in a straight line

Draw a diagram of the object and mark in all the forces acting, using an arrow to represent each force. (Do not forget weight, which is often not specifically mentioned in the question). Use arithmetic to find the resultant:

- **add** together forces which act in the **same** direction
- **subtract** forces which act in the **opposite** direction.

A diagram like this is called a **free body diagram**.

Example
A short time after take off, a rocket of mass 10000 kg has a thrust of 350000 N and experiences air resistance of 30000 N. Draw a free body diagram and find the resultant force acting on the rocket.



Total upward force = 350000 N
Total downward force = 100000 N + 30000 N = 130000 N
Resultant force upwards = 350000 – 130000 = 220000 N

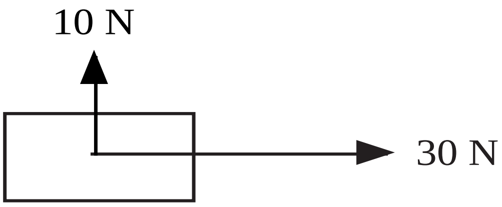
Combining forces at right angles

There are two possible methods for finding the size and direction of the resultant of two forces acting at right angles to each other.

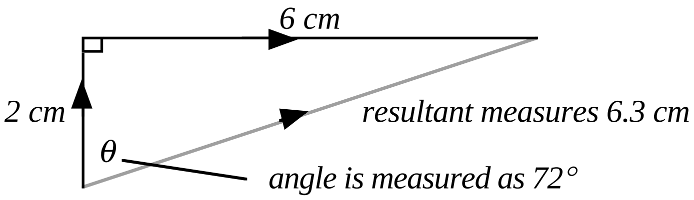
- Draw a scale diagram: (refer to Kinematics, Vectors page 3)
- Use Pythagoras and trig functions.

Example

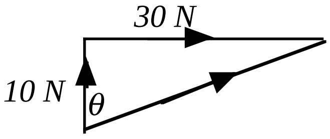
What is the resultant force produced by two forces of 10 N and 30 N which act on an object as shown in the diagram?



Method 1: Choose Scale: 1 cm = 5 N
Draw vectors head to tail, complete triangle, then measure resultant size and direction.



Resultant = 6.3 × 5 = 31.5 N at an angle of 72° to the 10 N force.
Method 2: Draw sketch of vector diagram, but not to scale.



Resultant $= \sqrt{30^2 + 10^2}$
$= 31.6$ *N*

$\tan\theta = 30 \div 10$
$= 3$

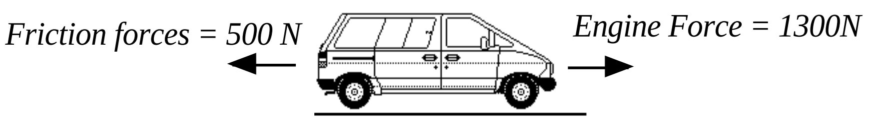
$\theta\ \tan^{-1} 3 = 72°$

Calculations using F = ma for more than one force

Draw a free body diagram and mark in all the known forces. Use this to calculate the resultant force (F in the equation) before using the equation.

Example

A car of mass 1000 kg experiences friction equal to 500 N. If the engine force is 1300 N, what will be the car's acceleration?



Resultant force $= 1300 - 500 = 800\ N$

$$a = \frac{F}{m} = \frac{800}{1000} = 0.8\ m/s^2$$

Acceleration due to gravity and gravitational field strength

Weight is the force which causes an object to accelerate downwards and has the value mg, where g is the gravitational field strength, see page 6.

The value of the acceleration caused by weight can be calculated from Newton's second law, using the equation F = ma where F is now the weight W, and W = mg.

$$\text{acceleration due to gravity} = \quad a = \frac{F}{m} = \frac{mg}{m} = g \quad \text{where g is in m/s}^2$$

The numerical values of the acceleration due to gravity and gravitatonal field strength are equal.

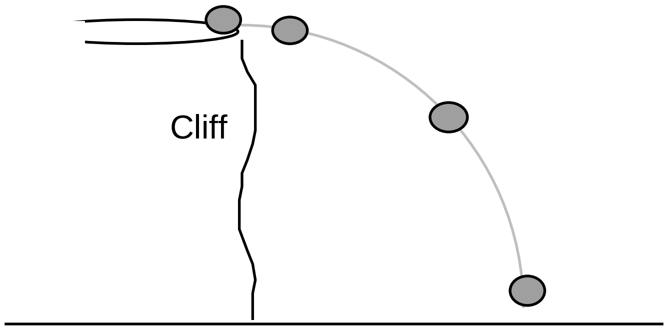
Their units, N/kg and m/s^2 are also equivalent.

Projectile Motion

A projectile is an object which has been given a forward motion through the air, but which is also pulled downward by the force of gravity. This results in the path of the projectile being curved.
A projectile has two **separate** motions at right angles to each other.
Each motion is **independent** of the other.

The **horizontal** motion is at a **constant velocity** since there are no forces acting horizontally (air resistance can be ignored).
Horizontal distance travelled = horizontal velocity × time in the air. ($s_H = v \times t$)
The **vertical** motion is one of **constant acceleration**, equal to g.
For projectiles which are projected horizontally, the initial vertical velocity is zero.
For vertical calculations, use $v = u + at$, where $u = 0$ and $a = g$

Example
A ball is kicked horizontally at 5 m/s from a cliff top as shown below.
It takes 2 seconds to reach the ground.



a) What horizontal distance did it travel in the 2 seconds?
b) What was its vertical speed just before it hit the ground? *(Take $g = 10\ m/s^2$)*

Horizontal

a)
$v = 5\ m/s$
$= 2\ s$

$s_H = v \times t$
$= 5 \times 2$
$= 10\ m$

Vertical

b)
$u = 0$
$a = 10\ m/s^2$
$t = 2\ s$

$v = u + at$
$= 0 + 10 \times 2$
$= 20\ m/s$

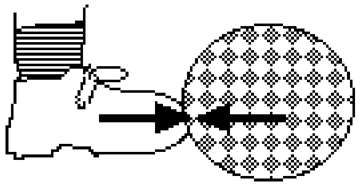
MOMENTUM AND ENERGY

Newton's Third Law

Newton noticed that forces occur in pairs. He called one force the **action** and the other the **reaction**. These two forces are always **equal in size, but opposite in direction**. They do not both act on the same object.
Newton's Third Law can be stated as:
If an object A exerts a force (the action) on object B, then object B will exert an equal, but opposite force (the reaction) on object A.

Newton Pairs

The two forces described above are called a Newton Pair. For example, a Newton pair occurs when footballer kicks a ball.



Object A is the foot. Object B is the ball.
When the player kicks the ball, the foot exerts a force to the right on the ball.
The ball exerts an equal force to the left on the foot.

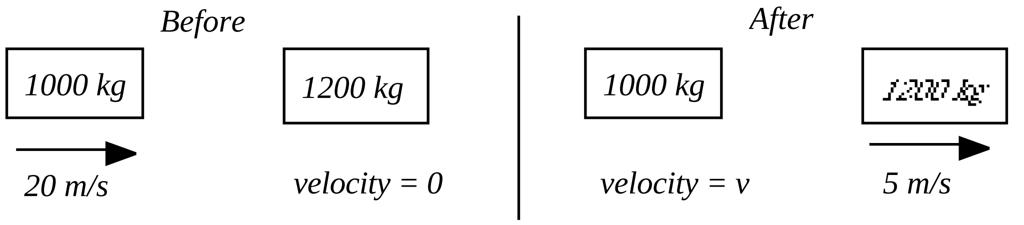
Momentum

Momentum is the product of mass and velocity. Its unit is the kilogram metre/second (kg m/s)
Momentum is a **vector** quantity, but this course will only consider situations where all the objects move in the same direction.

Conservation of momentum

When two objects collide, the momentum of each changes as a result of the forces acting between the objects. However, **providing there are no external forces, the total momentum remains constant before and after the collision.**
This statement is known as the Law of Conservation of Momentum. This law can be used to calculate velocities in collisions.

Example
A car of mass 1000 kg travelling at 20 m/s collides with a stationary van of mass 1200 kg. If the van moves off at 5 m/s, what will be the velocity of the car after the collision?



Total momentum before = Total momentum after

$(1000 \times 20) + 0 = (1000 \times v) + (1200 \times 5)$

$20000 = 1000\,v + 6000$

$1000\,v = 14000$

velocity of car after = 14 m/s forwards.

Work and Energy

Energy

Energy cannot be destroyed, but it can be changed from one form into another. All forms of energy are measured in the same unit: the **joule (J).**
When a force causes movement, some energy is changed from one form to another (it is **transformed**) and we say that **work is done**.
For example, the force of friction causes kinetic energy to be transformed into heat.

Work

The work done is a measure of the energy transformed. It is equal to the force multiplied by the distance the force moves. The force and distance must be measured in the **same direction**.
Work is measured in the same units as energy: joules. The symbol for work is E_w.

work done in joules

$$\boxed{\mathbf{E_w = F \times s}}$$

distance force moves in metres

force in newtons

Example
A dog pulls a 4 kg sledge for a distance of 15 m using a force of 30 N.
How much work does the dog do?

$F = 30\ N \qquad Ew = F \times d$
$d = 15\ m \qquad\quad = 30 \times 15$
$\qquad\qquad\qquad\quad = 450\ J$

Work done is 450 J. (Note that the mass was not required.)

Power

Power is the rate of doing work. It is measured in watts. 1 watt equals 1 joule per second.

power in watts

$$\boxed{\mathbf{P = \frac{E}{t}}}$$

energy or work done in joules

time in seconds

Example
A cyclist uses a force of 60 N and travels 2 km in 8 minutes. What is her average power?

$F = 60\ N$ Work done $E_w = 60 \times 2000$
$d = 2\ km = 2000\ m \qquad = 120000\ J$
$t = 8\ min = 480\ s$

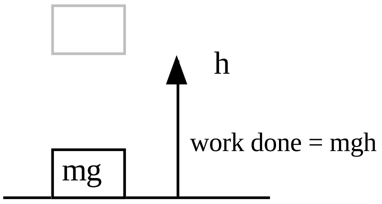
$$P = \frac{E_w}{t}$$

$$= \frac{120000}{480} = 250\ W$$

Gravitational potential energy

An object which is raised up to a high position is said to have gravitational potential energy. The work done against gravity to raise it equals the energy transformed into potential energy.

