Rosary School – Marj Elhamam

Chapter 2 Forces and Shape

Name: __________________ Date: ____ /____ / 2025

Grade: 9 (   ) Subject: **Physics**

Summary notes

Objectives:

1.11 describe the effects of forces between bodies such as changes in speed, shape or direction

1.12 identify different types of force such as gravitational or electrostatic

1.13 understand how vector quantities differ from scalar quantities

1.14 understand that force is a vector quantity

1.15 calculate the resultant force of forces that act along a line

1.16 know that friction is a force that opposes motion

1.22 *practical: investigate how extension varies with applied force for helical springs, metal wires and rubber bands*

1.23 know that the initial linear region of a force-extension graph is associated with Hooke's law

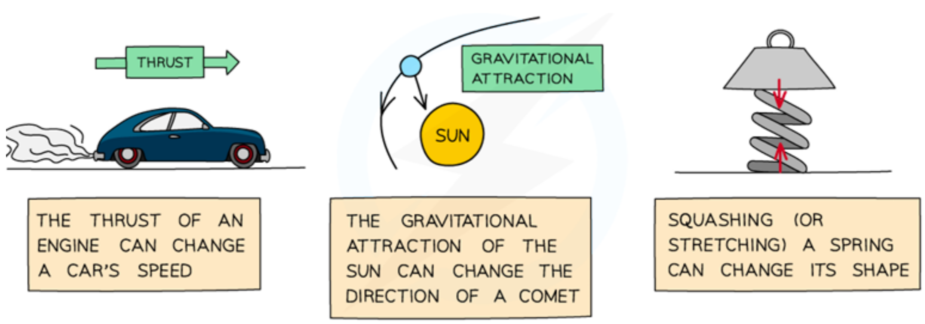
1.24 describe elastic behaviour as the ability of a material to recover its original shape after the forces causing deformation have been removed

Effects of Forces

A **force** is a **push** or **pull** that arises from the **interaction** between objects.

Forces can affect bodies in a variety of ways:

- Changes in speed: forces can cause bodies to speed up or slow down.
- Changes in direction: forces can cause bodies to change their direction of travel.
- Changes in shape: forces can cause bodies to stretch, compress, or deform.

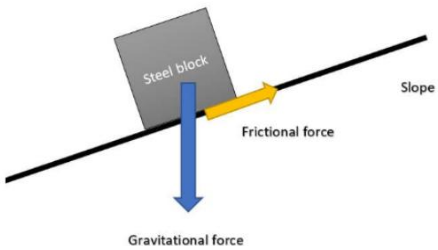


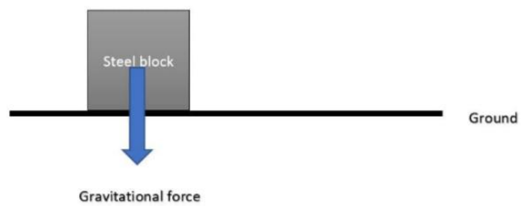
The effects of forces on objects

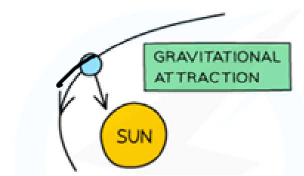
<u>Types of Forces</u>

There are many types of force. Some examples include:

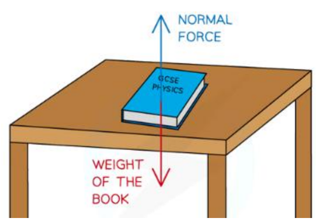
- **Gravitational force (or weight)** - the force of attraction between any two objects with mass (like the Earth and the Moon). The **weight force** always acts **downwards** to the centre of the mass. The more massive the object, the greater the gravitational force exerted by it.
- When a football is thrown (or kicked), the gravitational pull of the Earth on the football pulls it toward the (centre of the) Earth



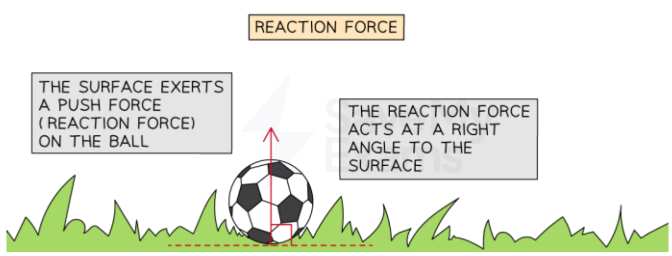




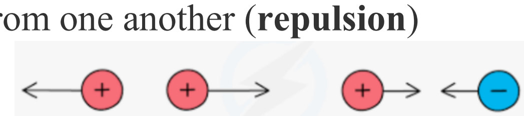
- **Normal reaction force** - the force between any two objects in contact (like the upwards force from a table on a book). When an object rests on a surface, the **surface** exerts a push force on the **object**. This reaction force acts at right angles (perpendicular) to the surface. Normal means that the force is always 90° to the surface.



Reaction force acting on a football



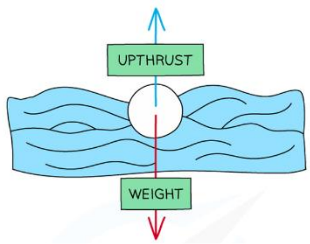
- **Electrostatic** - the force between any two objects with **charge** (like a proton and an electron). **Like charges repel** one another, and **opposite charges attract** one another. When an electron gets close to a positively charged ion, the ion exerts a pull force on the electron (**attraction**). When an electron gets close to another electron, the electrons experience a push force from one another (**repulsion**)



Like charges experience a repulsive push force and opposite charges experience an attractive pull force

- **Thrust** - the force pushing a vehicle (like the push from rocket engines on the shuttle). Thrust is a force produced by an engine that **speeds up** the motion of an object. The engine of a car exerts a thrust force and increases its speed.

