Wallace Hall Academy

CfE Higher Physics

Unit 1 - Dynamics Notes

Name ___________________

Equations of Motion

Vectors and Scalars (Revision of National 5)

It is possible to split up quantities in physics into two distinct groups, those that need a direction and those that don't. Some are obvious - it makes sense that force has direction; you can push or pull but you need to specify the direction.
It would be nonsense to give a direction to time. To say: "It took 5 seconds East" just isn't right. It is important that you are familiar with which quantity falls into which grouping.

A scalar is a quantity that can be described by just a size and a unit. e.g. time - 30 s, mass - 20 kg.

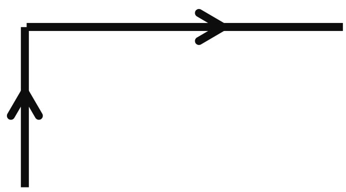
A vector is a quantity that is fully described with a size and *direction*. e.g. force - 50 N downwards velocity - 20 ms^{-1} East.

Adding Vectors (Revision of National 5)

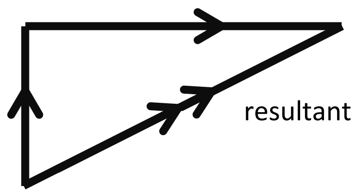
The addition of two vectors is called the ***resultant*** vector.
When you add vectors they have to be added ***tip-to-tail***.

- Each vector must be represented by a straight line of suitable scale. e.g. 4.5 km = 4.5 cm
- The straight line must have an arrow head to show its direction. Put the arrow in the middle of the line so as not to disrupt the accurate length of the line. i.e.

- The vectors must be joined one at a time so that the tip of the previous vector touches the tail of the next vector. i.e.



- A straight line is drawn from the starting point to the finishing point and the starting angle is marked.

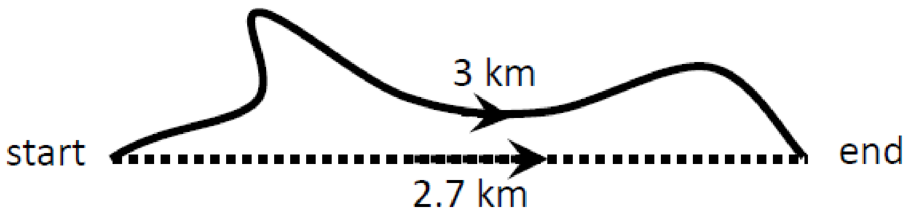


- The resultant should have **2 arrow heads to make it easy to recognise**.
- If using a scale diagram the length and direction of this straight line gives the resultant vector.
- Alternatively you can use Pythagoras and SOHCAHTOA.

Distance and Displacement (Revision of National 5)

The **distance** travelled by an object is the **sum of the distances** of each stage of the journey.
Since each stage has a different direction, the total distance has no single direction and therefore distance is a scalar.
The **displacement** of an object is the **shortest route between the start and finish point measured in a straight line**. Displacement has a direction and is a vector.

Consider the journey below. A person walks along a path (solid line) from start to end.



They will have walked further following the path than if they had been able to walk directly from start to end in a straight line (dashed line).
The solid line denotes the **distance** = 3km. The dashed line denotes the **displacement** = 2.7 km East

<u>Example</u>
A woman walks her dog 3 km due North (000) and then 4 km due East (090)

a) Calculate her distance travelled
b) Calculate her displacement

<u>Solution</u>

Speed and Velocity (Revision of National 5)

Speed is defined as the **distance travelled per second** and is measured in **metres per second**, **or ms^{-1}.** Since distance and time are both scalar quantities then speed is also a scalar quantity.
The equation for speed is:

$$d = vt$$

Velocity is defined as the **displacement travelled per second** and is measured in **metres per second**, **or ms^{-1}**. Since displacement is a vector quantity that means that velocity is also a vector and has the symbol **v**.
The equation for velocity is:

$$s = vt$$

<u>Example</u>
Michael jogs 500 m North then 700 m West in a time of 3 minutes.

(a) Calculate the distance he runs during the 3 minutes.
(b) Calculate his displacement from the starting point after the 3 minutes.
(c) Calculate his average speed.
(d) Calculate his average velocity.

<u>Solution</u>

Acceleration (Revision of National 5)

Acceleration is the change in velocity per second.

e.g. An acceleration of 4.2 ms^{-2} means the objects velocity changes by 4.2 ms^{-1} every second.

The 3 Equations of Motion

The 3 Equations of Motion (s u v a t)

The equations of motion can be applied to any object moving with constant acceleration in a straight line. You must be able to:

- select the correct formula;
- identify the symbols and units used;
- carry out calculations to solve problems of real life motion.

You should learn how to derive the equations. This rarely comes up in exams but it is a useful skill and will also develop your understanding of the equations of motion.

Equation of Motion 1 : $v = u + at$ – found be re-arranging the acceleration equation.

Equation of Motion 2: $s = ut + \frac{1}{2}at^2$ – found by calculating the area underneath a velocity – time graph.

Equation of Motion 3: $v^2 = u^2 + 2as$ – found by combining equations 1 and 2.

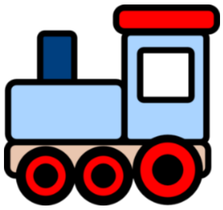
The 3 Equations of Motion (examples)

The key when completing suvat examples is to fill out the data table accurately to allow you to select the correct equation.

Example

A train accelerates from 30 ms^{-1} to 80 ms^{-1} with an acceleration of 2 ms^{-2}. Calculate how long this acceleration takes.

Solution



Example

James starts from rest and then accelerates at 0.4 ms^{-2} for 5 s. Calculate how far he travels during this time.

Solution

Example

A dog travels a distance of 30 m after starting from rest and finishing at a speed of 5 ms^{-1}. Calculate the dogs' acceleration.

