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Oxford Cambridge and RSA

AS and A LEVEL

Delivery Guide

PHYSICS A

H156/H556
For first teaching in 2015

Kinematics and Dynamics

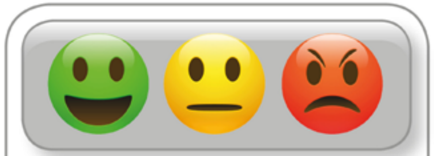
Version 2

AS and A LEVEL
PHYSICS A

Delivery guides are designed to represent a body of knowledge about teaching a particular topic and contain:

- Content: A clear outline of the content covered by the delivery guide;
- Thinking Conceptually: Expert guidance on the key concepts involved, common difficulties students may have, approaches to teaching that can help students understand these concepts and how this topic links conceptually to other areas of the subject;
- Thinking Contextually: A range of suggested teaching activities using a variety of themes so that different activities can be selected which best suit particular classes, learning styles or teaching approaches.

If you have any feedback on this Delivery Guide or suggestions for other resources you would like OCR to develop, please email resources.feedback@ocr.org.uk



Module 3: Forces and motion

The term 'force' is generally used to indicate a push or a pull. It is difficult to give a proper definition for a force, but in physics we can easily describe what a force can do.

A resultant force acting on an object can accelerate the object in a specific direction. The subsequent motion of the object can be analysed using equations of motion. Several forces acting on an object can prevent the object from either moving or rotating. Forces can also change the shape of an object. There are many other things that forces can do.

In this module, learners will learn how to model the motion of objects using mathematics, understand the effects that forces have on objects, learn about the important connection between force and energy, appreciate how forces cause deformation and understand the importance of Newton's laws of motion.

Learners will observe what motion is, and then seek to explain it in terms of the forces acting upon it. Some of the material may be counter-intuitive at first (for example, a moving object may well have zero resultant force acting upon it), but the acceptance by the student of the idea of forces acting in pairs is crucial for progress. Once this has been achieved, the motion of objects can be more deeply understood, calculated and predicted.

The equations of motion are powerful tools for measuring and predicting the motion of objects in situations where there is uniform acceleration. The division of motion into vertical and horizontal components is a challenge at first, but this skill is fundamental to understanding the motion of projectiles. There are many experiments that the student can use to investigate projectile motion, both inside and outside the classroom.

The effect of forces on objects are elegantly summarised in Newton's Laws of Motion, and these can be investigated using simple practical approaches. The difference between mass and weight needs to be understood at an early stage, and the use of free body diagrams in describing the forces acting on objects is an important aid to visualising situations where many forces are acting. The presence of balanced forces acting on objects in a state of uniform motion can challenge the student's perception of the world around them, and the shifting of the student's perception to a better understanding of forces is a key milestone in successful A level study.

Explaining terminal velocity in terms of the forces acting on an object as it passes through a resistive medium allows learners to develop their literary descriptive skills alongside an understanding of how the forces acting on an object change as the velocity of the object changes. Clear scientific explanation using sound physics principles is a key skill at A level and beyond, and the proper use of technical vocabulary in clearly written scientific explanations is a key learning outcome.

The concept of turning forces present in equilibrium systems can present significant difficulties to the student, but these are usually of visualisation. The learner should be first introduced to a simple single pivot system (such as in Learner Resource 1), and successful completion of this practical activity will allow the learner to access more complex systems involving more than one pivot point. The key to success is the identification of a suitable pivot point at which to use the Principle of Moments – systems that seem at first to be rather complex soon turn out to be simple when the Principle is properly applied. Learners can be concerned about the level of mathematical skill required in moments questions but they need not be – provided the pivot point is chosen sensibly, building the mathematical model is a simple process and solving it needs no more than simple simultaneous equation solving techniques.

The concept of the centre of mass is an important one in physics, and its definition is a simple one. The experimental location of the centre of mass for regular and irregular objects is covered in the Thinking Contextually section, and this can provide the student with an elegant and memorable learning experience.