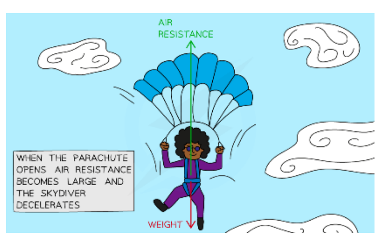
- **Upthrust** - the upward force on any object in a fluid (like a boat on the surface of a river).
    - When an object is fully or partially **submerged** in a **fluid**, the fluid exerts an **upward-acting** push force on the object. A boat floats on a lake due to the **upthrust** exerted by the water on the boat. A ball held underwater will shoot upwards when released due to the upthrust exerted by the water pushing it back to the surface
    - When an object **floats**, the upthrust is **equal** to the weight of the object. If the weight of the object is greater than the upthrust, it **sinks**. If the upthrust is bigger than the weight to the object it **rises**.



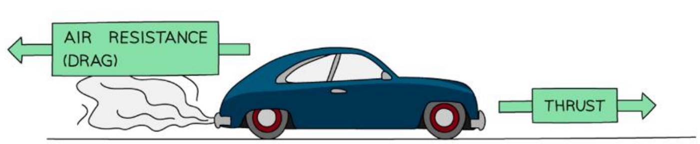
- **Drag** - the force of friction between objects moving through the air (**air resistance**), like a skydiver in freefall, or between objects moving through a liquid (**liquid resistance**). Drag force is a type of **frictional force** that occurs when an object moves through a **fluid** (a gas or a liquid). The particles in the fluid **collide** with the object moving through it and **slow** its **motion.** When a pebble is thrown into water, the water molecules flow against its solid surface, causing it to slow down.

Air resistance:

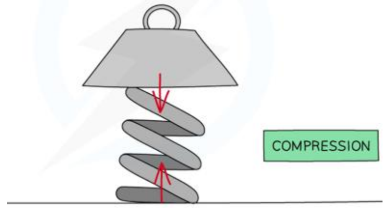
Air resistance is a specific type of **drag** force and is therefore also a **frictional** force. Air resistance occurs when particles of air **collide** with an object moving through it and **slows** its **motion**. When a skydiver opens their parachute, air resistance opposes their motion and reduces their speed so it is safe to land.



A skydiver uses air resistance to reduce their speed so that they can land safely

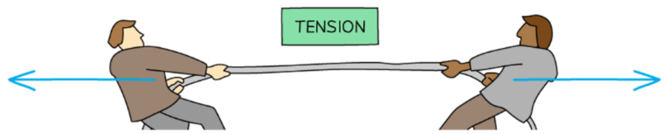


- **Compression** - forces that squeeze an object (like squeezing a spring)



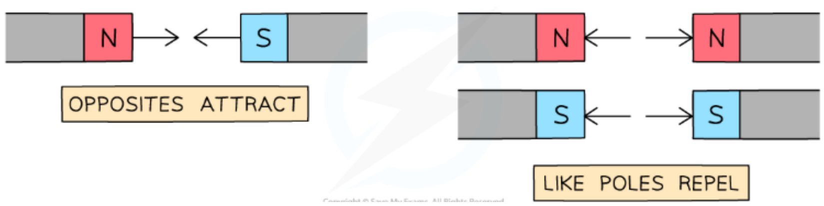
- **Tension** - forces that stretch an object (like two teams in a tug-of-war). Tension occurs in an object (like a rope or spring) that is **stretched.** When a **pull** force is exerted on **each end** of an object, **tension** acts across the length of the object

When two people pull a rope in opposite directions, tension acts along the rope and pulls back on each person.



- **Magnetic forces** –There is a **magnetic** force between objects with **magnetic poles.**

Like poles repel one another, **opposite poles attract** one another. When a north pole gets close to a south pole, they experience a pull force from one another (**attraction**). When a north pole gets close to a north pole, they experience a push force from one another (**repulsion**)



Opposite poles experience an attractive pull force, and like poles experience a repulsive push force

Exam Tips:

The force of gravitational attraction on an object is called its **weight**. Remember not to refer to this force as simply 'gravity', as this term can mean several different things, and examiners will probably mark it as wrong.

Similarly, when referring to **air resistance**, avoid using terms like 'wind resistance' (there is no such thing!) or 'air pressure', which is a different concept. **Drag** is an acceptable alternative to the force of air resistance because air resistance is a special type of drag.

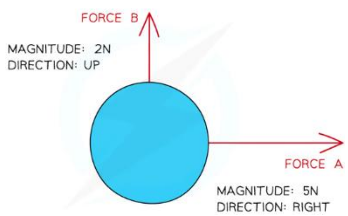
Scalar & vector quantities

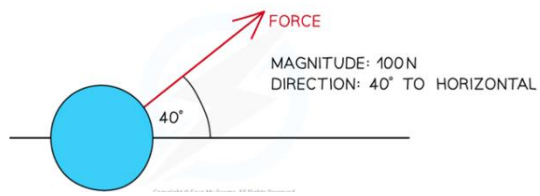
- All quantities can be one of two types:
  - a **scalar**
  - a **vector**

- **Scalars** are quantities that have **magnitude** but not direction, for example, **mass** is a **scalar** quantity because it has **magnitude** but no direction.
    - **Vectors** are quantities that have both **magnitude** and **direction.** For example, **weight** is a **vector** quantity because it is a force and has **both** magnitude and **direction**.

