Section 1 - On the Move

Speed

Speed is the distance travelled by an object in one second (usually expressed in metres per second, m/s).

Average and Instantaneous Speed

The **average speed** of an object is the average for the whole journey (total distance travelled divided by time taken). This is usually given the symbol $\bar{v}$ ("v-bar")

The **instantaneous speed** of an object is it's speed at one particular point during the journey.

Speed, Distance and Time

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

m/s   m   s

$$d = v\,t$$

$$v = \frac{d}{t}$$

$$t = \frac{d}{v}$$

Measuring Average Speed

stopclock

1.45 s

vehicle

A   B

Measure distance travelled with a ruler.

Measure time taken to travel with a stop clock.

$$\text{Average speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

Measuring Instantaneous Speed

electronic timer

0.023 s

card

light gate

vehicle

Measure length of card with a ruler.

Measure time taken for card to pass through light gate with an electronic timer.

$$\text{Instantaneous speed} = \frac{\text{length of card}}{\text{time through gate}}$$

Accuracy when Measuring Speed

When speed is measured using a stopclock a less accurate measurement is obtained then when using an electronic timer. This is because of **human reaction time**.

Speed During a Journey

During a journey the instantaneous speed of a vehicle will change. For example at one point a car may be travelling along a street at 30 mph and when it is stopped at traffic lights it's speed is 0 mph. These speeds can be very different from the average speed which may be something like 8 mph.

Acceleration

The acceleration of a vehicle is how much it's speed changes each second.

Acceleration is usually measured in metres per second per second (m/s/s or m/s^2 or ms^{-2}) although miles per hour per second (mph/s) can also be used sometimes.

Acceleration can be calculated by dividing the change in speed by the time taken for the change.

$$\text{acceleration} = \frac{\text{change in speed}}{\text{time}}$$

Acceleration, Speed and Time

$$\text{acceleration} = \frac{\text{final speed - initial speed}}{\text{time}}$$

m/s
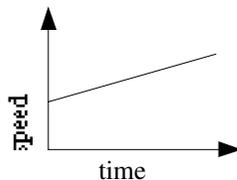
m/s/s

s

v-u

a   t
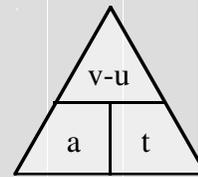
$$v-u = at$$

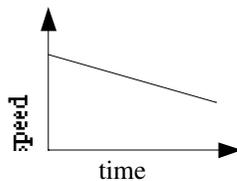$$a = \frac{v-u}{t}$$

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

Speed-Time Graphs

constant speed
(no acceleration)
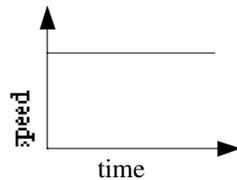
speed

time

increasing speed
(acceleration)

speed

time

decreasing speed
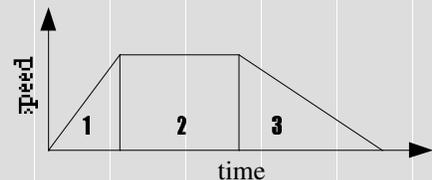(deceleration)

speed

time

Using Speed-Time Graphs

Accelerations and decelerations can be calculated from a speed-time graph using the above equations.

The distance travelled is equal to the area under the graph.

e.g.

speed

1   2   3

time

distance = area under graph
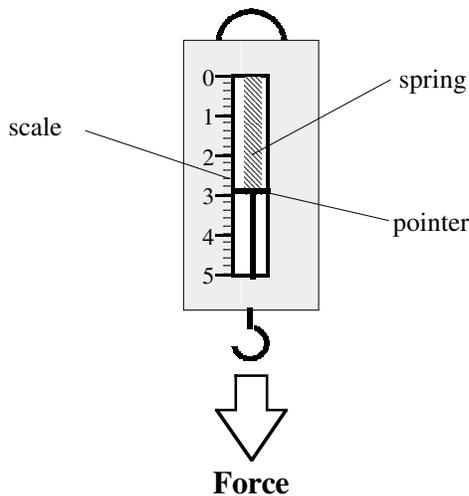= area 1 + area 2 + area 3

Section 2 - Forces at Work

Forces

Forces can **change the shape, speed and direction** of motion of an object.

Force is measured in units called **newtons** (N).

Newton Balance

The instrument used to measure forces is called a **Newton balance**.

When a force is applied to the balance the spring becomes longer. The increase in length is directly proportional to the force applied.

Weight and Mass

The **weight** of an object is the force on it due to the Earth's gravitational pull. Since it is a force weight is measured in newtons (not kilograms!)

The **mass** of an object is the amount of matter that makes up the object and is measured in kilograms.

To calculate the weight (in newtons) of an object on Earth multiply the mass (in kilograms) by 10.

The mass of an object remains the same no matter where the object is in the universe but the weight of an object depends on the gravitational field at that point in space.

Gravitational Field Strength

The **gravitational field strength**, **g**, of a planet is the *weight per unit mass of an object* on that planet. Gravitational field strength therefore has units of N/kg.

For example on Earth g = 10 N/kg, whereas on Mars g =3.8 N/kg.

Weight, Mass and g

kg

weight = mass x gravitational field strength

N   N/kg

$$W = mg$$

$$m = \frac{W}{g}$$

$$g = \frac{W}{m}$$

Friction

Friction is a force that opposes the motion of an object.

Air resistance, or drag, is the force of friction due to an object's motion through the air.

