Speed, Velocity, Distance and Displacement

6th Oct

Speed tells us the distance covered by an object in a unit of time, regardless of direction.

It is a scalar quantity.

Velocity is the speed in a certain direction and is a vector quantity.

Distance tells us how far an object has moved between two points, regardless of direction (scalar).

The displacement of an object tells us the distance the object has moved in a straight line between two points, and always has a direction associated (vector).

Acceleration is the rate of change of velocity (vector quantity).

Graphs of Motion

The graphs tend to have either displacement, velocity or acceleration on the y-axis and always have time on the x-axis.

The GRADIENT of a displacement-time graph gives us VELOCITY.

The GRADIENT of a velocity-time graph gives us ACCELERATION.

The AREA enclosed by a velocity-time graph gives us the DISPLACEMENT.

$$
\begin{tikzcd}
\text{displacement} \arrow[d, bend right, "\text{gradient}"'] \\
\text{velocity} \arrow[d, bend right, "\text{gradient}"'] \arrow[u, bend right, "\text{area}"'] \\
\text{acceleration} \arrow[u, bend right, "\text{area}"']
\end{tikzcd}
$$

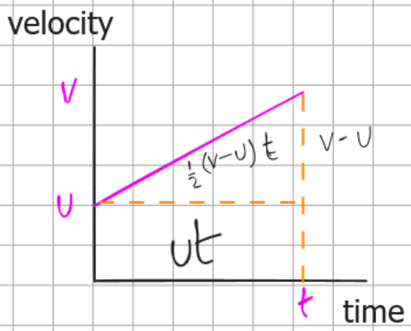
Uniform Acceleration

10th Oct

If an object has a CONSTANT ACCELERATION it is accelerating uniformly.

In following derivation:

s = displacement
u = initial velocity
v = final velocity
a = acceleration
t = time



Average velocity = $\frac{(v+u)}{2}$

Displacement = average velocity x time, $\boxed{s = \frac{(v+u)}{2}t}$

Displacement = area under v-t graph

$$s = ut + \frac{1}{2}(v-u)t$$

We know, by definition that: $a = \frac{v-u}{t}$, $(v-u) = at$, $\boxed{v = u + at}$, $t = \frac{v-u}{a}$

Hence; $\boxed{s = ut + \frac{1}{2}at^2}$

We know that: $s = \frac{(v+u)t}{2}$ and $t = \frac{v-u}{a}$

Hence: $s = \frac{(v+u)(v-u)}{2a}$, $s = \frac{v^2 - u^2}{2a}$

So: $\boxed{v^2 = u^2 + 2as}$

When using the equations of motion we usually write a list:

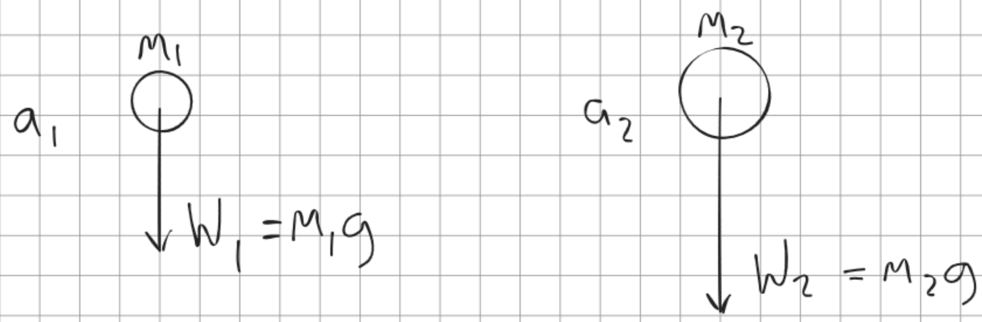
s =
u =
v =
a =
t =

We populate the list with what we have been told, and place a '?' next to what we to calculate. We need to be very careful with DIRECTION. s, u, v and a are VECTORS.

We assign a positive direction, and anything acting in the opposite direction would be NEGATIVE.

Acceleration in Freefall

14th Oct



In the absence of drag, the weight acts as the resultant force accelerating the obects.

