

Forces Notes

Science Exams Sorted



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This booklet covers the majority of the forces topic for OCR A. It's a bit of a big booklet so please feel free to cover small bits at a time. 😊 So, let's start with an important question, what is a force?

A force: the push or pull on an object that has mass, which causes it to change its velocity.

Velocity: speed in a given direction, it has the unit of m/s.

All forces can be grouped into two categories. These are either contact or non-contact forces.

Contact forces: are forces that act between two objects that are physically touching.

Examples include friction and air resistance and tension.

Non-contact forces: are forces that act between two objects that are not physically touching.

Examples include gravitational force, electrostatic force and magnetic force.

Scalar and Vector Quantities

First, what is a "quantity"? A quantity is a measure of the amount of whatever unit we are dealing with.

Scalar quantities: are measures that only have a size.

Some examples of scalar quantities are:

- **Mass** – measured in kilograms (kg)
- **Temperature** – measured in degrees Celsius (°C)
- **Distance** – measured in metres (m)

Vector quantities: are measures that have a size and a direction included in them.

Some examples of vector quantities are:

- **Velocity** – metres per second (m/s). This could be moving forwards for example.
- **Acceleration** – metres per second² (m/s²).
- **Force** – newtons (N).

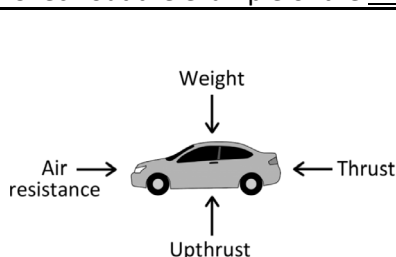
Resultant force: the force that results (comes out of) from two or more forces meeting.

Exam note: resultant forces quite often appear with free body diagrams. Though then can also come up on their own as an addition or subtraction questions.

Free Body Diagrams

What are free body diagrams? These are diagrams that show the forces that are acting on an object.

Check out the example of the moving car below 😊



Here we see that there are four forces acting on this moving car, let's look at each.

- **Weight** – this is the force pushing the car towards the earth. This is due to its mass multiplied by its gravity.
- **Upthrust** – this is the reaction force pushing the car away from the earth.
- **Thrust** – this is the force that pushes the car forwards.
- **Air resistance /drag** – this is the reaction force against thrust that pushes that car back. If the object was a boat, we could use water resistance instead of air resistance.

Examples of calculating resultant forces using free body diagrams

The figure below shows a plane accelerating at take-off. Calculate the resultant force experienced by the plane.

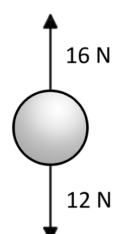


All we need to do here is take one force away from the other 😊

$$120\,000\text{ N} - 54\,000\text{ N} = 66\,000\text{ N}$$

The figure below shows a ball bouncing upwards.

Calculate the resultant force experienced by the ball.



$$16\text{ N} - 12\text{ N} = 4\text{ N}$$

Resultant Force (Vector) Diagrams

These problems are also called scale diagrams or vector diagrams, it doesn't really matter they are the same thing. These diagram problems often cause issues for students. The main thing with these, as with many diagram-based questions, is practise. Practise plenty of these and you'll be absolutely fine 😊 Also don't rush these!

What is a vector diagram? A vector diagram is a visual way of showing the magnitude (size) and direction of a resultant force on an object.

How do we do these problems? Oh that depends on what **TYPE** of vector diagram it is! There are **two types!!**

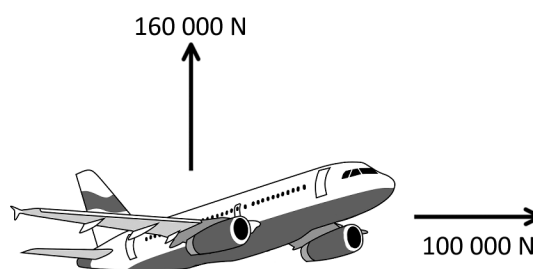
Type 1: Diagrams that **are** right angled triangles. These are the most straightforward as we can use Pythagoras's theorem for completing them. These are lovely problems and very quick to do. See **example 1** below for one of these.

Type 2: Diagrams that **are not** right angled triangles. We can't use Pythagoras's theorem to do these problems I recommend doing these problems with a **compass**. Now, you might have been taught to use "**the parallelogram**" to do these, that does work but using a compass is faster and easier and that's the one I use as I'm naturally lazy 😊 See **example 2** for a talk through of how to do these with a compass.

