Unit 1: Physics on the Go

Chapter: Mechanics

1 use the equations for uniformly accelerated motion in one dimension, $v = u + at$, $s = ut + ½at^2$, $v^2 = u^2 + 2as$

1. $v = u + at$
2. $s = ut + ½ at^2$
3. $v^2 = u^2 + 2as$

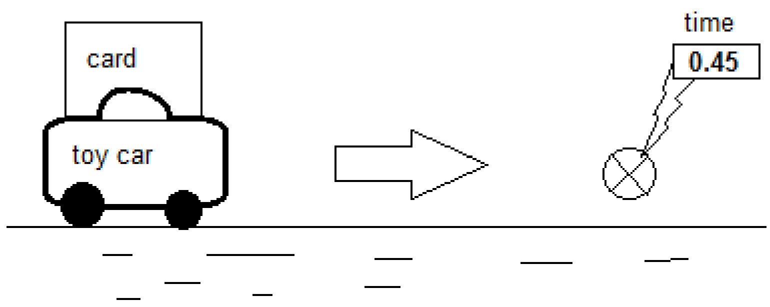
2 demonstrate an understanding of how ICT can be used to collect data for, and display, displacement/time and velocity/time graphs for uniformly accelerated motion and compare this with traditional methods in terms of reliability and validity of data

Motion can be represented using graphs. Traditionally, data might have been collected using rulers and stopwatches. ICT methods are now readily available, for example using a motion sensor.

This setup records displacement at regular intervals and can be used to create graphs of displacement against time or velocity against time. Light gates can also be used to measure motion. Both of these methods will eliminate human error, so time or displacement will be measured more accurately. They also allow greater precision than stopwatches. The data will have improved validity and reliability. With light gates, the length of the object interrupting the beam, or the distance between the gates, must still be measured manually.

Experiment: Determine speed and acceleration, for example use light gates

Measuring speed using light gate method

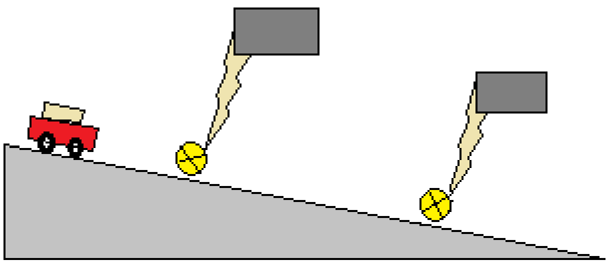


1. Attach a cart of measured length centrally to the top of the toy car.

2. Air track ensures a frictionless way for the toy car.
3. A gentle push can move the toy car at a steady speed.
4. Arrange for the card to block a light gates beam as it passes through it.
5. Electronic timer measures how long the card takes to pass through the beam.
6. Now calculate the toy car's average velocity as it passes the light gate by:

$$v = \frac{length\ of\ the\ card}{interuption\ time}$$

Measuring acceleration using light gate method



1. A card is mounted on the top of a trolley. The length of the card is measured.
2. One light is set at the top of the track and the second one is at the end of the track.
3. The trolley is given a gentle push to move through the track.
4. When the trolley passes through the first light gate the electronic timer measures the t_1 to cross the length of the card.
5. So the velocity at the position of first light gate is measured by velocity.
   a. V_1= length of the first card $\div t_1$
6. During passing the second light gate, if the time measured by electronic timer is t_2 then the velocity can be measured by:
   a. V_2 = length of the second card $\div t_2$
7. The time t_3 is measured for the trolley to travel from first light gate to the second light gate by using a stopwatch.
8. Now acceleration is = velocity difference$\div t_3$

   = {(length of the first card $\div t_1$)-(length of the second card $\div t_2$)} $\div t_3$

3 identify and use the physical quantities derived from the slopes and areas of displacement/time and velocity/time graphs, including cases of non-uniform acceleration

Displacement – time graphs

The line on a displacement – time graphs is straight if the object is moving with constant velocity. A curve shows that the object is accelerating.