From Newton's Second Law: $F = ma$ (F is resultant force)

$$W_1 = m_1 a_1 \qquad W_2 = m_2 a_2$$

$$\cancel{m_1} g = \cancel{m_1} a_1 \qquad \cancel{m_2} g = \cancel{m_2} a_2$$

$$a_1 = g \qquad a_2 = g$$

In the absence of drag, ALL objects accelerate downwards with the magnitude of the acceleration being equal to the gravitational field strength.

On Earth, g = 9.81 N kg^{-1}

Objects dropped from rest:
- typically treat downwards as + direction
- $a = 9.81 \text{ m s}^{-2}$
- $u = 0 \text{ m s}^{-1}$

Objects thrown downwards:
- As above, but 'u' has some positive value

Objects thrown upwards:
- split the journey into two parts; upwards and coming to a stop when it reaches maximum height, and downwards as if it were dropped from the maximum height
- in the absence of drag the journey is symmetrical (same time to reach max height as to fall from max height)
- $v = 0 \text{ m s}^{-1}$ at max height
- upwards typically + for first part of journey

An alternative method when dealing with objects that are thrown upwards is is to use:

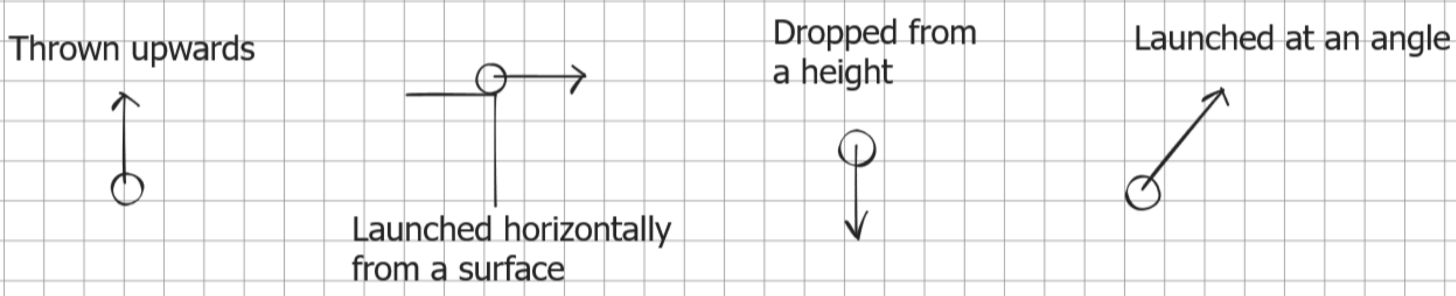
$$s = ut + \tfrac{1}{2}at^2$$

Finding t when s = 0 m will give us the two times at which the object is at the starting position.

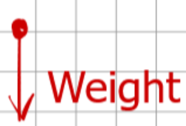
Projectile Motion

24th Oct

In the three scenarios below, the only force acting on the object during its motion is its weight. This force acts vertically, so only the vertical component of the object's velocity changes.

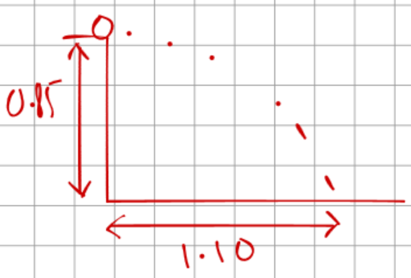


In the absence of drag, the free body diagrams for all these objects is the same:



When analysing the motion of projectiles we MUST consider the motion in two separate parts: its VERTICAL MOTION (use SUVAT) and its HORIZONTAL MOTION (objects have constant horizontal velocity).

Example: A ball was launched horizontally from a desk 0.85m high. It hit the floor 1.10m away from the desk. What was its initial launch velocity?