Forces as Vectors

- Force is a **vector** quantity because it describes both **magnitude** and **direction**.
- The **length** of the arrow represents the **magnitude** of the force.
- The **direction** of the arrow indicates the **direction** of the force.
- The **scale** of the arrows should be **proportional** to the relative magnitudes of the forces. An arrow for a 4 N force should be twice as long as an arrow for a 2 N force.
- The arrows should be labelled with the names of the forces, or a description of the forces. For example, weight, or the gravitational pull of the Earth on the object





- Not all forces are directed perfectly horizontally or vertically and thus need to have an angle described. It is useful to describe an angle with respect to the vertical or the horizontal.

Example 1:

a. Which of the following is a vector quantity? [1]
   A. Density B. Force. C. Mass D. Speed

b. Which of the following is a scalar quantity? [1]
   A. Acceleration. B. Energy. C. Momentum D. Velocity

c. Astronaut A is in charge of training junior astronauts. For one of their sessions, they would like to explain the difference between mass and weight.
   Suggest how Astronaut A should explain the difference between mass and weight, using definitions of scalars and vectors in your answer. [4]

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Example 2:

The diagram shows the driving force on a sports car as it moves along a race track.

Name **two** forces the opposes the driving force. [2]

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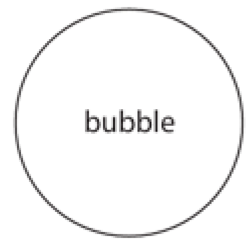
Example 3: Jan 2021 1PR

A glass contains fizzy water. Bubbles of carbon dioxide form at the bottom of the glass and rise to the surface

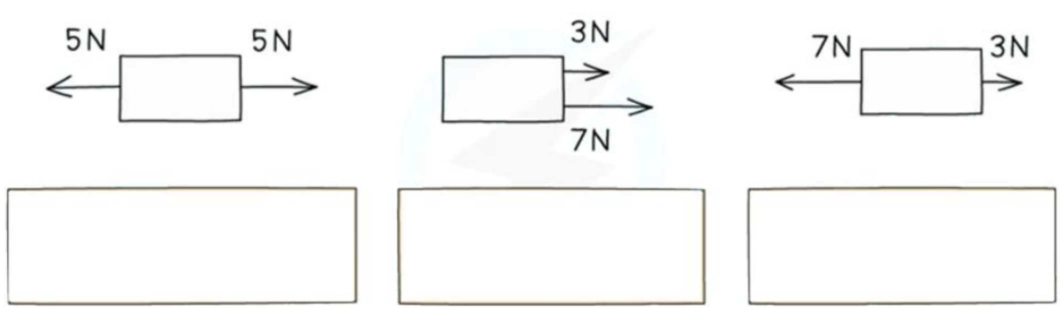
A force called upthrust acts vertically upwards on the bubble. When the bubble is released, it accelerates vertically upwards.

Draw two labelled arrows on the diagram to show the forces on the bubble as it is released.



Calculating Resultant Force

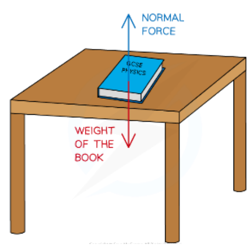
- A **resultant force** is a single force that describes all the forces operating on a body.
- When many forces are applied to an object they can be combined (added) to produce one final force which describes the combined action of all the forces.
- This single resultant force determines:
  1. The **direction** in which the object *will move* as a result of all of the forces.
  2. The **magnitude** of the final force experienced by the object.
- The resultant force is sometimes called the **net force**.
- Resultant forces can be calculated by adding or subtracting all the forces acting on the object.
- Forces working in **opposite** directions are **subtracted** from each other
- Forces working in the **same** direction are **added** together.
- If the forces acting in opposite directions are equal in size, then there will be **no resultant force** – the forces are said to be **balanced**.



- When calculating resultant forces, always remember to provide **units** for your answer and to state whether the force is to the right, to the left, up or down. Always provide your final answer as a description of the **magnitude** and the **direction**.
- **Balanced forces** mean that the forces have combined in such a way that they cancel each other out and no **resultant force** acts on the body.
- **Unbalanced forces** mean that the forces have combined in such a way that they do not cancel out completely and there is **a resultant force** on the object.

Balanced forces

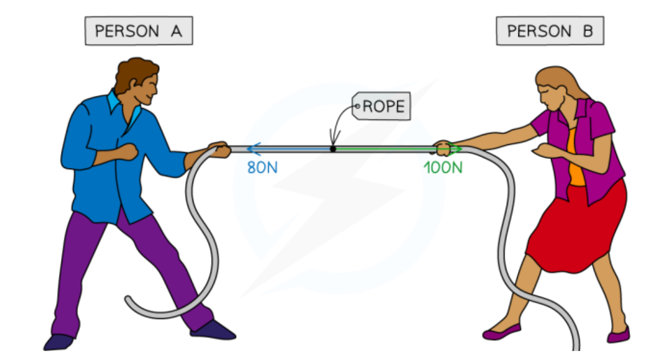
- Balanced forces mean that the forces have combined in such a way that they cancel each other out and no resultant force acts on the body.
  - For example, the weight of a book on a desk is balanced by the normal force of the desk
  - As a result, no resultant force is experienced by the book, the book and the table are equal and balanced.



