How fast can things go?

Lecture 2: Newton's Laws of motion

- **investigate and apply theoretically and practically Newton's three laws of motion in situations where two or more coplanar forces act along a straight line and in two dimensions**

Paper	Multiple choice	Idea	Short Answer	Idea
2019	11	$F_{net} = 0$		
2019 NHT			9	Vertical connected bodies
2018	5 6	Forces Graphs	*8a b	Horizontal connected bodies Horizontal connected bodies
2018 NHT	8 9	Connected bodies Connected bodies		
2017	7 9	Newton's Laws SUVAT		
2017 NHT			1a b c	SUVAT Newton Newton
2016			1a *b	SUVAT Newton
2015			2a b	Connected bodies Connected bodies
2014			1a *b	SUVAT Horizontal connected bodies
2013			1a *b 2a *b	Inclined plane Inclined plane Connected bodies Connected bodies
2012			3 4a **b 5a b c d	Resolving forces Vertical connected bodies Vertical connected bodies Horizontal connected bodies Horizontal connected bodies Horizontal connected bodies Horizontal connected bodies
2011			1 2 3 7 8	Horizontal connected bodies Horizontal connected bodies SUVAT Vertical connected bodies Vertical connected bodies
2010			*3	Connected bodies
2009				
2008			1 2	Horizontal connected bodies Horizontal connected bodies
2007			1 6 7	SUVAT Newton's Laws Newton's Laws

Paper	Multiple choice	Idea	Short Answer	Idea
2006			1 2	$F_{net} = 0$ Newton's Laws
2005			4	Newton's Laws
2004			1 2 3 8 9	Newton's Laws SUVAT Newton's Laws Newton's Laws Newton's Laws
2003	5	Graphs	1 2 3 4 8 9 *10 *14	Graphs Graphs Graphs SUVAT Horizontal connected bodies Horizontal connected bodies Horizontal connected bodies Newton's third law
2002	3 *4	SUVAT SUVAT	1 2	SUVAT SUVAT

Star rating

* indicates that the average mark for this question was less than 50%
** indicates that the average mark for this question was less than 25%

Straight line motion (SLM) can be grouped into the following ideas.

Basic concepts
SUVAT
Graphs
Change in velocity

Forces can be grouped into the following ideas.

Basic concepts
Newton's Laws
$F_{net} = 0$
Resolving forces
Inclined planes
Horizontal connected bodies
Vertical connected bodies
Connected bodies
Hooke's Law (Horizontal)

Equations of motion

The following relationships hold for **straight line motion with constant acceleration**.

Equation	Includes	Omits
$v_{av} = \frac{x_2 - x_1}{\Delta t}$		
$a = \frac{v - u}{t} = \frac{\Delta v}{\Delta t}$		
$v = u \pm at$	u, v, a, t	x
$v^2 = u^2 \pm 2ax$	u, v, a, x	t
$x = ut \pm \frac{1}{2}at^2$	u, a, x, t	v
$x = \frac{(u + v)}{2}t$	u, v, x, t	a

Graphical techniques

When given a graph in the exam, look at three things on the graph before even reading the question:

type of graph (x - t, v - t, etc) **the units on the axis** **the limit on each axis.**

Graph type / Found from	x - t	v - t	a - t
Direct reading	'x' at any 't' 't' at any 'x'	'v' at any 't' 't' at any 'v'	'a' at any 't' 't' at any 'a'
Gradient	Instantaneous velocity at any point. v_{av} between any two points	Instantaneous 'a' Average 'a'	
Area under graph		Change in position	Change in velocity

Units

Use the MKSA system of units. All values should be in **M**etres, **K**ilograms, **S**econds and **A**mperes.

To convert from km h^{-1} to m s^{-1} you need to divide by 3.6, this should be on your cheat sheet.
e.g 100 kph = 27.8 m s^{-1}

Vectors and Scalars

Vectors are quantities that have a magnitude and a direction.
E.g. displacement, velocity, and acceleration, force, weight, momentum, impulse, torque, Electric field, Magnetic field, gravitational field.