Imagine a mass of m kg lifted through a height of h metres:



Force needed = weight of m kg = mg newtons
Work done = force x distance = mg x h
potential energy = mgh joules

$$\boxed{\mathbf{E_p = mgh}}$$

gravitational potential energy gained in joules
h is height gained in metres
mass in kg
gravitational field strength (10 N/kg on Earth)

Example
A chairlift raises a skier of mass 50 kg to a height of 250 m. How much potential energy does the skier gain?

$m = 50\ kg$ $\qquad E_p = mgh$
$g = 10\ N/kg$ $\qquad = 50 \times 10\ \ 250$
$h = 250\ m$ $\qquad = 125000\ J$

Kinetic energy
Kinetic Energy is the energy associated with a moving object. It is measured in joules and has the symbol E_k.
The kinetic energy of a moving object depends on the mass of the object and on the square of its velocity.

$$\boxed{\mathbf{E_k = \frac{1}{2}\ mv^2}}$$

kinetic energy in joules
speed in m/s
mass in kg

Example
How much kinetic energy does a car of mass 1000 kg have when it is travelling at 20 m/s (approx 50 miles per hour)?

$m = 1000\ kg \qquad Ek = \frac{1}{2}mv^2 \qquad = \frac{1}{2} \times 1000 \times 20^2 = 200000\ J$
$v = 20\ m/s$

Kinetic energy and stopping distances

The stopping distance of a vehicle consists of two parts: thinking distance and braking distance. The **thinking** distance increases with speed. Thinking distance = speed × reaction time.

To stop a vehicle, the brakes do work to transform the kinetic energy into heat. This work equals the (braking force × the braking distance). The **braking** distance must therefore increase as the speed and kinetic energy of the vehicle increase.

Efficiency

Machines can be used to transform one kind of energy into another. For example, an electric motor transforms electricity into kinetic energy. This energy might be further transformed into potential energy if the motor is used to drive a lift. However, not **all** the electrical energy which is supplied to the motor will be transformed into the final **useful** form of energy. Some may be transformed into heat, due to friction, and sound. Although no energy has been destroyed, some is ‘wasted’ because it cannot be used. This makes the machine inefficient. Efficiency is measured by expressing the **useful** energy output as a percentage of the **total** energy input.

Formula for efficiency

$$\boxed{\%\ \text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times \frac{100}{1}}$$

The same formula can be applied to power rather than energy.

Example

What is the efficiency of an electric hoist which uses a 400 W motor if it takes 10 s to lift a 60 kg load to a height of 4 m?

$P = 400\ W$
$t = 10\ s$
$m = 60\ kg$
$h = 4\ m$

Useful energy out $= \text{potential energy}$
$= mgh$
$= 60 \times 10 \times 4$
$= 2400\ J$

Total energy in $= Pt$
$= 400 \times 10$
$= 4000\ J$

$$\%\ \text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times \frac{100}{1}$$

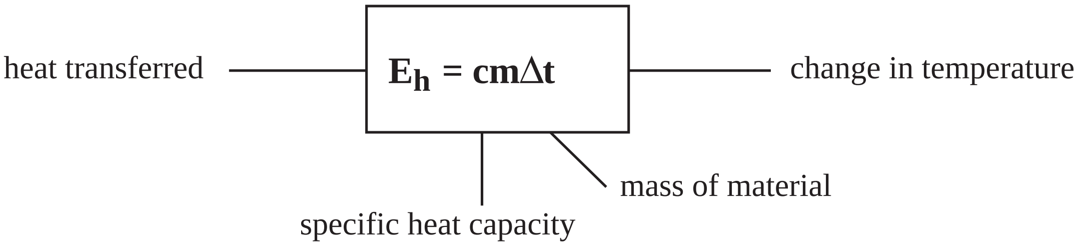
$$= \frac{2400}{4000} \times \frac{100}{1}$$

$$= 60\%$$

HEAT

Specific Heat Capacity

The specific heat capacity of a substance is the amount of heat energy required to change the temperature of 1 kg of a substance by 1 °C.
Specific heat capacity is calculated using the formula:



Units

The unit for specific heat capacity is the joule per kilogram degree celsius (J/kg °C).

Example
When a kettle containing 2 kg of water (specific heat capacity 4200 J/kg °C) cools from 40 °C to 20 °C, calculate the heat given out by the water.

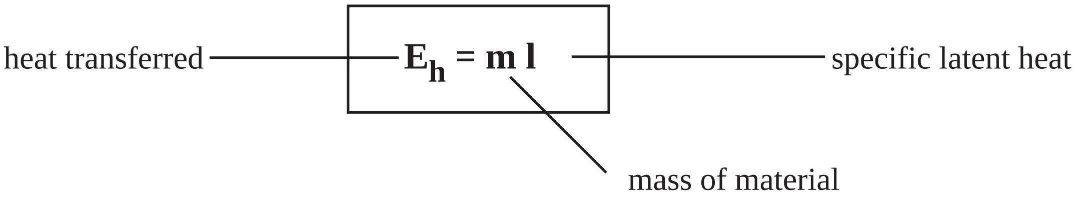
$c = 4200$ J/kg °C $\quad m = 2$ kg $\quad T_2 = 40$ °C $\quad T_1 = 20$ °C $\quad E_h = ?$
$E_h = cm\Delta T = 4200 \times 2 \times (40 - 20) = 168000$ J or 168 kJ

Changes of State

When ice at its melting point of 0 °C gains heat energy, it changes into water, also at 0 °C. When the process is reversed, water at its freezing point of 0 °C changes into ice at 0 °C. In this case energy is released with no change in temperature.

Specific Latent Heat

The specific latent heat of a substance is the energy involved in changing the state of 1 kg of the substance without any temperature change.
Specific latent heat of a substance is calculated using the formula:



The specific latent heat of **vaporisation** is the heat energy required to change 1 kg of liquid to vapour without temperature change.
The specific latent heat of **fusion** is the heat energy required to change 1 kg of a solid to liquid without change in temperature.

Units

The unit for specific latent heat is the joule per kilogram, J/kg.

Example

A mass of 2.5 kg of ammonia at its boiling point is vaporised when 6500 J of heat is supplied to it. Calculate the specific latent heat of vaporisation of ammonia.

$m = 2.5\ kg \qquad E_h = 6500\ J \qquad l = ?$

$$l = \frac{E_h}{m} = \frac{6500}{2.5} = 2600\ J/kg$$

Principle of Conservation of energy

The total amount of energy remains constant during energy transfers. Energy cannot be created or destroyed but simply transformed to one of its many forms.

Example 1

A piece of brass of mass 2 kg is dropped onto a hard surface without rebounding resulting in a temperature rise of 1 °C. Calculate the speed with which the brass hits the surface.

$m = 2\ kg \qquad \Delta T = 1\ ^\circ C \qquad c = 370\ J/kg\ ^\circ C \qquad v = ?$

Assuming all the kinetic energy of the brass is changed on impact to heat in the brass,

Kinetic energy lost by brass = Heat energy produced in brass

$$\frac{1}{2} mv^2 = c\,m\Delta T$$

$$\frac{1}{2} v^2 = c\Delta T$$

$$v^2 = 2 \times 370 \times 1$$

$$v = 27\ m/s$$

Example 2

Calculate the time taken for a 500 W heater to melt 2 kg of ice at 0 ∞C.

Latent heat of fusion of ice $= 3.34 \times 10^5\ J/kg$

$P = 500\ W \qquad m = 2\ kg \qquad l = 3.34 \times 10^5\ J/kg \qquad t = ?$

Energy required to melt the ice $\quad E = ml = 2 \times 3.34 \times 10^5$

$$= 6.68 \times 10^5\ J$$

Time taken to melt ice $\quad t = \frac{E}{P} = \frac{6.68 \times 10^5}{500}$

$$t = 1336\ s$$

ACTIVITY 1

Title: **Average Speed**

Aim: To measure some average speeds.

Apparatus: Measuring tape, stopclock, chalk.

Instructions

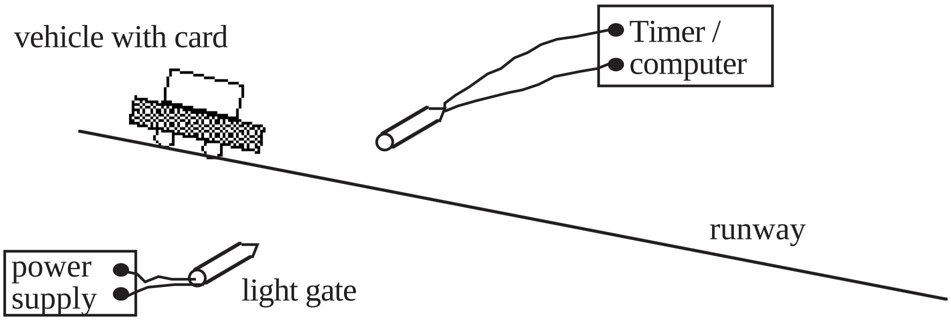
- Mark out a suitable distance on a safe area of ground.
- Measure how long someone takes to walk that distance.
- Repeat the timing for jogging and sprinting.
- If possible, repeat for cycling.
- Calculate the average speed for each result.
- Present your results in table form.

Activity	Distance travelled (m)	Time taken (s)	Average speed (m/s)

ACTIVITY 2

Title: **Variation of instantaneous speed with time for an object moving down a slope** (Outcome 3)

Apparatus: Runway, vehicle with card, light gate, electronic timer or computer, stopclock.