Solution

Graphing Motion

Graphs

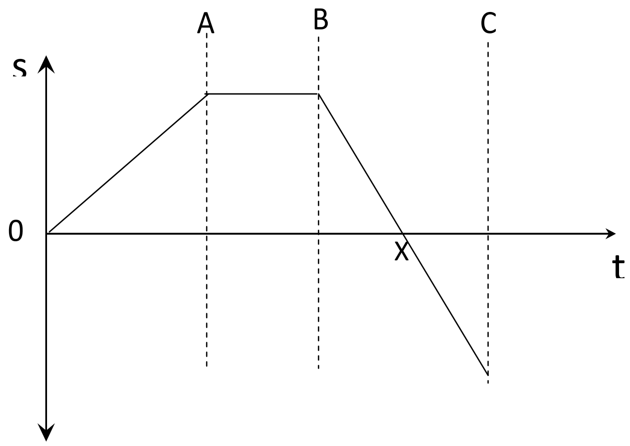
In this section we will be examining three types of motion-time graphs.

Displacement-time graphs
Velocity-time graphs
Acceleration-time graphs

If you have an example of one of these types of graph then it is possible to draw a corresponding graph for the other two factors.

Displacement – time graphs

This graph represents how far an object is from its starting point at some known time. Because displacement is a vector it can have positive and negative values. (+ve and –ve will be opposite directions from the starting point).



OA – the object is moving away from the starting point. It is moving a constant displacement each second. This is shown by the constant gradient. What does this mean?

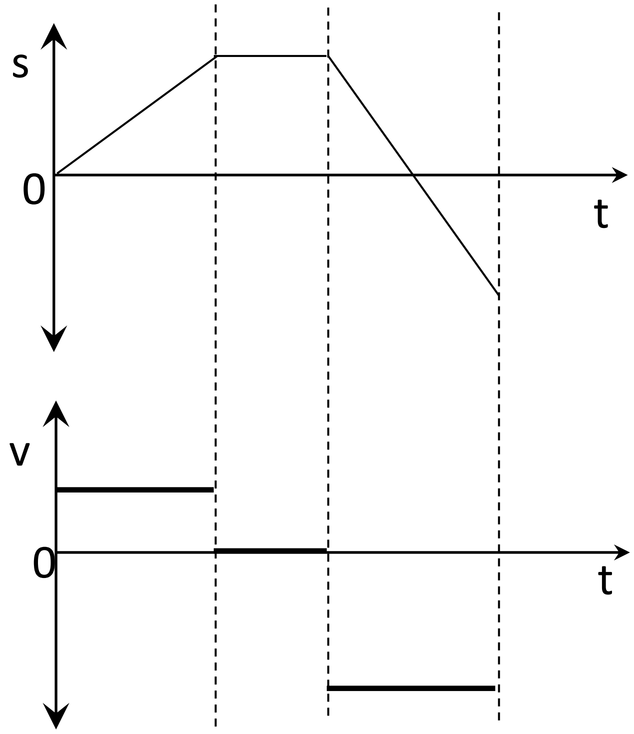
We can determine the velocity from the gradient of a displacement time graph.

$$\boldsymbol{gradient = \frac{displacement}{time} = velocity}$$

AB – the object has a constant displacement so is not changing its position, therefore it must be at rest. The gradient in this case is zero, which means the object has a velocity of zero [at rest]

BC – the object is now moving back towards the starting point, reaching it at time x. It then continues to move away from the start, but in the opposite direction. The gradient of the line is negative, indicating the change in direction of motion.

Converting Displacement – time Graphs to Velocity-time Graphs



The velocity time graph is essentially a graph of the gradient of the displacement time graph. It is important to take care to determine whether the gradient is positive or negative.

The gradient gives us the information to determine the direction an object is moving.

There are no numerical values given on the graphs above. Numbers are not needed to allow a description. The will need to be used however if we were to attempt a numerical analysis.

Velocity – time Graphs

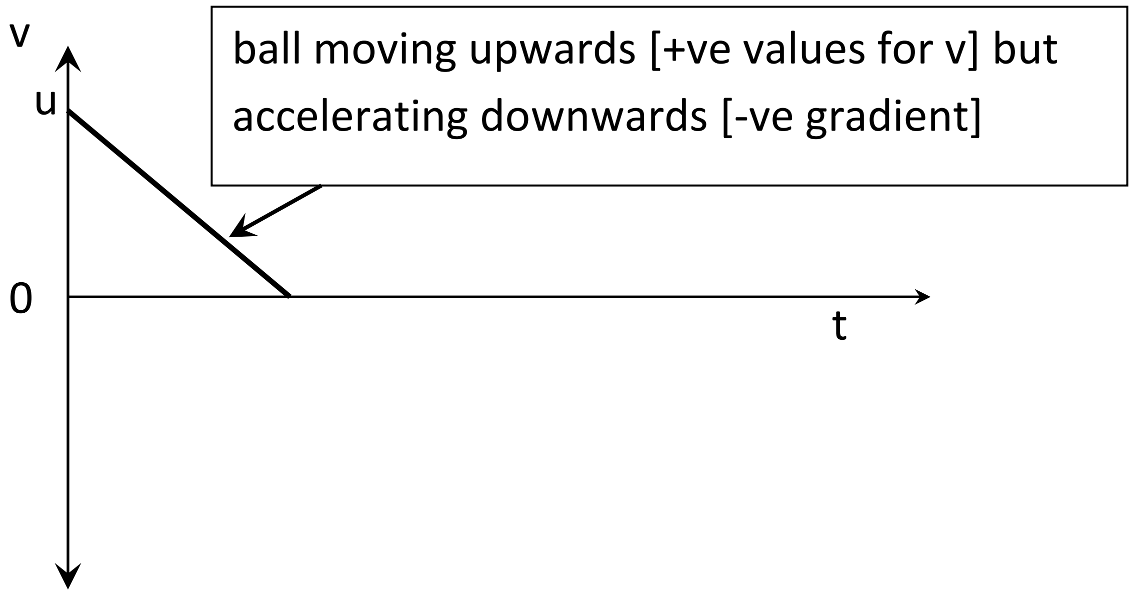
It is possible to produce a velocity time graph to describe the motion of an object. All velocity time graphs that you encounter in this course will be of objects that have constant acceleration.