Compass note: please do practise using your compass. It's something that is not taught or practised enough in school.

Also, I recommend getting a **Helix bow compass** for these as they're much better than the compass where you have to put the pencil in. They don't move about and it comes in a handy case. They cost about £6 on Amazon and the one I have is 14 years old so they definitely last.

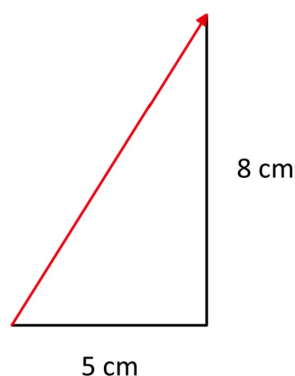
Example 1: A passenger aircraft is climbing having just taken off. It is experiencing an upthrust of 160 000 N and a thrust of 100 000 N to the right. Scale 1 cm = 20 000 N.



Determine the magnitude and direction of the resultant force on the aircraft.

Give your answer to three significant figures.

Here we treat the problem like a Pythagoras problem and solve using Pythagoras's theorem, with the resultant force always being the hypotenuse.



Step 1: Draw a right angled triangle and use Pythagoras to find the length of the missing side.

$$a^2 + b^2 = c^2$$

$$5^2 + 8^2 = c^2$$

$$25 + 64 = c^2$$

$$c^2 = 89$$

$$c = \sqrt{89} = 9.43 \text{ cm}$$

Step 2: Multiply this length by the scale factor given.

Force = distance × scale factor

$$\text{Force} = 9.43 \times 20\,000$$

$$\text{Force} = 188\,679.62$$

$$\text{Force} = 189\,000 \text{ N}$$

Step 3: use trigonometry to determine the direction.

We have the opposite side (8 cm) and the adjacent side (5 cm). We need to find the angle.

Use $\tan(\theta) = \text{opposite} \div \text{adjacent}$.

$$\tan(\theta) = 8 \div 5 = 1.6$$

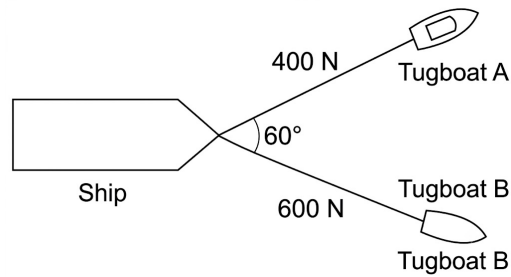
$$\theta = \tan^{-1}(1.6) = 58.0^\circ$$

The direction is 58.0° to the horizontal (line).

Example 2: Two tugboats are pulling a large ship into a harbour.

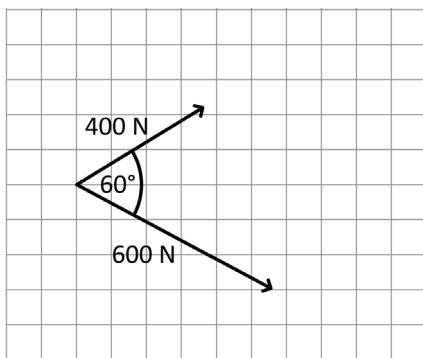
Tugboat A pulls with a force of 400 N. Tugboat B pulls with a force of 600 N.

The angle between the two towing cables is 60° . The figure below shows the boats.

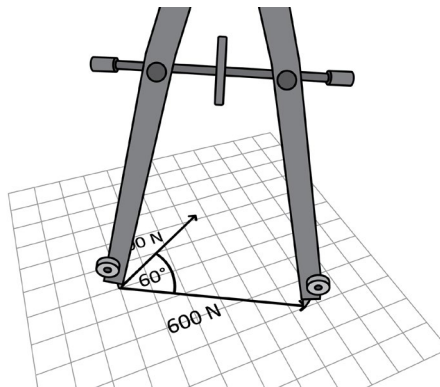


Using a scale of $1\text{ cm} = 100\text{ N}$, draw a vector diagram to find the resultant force acting on the ship.

Let's do this in steps 😊 **Step 1** – draw a scale diagram with two lines, where one is 6 cm in length and the other is 4 cm in length with an angle of 60° between them. This is shown below.