Vertically:

$s = 0.85\,m$
$u = 0\ ms^{-1}$
$v = ?$
$a = 9.81\,ms^{-2}$
$t = ?$

$s = ut + \frac{1}{2}at^2$

$0.85 = \frac{1}{2} \times 9.81 \times t^2$

$\sqrt{\frac{2 \times 0.85}{9.81}} = t$

$t = 0.42\,s$

Horizontally: $s = vt$

$v = \frac{1.10}{0.42} = 2.64\,ms^{-1}$

Newton's Laws of Motion

10th Nov

First Law: an object will remain at a constant velocity unless acted upon by an external resultant force

Law of inertia: objects tend to keep the same direction and speed of motion unless a resultant force acts upon them

Second Law: Acceleration is directly proportional to the resultant force.
Acceleration inversely proportional to the mass of an object.
Objects always accelerate in the direction of the resultant force.

$$\left.\begin{array}{l} a \propto F \\ a \propto \frac{1}{m} \end{array}\right\} \quad a \propto \frac{F}{m} \qquad a = k\frac{F}{m}$$

(k is 1 in standard units)

F = ma
(resultant force = mass x acceleration)

Newton's Third Law: If Object A exerts a force on Object B, then Object B exerts a force of EQUAL MAGNITUDE (and of the same type), and in the OPPOSITE DIRECTION on Object A.

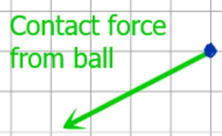
This is the only one of Newton's laws of motion that requires us to look at multiple objects interacting. This is usually the law that we start with, when attempting to explain observations in terms of Newton's laws.

Example application of Newton's Laws

We knew there would be a force from the head on the ball, and then used N3L to ascertain that there must also be a force from the ball on the head.

To see the effect of these forces we must now consider each object individually, by drawing a FREE BODY DIAGRAM for each.

Head:



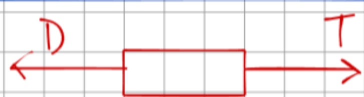
N1L tells us that the head's velocity will not remain constant here.

N2L tells us the head will accelerate away from the contact point with the ball.

Football:

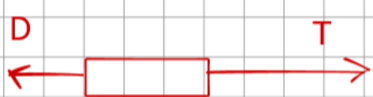
In addition to points like the ones above, N2L also tells us the football will have a greater acceleration than the head as it has lower mass and both objects experience the same resultant force.

When dealing with accelerating objects and calculations we can use a similar method to the one used with objects in equilibrium, but with one minor change.



Object in equilibrium

$\therefore\ T = D$
(magnitudes)



Object accelerating

Sketch a free body diagram ✓

Write expression for resultant force, F ✓ $F = T - D$

Replace F with ma ✓ $ma = T - D$

Q1.

A firework is fired vertically up into the air and subsequently falls to the ground.

Which quantity relating to the motion of the rocket is never zero before it hits the ground?
Assume that air resistance is negligible.

A	acceleration	☒
~~B~~	velocity	☐
~~C~~	momentum	☐
~~D~~	kinetic energy	☐

9.81

v

9.81

v

(Total 1 mark)

Q2.

A Formula 1 racing car uses up its fuel during the race, causing its lap times to decrease.

m↓

The lap times decrease because

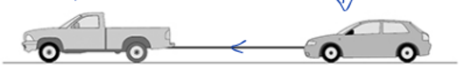
N2L

A	the acceleration of the car increases.	☒
~~B~~	the drag forces on the car decrease.	☐
C	the maximum speed of the car increases.	☐
~~D~~	the tyres become worn, reducing the friction with the road.	☐

(Total 1 mark)

Q3.

A truck of mass 2.1×10^3 kg tows a car of mass 1.3×10^3 kg along a horizontal road.
The total resistive force on the car is 1100 N.
The acceleration of the car and truck is 2.3 m s^{-2}.



What is the tension in the tow rope?

A	3000 N	☐
B	4100 N	☒
C	7800 N	☐
D	8900 N	☐

T

1100 N

$a = 2.3\ \text{m s}^{-2}$

$F = T - 1100$

$T = F + 1100$

$T = ma + 1100$

$= (1300 \times 2.3) + 1100$

(Total 1 mark)

Q4.

A rocket of mass 12 000 kg accelerates vertically upwards from the surface of the Earth at 1.4 m s^{-2}.

What is the thrust of the rocket?

A	1.7×10^4 N	☐
B	1.7×10^5 N	☐
C	1.3×10^5 N	☒
D	1.6×10^5 N	☐

Thrust

Mg

$F = T - mg$

$T = F + mg$

$= Ma + mg$

(Total 1 mark)

Q5.

A parachutist descends to the ground at a constant speed with the parachute open.

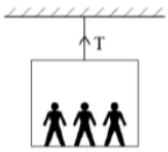
Which force, together with the parachutist's weight, makes a pair according to Newton's third law of motion?