A book resting on a table is an example of balanced forces

Unbalanced forces

- Unbalanced forces mean that the forces have combined in such a way that they do not cancel out completely and there is a resultant force on the object
  - For example, imagine two people playing a game of tug-of-war, working against each other on opposite sides of the rope
  - If person A pulls with 80 N to the left and person B pulls with 100 N to the right, these forces do not cancel each other out completely
  - Since person B pulled with more force than person A the forces will be unbalanced and the rope will experience a resultant force of 20 N to the right



A tug-of-war is an example of when forces can become unbalanced

Unbalanced Forces, Mass & Acceleration

- When forces combine on an object in such a way that they do not cancel out, there is a resultant force on the object
- This resultant force causes the object to accelerate (i.e. change its velocity)
  - The object might speed up
  - The object might slow down
  - The object might change direction

<u>Friction</u>:

- Friction is defined as: The force which **opposes the motion** of an object and slows it down. It always acts in the **opposite** direction to object's **motion**.
- Friction emerges when two (or more) surfaces rub against each other: At a molecular level, both surfaces contain imperfections. These imperfections tend to push against each other.
- Friction allows cars' wheels to grip the road and makes objects accelerate.
- Friction wears out surfaces and reduces efficiencies as energy will be wasted to the surroundings as heat.
- Friction can be reduced on a moving object in the laboratory- using air-tracks- to a very low value. Such an object will continue to move in a straight line at a constant speed once set in motion even when the thrust force is no longer acting on it.

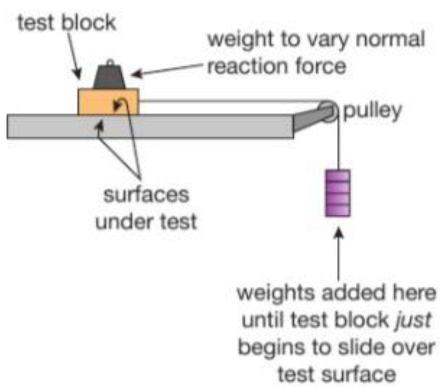
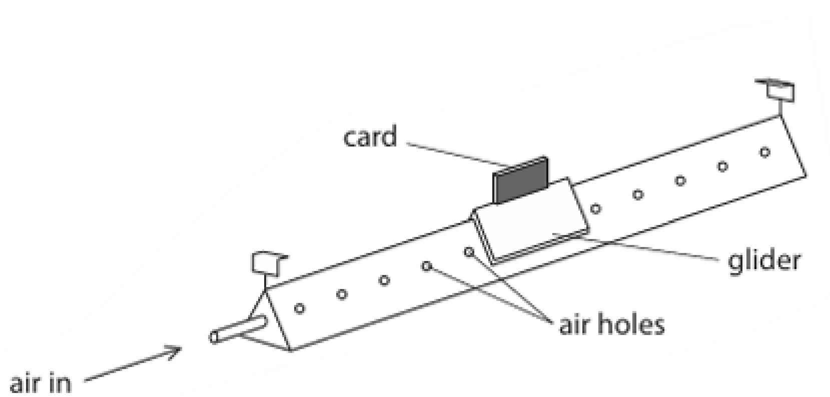


Figure 2.9 This apparatus can be used to investigate friction.



<u>Forces and changing shape:</u>

- When some objects, such as springs or rubber bands, are stretched they will return to their original shape and length once the forces are removed.
- Other materials, such as plastic, remain permanently deformed (stretched).
- A change of shape is called a **deformation** and can either be: **Elastic or Inelastic (plastic)**

Elastic deformation

- Elastic deformation is defined as:
  The ability of a material to recover its original shape after the forces causing deformation have been removed.

- Examples of materials that undergo elastic deformation are steel springs, rubber bands, fabrics.

Inelastic (plastic) deformation

Inelastic deformation is defined as:
The **permanent change** in the shape of a material after the forces causing deformation have been removed.
Examples of materials that undergo inelastic deformation are plastic, clay, glass.

<u>Hooke's Law</u>:

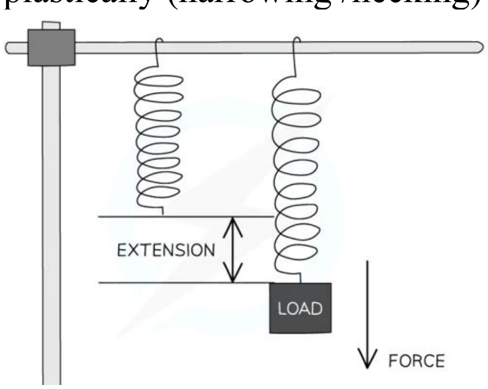
Springs change length when a force acts on them, and they return to their original length when the force is removed.