Scalars are quantities that only have a magnitude,
E.g. mass, speed, distance travelled, time, area, density, energy.

Change in velocity

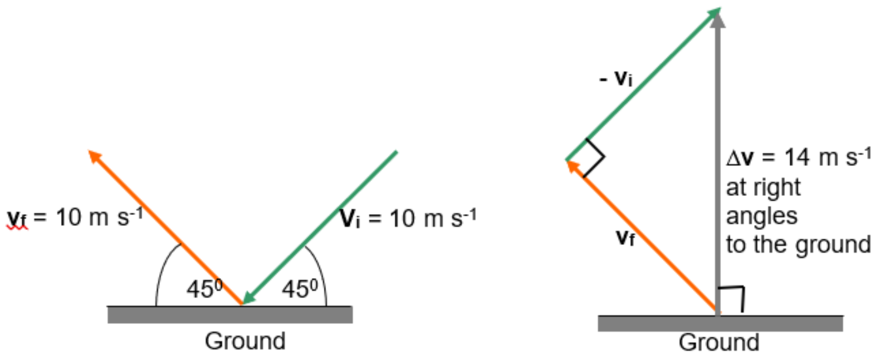
The change in anything is defined as the 'final' – 'initial'.
If the quantity that you are finding the change in is a vector, then you need to take the directions of the initial and final into consideration.
Remember, that to subtract a vector you add the negative of the vector.

When an object collides with another and changes its velocity, its change in velocity is a vector quantity found by subtracting the initial velocity from the final velocity.

Change in velocity = final velocity - initial velocity

$\Delta \mathbf{v} = \mathbf{v}_f - \mathbf{v}_i$

If a ball bounces off a wall, the change in velocity can be determined graphically in a vector diagram.



Newton's 1st Law of motion

Every object remains at rest, or in uniform motion in a straight line (the velocity may be a non-zero constant), unless acted on by some external force.

Newton's 2nd Law of motion

The rate of change of momentum is equal to the resultant force causing the change.

$\mathbf{F} = \frac{mv - mu}{t}$ since $\mathbf{a} = \frac{v - u}{t}$ $\therefore$ $\mathbf{F}.t = m\mathbf{v} - m\mathbf{u}$

Impulse (change in momentum) i.e. $\mathbf{I} = \mathbf{p}_2 - \mathbf{p}_1$. is always the area under F-t graph.

When the force is constant, it also equals $F\Delta t$.

Area under "**F** - t" graph = **Impulse** = Δ **momentum = F Δ t**

TOTAL MOMENTUM BEFORE IMPACT EQUALS THE TOTAL MOMENTUM AFTER IMPACT.

$\therefore$ $\mathbf{P}_{(total)}$ is constant before, during and after the collision.