Scenario: The Bouncing Ball

Lydia fires a ball vertically into the air from the ground. The ball reaches its maximum height, falls, bounces and then rises to a new, lower, maximum height.

Part One of Graph

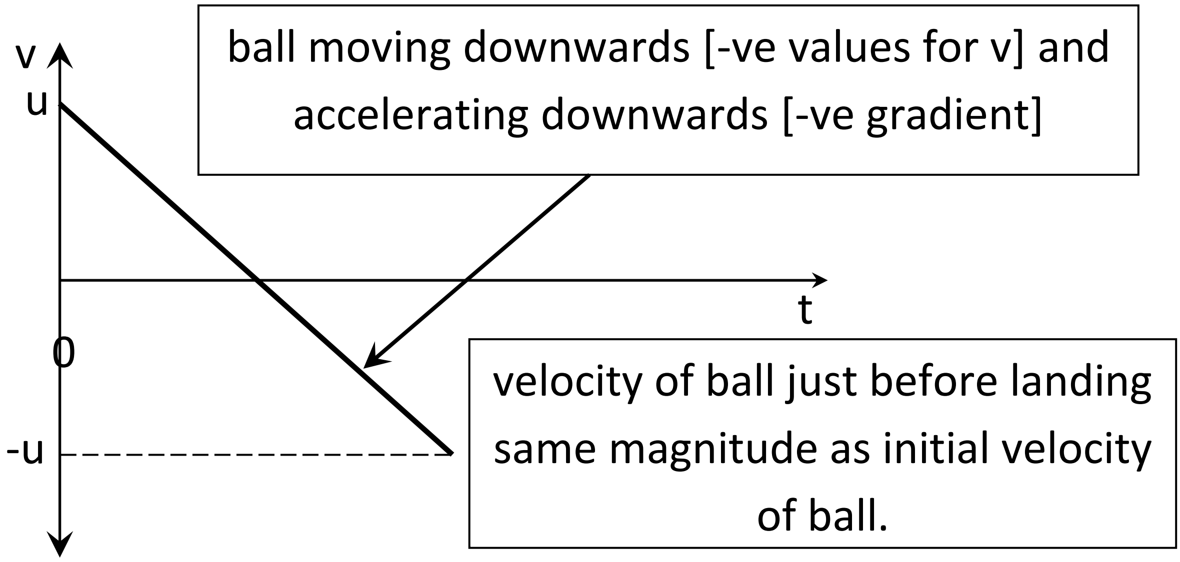
The original direction of motion is upwards and we always define upwards as the positive direction. The ball will be slowing down whilst it is moving upwards, having a velocity of zero when it reaches maximum height. The acceleration of the ball will be constant if we ignore air resistance.



Velocity – time Graphs (continued)

Part Two of Graph

Once the ball reaches its maximum height it will begin to fall downwards. It will accelerate at the same rate as when it was going up. The velocity of the ball just before it hits the ground will be the same magnitude as its initial velocity upwards

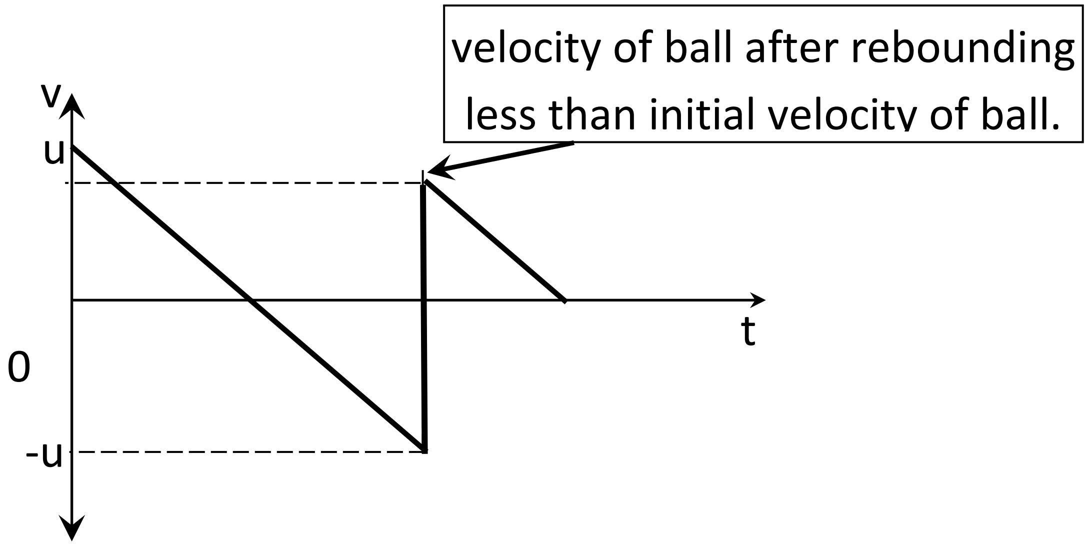


Part Three of Graph

The ball has now hit the ground. At this point it will rebound and begin its movement upwards.

In reality there will be a finite time of contact with the ground when the ball compresses and regains its shape. In this interpretation we will regard this time of contact as zero.

The acceleration of the ball after rebounding will be the same as the initial acceleration. The two lines will be parallel.