Situations in which friction is **increased** include: i)   applying the brakes of a car
ii) opening a parachute
iii) wearing rubber soled shoes for rock climbing

Situations in which friction is **decreased** include: i)   making racing cars streamlined
ii) oiling moving parts in a car engine
iv) using an air cushion on an 'air hockey' table

Balanced Forces

When *equal forces act in opposite directions* they are called **balanced forces**.

e.g.

100 N ← [cart] → 100 N
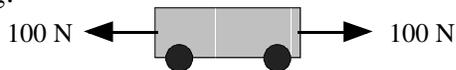
Balanced forces are equivalent to no forces at all.

When balanced forces (or no forces at all) act on an object it remains at rest or continue to move at a steady speed in a straight line. This is known as **Newton's First Law of Motion**.

If an object is moving at a steady speed then the forces on it must be balanced.

e.g. If a car is moving at steady speed then the engine force must be balanced by the frictional forces.

Seatbelts

When a car brakes (or crashes) there is a force acting against the car slowing it down. If the passenger was not wearing a seatbelt they would (according to Newton's First Law of Motion) continue to move forwards at constant speed (until they hit the windscreen or dashboard). A seatbelt is therefore used to provide a backwards force to stop the passenger from continuing to move forward at constant speed

Unbalanced Forces

When unbalanced forces act on a object the object changes speed (or direction). The acceleration due to an unbalanced force depends on the mass of the object and can be calculated using **Newton's Second Law.**

When the force stays constant and the mass increases the acceleration decreases.

When the mass stays constant and the force increases the acceleration increases.

Newton's Second Law

$$\text{unbalanced force} = \text{mass} \times \text{acceleration}$$

N   kg   m/s/s

$$F = ma$$

$$m = \frac{F}{a}$$

$$a = \frac{F}{m}$$
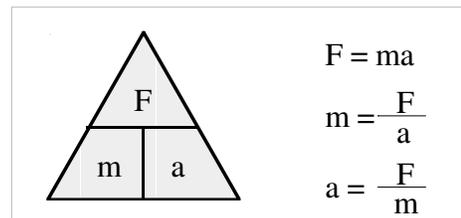
If more than one force acts on an object it is necessary to work out the unbalanced force before using the above equation.

Section 3 - Movement Means Energy

Vehicle Energy Transformations

Energy is changed from one form to another during an vehicle's motion. However, the total amount of energy remains constant. In other words energy can neither be created nor destroyed. (This is known as the **principle of conservation of energy**).

Examples of energy transformations during a car journey include:

accelerating	-	chemical to kinetic (and heat) energy
constant speed	-	chemical to heat energy
braking	-	kinetic to heat energy
moving uphill	-	chemical to potential (and heat) energy
moving downhill	-	potential to kinetic (and heat) energy

Very often during energy transformations some energy is "lost" as heat due to friction.

Work Done

Work done is a measure of the energy transferred during an energy transformation.

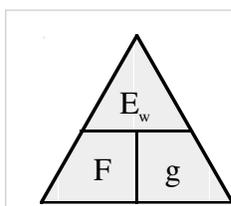Work done has the symbol E_w (or sometimes W_k) and is measured in joules (J).

Power

Power is the **rate at which energy is transferred** during an energy transformation.

Power has the symbol P and is measured in watts (W).
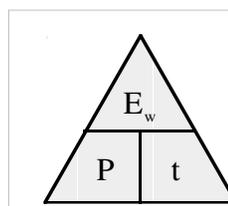
Work done, Force and Distance

$$\text{work done} = \text{force x distance}$$

N

J   m

$$E_w = Fd$$

$$F = \frac{E_w}{d}$$

$$d = \frac{E_w}{F}$$

(triangle: E_w over F | g)

Power, Work (Energy) and Time

$$\text{power} = \frac{\text{work done}}{\text{time}}$$

J

W   s

$$E_w = Pt$$

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

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

(triangle: E_w over P | t)

Gravitational Potential Energy

The change in gravitational potential energy, E_p, of an object is the work done against gravity (lifting) or by gravity (falling).

Gravitational potential energy is measured in joules (J).

Kinetic Energy

Kinetic energy, E_k, is the energy an object has due to it's motion.

Kinetic energy is measured in joules (J)

The kinetic energy of an object depends on both it's mass and speed. Increasing the mass and/or the speed of the object increases it's kinetic energy.

Gravitational Potential Energy, Mass and Height

kg

gravitational pot. energy = mass x g x height

J   N/kg   m

(on Earth g = 10 N/kg)

$$E_p = mgh$$

$$m = \frac{E_p}{gh}$$

$$h = \frac{E_p}{mg}$$

Kinetic energy, Mass and Speed

kg

kinetic energy = ½ x mass x speed^2

J   ms^{-1}

$$E_k = \tfrac{1}{2}mv^2$$

$$m = \frac{E_k}{\tfrac{1}{2}v^2}$$

$$v^2 = \frac{E_k}{\tfrac{1}{2}m}$$

Conservation of Energy

During any energy transformation *the total amount of energy stays the same*. This is known as the **principle of conservation of energy**.

The principle of conservation allows numerical problems involving different forms of energy to be solved. For example, when a vehicle rolls down a slope, gravitational potential energy is converted into kinetic energy and heat (work done by friction). Calculations can be performed on each of the separate forms of energy (E_p=mgh , E_k=½mv^2 and E_w=Fd) but it is also known that the total amount of energy stays the same and so (in this case) $E_p = E_k + E_w$.