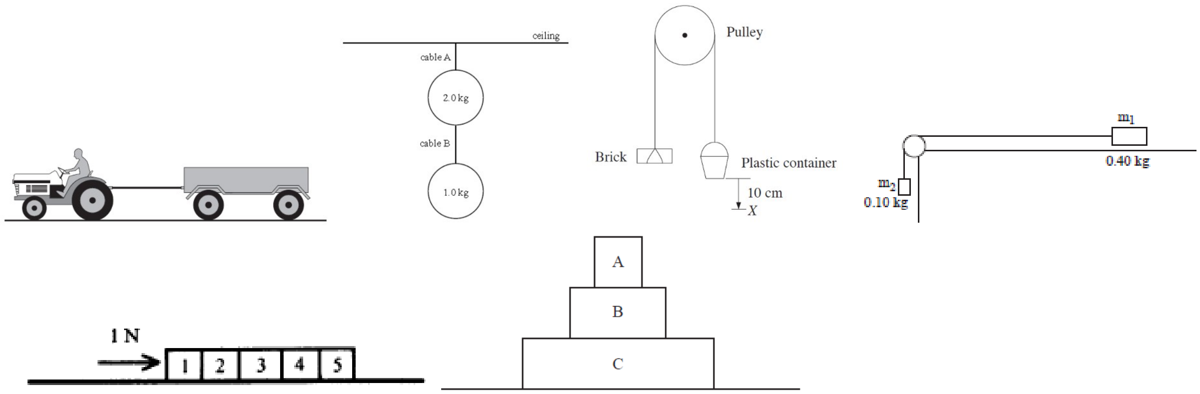
Newton's 3rd Law of motion

Action and reaction are equal and opposite. The force on A by B is equal and opposite to the force on B by A. This is summarised as $\mathbf{F}_{\text{on A by B}} = -\mathbf{F}_{\text{on B by A}}$ (the minus sign is to give the direction of the force vector).For the forces to be an action reaction pair, the subjects of the two statements need to be interchanged.

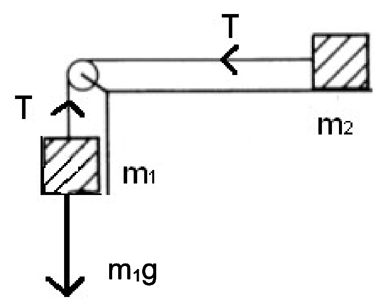
This concept is often tested using a book on a table. The action reaction pair of forces are: the weight force of the **on the book by Earth**, and the force of the **on the Earth by the book**. Many students get this incorrect, because they use the normal reaction as the other part of the pair.

Connected Bodies

Connected bodies can either be linked by a string/rod etc. or they can be touching one another. They can be horizontal, vertical of both. They can be pushing or pulling. The solution process is the same for all.



Problems involving the motion of two bodies connected by strings are solved on the following assumptions: the string is assumed light and inextensible so its weight can be neglected and there is no change in length as the tension varies. Tension forces are pulls exerted by a string on the bodies to which it is attached.



To solve these problems, consider the vertical direction first.

$$m_1g - T = m_1a$$

The direction of this acceleration must be downwards.
This leads to: $T = m_1g - m_1a$

The tension in the string is the same in both directions, therefore

$$T = m_2a.$$

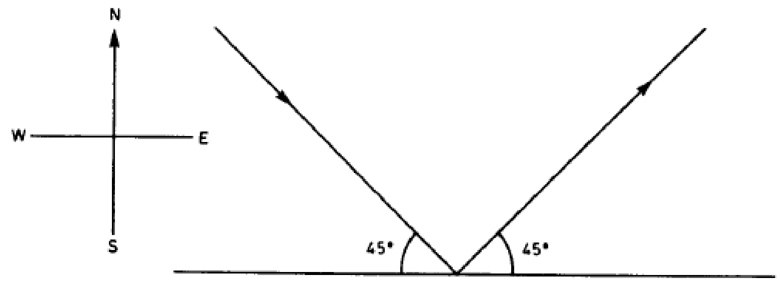
Since both bodies are connected by an inextensible string, both bodies must have the same acceleration. The vertical forces acting on m_2, (not shown) cancel each other out, and do not impact on its motion.

$$a = \frac{m_1}{m_1 + m_2}g$$

Combing these two equations gives

$$T = \frac{m_1m_2}{m_1 + m_2}g$$

Questions



A particle of mass *m*, travelling south-east at constant speed *v*, hits a wall and then travels north-east at the same speed *v*.