A	the drag force on the parachutist from the air	☐
B	the tension in the strings of the parachute	☐
C	the gravitational force of the parachutist on the Earth	☐
D	the lift force on the parachute from the air	☐

(Total 1 mark)

Q6.

A lift and its passengers with a total mass of 500 kg accelerates upwards at 2 m s^{-2} as shown. Assume that g = 10 m s^{-2}.



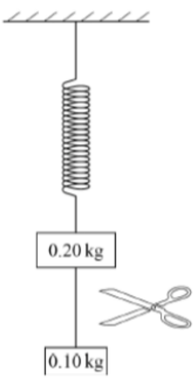
What is the tension in the cable?

A	1000 N	☐
B	4000 N	☐
C	5000 N	☐
D	6000 N	☐

(Total 1 mark)

Q7.

A 0.20 kg mass is suspended from a spring. A 0.10 kg mass is suspended from the 0.20 kg mass using a thread of negligible mass.
The system is in equilibrium and the thread is then cut.



What is the upward acceleration of the 0.20 kg mass at the instant that the thread is cut?

A	3.3 m s^{-2}	☐
B	4.9 m s^{-2}	☐
C	6.5 m s^{-2}	☐
D	9.8 m s^{-2}	☐

(Total 1 mark)

Q8.

A suitcase weighing 200 N is placed on a weighing scale in a lift.
The scale reads 180 N when the lift is moving.

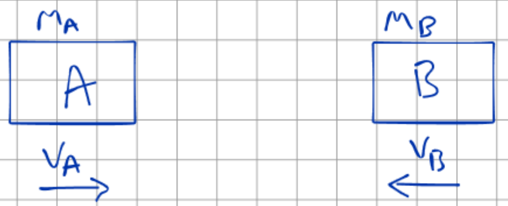
The lift is

A	moving down at a constant velocity.	☐
B	moving down with a decreasing velocity.	☐
C	moving up at a constant velocity.	☐
D	moving up with a decreasing velocity.	☐

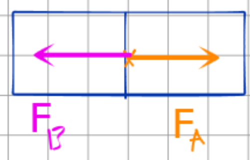
(Total 1 mark)

Collisions 24th Nov

Consider two objects, A and B, colliding with each other.



During the collision:



Object A exerts a force on Object B, therefore Object B exerts a force on Object A that has the same magnitude but is in the opposite direction. (According to N3L)

Both objects will accelerate as they experience a resultant force (N1L).

Note: this can be considered an ISOLATED SYSTEM as there are no external forces acting on it.

For each object: $F = ma$ (from N2L)

$$F = \frac{m\Delta v}{t}$$

$$\underbrace{Ft}_{\text{impulse}} = \underbrace{m\Delta v}_{\text{change in momentum}}$$

Each object experiences the SAME FORCE for the SAME TIME:

For object A: $Ft = m_A \Delta v_A = \Delta p_A$

For object B: $-Ft = -m_B \Delta v_B = \Delta p_B$

So, the total change in momentum for the whole system:

$$\Delta p = \Delta p_A + \Delta p_B$$
$$= m_A \Delta v_A + (-m_B \Delta v_B)$$
$$\Delta p = Ft + (-Ft)$$
$$\Delta p = 0$$

This tells us that in an isolated system TOTAL MOMENTUM IS CONSERVED.
The total momentum of all objects in an isolated system is the same before and after any event (collision, explosion).

Any momentum lost by one object, is gained by the other.

momentum = mass x velocity

$p = mv$

Resultant force = rate of change of momentum

$$F = \frac{m\Delta v}{t}$$

change in momentum = $m\Delta v$

Impulse = Ft (also be equal to change in momentum)

28th Nov

In isolated systems total momentum is conserved. Energy is also conserved in this type of system.

Energy can be transferred between different energy stores during collisions and explosions.

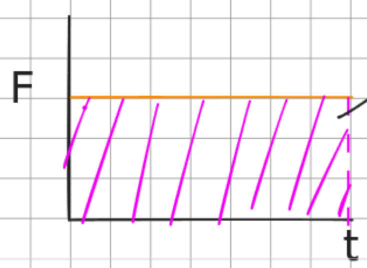
In an ELASTIC COLLISION the TOTAL KINETIC ENERGY of the system is conserved.