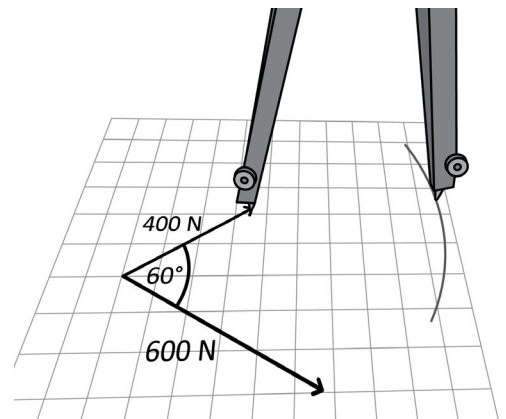


Step 2: set your compass to 6 cm, which is the length of the 600 N line.

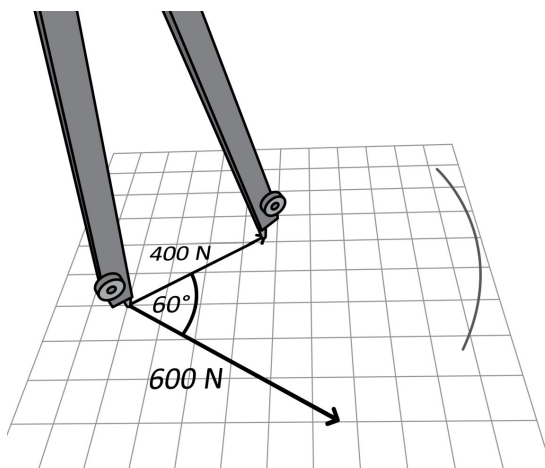


Step 3: this is a fun one 😊 pick up your compass and without changing the width of the compass bring the point to the end of the 4 cm line (400 N) and mark a long arc.

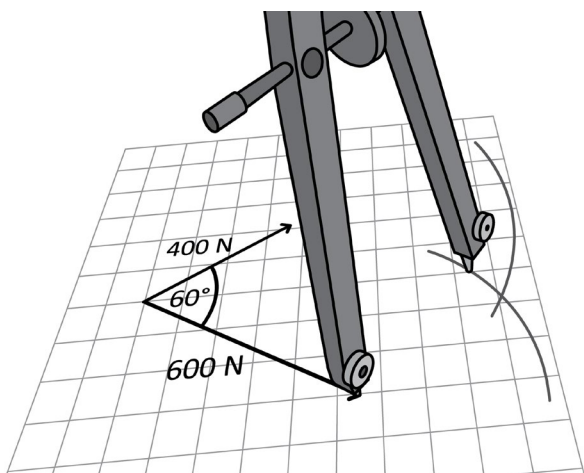
Note: this is why the bow compass is great for this as the middle bar stops the compass from moving and increasing our accuracy.



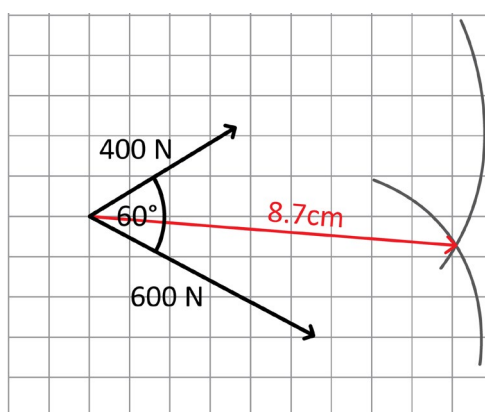
Step 4: Now pop your compass point back to the start point and this time set it to 4 cm which is the length of the 400 N line.



Step 5: another fun one 😊 pick up your compass and without changing the width of the compass bring the point to the end of the 6 cm line (600 N) and mark another arc. Our two arcs should meet each other.



Step 6: draw a line from where our starting point to where the two arcs met. The length of this new line will give us the size of our resultant force, once we apply the scale of course.



Final step: so we know our line is 8.7 cm long and the scale was 1 cm = 100 N so we're just going to multiply 8.7 by 100 to find the size of the resultant force.

$$8.7 \times 100 = \mathbf{870\ N}$$

I hope that helps 😊

Weight

Weight: is a force acting on an object due to the mass of the object and the gravitational field that the object is in. As it is a force it is measured in newtons.

Gravitational field strength: is the attraction between two objects which have mass. The bigger the mass of the objects the bigger the attraction between them.

The gravitational field strength can be different from question to question, the value for earth will be different to the value for the moon for example. It should say in the question what value to use for the gravitational field strength.

Exam note: if we are not given a value for gravitational field strength we can use 9.8 N/kg.