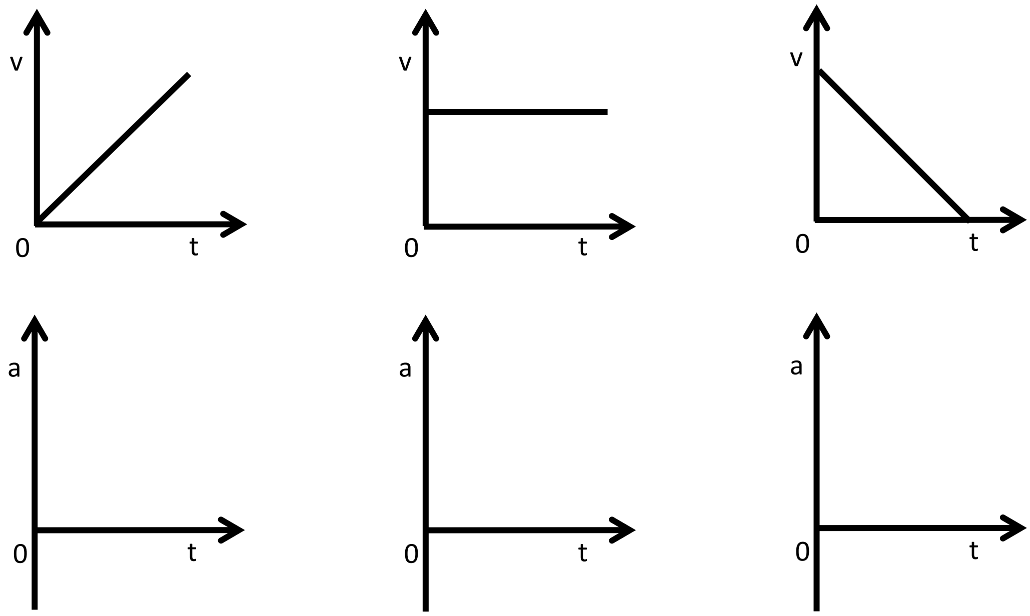
This is the velocity time graph of the motion described in the original description.

Converting Velocity – time Graphs to Acceleration – time Graphs

What is important in this conversion is to consider the gradient of the velocity-time graph line.

$$\boldsymbol{gradient = \frac{change\ in\ velocity}{time} = acceleration}$$

There are onlt 3 types of graph you will need to consider.

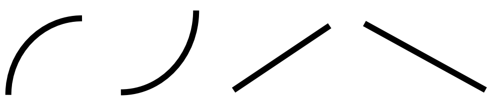


All acceleration time graphs you are asked to draw will consist of horizontal lines, either above, below or on the time axis.

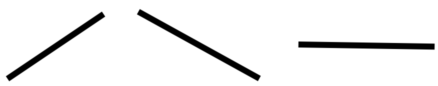
<u>Reminder from National 5</u>
The area under a speed time graph is equal to the distance travelled by the object that makes the speed time graph.
In this course we are dealing with vectors so the statement above has to be changed to:
The area under a **velocity** time graph is equal to the **displacement** of the object that makes the velocity time graph.
Any calculated areas that are below the time axis represent **negative** displacements.

Hints for dealing with s-t, v-t and a-t graphs in Higher Physics

- **s-t graphs are usually curves or lines at an angle**



- **v-t graphs are usually lines at an angle or horizontal lines**

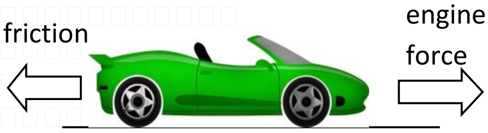


- **a-t graphs are <u>always</u> horizontal lines**

Forces, Energy and Power

Newton's 1st Law of Motion (Revision of National 5)

An object will remain at rest or travel in a straight line at a constant velocity (or speed) if the forces are balanced.



- If we consider the car moving in a straight line. If the engine force = friction, it will continue to move at a constant velocity (or speed) in the same direction.
- If the same car is stationary (not moving) and all forces acting on it are balanced (same as no force at all) the car will not move.

Newton's 2nd Law of Motion (Revision of National 5)

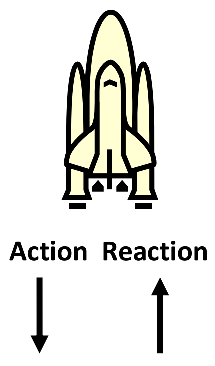
When applying an unbalanced force to an object it will accelerate according to F = ma.

Newton's 3rd Law of Motion (Revision of National 5)

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 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 (do not confuse this with balanced forces).

For example: Rocket flight



Action: The rocket pushes gases out the back

Reaction: The gases push the rocket in the opposite direction.

Free body diagrams

Examples you will encounter in this course will often include 2 or more forces and it is essential that you are able to draw simple diagrams to show where these forces act. Sometimes you will be asked to draw a diagram and sometimes you won't but wherever possible a diagram should be drawn as it will help you understand the problem.

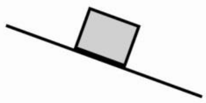
The forces to consider when drawing free body diagrams are

- T – Tension (when a rope or string supports an object)
- A – Air resistance (acts against an object opposing its motion)
- W – Weight (acts downwards in <u>all</u> examples)
- E – Engine force (acts in the direction of motion where there is an accelerating force)
- F – Friction (acts against an object opposing its motion)
- R – Reaction (acts at right angles to a surface and often balances weight)

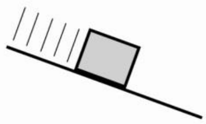
On the diagrams below indicate and label all of the forces acting (use a pencil initially).