The gradient of a displacement – time is change in displacement/change in time which is velocity.

$$v = \frac{\Delta s}{\Delta t}$$

This is also described as rate of change of displacement. Note that the units for the gradient are the units of the y-axis divided by the units of x-axis, i.e. m/s . If the object is accelerating, the velocity is found from the gradient of a tangent to the line.

Velocity – time graphs

The gradient of a velocity-time graph is the change in velocity/change in time, which is acceleration.

$$a = \frac{\Delta v}{\Delta t}$$

This is also described as rate of change of velocity. The area between the line and the time axis on a velocity-time graph is equal to the displacement.

4 investigate, using primary data, recognise and make use of the independence of vertical and horizontal motion of a projectile moving freely under gravity

Projectile

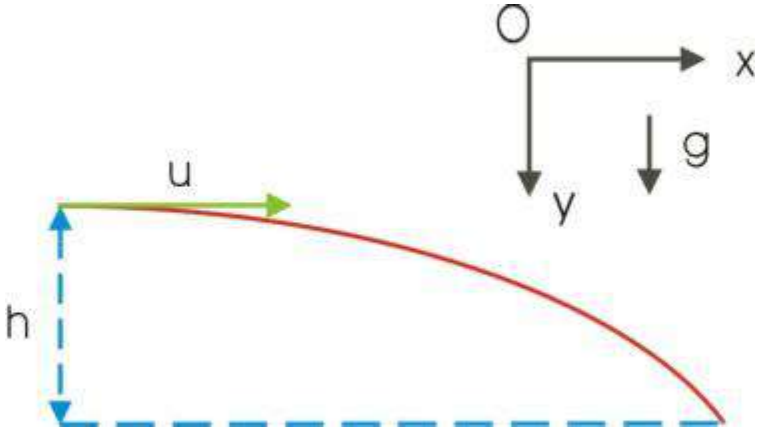
A projectile is an object which is projected. A force acts on it to start it moving and it is then subjected to a constant force while it means that the object is in free fall in the Earth's gravitational field.

Characteristics

1. Only downwards force act on it.
2. It has acceleration in the downwards direction.
3. In the horizontal direction, it has no acceleration.
4. The path travelled by a projectile is parabolic.

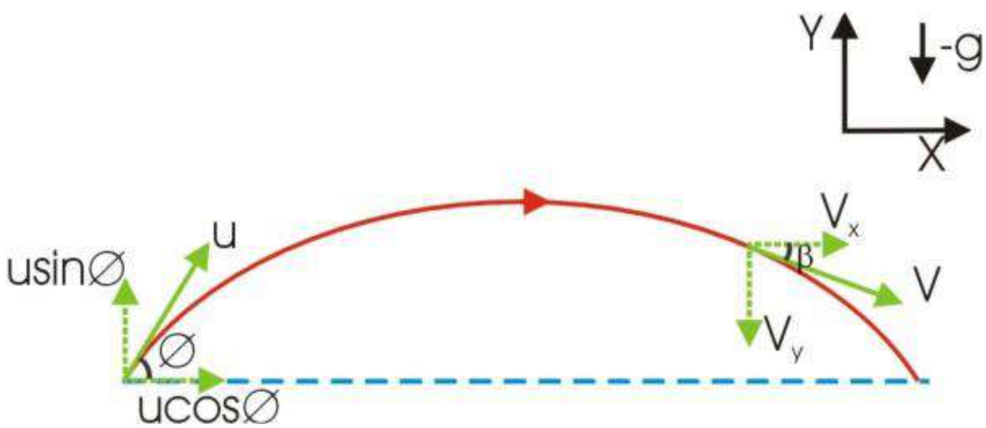
Horizontal projection

The diagram shows an object that has been projected horizontally and is now falling freely under gravity. The horizontal velocity is the same at each point, but the downward velocity is increasing. The path followed is determined by the resultant velocity at each instant and is parabolic.