Instructions

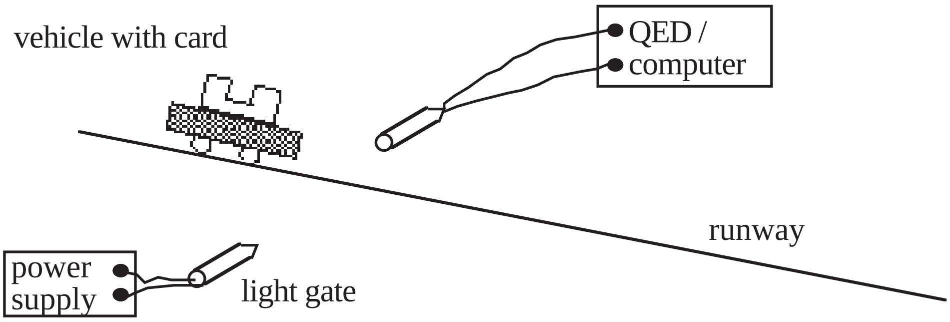
- Organise the timer/computer to measure the instantaneous speed of the vehicle as the vehicle passes through the light gate.
- Set the runway at a small angle such that the vehicle will accelerate as it runs down.
- Place the light gate about one third of the way down the runway.
- Release the vehicle from the top of the runway and measure the time taken to reach the light gate and the instantaneous speed as it passes the light gate.
- Move the light gate further down the slope and repeat the measurements for at least four more positions.
- Use an appropriate format to show the variation of speed with time.

ACTIVITY 3

Title: **Acceleration**

Aim: Measurement of acceleration with distance of release on a slope.

Apparatus: Runway, vehicle with double card, light gate, computer or QED, metre stick.



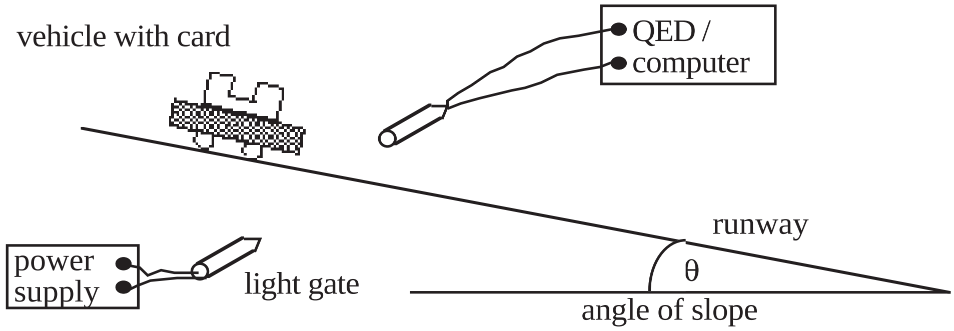
Instructions

- Organise the QED/computer to measure the acceleration of the vehicle as the vehicle passes through the light gate.
- Measure and mark increasing distances from the top of the runway.
- Place the light gate at the first mark, release the vehicle from the top of the slope and measure the acceleration as it passes the light gate.
- Repeat this and find the average acceleration.
- Repeat for increasing distances from the top of the runway.
- Present your results in a table.

ACTIVITY 4

Title: **Variation of acceleration with changing slope of ramp** (Outcome 3)

Apparatus: Runway, vehicle with double card, light gate, computer or QED, clinometer or board protractor.



Instructions

- Organise the QED/computer to measure the acceleration of the vehicle as the vehicle passes through the light gate.
- Set the runway up at an angle.
- Measure the angle of this slope.
- Place the light gate so that the card cuts the beam as the vehicle passes.
- Release the vehicle and measure the acceleration as it passes through the light gate.
- Change the angle of the slope and repeat the measurements for other angles.
- Use an appropriate format to show the variation of acceleration with angle of slope.

ACTIVITY 5

Title: **Forces and the Newton Balance**

Aim: To use the newton balance to pull and lift various known masses.

Apparatus: Newton balance
Selection of masses of known size

Diagram 1

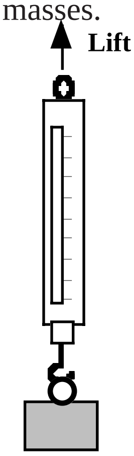


Diagram 2

Instructions

- Use the newton balance as in Diagram 1 to pull each mass across the top of your desk.
- Compare the force required to
  a) start the mass moving
  b) keep the mass moving slowly at a steady speed
  c) keep the mass moving quickly at a steady speed.
- Explain how the newton balance is used to measure force.

Instructions

- Use the newton balance as in Diagram 2 to lift each mass.
- Compare the force required to
  a) support the mass so that it is not moving
  b) move the mass upwards at a steady speed
  c) move the mass downwards at a steady speed.
- Record your results in a table, recording the mass in kilograms (kg).
- Extend your table, calculate the ratio of weight to mass; ie. $\frac{\text{weight}}{\text{mass}}$ in N/kg.
- State the name given to this ratio.

ACTIVITY 6

Title: **‘g’ and the Solar System**

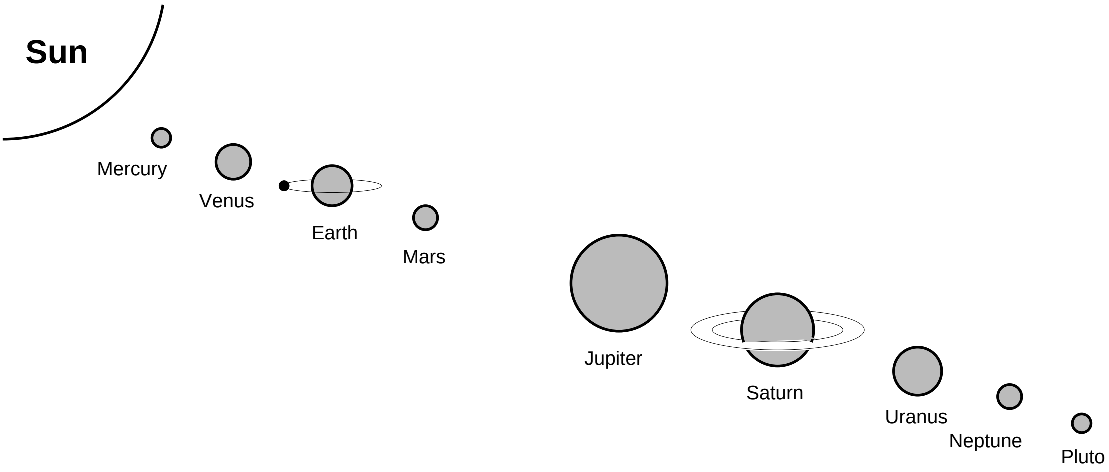
Aim: To obtain and present information on values of ‘g’ for other planets.

Instructions

- Read the information below on ‘g’ for other bodies in the Solar System.

Planet	g (N/kg)
Mercury	3.7
Venus	8.8
Earth	10
(Moon)	1.6
Mars	3.8
Jupiter	26.4
Saturn	11.5
Uranus	11.7
Neptune	11.8
Pluto	4.2

- Calculate your own weight on each of the planets.
- i) Find out the distance of each of the planets from the Sun.
  ii) Present the above information on ‘g’ on a drawing of the Solar System.

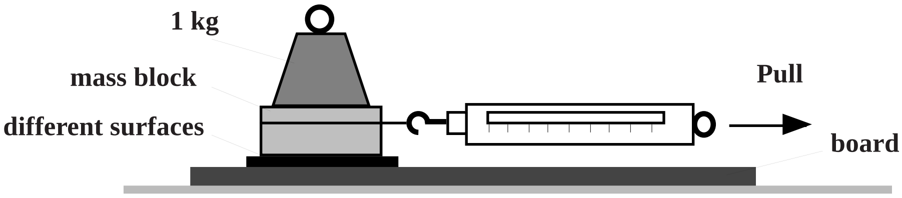


ACTIVITY 7

Title: **Friction and Movement**

Aim: To investigate the force of friction between various surfaces.

Apparatus:
Newton balance
Block of wood
Different surface materials
A range of masses from 1 kg upwards.



Instructions

- Set up the apparatus as shown above using one of the surface materials.
- Using the newton balance, pull the block along the board at a steady speed.
- Record the reading on the balance in a table.
- Repeat the above for different surface materials.
- Repeat the above increasing the mass on top of the block.

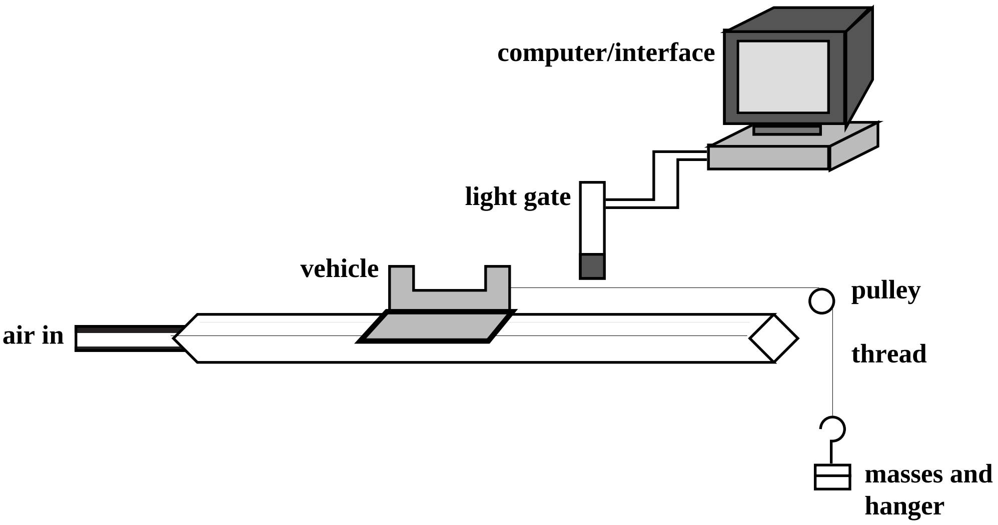
Results

- List the surfaces in order of increasing friction with the wooden block.
- For each of the surfaces, plot a graph of the mass on block against the pulling force.

ACTIVITY 8A

Title: **Relationship Between Acceleration and Applied Force** (Outcome 3)

Apparatus:
Linear air track
400 g air track vehicle
10 g masses and 10 g hanger
Light gate
Computer interface to measure acceleration.