1. A stationary box sitting on a table

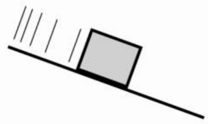
2. A box sitting stationary on a ramp



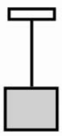
3. A box moving at a constant velocity down a ramp



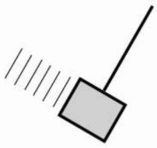
4. A box accelerating down a ramp



5. A box hanging from a piece of string

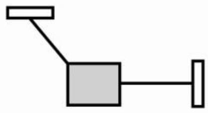


6. A box swinging at a constant velocity from a piece of string



7. A box orbiting high above the Earth where there is no atmosphere

8. A box tied stationary by two pieces of string



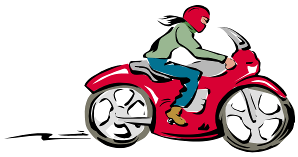
Draw a free body diagram for a car driving along a flat surface.

Draw a free body diagram for a rocket accelerating away from Earth after take-off.

Resultant Forces – Horizontal and Vertical

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. Remember that **Friction** is a resistive force which acts in the **opposite** direction to motion.

<u>Example</u>: Horizontal
A motorcycle and rider of combined mass 650 kg provide an engine force of 1200 N. The friction between the road and motorcycle is 100N and the air resistance is 200N.

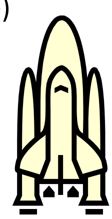


Calculate:

a) the unbalanced force acting on the motorcycle
b) the acceleration of the motorcycle

<u>Solution</u>

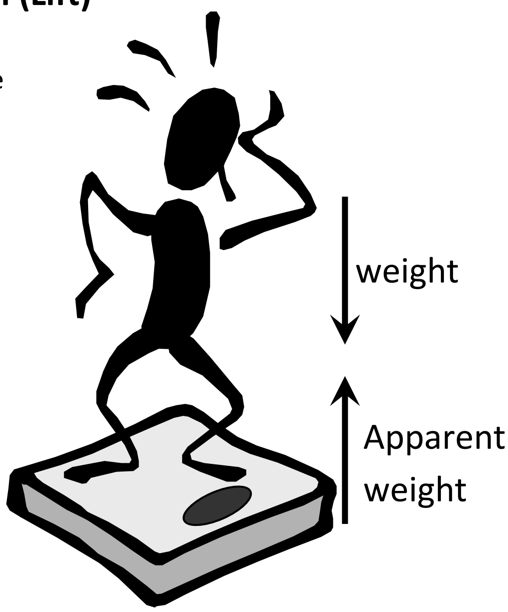
<u>Example</u>: Vertical
At launch, a rocket of mass 20 000 kg accelerates off the ground at 12 ms^{-2} (ignore air resistance)



a) Draw a free body diagram to show all the vertical forces acting on the rocket as it accelerates upwards.
b) Calculate the engine thrust of the rocket which causes the acceleration of $12ms^{-2}$.

<u>Solution</u>

Resultant Forces – Vertical (Lift)



Have you noticed that when you are in a lift you experience a strange feeling when the lift starts to move and as it begins to slow to a stop. However, when the lift is in the middle of its journey you cannot tell if you are moving at all.

This is because at the start and end of the journey you will experience an acceleration and consequently an unbalanced force. This unbalanced force is what you ‘feel’.

When you stand on a set of scales (Newton Balance) the reading on the scales is actually measuring the **upwards** force.
This is the force the scales exert on you.
We will call this the **Apparent Weight**.
Now this is fine when you are in your bathroom trying to find your weight as you and your bathroom scales will be stationary and so your weight will be equal to the upwards force (balanced forces).

When you weigh yourself when you are accelerating the reading on the scales will **not** be your weight. The reading will give you an indication of the unbalanced force acting on you, which could then be used to calculate an acceleration. This unbalanced force could be acting up or down depending on the magnitude and direction of the acceleration.

This can be summarised by $$R = W \pm F$$

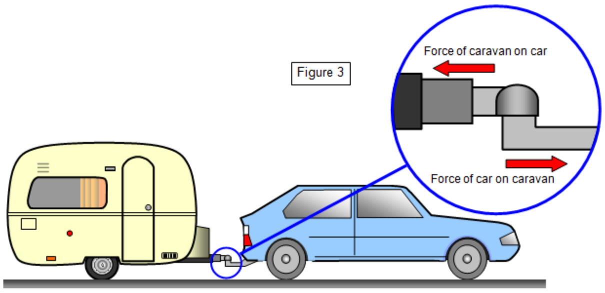
R describes the apparent weight (reading on the scales) or Tension in the cable.
W describes the actual weight of the lift.
+ should be used when moving upwards, - should be used when moving downwards.
F will be +ve when accelerating, F will be –ve when decelerating.

Example
A man of mass 70 kg stands on a set of bathroom scales in a lift. Calculate the reading on the scales when the lift is accelerating downwards at 2 ms^{-2}.

Solution

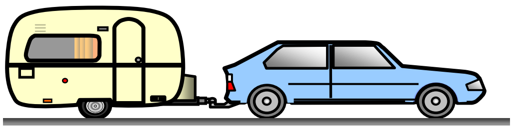
Internal Forces

An example of an internal force is the tension in the towbar (magnified below) when a car is pulling a caravan.



In Higher Physics, a very common question in the SQA exam you are asked is to calculate the tension between the two objects.