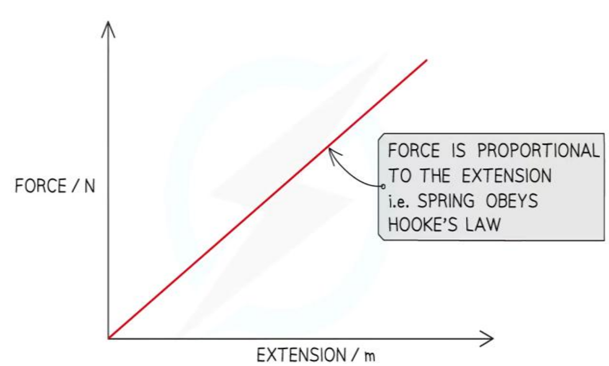
The relationship between the **extension** of an elastic object and the applied **force** is defined by **Hooke's Law.**

- Hooke's Law states that:

The <u>extension</u> of an elastic object is <u>directly proportional</u> to the <u>force</u> applied, up to the <u>limit of proportionality.</u>

- **Directly proportional** means that as more force is applied, the greater the extension (and vice versa). If the force doubles, then the extension will double. If the force halves, then the extension will halve.
- The **limit of proportionality** is:
  - the point where if more force is added, the extension is no longer proportional to the force.
  - The elastic object starts to stretch more for each increase in the load force.
  - The extension beyond the limit of proportionality does not follow Hooke's law.
  - The elastic material can still return to its original length as you take the weights off until it reaches another point called the **elastic limit**.
- If the elastic object was stretched beyond the **elastic limit**, it will not return to its original length as you take the weights off.
- Hooke's law applies to metal springs and wires. If a wire is stretched, the extension is proportional to the load up to a certain load, then some wires break, others extend plastically (narrowing /necking) before breaking.



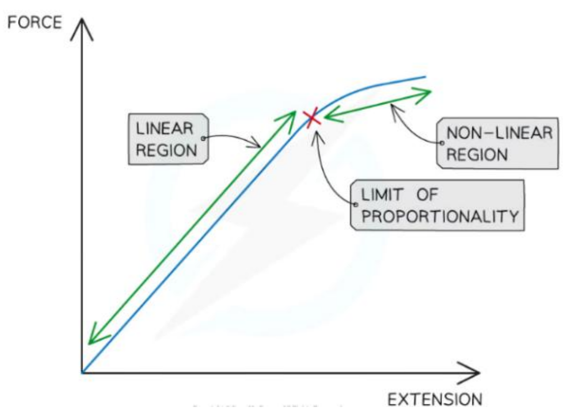


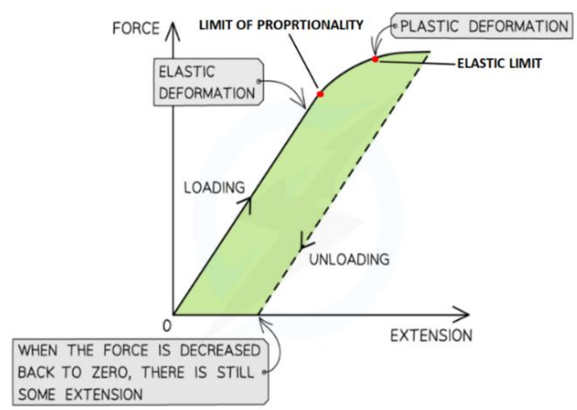
Hooke's Law states that a force applied to a spring will cause it to extend by an amount proportional to the force

The spring on the right has undergone inelastic deformation, it's shape has been permanently deformed

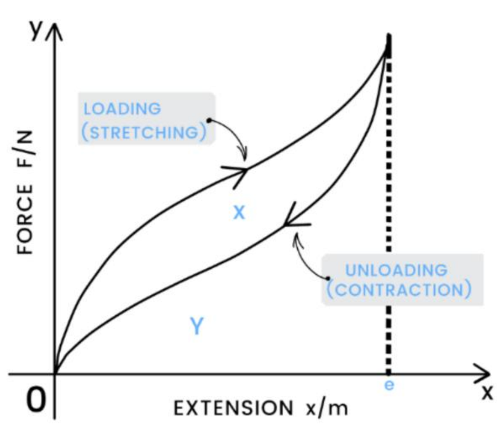
The Force-Extension Graph

- Hooke's law is **the linear** relationship between force (F/N) and extension (x/m).
- This is represented by a straight line on a force-extension graph.
- Any material **beyond its limit of proportionality** will have a **non-linear** relationship between force and extension.





- Elastic bands are usually made of rubber. They are elastic material. When an elastic band stretches under load, the graph is not a straight line, showing that elastic bands don't obey Hooke's law.
- The extension produced by a given load force is different when increasing the load force (loading) to when you decrease the load (unloading). The graph will look like an S shape.



Question 9 page 27:

9 The information in the following table was obtained from an experiment with a spring of original (unstretched) length 5 cm.

Load force on spring /newtons	Length of spring /cm	Extension of spring /cm
0	5.0	
2	5.8	
4	6.5	
6	7.4	
8	8.3	
10	9.7	
12	12.9	

a Copy and complete the table by calculating the extensions produced by each load.

b Use your table to plot a graph of force (y-axis) against extension (x-axis).

c Mark on your graph the part that shows Hooke's law.

d Sketch the shape of the graph you would expect if you carried out the same experiment using an elastic band instead of a spring.