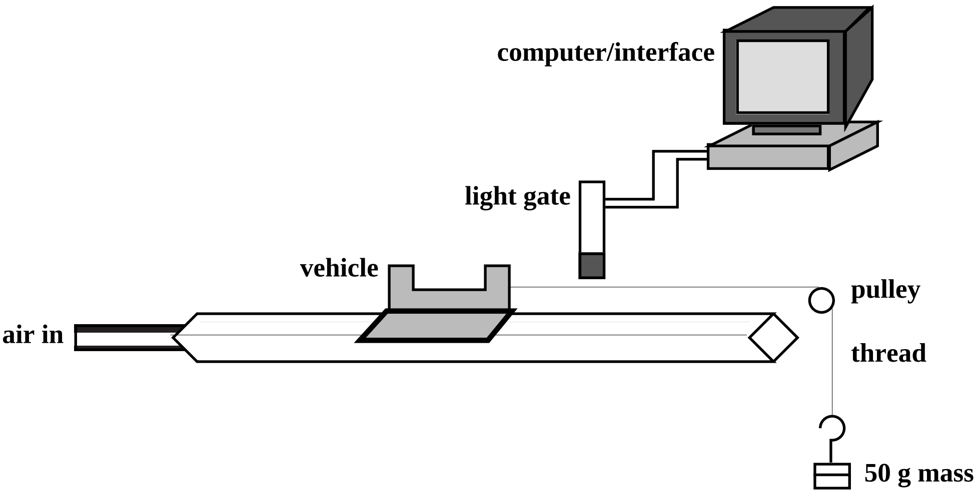
Instructions

- Place the 400 g vehicle on the air track and attach 50 g mass to the thread over the pulley.
- Calculate the weight of the mass and hanger - this is the applied force.
- Release the vehicle so the mask passes through the light gate.
- Measure the acceleration using the computer/interface.
- Remove 10 g from the hanger and place on the vehicle (so that the overall mass stays constant).
- Record the new applied force.
- Release the vehicle and record the acceleration produced.
- Repeat, moving 10 g each time.
- Use an appropriate format to show the variation of the acceleration with the force applied.

ACTIVITY 8B

Title: **Relationship Between Acceleration and Mass of Object** (Outcome 3)

Apparatus:
Linear air track
200 g and 400 g vehicle
10 g masses and 10 g hanger
Light gate
Computer interface to measure acceleration.



Instructions

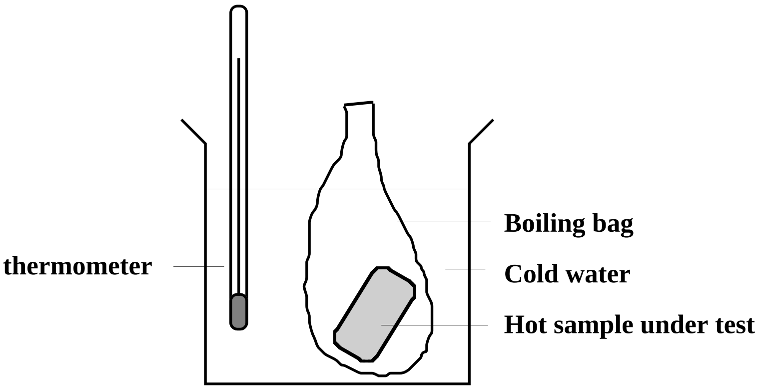
- Place the 200 g vehicle on the air track and attach 50 g mass to the thread over the pulley.
- Calculate the weight of the mass and hanger - this is the applied force.
- Release the vehicle so the mask passes through the light gate.
- Measure the acceleration using the computer/interface.
- Using the same applied force, replace the 200 g vehicle with the 400 g vehicle and attach to the thread and hanger.
- Release the vehicle and record the acceleration produced.
- Repeat for different masses of vehicle.
- Use an appropriate format to show the variation of acceleration with mass.

ACTIVITY 9

Title: **Storing heat**

Aim: To investigate the effectiveness of different materials for storing heat.

Apparatus: 100 g samples of various materials (e.g. copper, aluminium, crushed brick, water and cooking oil) all sealed in boiling bags, 400 ml beakers, container of boiling water, measuring cylinder and thermometers.



Instructions

- Set up the apparatus as shown.
- Copy the table of results.
- Take three samples (one metal, one non-metal, one liquid) and place them in the container of boiling water for ten minutes. Keep the opening of the bag out of the water and take care not to burst the bags.
- Measure 100 ml of cold water into each of three beakers.
- Note the temperature of the cold water in each beaker.
- Remove the bags from the boiling water, shake them, and quickly place one in each of the beakers of cold water.
- Stir the bags around and note the highest temperature reached by the water for each of the bags.
- Enter your results, and the class results, in the table.

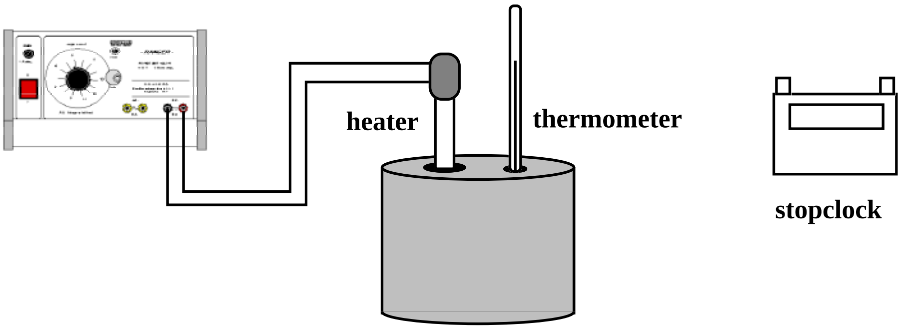
Substance	Temp of cold water at start (°C)	Highest temp reached (°C)	Rise in temp (°C)	Order of merit

ACTIVITY 10

Title: **Specific heat capacity**

Aim: To measure the specific heat capacity of a different metals.

Apparatus: 1 kg metal blocks, thermometer, immersion heater, power supply, stopclock.



Instructions

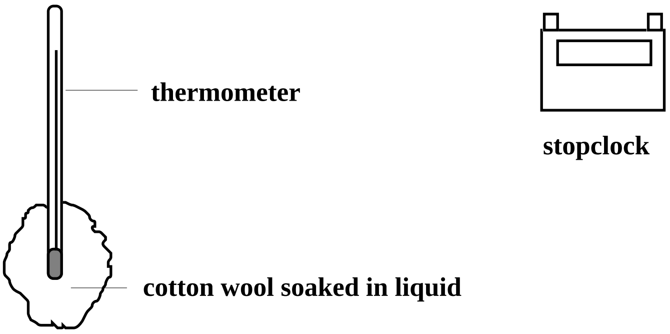
- Set up the apparatus as shown.
- Note the value of the power of the heater.
- Note the temperature of the metal block before heating.
- Note the temperature of the metal block after heating for 5 minutes.
- Calculate the electrical energy supplied to the heater.
- Calculate the specific heat capacity of the metal.

ACTIVITY 11

Title: **Cooling**

Aim: To investigate the effect of cooling by evaporating liquids.

Apparatus: Thermometers, cotton wool, different liquids, stopclock.



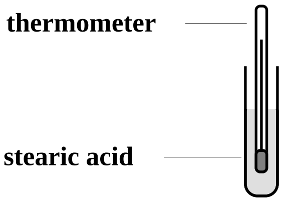
Instructions

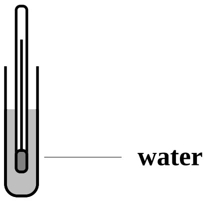
- Set up the apparatus as shown.
- Soak the cotton wool in one of the liquids.
- Record the initial temperature and then the temperature on the thermometer after five minutes.
- Repeat with another liquid.
- Write a short note about the experiment.
- Explain the results in terms of heat energy transfer.

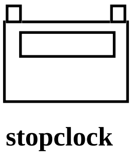
ACTIVITY 12

Title: **Investigation of a cooling curve for a liquid** (Outcome 3)

Apparatus: Boiling tube containing stearic acid, boiling tube containing water, beaker, 2 thermometers, stopclock, test tube rack and bunsen burner.







Instructions

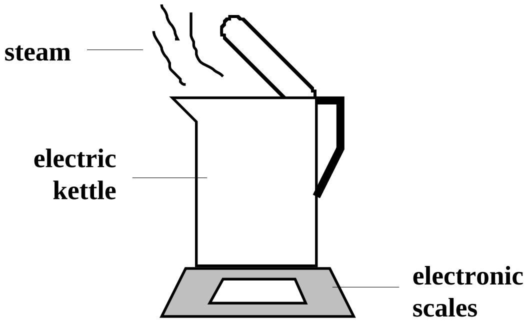
- Place the boiling tubes of water and stearic acid in a beaker of heated water until the stearic acid is completely melted.
- Remove the boiling tubes from the hot water and place them in a test tube rack.
- Note their initial temperatures.
- Record the temperature in each boiling tube every minute for twenty minutes.
- Use an appropriate format to compare the temperature change with time for the two substances.

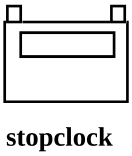
ACTIVITY 13

Title: **Latent heat of vaporisation**

Aim: To measure the specific latent heat of vaporisation of water.

Apparatus: Scales, electric jug kettle with automatic cut-off overridden, stopclock.





Instructions

- Set up the apparatus as shown.
- Note the power rating of the kettle.
- Switch the kettle on and allow the water to boil; at this point note the balance reading and start the stopclock.
- Stop the clock after 0.2 kg of water has boiled off.
- Calculate the amount of energy required to evaporate 0.2 kg of water using $E = P \times t$.
- Calculate how much energy is required to evaporate 1 kg of boiling water. This is the specific latent heat of vaporisation of water.

KINEMATICS PROBLEMS

Speed, distance and time

1. A runner completes a 200 m race in 25 s. What is his average speed in m/s?

2. A friend asks you to measure his average cycling speed along flat road. Describe which measurements you would take and the measuring instruments you would use.