Equilibrium systems with more than two forces acting are dealt with using the Triangle of Forces. The student can use both mathematical and drawing methods to determine the magnitudes and directions of the three forces acting, and the equivalence of the two techniques can be seen as a validation of both. Learners are known to enjoy competitive challenges, and the competition between mathematical and diagrammatical methods to determine the Triangle of Forces can provide a sense of victory as well as a better insight into how forces act.

The final part of the Module looks at the forces that solids, liquids and gases can exert on each other. The density of an object is a simple concept, but its measurement, especially for irregular objects, can seem daunting. However, learners can determine the volume of irregular objects using the same technique as Archimedes did many centuries ago in Ancient Greece, showing that whilst some ideas change with time, the fundamental principles of physics do not. The concept of pressure is introduced for solids, liquids and gases (the idea that gas can exert considerable pressure can come as a surprise to some learners), and the idea of liquids exerting upwards forces on solids allows learners to understand why some objects float and some do not.

Practical activities covered by the material in this module fit into PAG1 Investigating motion, and also into PAG10 Investigating Simple Harmonic Motion, PAG11 Investigation and PAG12 Research Skills. All of the How Science Works (HSW) elements (HSW 1 to HSW 12) can also be addressed by a suitable combination of the practical activities described in this Delivery Guide. Assessment Objectives AO1 to AO3 are also met by the material and suggested activities in this Module.

3.1 Motion

This section provides knowledge and understanding of key ideas used to describe and analyse the motion of objects in both one-dimension and in two-dimensions. It also provides learners with opportunities to develop their analytical and experimental skills.

3.1.1 Kinematics

The motion of a variety of objects can be analysed using ICT or data-logging techniques (HSW3). Learners also have the opportunity to analyse and interpret experimental data by recognising relationships between physical quantities (HSW5).

(a) displacement, instantaneous speed, average speed, velocity and acceleration

(b) graphical representations of displacement, speed, velocity and acceleration

(c) displacement-time graphs; velocity is gradient

(d) velocity-time graphs; acceleration is gradient; displacement is area under graph.

3.1.2 Linear Motion

(a)

(i) the equations of motion for constant acceleration in a straight line, including motion of bodies falling in a uniform gravitational field without air resistance

$v = u + at \quad s = \frac{1}{2}(u + v)t$

$s = ut + \frac{1}{2}at^2 \quad v^2 = u^2 + 2as$

These equations of motion are given on the Data Sheet, but it is very important that learners are able to select and manipulate the correct equation to find the required unknown quantity, using mathematical techniques at Level 2.

(ii) techniques and procedures used to investigate the motion and collisions of objects

(b)

(i) acceleration *g* of free fall (example method shown in the Practical Activity 1.2 'Determining the Terminal Velocity in a Viscous Liquid')

(ii) techniques and procedures used to determine the acceleration of free fall using trapdoor and electromagnet arrangement or light gates and timer as detailed in Practical Activity 1.1

(c)

reaction time and thinking distance; braking distance (as shown in the Practical Activity and stopping distance for a vehicle)

3.1.3 Projectile motion

(a) independence of the vertical and horizontal motion of a projectile

(b) two-dimensional motion of a projectile with constant velocity in one direction and constant acceleration in a perpendicular direction.

3.2 Forces in action

This section provides knowledge and understanding of the motion of an object when it experiences several forces and also the equilibrium of an object. Learners will also learn how pressure differences give rise to an upthrust on an object in a fluid.

Experimental work must play a pivotal role in the acquisition of key concepts and skills (HSW4).

3.2.1 Dynamics

(a) net force = mass x acceleration; $F = ma$

(b) the newton as the unit of force

(c) weight of an object; $W = mg$

(d) the terms tension, normal contact force, upthrust and friction

(e) free-body diagrams

(f) one- and two-dimensional motion under constant force.

3.2.2 Non-linear motion

(a) drag as the frictional force experienced by an object travelling through a fluid

(b) factors affecting drag for an object travelling through air

(c) motion of objects falling in a uniform gravitational field in the presence of drag

(d) (i) terminal velocity

(ii) techniques and procedures used to determine terminal velocity in fluids.