Core practical 2: investigating force & extension

Experiment 1: investigating force and extension for springs and rubber bands

- The aim of this experiment is to investigate the relationship
- between **force** and **extension** for a spring and a rubber band:

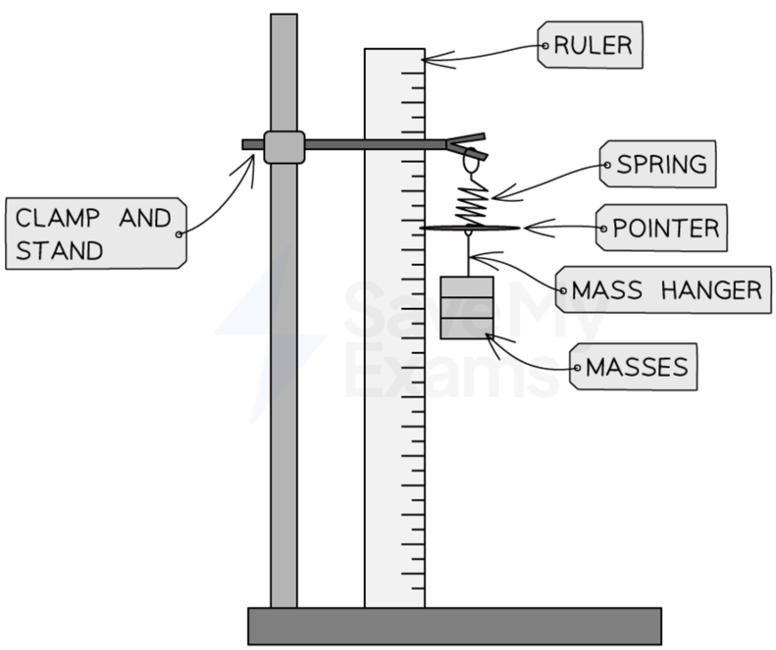
Variables

- **Independent variable** = Force, *F*
- **Dependent variable** = Extension, *x*

Equipment list

Equipment	**Purpose**
Clamp and stand	To apply an upward force to the spring and rubber band
Ruler	To measure original length and extension
Spring and rubber band	To measure the extension of
5 × 100 g masses	To apply a downward force to the spring and rubber band
100 g mass hanger	To hold additional masses
Pointer (also called a fiducial marker)	To accurately read the extension from the ruler
G-clamp	To secure the clamp stand to the bench so that the equipment does not fall over

- **Resolution** of measuring equipment:
    - Ruler = 1 mm



Example set-up of the equipment used to investigate force and extension for a spring

Method

1. Align the marker to a value on the ruler with no mass added, and record this initial length of the spring / rubber band
2. Add the 100 g mass hanger onto the spring / rubber band
3. Record the mass (in kg) and position (in cm) from the ruler now that the spring / rubber band has extended
4. Add another 100 g to the mass hanger
5. Record the new mass and position from the ruler now that the spring / rubber band has extended further
6. Repeat this process until all masses have been added
7. Remove the masses and repeat the entire process again, until it has been carried out a total of three times, and an average length (for each mass attached) is calculated

Example results table

F = mg

AVERAGE LENGTH – ORIGINAL

MASS/kg	FORCE/N	LENGTH 1/m	LENGTH 2/m	LENGTH 3/m	AVERAGE LENGTH/m	EXTENSION/m
0						
0.1						
0.2						
0.3						
0.4						
0.5						
0.6						

Analysis of results

- The force, *F* added to the spring / rubber band is the **weight** of the mass
- The weight is calculated using the equation:

$$W = m \times g$$

- Where:
  - W = weight in newtons (N)
  - m = mass in kilograms (kg)
  - g = gravitational field strength on Earth in newtons per kg (N/kg)
- Therefore, multiply each mass by gravitational field strength, *g*, to calculate the force, *F*
  - The force can be calculated by multiplying the mass (in kg) by 10 N/kg
- The **extension *x*** of the spring / rubber band is calculated using the equation:

x = average length – original length

- The final length is the length of the spring / rubber band recorded from the ruler after the masses were added
- The original length is the length of the spring / rubber band when there were **no** masses attached

1. Plot a graph of the force against extension for the spring / rubber band / metal wire
2. Draw a line or curve of best fit
3. If the graph has a **linear** region (is a straight line), then the force is **proportional** to the extension

Evaluating the experiments

Systematic errors

- Make sure the measurements on the ruler are taken at eye level to avoid **parallax error**

Random errors

- The accuracy of such an experiment is improved with the use of a pointer (a fiducial marker)
- Wait a few seconds for the spring / rubber band to fully extend when a mass is added, before taking the reading for its new length
- Make sure to check whether the spring has not gone past its **limit of proportionality** otherwise, it has been stretched too far

Safety considerations

- Wear goggles during this experiment in case the spring or rubber band snaps.
- Stand up while carrying out the experiment, making sure no feet are directly under the masses.
- Place a mat or a soft material below the masses to prevent any damage in case they fall
- Use a G clamp to secure the clamp stand to the desk so that the clamp and masses do not fall over.
- As well as this, place each mass carefully on the hanger and do not pull the spring so hard that it breaks or pulls the apparatus over.