3. An athlete takes 4 minutes 20 s to complete a 1500 m race. What is the average speed?

4. On a fun run, a competitor runs 10 km in 1 hour. What is her average speed in
   a) km/h b) m/s?

5. Describe how you could measure the average speed of a car as it passes along the road outside your school/college.

6. Concorde can travel at 680 m/s (twice the speed of sound).
   How far will it travel in 25 s at this speed?

7. A girl can walk at an average speed of 2 m/s. How far will she walk in 20 minutes?

8. How long will it take a cyclist to travel 40 km at an average speed of 5 m/s?

9. How long (to the nearest minute) will the Glasgow to London shuttle take if it flies at an average speed of 220 m/s for the 750 km flight?

10. How long, to the nearest minute, will a car take to travel 50 km if its average speed is 20 m/s?

11. Look at this timetable for a train between Edinburgh and Glasgow:

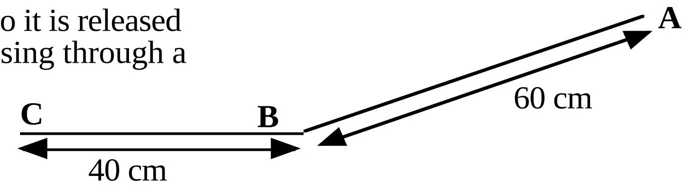
Station	Time	Distance from Glasgow
Glasgow	0800	0 km
Falkirk	0820	34 km
Linlithgow	0828	46 km
Edinburgh	0850	73 km

   a) What was the average speed for the whole journey in m/s?
   b) What was the average speed in m/s between Glasgow and Falkirk?
   c) Explain the difference in average speeds in a) and b).

12. Describe how you would measure the instantaneous speed of a vehicle as it reached the bottom of a slope.

13. In an experiment to measure instantaneous speed, these measurements were obtained:-
    Reading on timer = 0.125 s
    Length of car = 5 cm
    Calculate the instantaneous speed of the vehicle in m/s.

14. A trolley with a 10 cm card attached to it is released from A and runs down the slope, passing through a light gate at B, and stopping at C.
Time from A to B = 0.8 s.
Time on light gate timer = 0.067 s



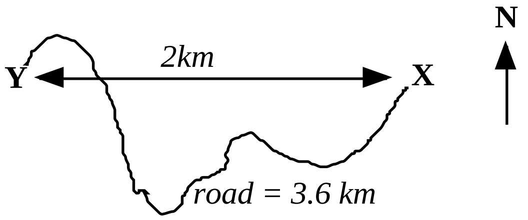
a) What is the average speed between A and B?
b) What is the instantaneous speed at B?

Vectors and Scalars

15. What is the difference between a vector quantity and a scalar quantity?

16. Use your answer to question 15 to explain the difference between distance and displacement.

17. A man walks from X to Y along a winding road.

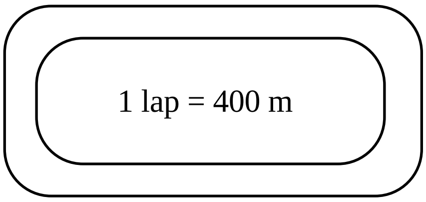


a) What is his displacement at the end of his walk?
b) What distance has he walked?

18. If the walker in question 17 took 40 minutes for his walk, what was
a) his average speed
b) his average velocity?

19. One complete lap of a running track is 400m.

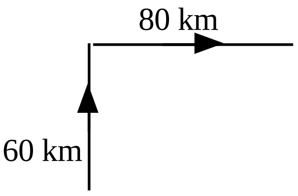
An athlete completes one lap in 48 s in the 400 m race. What is his
a) distance travelled
b) displacement
c) average speed
d) average velocity.



20. Repeat Q 19 for a runner in the 800 m race whose winning time was 1 min 54 s.

21. A car travels 40 km north, then turns back south for 10 km. The journey takes 1 hour. What is
a) the displacement of the car
b) the distance the car has travelled
c) the average velocity of the car }use km h^{-1}
d) the average speed of the car? }

22. A car drives 60 km north, then 80 km east, as shown in the diagram. The journey takes 2 hours.
Calculate the
a) distance travelled
b) displacement
c) average speed
d) average velocity.



Acceleration

23. A Jaguar can reach 27 m/s from rest in 9.0 s. What is its acceleration?

24. The space shuttle reaches 1000 m/s, 45 s after launch. What is its acceleration?

25. A car reach 30 m/s from a speed of 18 m/s in 6 s. What is its acceleration?

26. A train moving at 10 m/s increases its speed to 45 m/s in 10 s. What is its acceleration?

27. A bullet travelling at 240 m/s hits a wall and stops in 0.2 s. What is its acceleration?

28. A car travelling at 20 m/s brakes and slows to a halt in 8 s. What is the deceleration?

29. Describe how you would measure the acceleration of a small vehicle as it runs down a slope in the laboratory.

30. On approaching the speed limit signs, a car slows from 30 m/s to 12 m/s in 5 s. What is its deceleration?

31. A bowling ball is accelerated from rest at 3 m/s^2 for 1.2 s. What final speed will it reach?

32. How long will it take a car to increase its speed from 8 m/s to 20 m/s if it accelerates at 3 m/s^2?

33. A cyclist can accelerate at 0.5 m/s^2 when cycling at 4 m/s. How long will she take to reach 5.5 m/s ?

34. The maximum deceleration a car's brakes can safely produce is 8 m/s^2. What will be the minimum stopping time if the driver applies the brakes when travelling at 60 mph (27 m/s).

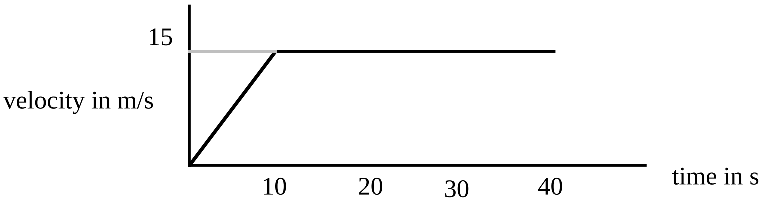
35. The table below gives some performance figures for cars.

Car	**Time for 0 - 60 mph**	**max. speed in mph**
Mondeo 1.8 LX	10.2 s	122
Peugeot 106 XN 1.1	12.5 s	103
Renalt Clio RL	14.3 s	95
Nissan Micra 1.0 S	15.2 s	89
Porsche Boxster	6.5 s	139

a) Which car has the smallest acceleration?
b) Which car has the largest acceleration?
c) Assuming that the acceleration remained constant, how long would it take for the following cars to reach their top speed?
   i) Mondeo ii) Porsche

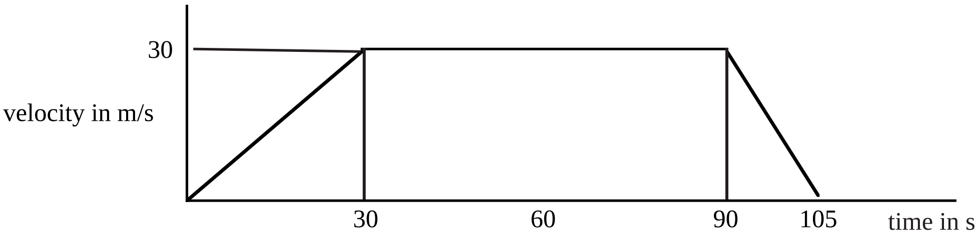
Velocity - time graphs

36. The graph below shows how the velocity of a car varies over a 40 s period.



a) Describe the motion of the car during this 40 s period.
b) Calculate the acceleration of the vehicle.
c) How far does the car travel while accelerating?
d) What is the total distance travelled by the car?

37. Use the graph below to answer the following questions.

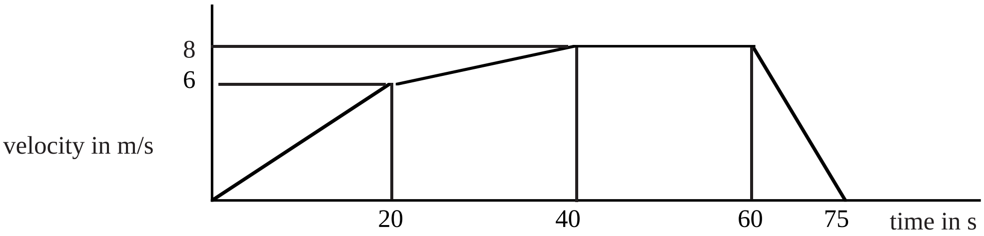


a) During which time is the vehicle travelling at a constant velocity?
b) Calculate the values of i) the initial acceleration ii) the final deceleration
c) What is the braking distance of the car?
d) What is the total distance travelled?
e) What is the average velocity of the car?

38. Draw a velocity-time graph to describe the following motion:-
A car accelerates from rest at 2 m/s for 8 s, then travels at a constant velocity for 12 s, finally slowing steadily to a halt in 4 s.

39. For the vehicle in the previous question, what are the values of
a) the maximum velocity
b) the distance travelled
c) the average velocity?

40. The graph below describes the motion of a cyclist.



a) What is the value of the maximum positive acceleration?
b) Show by calculation whether the cyclist travels farther while accelerating, or while cycling at the maximum velocity.

DYNAMICS PROBLEMS

Gravity, mass and weight

The data table on the right may be required for questions 41-48.
Assume the questions refer to the Earth unless otherwise stated

Planet	g (N/kg)
Mercury	3.7
Venus	8.8
Earth	10
Mars	3.8
Jupiter	26.4
Saturn	11.5
Uranus	11.7
Neptune	11.8
Pluto	4.2

41. What is the weight of a 10 kg bag of potatoes?

42. What is the weight of a 250 g bag of sweets?

43. What is the mass of a 450 N girl?

44. What is the weight of a 10,000 kg spacecraft on
    a) Earth b) Mars c) Venus?

45. What would a 60 kg man weigh on Jupiter?

46. Which planet's gravity is closest to our own?

47. An astronaut who weighs 700 N on Earth goes to a planet where he weighs 266 N. Calculate his mass and state which planet he was on.