Example 1 1980 Question 17, 1 mark

The acceleration of the particle while it is in contact with the wall is

A. zero

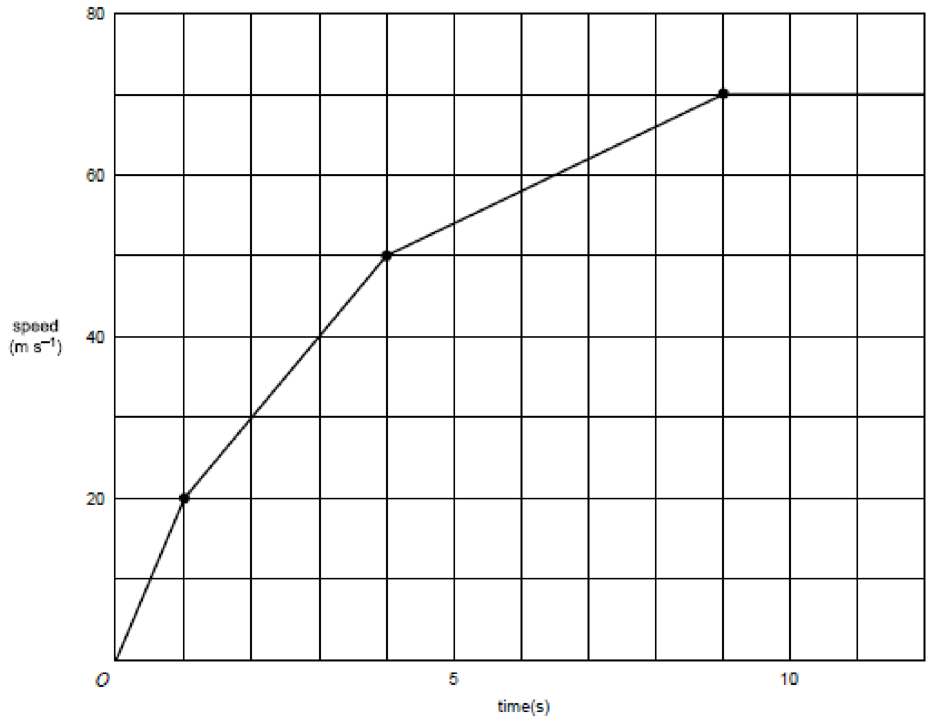
B. towards the east

C. towards the west

D. towards the north

E. changing from south-east to north-east

The figure shows the speed vs time graph of a racing car accelerating through the gears with constant acceleration in each gear. The car was initially at rest.



Example 2 2003 Question 1, 2 marks

Calculate the distance travelled by the car during the first **four** seconds of the motion.

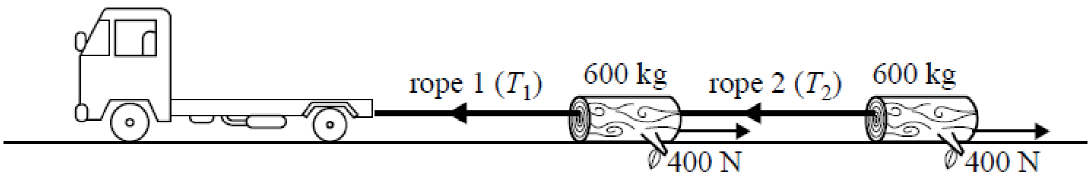
Example 3 2003 Question 2, 2 marks

Determine the magnitude of the acceleration of the car at ***t* = 3.0 s**.

Example 4 2003 Question 3, 2 marks

Calculate the average speed of the car during the first **twelve** seconds of the motion.

A truck is dragging two logs along level ground in a straight line. The mass of each log is 600 kg and each log experiences a constant retarding friction force of 400 N with the ground.
The connections between the truck and the logs are made with ropes that have a breaking force of 2400 N. T_1 and T_2 are the tensions in the ropes. The truck and the logs are moving towards the **left**.



Example 5 2012 Question 5a, 1 mark

Calculate the magnitude of *T*1 when the truck is driving at a constant speed.

Example 6 2012 Question 5b, 2 marks

The truck then accelerates at a rate of 0.50 m s^{-2}. Calculate the magnitude of T_2.

Example 7 2012 Question 5c, 2 marks

At a point in time, the driver observes that the speed of the truck is 4.0 m s–1. The truck then keeps accelerating at 0.50 m s^{-2} for another 20 m. Calculate the speed of the truck at the end of the 20 m.

Example 8 2012 Question 5d, 3 marks

The ropes have a breaking force of 2400 N. Rope 1 connects the truck to the front log and rope 2 connects the two logs. The truck, still on level ground, increases its acceleration until one of the ropes is about to break. Identify which rope is about to break, and calculate the magnitude of the acceleration of the truck and the logs at this instant.