Examiner Tips and Tricks

Remember - for the spring and rubber band, the extension measures how much the object has stretched by and can be found by **subtracting the original length from each of the subsequent lengths.**

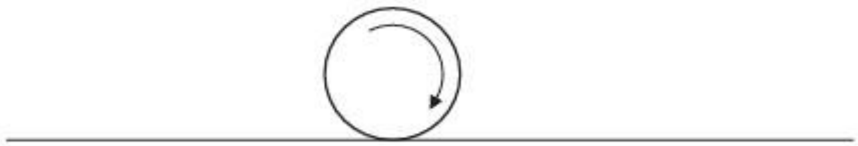
A common mistake is to calculate the increase in length by each time instead of the total extension. If each of your extensions is roughly the same, then you might have made this mistake!

Past papers questions:

1- (4Ph0-W 2015- paper 1P – Q13)

A golfer practises hitting balls on a golf course.

(a) Ball X rolls along level ground, as shown in the diagram.



(i) Add labelled arrows to the diagram to show the directions of two of the forces acting on ball X.

(2)

(ii) Explain why ball X slows down and stops.

(3)

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(b) The golfer hits ball Y at an angle into the air.

He gives it the same initial kinetic energy as ball X.

Suggest why ball Y travels much further than ball X before it stops.

(1)

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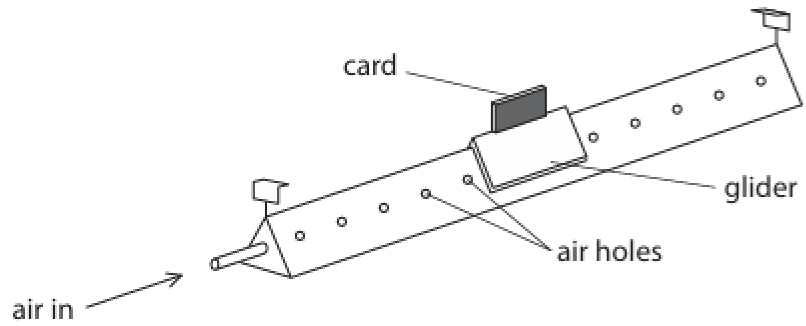
2- (4Ph0-W 2016- paper 1P – Q4)

The diagram shows an air track that can be used to investigate motion.

Air comes out through a series of small holes in the air track.

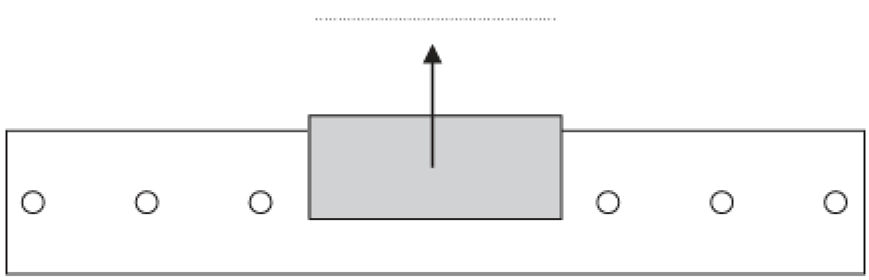
A small glider floats on a cushion of air.



(a) (i) The diagram below shows the glider at rest on the air track.

Complete the diagram to show the forces acting on the glider.
Label the forces.
One force arrow has been drawn for you.

(3)



(ii) Explain what effect the cushion of air has on the movement of the glider.

(2)

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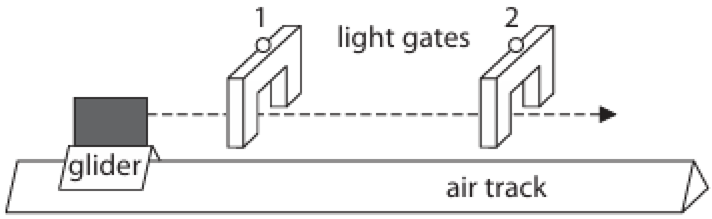
(b) Two light gates connected to a data logger are placed above the air track so that the card will pass through them.

The glider moves at a constant speed to the right.



The length of the card is 8.3 cm.

The card takes 314 ms to pass through the first light gate.

(i) State the relationship between average speed, distance moved and time taken.

(1)

(ii) Calculate the average speed of the card as it passes through the first light gate.

(2)

average speed = ... cm/s

(iii) State the time taken for the card to pass through the second light gate.

(1)

time taken = ...ms

(Total for Question 4 = 9 marks)

3- (4Ph0-S 2016- paper 1P – Q8)

A student investigates whether a spring obeys Hooke's law.

She uses the apparatus shown in the photograph.

(a) Which additional measuring instrument does the student need for the investigation?

(1)

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(b) Explain how the student can investigate whether the spring obeys Hooke's law.

(5)

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(Total for Question 8 = 6 marks)

4- (4Ph0-W 2016- paper 1P – Q11)

A student investigates the extension of an elastic band for different forces.

(a) (i) List the laboratory apparatus that the student needs for this investigation.

(3)

(ii) Extension, force and temperature are variables for this investigation.

Draw a line from each variable to its type.

(2)

variable	**type of variable**
extension	control
force	dependent
temperature	independent

(iii) Describe how the student can measure the extension of the elastic band when he adds a force of 12 N.

(2)

(b) The student obtains this data as he first adds weights to the elastic band (loading) and as he then removes weights from the band (unloading).

Force in N	Extension in cm
	Loading
0	0.0
2	2.3
4	5.3
6	9.8
8	15.3
10	20.0

Force in N	Extension in cm
	Unloading
0	0.0
1	1.4
3	5.0
7	14.8
9	19.1
10	20.0

He plots the loading data on a graph as shown.

(i) Suggest how the student could improve the quality of his data.