48. What would an astronaut weigh on Earth, if his weight on Venus was 528 N?

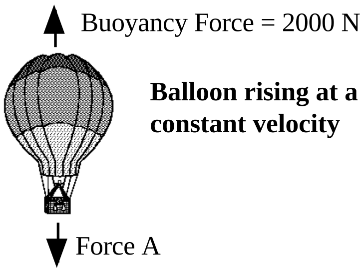
Friction

49. Describe two methods of
    a) increasing friction b) decreasing friction.

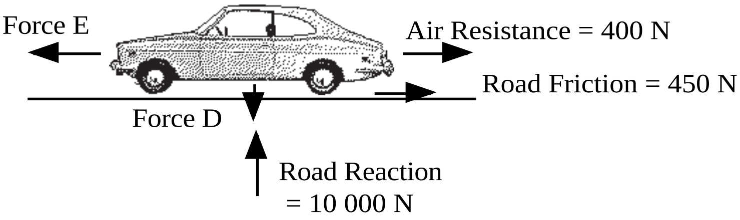
50. Where, in a bicycle, is friction deliberately
    a) increased b) decreased?

Balanced forces and Newton's First Law

51. The diagram shows the forces acting on a balloon as it rises.
    a) What will be the size of force A?
    b) If the balloon was falling at a constant velocity, what would be the size of force A?



52. The diagram below shows the forces acting on a car moving at constant velocity.



a) What can you say about the unbalanced force acting on this car?
b) How big is the engine force E?
c) What is the weight of the car D?

53. Explain, using Newton's First Law, why passengers without seat belts in a stationary car are thrown forwards in the car, when the car stops suddenly.

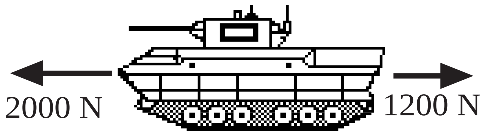
54. Explain how a parachutist reaches a terminal velocity.

Resultant forces

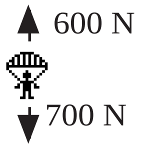
55. What is meant by the resultant force on an object?

56. What are the resultants of the following forces?

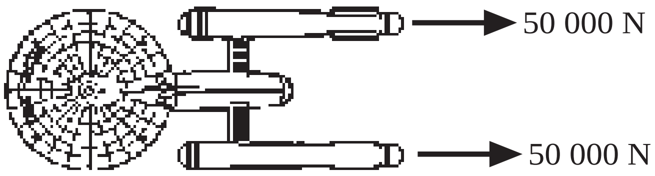
a)



b)

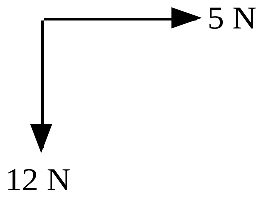


c)

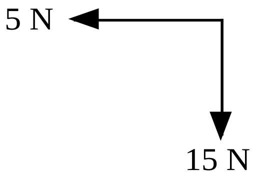


57. By using a scale diagram or otherwise, find the resultant of the following pairs of forces.

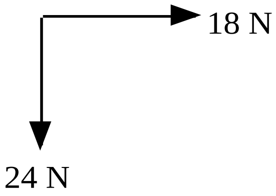
a)



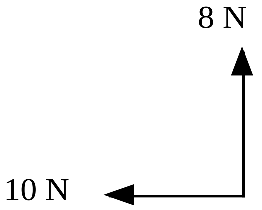
b)



c)



d)



Newton's Second Law

58. What force is needed to accelerate a 5 kg mass at 3 m/s^2 ?

59. What will be the acceleration of a 12 kg mass acted on by a force of 30 N?

60. What mass would accelerate at 2 m/s^2 when acted on by a 12 N force?

61. What force will accelerate 250 g at 2 m/s^2?

62. What force would be needed to accelerate a 10 tonne lorry at 1.5 m/s^2?
(1 tonne = 1000 kg)

63. Give two reasons why a car will have a smaller acceleration in similar conditions when a roof rack is added.

64. Describe an experiment to investigate the effect of varying the unbalanced force acting on a fixed mass.

65. A car of mass 1200 kg experiences friction equal to 500 N when travelling at a certain speed. If the engine force is 1400 N, what will be the car's acceleration?

66. A car of mass 2000 kg has a total engine force of 4500 N. The frictional drag force acting against the car is 1700 N. What is the acceleration of the car?

67. Two girls push a car of mass 1000 kg. Each pushes with a force of 100 N and the force of friction is 120 N. Calculate the acceleration of the car.

68. A boat engine produces a force of 10000 N and the friction and water resistance total 3500 N. If the mass of the boat is 2000 kg, what will be its acceleration?

69. A careless driver tries to start his car with the hand brake still on. The engine exerts a force of 2500 N and the hand brake exerts a force of 1300 N. The car moves off with an acceleration of 1.2 m/s^2. What is the mass of the car?

70. A car of mass 1200 kg can accelerate at 2 m/s^2 with an engine force of 3000 N. What must be the total friction force acting on the car?

71. A helicopter winches an injured climber up from a mountainside.
The climber's mass is 65 kg.
    a) What is the weight of the climber?
    b) If he is accelerated upwards at 1.0 m/s^2, what unbalanced force is required?
    c) What total upwards force must be produced by the helicopter?

72. An 800 kg car is accelerated from 0 to 18 m/s in 12 seconds.
    a) What is the resultant force acting on the car?
    b) At the end of the 12 s period the brakes are operated and the car comes to rest in a time of 5 s. What is the average braking force acting on the car?

Acceleration due to gravity and gravitational field strength

73. On the moon, where the gravitational field strength is 1.6 N/kg, a stone falls and takes 1.5 s to reach the surface. What is its velocity as it hits the surface of the moon?

Projectiles

74. A stone thrown horizontally from a cliff lands 24 m out from the cliff after 3 s. Find:
    a) the horizontal speed of the stone
    b) the vertical speed at impact.

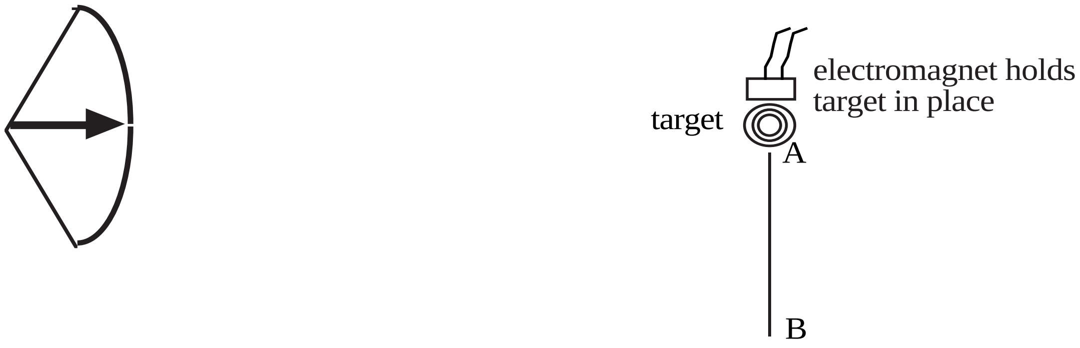
75. A ball is thrown horizontally from a high window at 6 m/s and reaches the ground after 2 s. Calculate:

a) the horizontal distance travelled
b) the vertical speed at impact.

76. An aircraft flying horizontally at 150 m/s, drops a bomb which hits the target after 8 s. Find:
   a) the distance travelled horizontally by the bomb
   b) the vertical speed of the bomb at impact
   c) the distance travelled horizontally by the aircraft as the bomb fell
   d) the position of the aircraft relative to the bomb at impact.

77. A ball is projected horizontally at 15 m/s from the top of a vertical cliff. It reaches the ground 5 s later. For the period between projection until it hits the ground, draw graphs with numerical values on the scales of the ball's
   a) horizontal velocity against time
   b) vertical velocity against time
   c) From the graphs calculate the horizontal and vertical distances travelled.

78. In the experimental set-up shown below, the arrow is lined up towards the target. As it is fired, the arrow breaks the circuit supplying the electromagnet, and the target falls downwards from A to B.



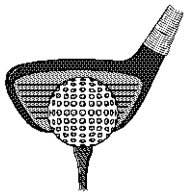
   a) Explain why the arrow will hit the target.
   b) Suggest one set of circumstances when the arrow would fail to hit the target (you must assume it is always lined up correctly).

MOMENTUM AND ENERGY PROBLEMS

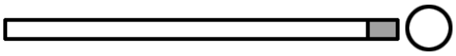
Newton's Third Law

79. State Newton's Third Law.

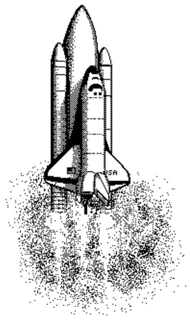
80. Identify the 'Newton pairs' in the following situations.



a) golf club strikes ball



b) snooker cue strikes ball



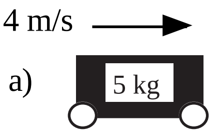
c) space shuttle on take off

(consider only the forces between the shuttle and the exhaust gases.)

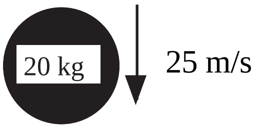
Momentum

81. What is the momentum of the body in each of the following situations:

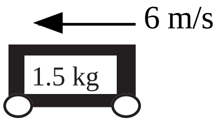
a)



b)



c)



82. State the principle of conservation of energy.

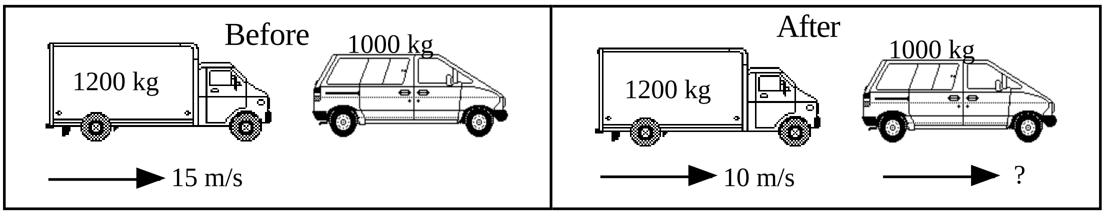
83. A trolley of mass 2 kg and travelling at 1.5 m/s collides and sticks to another stationary trolley of mass 2 kg. Calculate the velocity after the collision.

84. A car of mass 1200 kg and travelling at 20 m/s collides with a stationary car of mass 800 kg. If they move off together after the collision, calculate this new velocity.