A steel ball is dropped vertically on to a steel bench-top. *W* is the weight force acting on the ball and F_C is the contact force exerted on the ball by the bench at the instant of rebound when the ball is at rest.

***Example 9 1984 Question 24, 1 mark**

Which **one or more** of the following statements about *W* and F_C are correct?

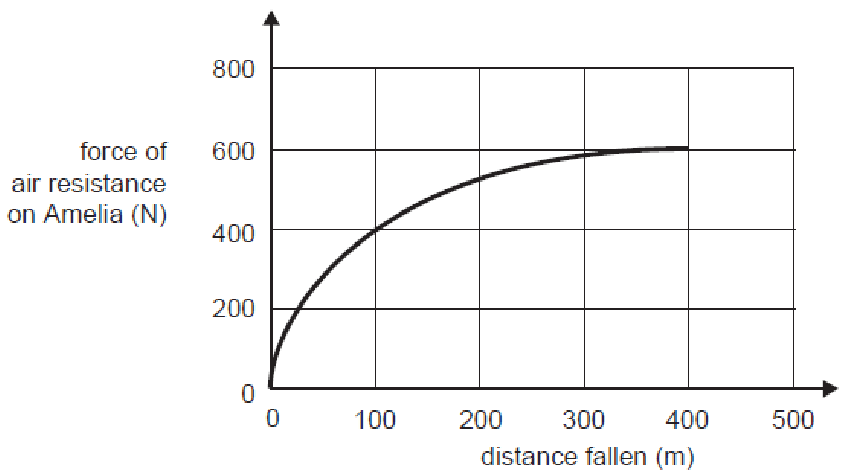
A *W* and F_C form an action-reaction pair and so are equal in magnitude.

B The ball is instantaneously at rest, so *W* and F_C cancel exactly to provide the necessary zero resultant force.

C the ball is accelerating upwards, so F_C must be greater than *W*.

D F_C may be greater or less in magnitude than *W* depending on whether the collision is elastic or inelastic.

Amelia, who has a mass of 60 kg including equipment, is skydiving. The air resistance on her as a function of the distance fallen is shown below. After falling a distance of 400 m, she has reached terminal velocity, and continues to fall at a constant speed until she opens her parachute.



Example 10 2007 Question 6, 2 marks

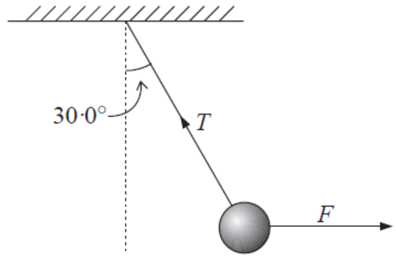
What is the magnitude of the **net** force on Amelia after falling 400 m?

Example 11 2007 Question 7, 3 marks

Calculate her acceleration when she has fallen 100 m.

Example 12 1999 NSW Question 5, 1 mark

An object of weight 10·0 N is attached to a string. It is held aside by a horizontal force *F* to make an angle of 30·0° to the vertical as shown in the diagram.



The magnitude of the tension *T* in the string is

A. 8·66 N

B. 10·0 N

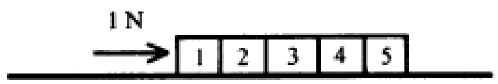
C. 11·5 N

D. 20·0 N

Example 13 2017 QLD Question 2, 2 marks

A 4 kg mass sits on a horizontal surface and has to be pushed with a force of 20 N in the horizontal before friction is overcome and it begins to move. At what angle would the surface need to be tilted before the mass would begin to slide down the surface?

Five identical blocks each of mass 1.0 kg are on a smooth, horizontal table. A constant force of 1 N acts on the first block as shown in the figure below.