The equation for weight is:

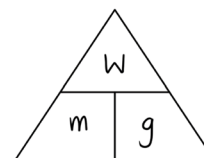
Weight = mass $\times$ gravitational field strength

$$W = m \times g$$

W = Weight in Newtons (N)

m = Mass (kg)

g = gravitational field strength (N/kg)



Work Done

Work done: is the energy transferred when a force moves an object over a distance. It is measured in Joules (J).

But, what is a Joule of work done? One Joule of work is done when a force of one Newton causes a displacement of one metre (1 J = 1 Nm). So, 1

Exam hint: questions in exam papers often give the distance in centimetres. This is a trap. We need to convert the centimetres into metres in order to do the question correctly. Watch out for this.

The equation for work done is:

Work done = force $\times$ distance

$$W = F \times d$$

W = work done in Joules (J)

F = force/weight of the object (N)

d = distance in metres (m)

Forces and Elasticity

As we know some objects, like springs and rubber bands, can bend and stretch and of course some objects, like glass, will not bend or stretch very much at all before they break. What is the difference here?

Well, some extensions are **elastic** and some are **inelastic**.

Elastic extension: when an object extends if a force is applied to it and when the force is removed the object returns to its original shape.

Inelastic extension: when an object extends if a force is applied to it and when the force is removed the object does not return to its original shape i.e. the object has been broken.

Extension: the formal way of saying an object has stretched. So, a stretch is an extension.

Compression: the formal way of saying that an object has been squeezed into a smaller shape.

Limit of proportionality: the point at which a spring will not go back to its original shape. So, once you go past the limit of proportionality the spring is inelastically deformed.

The equation for Hooke's law is:

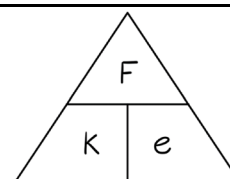
Force = spring constant $\times$ extension

$$F = k \times e$$

F = force on the object (N)

k = the spring constant.

e = the extension in metres (m)



Hooke's law is an example of direct proportion and on a graph it would appear as a straight line. If the spring goes past the limit of proportionality it will look like a curve on a graph. That way we can see what force has broken the spring. Most questions on this topic involve a graph.

Newton's Laws of Motion

Sir Issac Newton is considered by many to be the father of modern Physics.

He is probably best known for the apple falling and hitting him on the head story. This made him think about “**why**” that happened and this lead to him doing a lot of work on motion so coming up with his three laws of motion.



Sir Issac Newton

Newton's First Law

Newton's first law of motion: states that an object will remain stationary or moving at a constant speed in a straight line unless acted on by a resultant force.

What does this mean?

It's hard to see this law clearly on earth but it's a lot easier in space. Let's imagine that we are just floating in space, completely stationary, half way between earth and the moon. We cannot move in any direction. Even if we move our arms and legs nothing happens. We can't move as we don't have a resultant force.

What if I had a jet pack and used that in space, would I move then? Yes, as you now have a resultant force. But once the fuel runs out you will not be able to stop and you'll keep travelling in a straight line at the same speed unless you hit something or something hits you. That's Newton's first law 😊

Newton's Second Law

Newton's second law of motion: states that the force of an object is directly proportional to its inertial mass multiplied by its acceleration.

What is inertial mass? It's a measure of how difficult it is to change the velocity of an object.

What does Newton's second law mean?

Let's say that someone is going to throw one of two things at you. One is brick and the other is a pea. Both are going to get thrown at the same speed. Which would you prefer to get hit by? The Pea? Correct.

Why did you pick the pea? You know that the pea is much smaller than the brick. Even if it is going at the same speed as the brick. Therefore it will hit you with a lot less force 😊 So the force is equal to the mass multiplied by the acceleration. That's Newton's second law.

$$\text{Force} = \text{mass} \times \text{acceleration}$$

$$F = m \times a$$

F = Force in Newtons (N)

m = Mass (kg)

a = acceleration (m/s²)

Newton's Third Law

Newton's third law of motion: states that for each force there is an equal and opposite reaction force.

What does Newton's third law mean?

If you push against a wall, the wall pushes back on you with the exact same amount of force, but in the opposite direction.

Student note: A common mistake is thinking that our weight acting downwards and the normal contact force acting upwards from the floor are a third law pair. They aren't!

A real Newton's Third Law pair is: The Earth pulls you down with gravity (your weight), so you pull the Earth up with the exact same amount of gravity! That's Newton's third law 😊