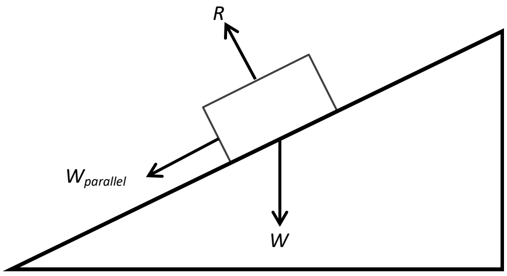
<u>Example</u>
A car of mass 700 kg pulls a 500 kg caravan with a constant engine thrust of 3.6 kN.
Calculate the tension in the towbar during the journey (ignoring friction)



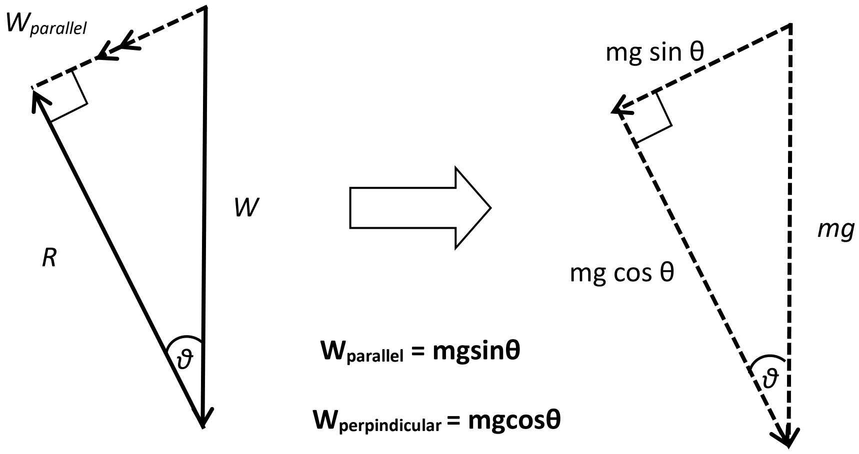
<u>Solution</u>

Forces on a Slope

Ever wondered why a ball rolls down a hill without being pushed or a skier can ski down a run without an initial force. In order to understand why this happens we need to look at the forces exerted on an object resting on a slope



W is the weight of the object and R is the reaction force acting perpendicular to the slope. If we draw these two forces tip to tail as described in section 1.1 we get the resultant force $W_{parallel}$ shown in the diagram below.



$W_{parallel}$ = mgsinθ

$W_{perpindicular}$ = mgcosθ

It is not necessary to be able to derive these equations and almost all questions rely on $W_{parallel}$ = mgsinθ

Example

A car of mass 1000 kg is parked on a hill. The slope of the hill is 20° to the horizontal. The brakes on the car fail. The car runs down the hill for a distance of 75 m until it crashes into a hedge. The average force of friction on the car as it runs down the hill is 250 N.

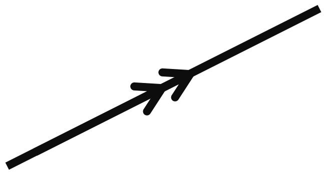
(a) Calculate the component of the weight acting down (parallel to) the slope.
(b) Calculate the acceleration of the car.
(c) Calculate the speed of the car just before it hits the hedge.

Solution

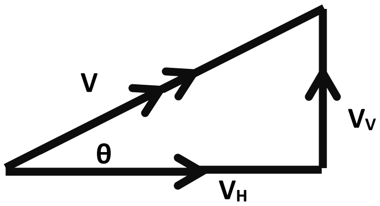
Resolving Vectors

We have seen that two vectors can be added to give the resultant using vector addition. We can also split a resultant vector into its horizontal and vertical components. This is useful in a range of **velocity** and **force** examples.

For example



Can be split into its horizontal and vertical components



horizontal component $V_H = V\cos\Theta$

vertical component $V_V = V\sin\Theta$

<u>Example</u>

A football is kicked at an angle of 70° at 15 ms^{-1}.

Calculate:

a) the horizontal component of the velocity;

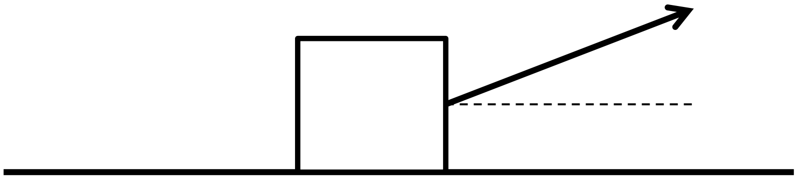
b) the vertical component of the velocity.

<u>Solution</u>

Resolving Vectors - continued

Example

A 10 kg box is being dragged along by a 30 N force at an angle of 20^0. There is a constant frictional force of 5 N.



Calculate:

a) the horizontal component of the force pulling the box;
b) the acceleration of the box;
c) how far the box will move in the first 3 s from rest.

Solution

Energy

Conservation of Energy

One of the fundamental principles of Physics is that of conservation of energy.

Energy cannot be created or destroyed, only converted from one form to another.

Work is done when converting from one form of energy to another. Power is a measure of the rate at which the energy is converted.

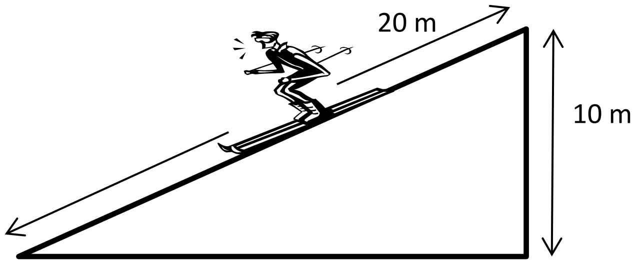
There are a number of equations for the different forms of energy:

$$E_w = Fs$$
$$E_k = \frac{1}{2} mv^2$$
$$E_p = mgh$$
$$E_h = cm\Delta T$$
$$E_h = ml$$
$$E = Pt$$

All forms of energy can be converted into any other form, so each of these equations can be equated to any other.

<u>Example</u>

A skier of mass 60 kg slides from rest down a slope of length 20 m.



Calculate:

(a) the potential energy of the skier at the top of the slope;

(b) the speed of the skier at the bottom of the slope.