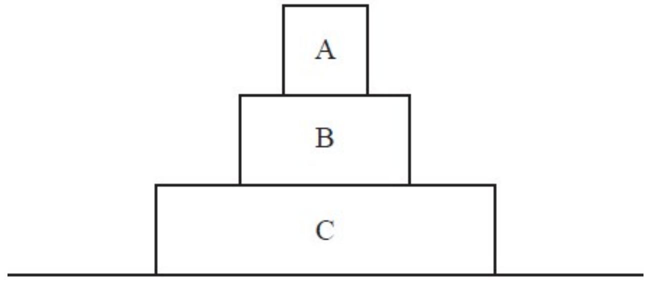
***Example 14 1985 Question 14, 1 mark**

What force does block 4 exert on block 5?

***Example 15 1985 Question 15, 1 mark**

What force does block 3 exert on block 4?

Three children's toy blocks, A (0.050 kg), B (0.10 kg) and C (0.20 kg), are sitting on a table as shown below.



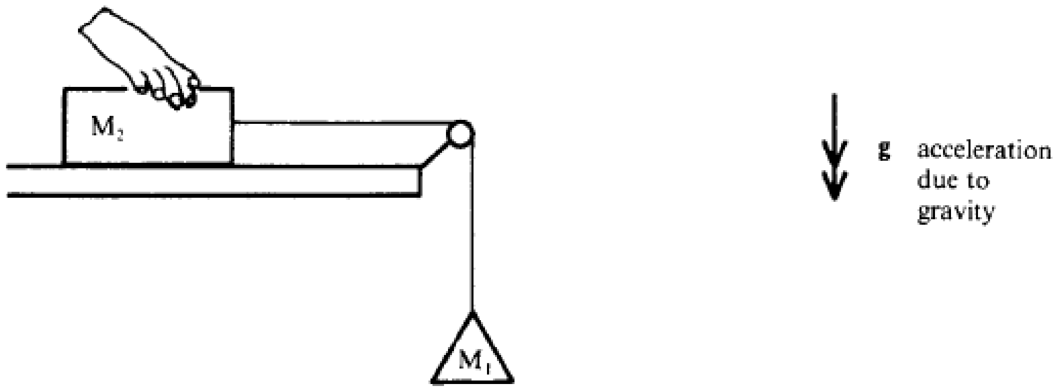
Example 16 2011 Question 7, 2 marks

What is the force by block C on block B?
Explain your answer in terms of Newton's laws.

Example 17 2011 Question 8, 2 marks

The table is now removed and the blocks free fall.
What is now the force by block B on block C?
Ignore air resistance,
Explain your answer.

A block of mass M_2 is held at rest on a horizontal frictionless table. A string is attached to a mass M_1 over a light frictionless pulley as shown below.



Example 18 1983 Question 7, 1 mark

If the block is then released, which of the statements below best describes the subsequent state of the block?

A The block starts to move with an acceleration $\frac{M_1 + M_2}{M_2}g$

B The block starts to move with an acceleration $\frac{M_1}{M_1 + M_2}g$

C The block starts to move with an acceleration g

D The direction of the motion depends on whether M_2 is greater or less than M_1.

Solutions

Example 1 **D (ANS)**

Example 2 **115 metres (ANS)**

Example 3 **10 m s^{-2} (ANS)**

Example 4 **52.1 m s^{-1} (ANS)**

Example 5 **T_1 = 800 N (ANS)**

Example 6 **T_2 = 700 N (ANS)**

Example 7 **v = 6 m s^{-1} (ANS)**

Example 8 **a = 1.33 m s^{-2} (ANS)**

Example 9 **C (ANS)**

Example 10 **F_{net} = 0 (ANS)**

Example 11 **0.33 m s^{-2} (ANS)**

Example 12 **C (ANS)**

Example 13 **θ = 31° (ANS)**

Example 14 **0.2 N (ANS)**

Example 15 **0.4 N (ANS)**

Example 16 **$F_{C\ on\ B}$ = 1.5 N (upwards) (ANS)**

Example 17 **$F_{B\ on\ C}$ = 0 (ANS)**

Example 18 **B (ANS)**