To check if a collision is elastic we can calculate the total kinetic energy before an event and after the event. If the total is the same, then the collision is elastic.

Force-time graphs

2nd Dec

Consider an object experiencing a resultant force (F) over a period of time (t), where the resultant force is constant:



This area tells us the IMPULSE the object experiences, which also corresponds to the CHANGE IN MOMENTUM.

Area = $F \times t$ (impulse)

$F \times t = m\Delta v$ (change in momentum)

Work Done and Power

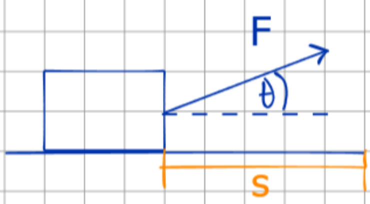
2nd Dec

Whenever energy is transferred WORK is done.

Work can be done by forces.

Work done = Force x distance moved in the direction of the force

Work done = Force in the direction of movement x distance moved



$$W = \underbrace{F\cos\theta}_{\text{component of F in the direction of the movement s}} \times s$$

in N m
(1 N m = 1 J)

Power is the RATE at which work is done; the amount of energy transferred each second.

$$P = \frac{W}{t}$$ in $J\,s^{-1}$ where $1\,W = 1\,J\,s^{-1}$

In scenarios where we multiple energy stores changing then:

$$\text{Average power} = \frac{\text{total energy transferred}}{\text{time taken}}$$

If an object is moving at a velocity v due to a driving force (F);

$$W = Fs \qquad P = \frac{W}{t} \rightarrow P = \frac{Fs}{t}$$

We can simplify this to: $\boxed{P = Fv}$ (as $v = s/t$)

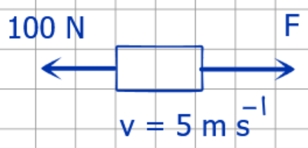
driving power

driving force

velocity at any given time

Note: the force in this equation is not necessarily the resultant force

Example:



An object travels at a steady speed of $5\ m\,s^{-1}$.
It experiences resistive forces of 100 N.
Calculate the power of its engine.

In equilibrium so F must be 100 N;

$$P = 100 \times 5$$
$$= 500\ W.$$

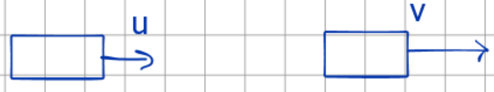
In this example all of the work being done by the engine is increasing the thermal store of the surroundings; work is being done against the resistive forces.

Energy Transfers

5th Dec

When objects change speed their KINETIC ENERGY changes:

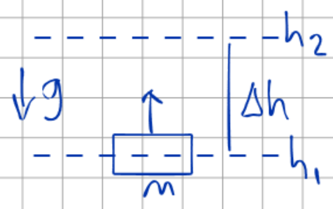
Kinetic energy of an object mass m, at speed v : $E_K = \frac{1}{2}mv^2$



$\Delta E_K = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$

When objects change height their GRAVITATIONAL POTENTIAL ENERGY changes:

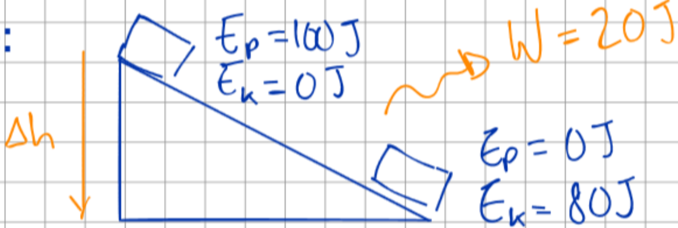
GPE of object mass m, in field strength g, at height h : $E_p = mgh$



$$\Delta E_p = mgh_2 - mgh_1$$
$$= mg(h_2 - h_1)$$
$$\Delta E_p = mg\Delta h$$

If an object falls then: $E_p \rightarrow E_K$. In the absence of resistive forces then ALL of the energy lost from GPE goes into KE. If there are resistive forces then some work is done against them. This work transfers energy to the thermal stores of the surroundings.

Example:



this energy was dissipated to the thermal stores of the surroundings