<u>Solution</u>

Collisions, Explosions and Impulse

Conservation of Momentum

Momentum is the measure of an object's motion and is the product of mass and velocity.

$$p = mv$$

Since velocity is a vector so is momentum, therefore momentum has a direction and we must apply the convention of + ve and – ve directions. We will define all movement from left to right as +ve and all movement from right to left as –ve.

The law of conservation of linear momentum states that **the total momentum before a collision equals the total momentum after a collision in the absence of external forces.**

Collisions

The law of conservation of momentum can be used to analyse the motion of objects before and after a collision and an explosion.

<u>Example</u>

A trolley of mass 4.0 kg is travelling with a speed of 3 ms^{-1}. The trolley collides with a stationary trolley of mass 5.0 kg and they move off together. Calculate the velocity of the trolleys immediately after the collision.

<u>Solution</u>

Kinetic Energy – Elastic and Inelastic Collisions

Elastic and Inelastic Collisions

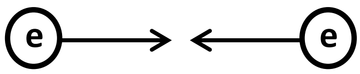
When two objects collide their momentum is **always** conserved but, depending on the type of collision, their kinetic energy may or may not be. Take the two examples below:

1.

If you were to witness this car crash you would hear it happen. There would also be heat energy at the point of contact between the cars.
These two forms of energy will have come from the kinetic energy of the cars, converted during the collision.
Here, kinetic energy is not conserved as it is lost to sound and heat. This is an **inelastic collision**.

In an **inelastic collision**
E_k before ≠ E_k after

2.



When these two electrons collide they will not actually come into contact with each other, as their electrostatic repulsion will keep them apart while they interact.
There is no mechanism here to convert their kinetic energy into another form and so it is **conserved** throughout the collision.

In an **elastic collision**
E_k before = E_k after

Elastic and Inelastic Collisions (continued)

<u>Example</u>

A car of mass 2000 kg is travelling at 15 m s^{-1}. Another car, of mass 1500kg is travelling at 5 m s^{-1} in the opposite direction. The 2000 kg car carries on at 6 ms^{-1}, at what speed will the 1500 kg car move away at.

(a) Calculate the speed and direction of the cars after the impact.
(b) State whether the collision elastic or inelastic. Justify your answer.
(c) State where the lost energy has gone.

<u>Solution</u>

Impulse

Impulse

During all collisions two objects will be in contact and the equations from Newton's second law and the equation for acceleration can be combined to explain the change in values during the collision as shown below.

Impulse is equal to 3 things:

- **Force x time (Ft)**
- **The change in momentum (mv – mu)**
- **The area under a Force - time graph**

To calculate each individually is straight forward but you will be expected to know that all 3 can be used to calculate impulse for the latter parts of questions.

Example

A ball hits a wall at 4 ms^{-1} and rebounds at 1.5 ms^{-1} during a 50 ms contact with the wall.

Calculate:

(a) the change in momentum experienced by the ball;
(b) the impulse during the collision;
(c) the average force exerted by the wall on the ball;
(d) the average force exerted by the ball on the wall.

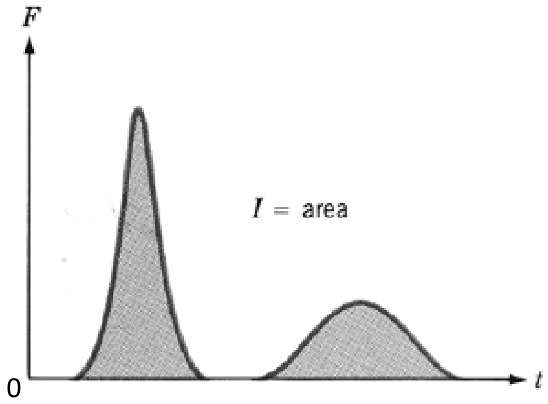
Solution

Impulse Graphs

In reality, the force applied is not usually constant and this is represented by plotting the force as a function of time.

The two graphs shown below show the Force-time graphs for a ball being bounced. The graph on the left is a golf ball on the graph on the right is a tennis ball. The peak force of the golf ball is higher than the peak force for the tennis ball. The contact time of the golf ball is less than the contact time of the tennis ball. This is why it would hurt more if you were struck with a golf ball rather than a tennis ball.

In the graphs shown to the right the area Underneath each is the same. This is Because the impulse is the same, it is Only the force and time of contact which Have changed

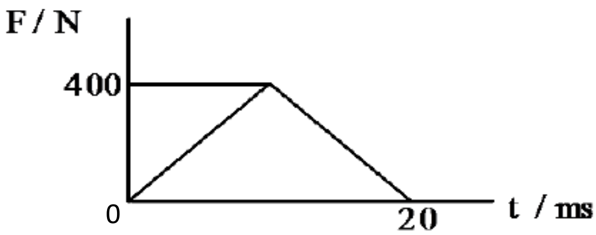


Example

A tennis ball of mass 100 g, initially at rest, is hit by a racquet.

The racquet is in contact with the ball for 20 ms and the force of contact varies over this period, as shown in the graph.

Calculate the speed of the ball as it leaves the racquet.

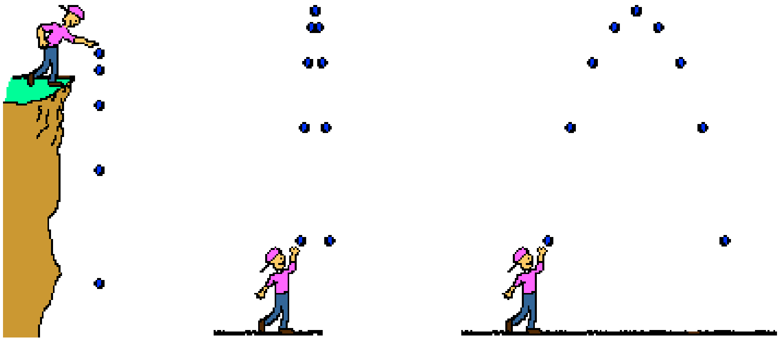


Solution

Gravitation

Projectiles

A projectile is any object, which, once projected, continues its motion by its own inertia and is influenced only by the downward force caused by gravity.