Projection at an angle

If an object is not launched horizontally or vertically, you start a problem by resolving the initial velocity into horizontal and vertical components. A problem will often involve calculating the time of flight by considering the vertical motion. Find the time to reach the maximum height (when the vertical component is zero) and double it. You then find the maximum horizontal distance travelled (known as the range) from the time of flight and the horizontal velocity.



Horizontal displacement

$$s = ut\cos\alpha$$

Vertical displacement

$$h = ut\sin\alpha - \frac{1}{2}gt^2$$

Range of a projectile

$$R = \frac{u^2 \sin \alpha}{g}$$

In absence of air resistance, the maximum range is achieved for a launch at angle of 45°.

Experiment: Strobe photography or video camera to analyse motion

5 distinguish between scalar and vector quantities and give examples of each

Physical quantities (i.e. things you can measure or calculate) can be classified as either **scalars** or **vectors**. A scalar quantity only has magnitude, not direction, but with a vector quantity you need to state the direction as well as the magnitude. For example, a bag of sugar has a mass of 1kg, but the force on it due to gravity is 9.8N downwards.

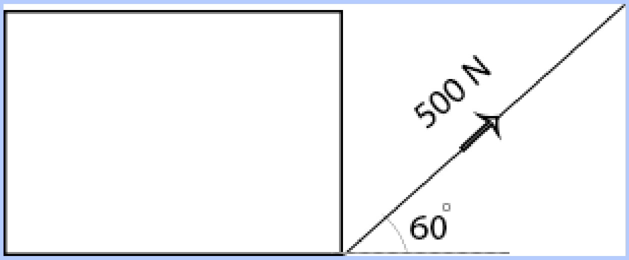
Common scalar quantities: distance, speed, mass, volume, energy, power.
Common vector quantities: displacement, velocity, acceleration, force.

6 resolve a vector into two components at right angles to each other by drawing and by calculation

A single vector can be represented as the sum of two perpendicular vectors, known as its **components**. Vectors at right angles can then be treated independently, and can have third magnitude added to other parallel vectors if necessary.

The components of a vector are found by using that vector as the diagonal of a parallelogram of vectors or as the hypotenuse of a right-angled triangle of vectors.

Example



A boy is pulling a block with a force of 500N with the horizontal. What force is applied along the surface of the earth? What force is applied upward on the block?

A: <u>Horizontal component</u> = P

$$\cos 60 = \frac{P}{500}$$

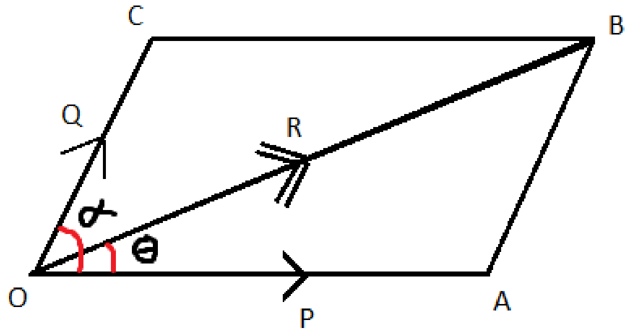
P = 250 N (Ans)

Vertical component = Q

$$\sin 60 = \frac{Q}{500}$$

Q = 433 N (Ans)

Parallelogram theorem

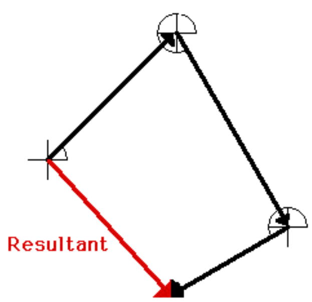


P and Q are represented by two arms: OA and OC. The resultant will be represented by the diagonal OB.

$$R = \sqrt{P^2 + Q^2 + 2PQ\cos\alpha}$$

$$\theta = \tan^{-1}\frac{\sin\alpha}{P + Q\cos\alpha}$$

Combining more than two vectors



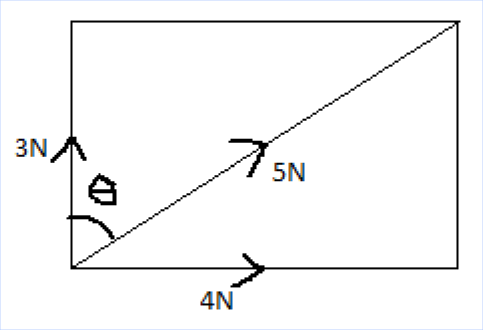
If there are more than two vectors, they can be combined by continuing the tip-to-tail procedure. The resultant is found by drawing from the tail of the first vector to the tip of the last.