3.2.3 Equilibrium

(a) moment of force

(b) couple; torque of a couple

(c) the principle of moments

(d) centre of mass of an object and its experimental determination

(e) equilibrium of an object under the action of forces and torques

(f) condition for equilibrium of three coplanar forces; triangle of forces.

3.2.4 Density and pressure

(a) density; $\rho = \frac{m}{V}$

(b) pressure; for solids, liquids and gases $p = \frac{F}{A}$

(c) $p = h\rho g$; upthrust on an object in a fluid; Archimedes' Principle.

Learner Activity 1

PAG 1.2 from our practical endorsement resources provides a method of measuring the terminal velocity of an object in a viscous fluid. The activity introduces learners to the concept of terminal velocity and viscosity by observing the motion of a ball bearing through a viscous liquid. Direct measurement allows the plotting of a velocity-time graph for the ball bearing as it falls past a series of distance markers, and filming of the motion of the ball bearing (as an extension activity) enables the student to check their measurements and further analyse the motion using smaller time increments if appropriate.

Learner Activity 2

Projectile motion can be studied using inclined plane experiments and video analysis of projectiles in motion (such as https://spark.iop.org/episode-207-projectile-motion#gref). Outdoor experiments using projectiles such as tennis balls, coupled with simple filming and measurement methods, allow the difference between vertical and horizontal motion to be investigated, as well as the optimal angle of launch to achieve the greatest horizontal and vertical range. Experiments such as these allow the learners to clearly visualise the difference between vertical and horizontal motion, and that the separation of the motion into vertical and horizontal components is often a key step in solving examination questions on this topic area.

Learner Activity 3

Free-fall experiments using dataloggers and timing gates are an excellent way of introducing the learner to the concept of the acceleration produced by the action of a gravitational field upon a mass placed within it. An example of an experimental technique to measure the value of g is given at https://spark.iop.org/investigating-free-fall-light-gate.

Learner Activity 4

A simple practical exercise in using the Principle of Moments in a single pivot system to measure the weight of a metre rule is given in Learner Resource 1. This setup could be extended to study the effect of multiple pivots, and if learners trialled the experiment using a single finger as a pivot point, they could gain an important qualitative insight into the different forces acting at different pivot points.

Thinking conceptually

Approaches to teaching the content

This theme introduces learners to the study of kinematics (which describes the motion of objects) and dynamics (which explains the motion of objects in terms of the forces acting). Learners should be given opportunities to gain knowledge of, and gain confidence in, methods of making measurements on moving objects, as well as on objects in equilibrium situations. Such opportunities should include the proper use of technical terms in appropriate contexts, making careful measurements of physical quantities using appropriate equipment, the handling and analysis of data and the use of graphical methods to analyse data and calculate quantities (eg displacement as the area underneath a velocity-time graph).

The theme starts with the observation and measurement of motion. Why do objects move? Why do they accelerate or decelerate? The answer is of course in the idea of forces, but they do come in pairs. This can seem a strange concept at first, but learners will need to accept it in order to successfully move on.

The motion of a variety of objects can be studied using a range of techniques, from simple distance-time measurements using a stopwatch and metre rule to measurement of displacement, velocity and acceleration using readily available datalogging techniques and accelerometers (building a simple accelerometer using a card, string, small bob and a protractor is a useful student extension exercise, especially when it comes to calibrating it). The graphical representation of motion can be learned using student measurement data, and several datalogging techniques allow this to be accomplished relatively easily. Learners can use such facilities to develop their IT analysis skills using the output from such datalogging techniques.

The equations of motion under conditions of uniform acceleration can be introduced after the basics of motion are learned. Laboratory techniques using inclined planes are useful in visualising the path of projectiles (particularly so if the small spheres being used are dipped in ink prior to launch on an inclined plane with paper placed on it), and the filming of real objects using simple apparatus can give the student an important insight into the separation of vertical and horizontal motion.

Measurement of *g* using free-fall techniques involving light gates and timers are well-established, and modern datalogging equipment offers plenty of scope for data acquisition. The data obtained in such experiments may also be useful in comparing the value of *g* obtained with that from pendulum experiments later in the course. Such experiments can also be a very good starting point for discussions of sources of experimental uncertainty, and the improvement of the technique to obtain values of *g* that are closer to the accepted value.