85. A skater of mass 70 kg is moving at 4 m/s when he bumps into a skater of mass 50 kg who is not moving. They move off together on the ice. What is their velocity immediately after the collision?

86. A target of mass 4 kg hangs from a tree by a long string. An arrow of mass 100 g is fired with a velocity of 100 m/s and embeds itself in the target. At what velocity does the target begin to move after the impact?

87. The diagram on the next page shows a collision between a moving van and a stationary car. After the collision the van continues to move forward, but with a reduced velocity as shown.
Calculate the velocity with which the car moves forward after the collision.



88. In a game of bowls one particular bowl hits the jack head on causing it to move forward. The jack has a mass of 300 g and was originally stationary. The bowl has a mass of 1 kg and was moving at a speed of 2 m/s before hitting the jack, but continued forwards at 1.5 m/s after the collision. What is the speed of the jack after the collision?

89. A van of mass 1800 kg hits a stationary car of mass 1200 kg. They lock together and move off at 12 m/s. What was the velocity of the van as it collided?

90. Police suspect that a van was breaking the speed limit when it collided with a parked car. Investigations provided them with the following data:-
mass of parked car = 800 kg
mass of van = 1000 kg
velocity of car after collision = 5 m/s
velocity of van after collision = 11 m/s
Show whether the van was breaking the 30 mph speed limit (equivalent to 13 m/s).

91. A pellet of mass 0.5 g is fired into plasticine on a stationary vehicle on a linear air track. The mass of the vehicle and plasticine is 100 g. The vehicle moves off as a result of the impact and a card mounted on it cuts through a light gate. The length of card is 10 cm. and the time recorded on the eletronic timer is 0.30 s.
a) Calculate the velocity of the vehicle in m/s
b) Calculate the velocity of the pellet before the collision.

Work and Energy

92. Copy and complete these examples of energy transformations.
a) Car moving at a steady speed along level road
chemical energy -> ________
b) Car accelerating along level road
chemical energy -> ________ + _______
c) Car braking
kinetic energy -> ________
d) Car freewheeling downhill (engine switched off)
________ -> ________ + _______

93. A locomotive exerts a pull of 10000 N to pull a train a distance of 400 m.
How much work is done?

94. A gardener does 1200 J pushing a wheelbarrow with a force of 100 N.
How far did she push the barrow?

95. A man uses up 1000 J by pulling a heavy load for 20 m. What force did he use?

96. A girl is pushing her bike with a force of 80 N and uses up 4000 J of energy. How far did she push the bike?

97. A man weighing 600 N climbs stairs in an office block which are 40 m high. How much work does he do?

98. A worker pushes a 4 kg crate along the ground for 3 m using a force of 20 N, then lifts the crate up to a ledge 1 m high. How much work does he do altogether?

Work, Power and Time

99. A man pushes a wheelbarrow for 60 m using a 50 N force. If he takes 10 s, what is his average power?

100. The man's son pushes the wheelbarrow for 60 m using the same force as his father, but he takes 13 s to do it.
How does a) his work b) his power compare to his father's?

101. A machine lifts a load of 4000 N to a height of 5 m in 20 s. What is its power?

102. A boy who weighs 600 N can run up stairs of vertical height 8 m in 12 s.
   a) What is his power?
   b) A girl who weighs 500 N takes 10 s to run up the stairs. What is her power?
   c) Do they do equal amounts of work?

103. Describe how you could estimate the average power of a student who is running up a flight of stairs. List measurements you would take, how you would obtain these, and indicate how you would calculate the result.

104. A lift can raise a total mass of 800 kg up 10 m in 40 s. What is its power?

105. A weight lifter lifts a mass of 250 kg from the ground to a height of 1.5 m in a time of 2 seconds. What was his average power during the lift?

106. A lift in a building can take a maximum of 10 people of average mass 70 kg.
The mass of the lift is 500 kg.
   a) What is the total weight of a full lift?
   b) What is the power needed to raise the lift up 30 m in 10 s?

107. A bucket of water of weight 250 N is to be lifted up a 30 m well by a 500 W motor. How long will it take to raise the bucket?

108. a) What will be the power of the electric motor of a lift which can raise a load of 4000 N at a steady speed of 2 m/s?
   b) What is the energy transformation?

Gravitational potential energy

109. A chairlift raises a skier of mass 60 kg to a height of 250 m.
     How much potential energy does the skier gain?

110. A brick of mass 3 kg rests on a platform 25 m above the ground on a building site.
     a) How much potential energy is stored in the brick?
     b) If the brick falls 25 m to the ground, how much potential energy will it lose?
     c) What form of energy will the brick gain?

111. Estimate how much gravitational potential energy **you** would gain if you were lifted 30m up to the top of a fun-ride.

112. An apple, mass 100 g, has 300 J of potential energy at the top of the Eiffel Tower.
     What is the height of the Eiffel Tower?

113. An astronaut of mass 70 kg climbs to a height of 5 m on the moon and gains 560 J of gravitational potential energy. What must be the gravitational field strength on the moon?

Kinetic energy

114. You are provided with an air track and vehicles, a light gate and timer and some elastic bands. Describe how you could use this apparatus to establish how kinetic energy depends on velocity. Include details of any measurements you would take and any additional measuring equipment needed.

115. Calculate the kinetic energy of the following:
     a) a 5 kg bowling ball moving at 4 m/s
     b) a 50 kg skier moving at 20 m/s
     c) a 0.02 kg bullet moving at 100 m/s.

116. a) How much kinetic energy does a 800 kg car have at a speed of 10 m/s?
     b) If it doubles its speed to 20 m/s, calculate its new kinetic energy?

117. A cyclist who is pedalling down a slope reaches a speed of 15 m/s. The cyclist and her cycle together have a mass of 80 kg.
     a) Calculate the total kinetic energy.
     b) Name two sources of this kinetic energy.

118. Calculate an **approximate** value for the kinetic energy of an Olympic 100 m sprinter as he crosses the line (time for race is about 10 s).

119. What is the speed of a stone of mass 2 kg if it has 36 J of kinetic energy?

120. A motor cyclist and his bike have a total mass of 360 kg and kinetic energy of 87120 J.
     What is his speed?

121. The apple in question 112 is dropped from the top of the Eiffel Tower.

a) How much kinetic energy would it have just before hitting the ground?
b) What will be its velocity as it hits the ground?

122. A car of mass 1000 kg is travelling at 20 m/s.
   a) How much kinetic energy does it have?
   b) If the maximum braking force is 5 kN, what will be the minimum braking distance?
   c) If the driver has a reaction time of 0.7 s, how far will the car travel during this ‘thinking time’?
   d) What will the total stopping distance be?

Efficiency

123. What is the efficiency of a machine which has a power input of 800 W and a power output of 600 W?

124. A machine which is 80% efficient uses 20000 J of energy. What is its energy output?

125. A motor which is 60% efficient has an output power of 480 W. What is its input power?

126. An electric motor rated at 500 W runs for 2 minutes and does 45 kJ of work.
   a) What is its input energy?
   b) What is its efficiency?

127. What is the efficiency of a motor rated at 750 W which can lift a 25 kg load to a height of 4 m in 2 s?

HEAT PROBLEMS

Specific Heat Capacity

128. 10000 J of energy raises the temperature of 1 kg of liquid by 2 °C. How much energy will be required to raise the temperature of 4 kg of the liquid by 1 °C?

129. The specific heat capacity of concrete is about 800 J/kg°C. How much heat is stored in a storage heater containing 50 kg of concrete when it is heated through 100 °C?

130. 1.344 MJ of heat energy are used to heat from 20 °C to 100 °C. Calculate the mass of water if the specific heat capacity of water is 4200 J/kg°C.

131. 9600 J of heat energy is supplied to 1 kg of methylated spirit in a polystyrene cup. Calculate the rise in temperature produced.
Take the specific heat capacity of methylated spirit to be 2300 J/kg°C.

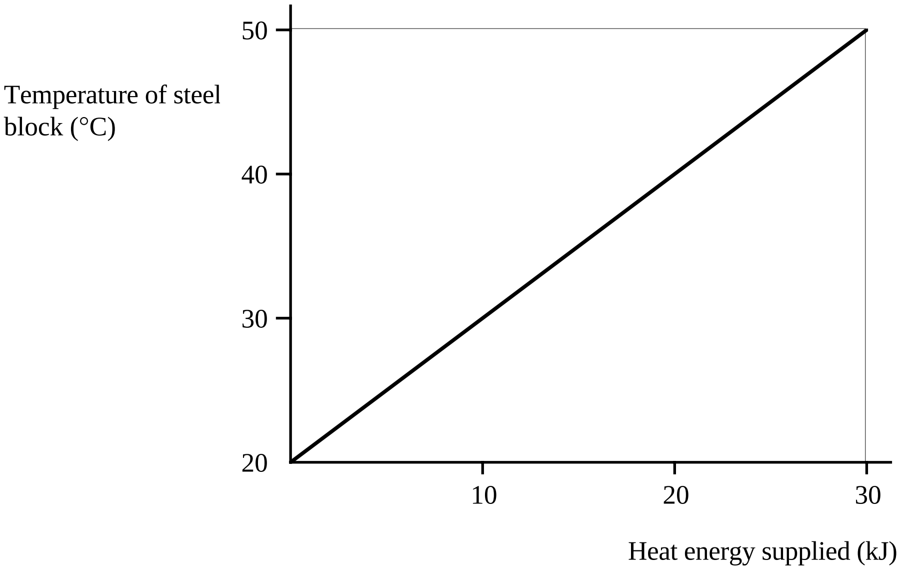
132. When 2.0×10^4 J of heat is supplied to 4 kg of paraffin at 10 °C in a container the temperature increases to 14 °C.
    a) Calculate the specific heat capacity of the paraffin.
    b) Explain why the result in part a) is different from the theoretical value of 2200 J/kg°C.

133. If a kettle containing 2 kg of water cools from 40 °C to 25 °C, calculate the heat given out by the water.

134. The temperature of a 0.8 kg metal block is raised from 27 °C to 77 °C when 4200 J of energy is supplied. Find the specific heat capacity of the metal.