7 combine two coplanar vectors at any angle to each other by drawing, and at right angles to each other by calculation

Perpendicular vectors

When two vectors are at right angles to each other, it may be easier to find the resultant by calculation, using Pythagoras' theorem and trigonometry.

Example
A block is being pushed at north with force of 3N and at east with force of 4N. Calculate the resultant force and its direction.



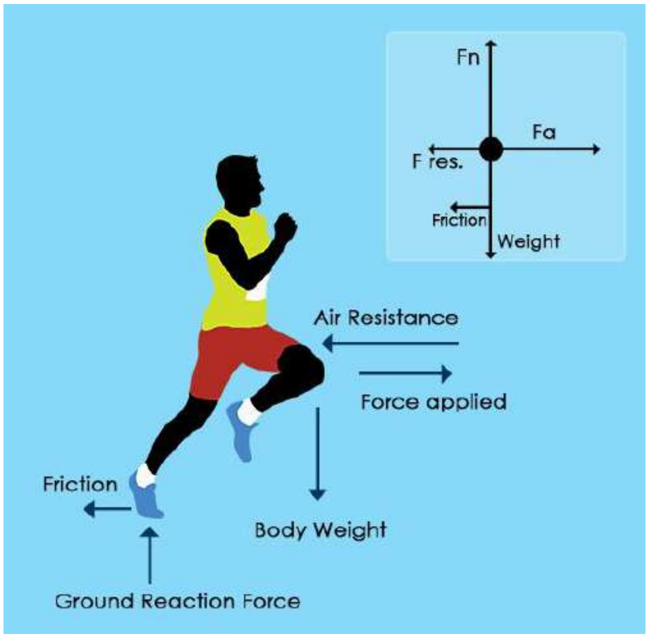
A: $R = \sqrt{4^2 + 3^2}$
= 5 N

$cos\theta = \frac{3}{5}$
$\theta = 53.1^o$

So the resultant force is 5N at angle of 53.1^o from the north.

8 draw and interpret free-body force diagrams to represent forces on a particle or on an extended but rigid body, using the concept of centre of gravity of an extended body

A diagram which shows all the forces acting on a body in a certain situation is called a free-body diagram. A free body diagram doesn't show forces acting on object other than the one we considered.



Experiment: Find the centre of gravity of an irregular rod

9 investigate, by collecting primary data, and use ∑F = ma in situations where m is constant (Newton's first law of motion (a = 0) and second law of motion)

Newton's first law of motion

This states that, if the forces acting on a body are in **equilibrium**, its velocity will remain constant.

Newton's second law of motion

If there is a resultant force, then there will be a change in velocity, i.e. an acceleration.

Newton's second law states that the acceleration of an object is proportional to the resultant force and inversely proportional to its mass. Taking these together:

resultant force = mass x acceleration

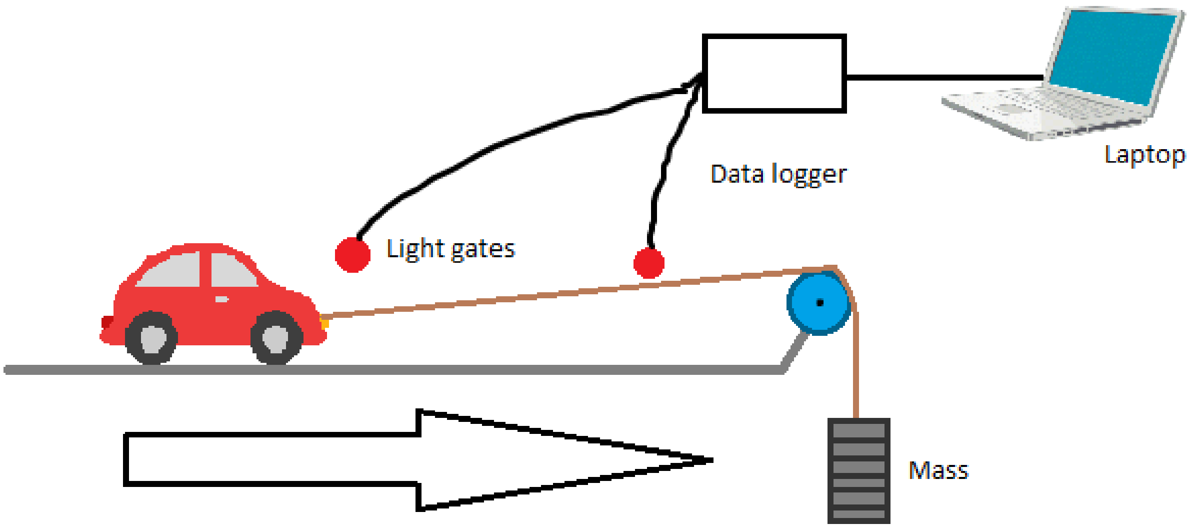
$$\sum F = ma$$

where, F is the force in N, m in mass in kg and a is acceleration in ms^{-2} (∑F means the sum of all forces, i.e. the resultant force). Acceleration and force are both vectors and must act in the same direction.

If the resultant force is zero, then acceleration will be zero. So Newton's first law is just a special case of the second law: if $\sum f = 0$, then $\Delta v = 0$.

Experiment: Use an air track to investigate factors affecting acceleration

Investigating: a ∝ F



1. Set up the apparatus as shown in the diagram.
2. After the car starts moving, the first light gate will measure the initial velocity and the next light gate, the final velocity. An electronic timer will be used to measure the time required to travel from first light gate to second. Using $a = \frac{v-u}{t}$, we can find the acceleration.
3. Now change the weight and repeat the experiment for more different values of acceleration and force.

Force F/N	Acceleration a/ms^{-2}
0.1	0.20
0.2	0.40
0.3	0.60
0.4	0.80
0.5	1.00
0.6	1.20

4. Plotting an acceleration-time graph, a straight line will show that acceleration is proportional to the resultant force.

Investigating: a ∝ 1/m

1. Follow the same diagram as previous.
2. After the car starts moving, the first light gate will measure the initial velocity and the next light gate, the final velocity. An electronic timer will be used to measure the time required to travel from first light gate to second. Using $a = \frac{v-u}{t}$, we can find the acceleration.
3. Now change the mass of the car by keeping the weight(force) constant. Repeat the experiment, and determine the acceleration for each case.

Mass/kg	Acceleration/ms^{-2}
0.5	1.00
0.6	0.83
0.7	0.71
0.8	0.63
0.9	0.55
1.0	0.50

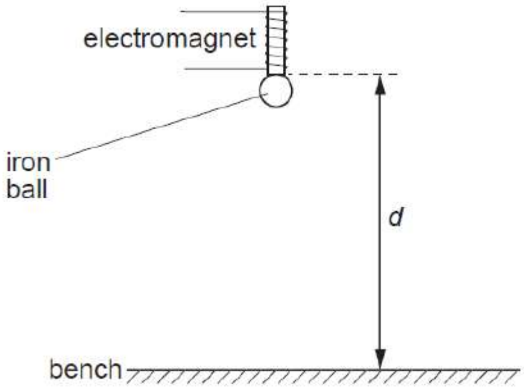
4. The results in table show that there is a different relationship between a and m. Here a ∝ 1/m. We can say that a is inversely proportional to m.