(2)

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(ii) Draw a curve of best fit through the loading data.

(1)

(iii) On the same axes, plot the unloading data.

(2)

(iv) Draw a curve of best fit through the unloading data.

(1)

(v) The student concludes that the band is an elastic material and that it obeys Hooke's law.

Discuss whether his conclusion is correct.

You should support your argument with data.

(3)

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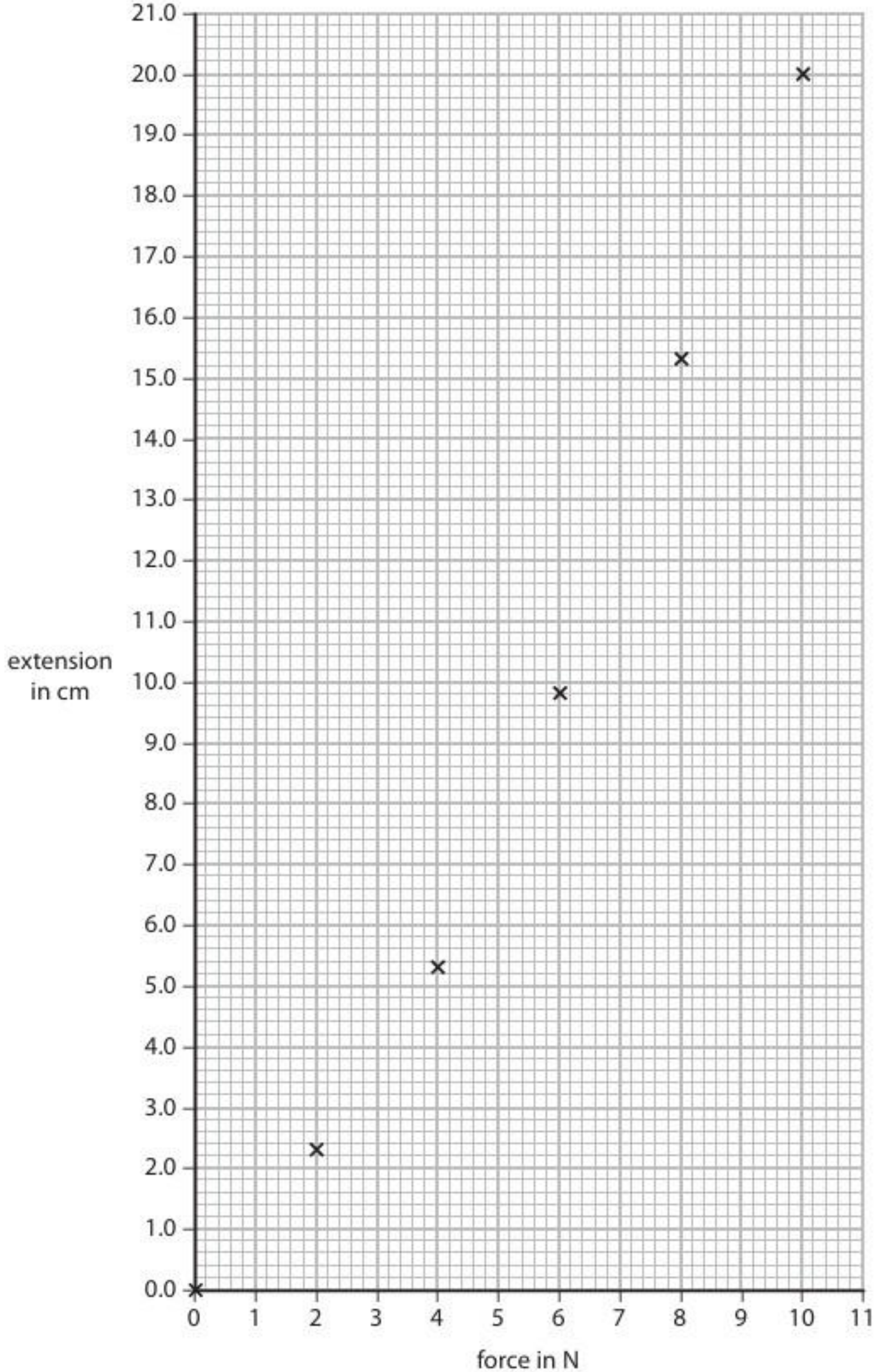

(Total for Question 11 = 16 marks)

5- (4Ph0-W 2015- paper 2P – Q4)

4 A student investigates the stretching of rubber bands.

She stretches four rubber bands as shown in the photograph.

She applies a force of 5.0 N and measures the length of the rubber bands.

She repeats the experiment with different numbers of rubber bands, using a force of 5.0 N each time.

The table shows her results.

Number of rubber bands	Stretched length in cm
1	43.2
2	28.0
3	21.5
4	
5	17.6
6	17.0

(a) (i) Estimate the length of the four rubber bands shown in the photograph and use your value to complete the table.

(1)

(ii) Suggest two reasons why your estimate may not be accurate.

(2)

1 ....

....

2 ....

....

(b) Suggest how the student made this investigation a fair test.

(1)

....

....

(c) (i) The number of rubber bands is a series of whole numbers.

State the name of this type of variable.

(1)

....

(ii) Display the results of the student's investigation on the grid.

(4)

(iii) Describe the relationship between the number of rubber bands and the stretched length.

(2)

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(Total for Question 4 = 11 marks)

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