135. The tip of the soldering iron is made of copper with a mass of 30 g. Calculate how much heat energy is required to heat up the tip of a soldering iron by 400 °C.
(specific heat capacity of copper = 380 J/kg°C)

136. The graph below represents how the temperature of a 2 kg steel block changes as heat energy is supplied. From the graph calculate the specific heat capacity of the steel.



Latent Heat

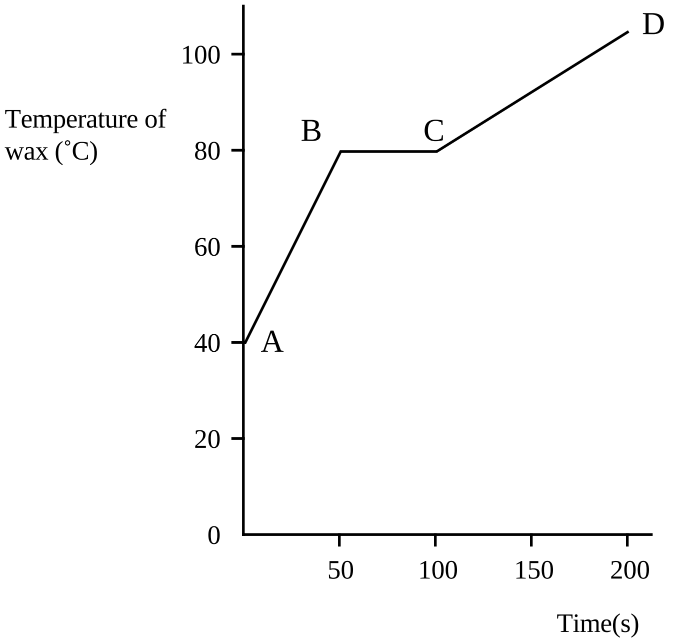
137. Calculate the amount of heat energy required to melt 0.3 kg of ice at 0 °C.
(Specific latent heat of fusion of ice = 3.34 x 10^5 J/kg)

138. Calculate the specific latent heat of fusion of naphthalene given that 6 x 10^5 J of heat are given out when 4.0 kg of naphthalene at its melting point changes to a solid.

139. Calculate what mass of water can be changed to steam if 10.6 kJ of heat energy is supplied to the water at 100 °C.
(Specific latent heat of vaporisation of water = 2.26 x 10^6 J/kg)

140. Ammonia is vaporised in order to freeze an ice rink.
a) Find out how much heat it would take to vaporise 1 g of ammonia.
b) Assuming this heat is taken from water at 0 °C, find the mass of water frozen for every gram of ammonia vaporised.
(Specific latent heat of vaporisation of ammonia = 1.34 x 10^6 J/kg
Specific latent heat of fusion of ice = 3.34 x 10^5 J/kg).

141. The graph below shows how the temperature of a 2 kg lump of solid wax varies with time when heated.



a) Explain what is happening to the wax in the regions AB, BC and CD.
b) If a 200 W heater was used to heat the wax, calculate the specific latent heat of fusion of the solid wax.

Principle of Conservation of Energy

142. If 200 g of water at 40 °C are mixed with 100 g of water at 10 °C and no energy is lost, what is the final temperature of the mixture?
(Specific heat capacity of water = 4200 J/kg°C)

143. If an immersion heater heats 300 g of water for 2 minutes and the temperature rises by 30 °C, find the power rating of the heater in watts.

144. A 350 W element is used to boil 300 g of water in a cup. The initial temperature of the water is 20 °C.
    a) How long will it take to reach 100 °C?
    b) State any assumptions made.

145. Meteors are small pieces of matter made mostly of iron. Few meteors hit the surface of the Earth because of the Earth's atmosphere. Assuming all the kinetic energy of the meteor changes to heat energy in the meteor, if a 0.001 kg meteor travelling at 30000 m/s crashes into the Earth's atmosphere resulting in a change in temperature of 20000 °C, calculate the specific heat capacity of the iron.

146. If a copper ball is dropped on a hard surface the ball is deformed, and we can assume all the kinetic energy is transferred to internal energy in the ball. From what height must the ball be dropped to raise its temperature by 2 °C?
(Specific heat capacity of copper = 380 J/kg°C)

147. An electric shower has a 1.5 kW heating element.
    a) How much heat energy can it give out in five minutes?
    b) If the element is used to heat 5 kg of water for 5 minutes, what would be the rise in temperature? (Specific heat capacity of water = 4200 J/kg).

148. A pupil put 2 litres of water at 20 °C into her 1000 W kettle. She switched it on and then forgot it for 15 minutes. Unfortunately, it did not have an automatic cut-out and when she came back the kitchen was full of steam. 1 litre of water has a mass of 1 kg.
    a) How much energy was required to bring the water to boiling point?
    b) How much electrical energy had been used altogether?
    c) How much water had been turned into steam?
    d) Which of your answers are approximate and why?

149. A heating coil carries an electrical current of 2 A for 100 s at a voltage of 20 V. If this is sufficient to boil away 20 g of liquid nitrogen at its boiling point, what is the specific latent heat of vaporisation of nitrogen?

150. A 200 g bun is put in a 600 W microwave oven for one minute. If its temperature rises from 15 °C to 45 °C, what is the specific heat capacity of the bun?

NUMERICAL ANSWERS

Kinematics

1. 8 m/s
3. 5.8 m/s
4. a) 10 km/h
   b) 2.8 m/s
6. 17000 m
7. 2400 m
8. 8000 s (2 h 13 min)
9. 57 min
10. 42 min
11. a) 24.3 m/s
    b) 28.3 m/s
13. 0.4 m/s
14. a) 0.75 m/s
    b) 1.5 m/s
17. a) 2 km west
    b) 3.6 km
18. a) 1.5 m/s
    b) 0.83 m/s west
19. a) 400 m
    b) 0
    c) 8.3 m/s
    d) 0
20. a) 800 m
    b) 0
    c) 7 m/s
    d) 0
21. a) 30 km north
    b) 50 km
    c) 30 km/h north
    d) 50 km/h
22. a) 140 km
    b) 100 km at (053)
    c) 70 km/h
    d) 50 km/h at (053)
23. 3 m/s^2
24. 22.2 m/s^2
25. 2 m/s^2
26. 3.5 m/s^2
27. 1200 m/s^2
28. –2.5 m/s^2
30. –3.6 m/s^2
31. 3.6 m/s
32. 4 s
33. 3 s
34. 3.4 s
35. a) Micra
    b) Porsche
    c) i) 20.7 s ii) 15.1s
36. b) 1.5 m/s^2
    c) 75 m
    d) 525 m
37. a) 30 - 90 s
    b) i) 1m/s^2 ii) –2 m/s^2
    c) 225 m
    d) 2475 m
    e) 23.6 m/s
39. a) 16 m/s
    b) 288 m
    c) 12 m/s
40. a) 0.3 m/s^2
    b) accelerating 200 m
       constant velocity 160 m

Dynamics

41. 100 N
42. 2.5 N
43. 45 kg
44. a) 100000 N
    b) 38000 N
    c) 88000 N
45. 1584 N
47. 70 kg Mars
48. 600 N
51. a) 2000 N
    b) 2000 N
52. b) 850 N
    c) 10000 N
56. a) 800 N to left
    b) 100 N down
    c) 100000 N to right
57. a) 13 N at (067)
    b) 15.8 N at (198)
    c) 30 N at (053)
    d) 12.8 N at (309)
58. 15 N
59. 2.5 m/s^2
60. 6 kg
61. 0.5 N
62. 15000 N
65. 0.75 m/s^2
66. 1.4 m/s^2
67. 0.08 m/s^2
68. 3.25 m/s^2
69. 1000 kg
70. 600 N
71. a) 650 N
    b) 65 N
    c) 715 N
72. a) 1200 N
    b) 2880 N
73. 2.4 m/s
74. a) 8 m/s
    b) 30 m/s
75. a) 12 m
    b) 20 m/s
76. a) 1200 m
    b) 80 m/s
    c) 1200 m
77. b) i) horizontal = 75 m
    ii) vertical = 125 m

NUMERICAL ANSWERS

Momentum and Energy

81. a) 20 kg m/s right
    b) 500 kg m/s down
    c) 9 kg m/s left
83. 0.75 m/s
84. 12 m/s
85. 2.3 m/s
86. 2.44 m/s
87. 6 m/s
88. 1.7 m/s
89. 20 m/s
90. yes - 15 m/s
91. a) 0.33 m/s
    b) 67 m/s
93. 4 MJ
94. 12 m
95. 50 N
96. 50 m
97. 24 kJ
98. 100 J
99. 300 W
101. 1000 W
102. a) 400 W
    b) 400 W
104. 2 kW
105. 1875 W
106. a) 12000 N
    b) 36 kW
107. 15 s
108. a) 8 kW
109. 150 kJ
110. a) 750 J
    b) 750 J
111. 300 × mass
112. 300 m
113. 1.6 N/kg
115. a) 40 J
    b) 10 kJ
    c) 100 J
116. a) 40 kJ
    b) 160 kJ
117. a) 9 kJ
118. approx 3 kJ
119. 6 m/s
120. 22 m/s
121. a) 300 J
    b) 77 m/s
122. a) 200 kJ
    b) 40 m
    c) 14 m
    d) 54 m
123. 75%
124. 16 kJ
125. 800 W
126. a) 60 kJ
    b) 75%
127. 67%

NUMERICAL ANSWERS

Heat

128. 20000 J
129. 4×10^6 J
130. 4 kg
131. 4.17 °C
132. 2 500 J/kg°C
133. 1.26×10^5 J
134. 105 J/kg°C
135. 4560 J
136. 500 J/kg°C
137. 1.002×10^5 J
138. 1.5×10^{5} J/kg
139. 0.0047 kg
140. a) 1.34×10^6 J
    b) 5.9×10^{-4} kg
141. b) 5000 J/kg
142. 30 °C
143. 315 W
144. a) 288 s
145. 625 J/kg°C
146. 76 m
147. a) 4.5×10^5 J
    b) 21.4 °C
148. a) 6.72×10^5 J
    b) 9×10^5 J
    c) 0.1 kg
149. 2×10^5 J/kg
150. 6000 J/kg°C