10 use the expressions for gravitational field strength g = F/m and weight W = mg

Gravitational field strength g is defined as the force per unit mass, in mathematical term: g=F/m. The SI unit is N kg^{-1} and it is a vector quantity.

The weight of an object is calculated from this relationship: W=mg.

Experiment: Measure g using, for example, light gates



1. The arrangement is done as shown in the diagram.
2. The iron ball is released by switching off the switch. As soon as it is done, the stopwatch will be started manually.
3. The time taken for the ball to reach the bench is measured. And the distance between the ball and benched is measured with a ruler

4. Calculation:
   $s = ut + ½ at^2$
   $= 0 + ½ gt^2$
   $g = 2s/t$
5. The value of g can be measured by this equation.

Experiment: Estimate, and then measure, the weight of familiar objects

11 identify pairs of forces constituting an interaction between two bodies (Newton's third law of motion)

Newton's third law of motion

This states that, if body A exerts a force on body B, then body B exerts a force of the same type on body A that is equal in magnitude and opposite in direction.

To describe the Newton's third law pair force in a given situation, just keep the magnitude and type of force the same and swap the direction and body acted on. For example, the Earth exerts a downward gravitational force of 10N on a rock, so the rock exerts an upwards gravitational force of 10N on the Earth.

12 use the relationship $E_k = ½mv^2$ for the kinetic energy of a body

Moving bodies have kinetic energy by virtue of their motion. The formula is:

kinetic energy = ½ x mass x (speed)^2

$$E_k = ½mv^2$$

A change in kinetic energy can also be found based on work done.

13 use the relationship $\Delta E_{grav} = mg\Delta h$ for the gravitational potential energy transferred near the Earth's surface

When an object is lifted, work is done against the downward gravitational force, i.e. the weight. The distance moved is the vertical height through which is the object is raised. Therefore,

change in gravitational potential energy = weight x change in height

$$\Delta E_{grav} = W \times \Delta h$$

and, as weight = mass x g

$$\Delta E_{grav} = mg\Delta h$$

The change in gravitational potential energy is related to the change in height – you don't need the total height above the ground. Also note that, although this is related to a specific direction, it is still a scalar quantity.

14 investigate and apply the principle of conservation of energy including use of work done, gravitational potential energy and kinetic energy

Principle of conservation of energy: Energy can be neither created nor destroyed, but it can be transferred. This means that, in any process, total energy at the start = total energy at the end.