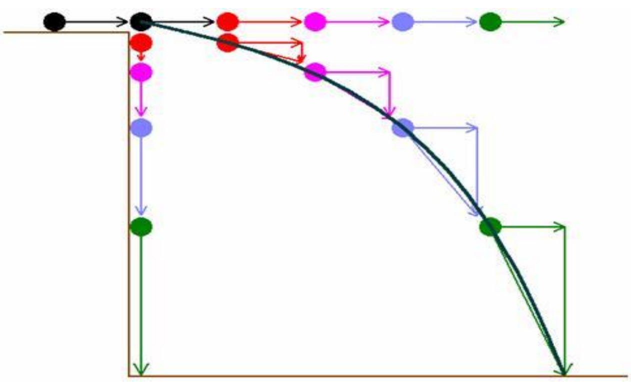
Most projectiles have both **horizontal and vertical** components of motion. The two components are not undergoing the same kind of motion and must be treated **separately**.

Horizontal Projection

Horizontally: there are no forces acting on the cannonball and therefore the horizontal velocity is constant.

Vertically: The force due to gravity is constant in the vertical plane and so the cannonball undergoes constant acceleration.

The combination of these two motions causes the **curved** path of a projectile.



<u>Example</u>

A cannonball is projected horizontally from the cliff with a velocity of 40 m s^{-1}. The cannonball lands 2.3 s later. Calculate:

(a) the vertical speed of the cannonball, just before it hits the water;

(b) how far away from the base of the cliff the cannonball will land.

<u>Solution</u>

Projection at an Angle

Almost all examples you will encounter in Higher Physics will involve projection at an angle.

For projectiles fired at an angle above a horizontal surface:

1. All upward values should be +ve and all downward values should be –ve.
2. The path of the projectile is symmetrical, in the horizontal plane, about the highest point. This means that:

initial vertical velocity = − final vertical velocity

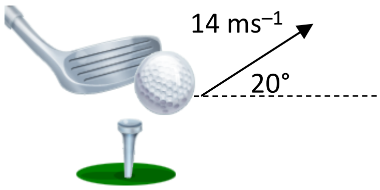
$$u_v = -v_v$$

3. The time of flight = 2 × the time to highest point.
4. The vertical velocity at the highest point is zero.

Example

A golfer hits a stationary ball and it leaves his club with a velocity of 14 ms^{-1} at an angle of 20° above the horizontal.

(a) Calculate:
 (i) the initial horizontal component of the velocity of the ball;
 (ii) the initial vertical component of the velocity of the ball.
(b) Calculate the maximum height reached by the golf ball.
(c) Calculate the total time of flight of the ball
(d) Calculate how far down the fairway does the ball land.



Solution

Dynamics

State the difference between scalar and vector quantities.

A scalar quantity is fully described by a size. A vector quantity is fully described by a size and a direction.

State what the gradient of a displacement-time graph is equal to.

Velocity

State what the gradient of a velocity-time graph is equal to.

Acceleration

There are curves on a graph, state whether it is most likely a displacement-time, velocity-time or acceleration-time graph.

Displacement-time

There are lines at an angle on a graph, state whether it is most likely a displacement-time, velocity-time or acceleration-time graph.

Velocity-time

There are only horizontal lines on a graph, state whether it is most likely a displacement-time, velocity-time or acceleration-time graph.

Acceleration-time

In a velocity time graph there are values of velocity above and below zero, state what this means.

The object has changed direction.

State what is meant by the acceleration of an object.

Acceleration describes how much an objects velocity changes per second.

State what is meant by an acceleration of 2.8 ms^{-2}.

The objects velocity increases by 2.8 ms^{-1} per second.

If an object is travelling at a constant velocity, describe the forces acting on it.

The forces are balanced.

As the velocity of an object increases, state what happens to the air resistance acting on it.

It increases.

A projectile is launched at an angle. Describe what effect changing the launch angle will have on the maximum height reached.

Increasing the launch angle will increase the maximum height reached. Decreasing the launch angle will decrease the maximum height reached.

If an object has balanced forces acting on it, describe its velocity.

It is either stationary or moving at a constant velocity.

State the equation which describes the component of an objects weight down a slope.

$F = mg \sin(\theta)$

While in a lift a person experiences the sensation of feeling heavier, describe what could be causing this.

They could be decelerating downwards or accelerating upwards.

While in a lift a person experiences the sensation of feeling lighter, describe what could be causing this.

They could be decelerating upwards or accelerating downwards.

While in a lift a person experiences no sensation about a change in weight, describe what could be causing this.

They could be stationary or moving at a constant velocity.

State the name of the force when one object pulls on another.

Tension

State which force is present in all force examples and state in which direction it acts.

Weight and it acts downwards.

State the law of conservation of momentum.

The total momentum before a collision is equal to the total momentum after a collision in the absence of external forces.

Describe what happens to the kinetic energy before and after a collision.

In elastic collisions kinetic energy is conserved. In inelastic collisions kinetic energy is not conserved, it can either increase or decrease.

Energy is often lost during collisions or other energy transfer scenarios, describe where it usually goes.

When energy is lost it is usually through heat.

Describe three ways of calculating the impulse on an object.

Impulse equals force x time. Impulse equals change in momentum. Impulse equals the area under a force-time graph.

Describe what adding a softer material in between a collision will do to the change in momentum, impulse, average force and contact time.

The impulse and change in momentum will remain unchanged as mass, initial velocity and final velocity are all unchanged. The average force will be reduced because the contact time will be increased.