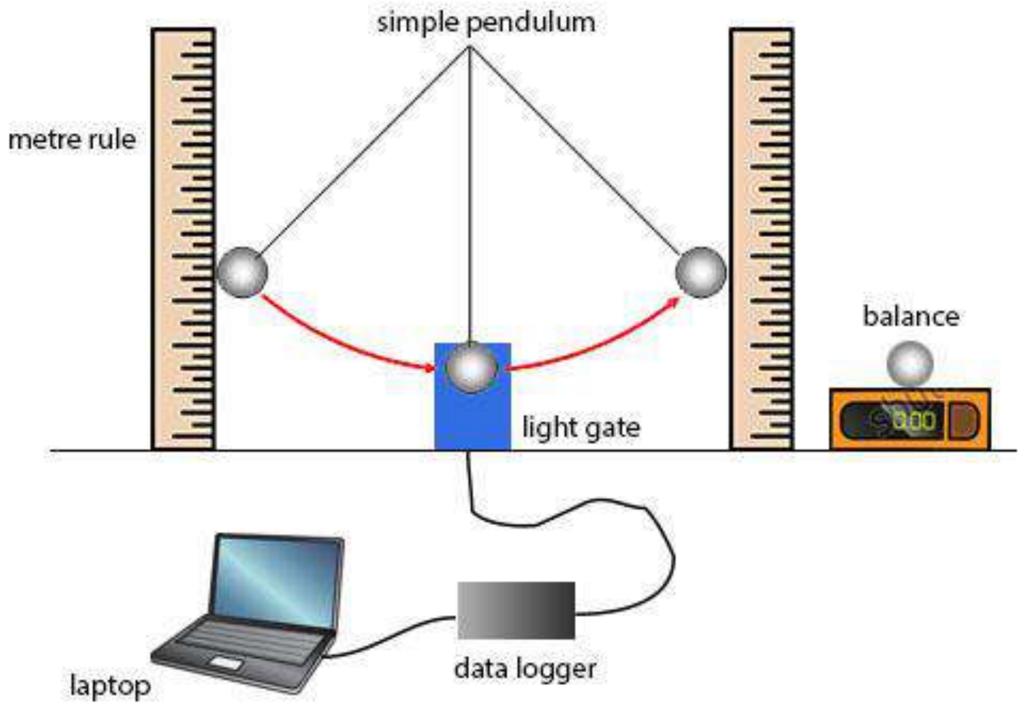
Energy transformation

Energy can be transferred by two ways: (i) Heating and (ii) Working

Heating: If we heat an object, it transfers energy to it using a temperature difference - perhaps, by means of flame. It is by means of temperature gradient.
Working: If we wish to transfer energy without making use of a temperature difference we do it by doing a work. For example, by lifting an object of the floor onto a table. It is by means of moving a force.

Experiment: Energy exchange in pendulum

Galileo pendulum experiment in which he determined that the pendulum would always return to some height illustrates the conservation of gravitational and potential energy nicely.



By careful measurement of the height a pendulum rises and falls through its swing. We can determine the gravitational potential energy it loses and gain throughout one oscillation. This can be then compared with kinetic energy as it passes through the lowest point. The experiment will show that the energy is constantly being transferred from kinetic energy to gravitational potential energy and vice versa.

Experiment: Use, for example, light gates to investigate the speed of a falling object

15 use the expression for work $\Delta W = F\Delta s$ including calculations when the force is not along the line of motion

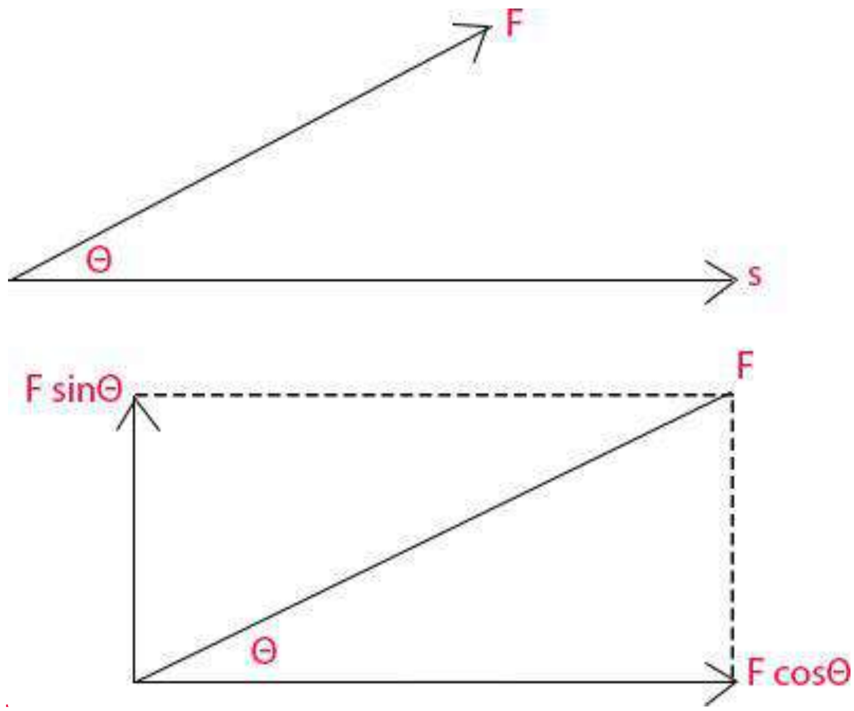
When a force acts on an object and transfers energy, work has been done. For example, someone pushes a car, which accelerates and gains kinetic energy. Energy is transferred from the person to the car as work is done by the person on the car.

work done = force x **distance moved in direction of force**

The SI unit of energy is joule (J).

Calculating force when displacement is different direction

Although work done is a scalar quantity, force and displacement are vectors, so their direction is important. If the force and the displacement are in different directions, the force must be resolved in order to calculate the work done. The figure below shows how this is done. In this figure, the force is resolved so that one component (F cosΘ) lies in the same direction as the displacement. This is the component of the force that is involved in transferring energy. The component of the force perpendicular to the displacement does no work, as it does not move in the direction which is acting.



Resolving a force to calculate work done. In this case, work done = F cosΘ x **s.**

16 understand some applications of mechanics, for example, to safety or to sports

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17 investigate and calculate power from the rate at which work is done or energy transferred

Power is the energy transferred to the time taken.

$$\textbf{Power} = \frac{energy\ transferred}{time\ taken}$$

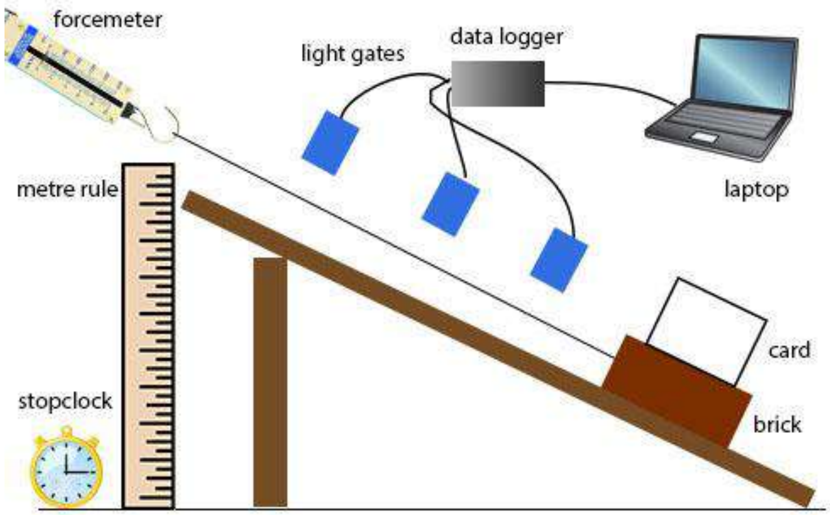
Relations of efficiency

$$efficiency = \frac{useful\ energy\ output}{energy\ input} \times 100\%$$

$$efficiency = \frac{useful\ power\ output}{power\ input} \times 100\%$$

Experiment: Estimate power output of electric motor (see 53)

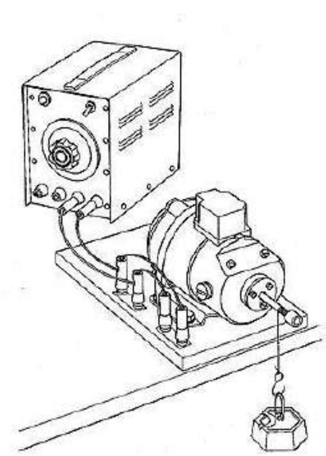
Investigating power and efficiency



A brick is pulled up a ramp at a constant velocity and using a constant force. The forcemeter measures the force and the light gates are used to measure the velocity of the brick. Now we can calculate the power output by, P = Fv

Power input can be calculated by P = work done / time. Work done = gain in GPE = mgh. The mass can be measured by an electronic balance, the height is measured by the metre rule and the time taken is measured by stopclock. Now efficiency can be calculated by n = power output /power input x 100%

Measuring the output power of an electric motor



The motor in figure is switched on until the load is raised almost up to the pulley wheel and is then switched off. A stopclock is used to measure the time, Δt, when the motor is working, and a metre rule is used to find the distance, Δh, through which the load is lifted. The experiment is repeated for a range of masses to investigate the effect of the load on the power output of the motor using the equation:

$$Power\ output\ of\ motor\ = \frac{\Delta GPE}{\Delta t} = \frac{mg\Delta h}{\Delta t}$$