Many learners that are studying this module may be undergoing a course of driving instruction, or be considering doing so. The introduction of the material on the factors involving the stopping distances of vehicles is therefore very timely and relevant, and is sure to start discussion amongst the Learners. Pacing out the distances required for a vehicle to stop under normal conditions from a range of initial velocities can act as a surprising reminder for young drivers, and the effects of distraction and sub-standard vehicle condition factors will be a shock to some.

Newton's Laws of Motion are fundamental to physics, and the material introducing $F=ma$ should already be familiar from GCSE study. However, the difference between mass and weight is not always well-understood, even at A level. The visualisation of forces in free body diagrams is an important tool to solving forces problem and the presence of some unexpected forces such as upthrust can be developing using such diagrams.

Non-linear motion reveals more of the real world to learners, since the presence of resistive forces is made real by the observation of small steel ball bearings falling through a viscous liquid. The effects of drag can be investigated using a practical approach, and the written descriptive skills of learners can be developed by exercises requiring a description of terminal velocity. Clear written explanations are a key part of communicating good physics, and this area offers an opportunity to continue to foster the development of such skills.

The idea of a turning force is a simple one, but its application to a wide variety of situations is something that challenges learners. The use of the Principle of Moments in simple single pivot systems should be investigated first before the wider use of moments is taught. Learners could develop their qualitative knowledge of the forces acting at more than one pivot point by using their fingers to balance a metre rule, and this can then be developed into studies of equilibrium systems such as bridges. The mathematics involved in the study of moments can sometimes be daunting for less confident learners, but an emphasis on the proper drawing of the equilibrium system and sensible choice of a suitable pivot point should allay most of the difficulties.

The Triangle of Forces for systems in equilibrium is a useful tool in solving problems, and learners with lower level mathematical skills can gain confidence by finding that the result of a drawing can be also calculated using simple mathematical tools – agreement between the two methods can often rid a learner of the thought that they cannot cope with the mathematics of physics.

The module ends with studying the forces that solids, liquids and gases can exert on one another. The density of regular solids is reasonably simple to ascertain, but the measurement of the volume of irregular solids can be a challenge until learners employ the method by Archimedes in Ancient Greece – learners could experience their own "Eureka" moment in connecting with physics from several centuries ago. The pressure exerted by liquids and gases can be investigated by reasonably simple techniques – the collapsing can experiment is an excellent introduction to the world of air pressure. The upthrust exerted by a liquid on a solid returns to the starting concept of forces acting in pairs, and so closes the loop on the student's journey through Forces and Motion.

It is important to encourage the discussion of experimental results and uncertainty in measurements, and this particular area is very well-suited to this key aspect of experimental physics. Such discussion should not be limited to results obtained in the learner's own laboratory, as there is much to be learned from a critical examination of data obtained by others. This should be aimed at developing a better understanding of repeatability and reproducibility, as well as increasing an appreciation of the effects of experimental uncertainties.

Learners should be encouraged to link their growing understanding of kinematics and dynamics to situations that they encounter in everyday life, such as the motion of vehicles, the motion of various objects during sporting activities and the design and construction of objects from bookcases to bridges.

Common misconceptions or difficulties learners may have

A particular difficulty for learners is the concept of terminal velocity, chiefly in explaining why an object will continue in uniform motion when the resultant force acting upon it is zero. The changes in forces acting (such as air resistance) with increasing velocity of a falling object is often overlooked by learners.

The calculation of the trajectory followed by projectiles can present difficulties, especially when vertical and horizontal motion are confused or not treated separately. The selection of the correct equation of motion from the data supplied, along with correct rearrangement of the formula, has proved problematic, and it is very important that learners can select and rearrange formulae correctly.

Learners may also encounter difficulty with the concept of forces acting in opposite pairs. This is even true in everyday situations, such as a football in flight, and the concept of pairs of coplanar forces needs to be firmly established in the minds of the learners.

The meaning of the word 'equilibrium' may also present difficulties, especially in systems where an understanding of balanced turning forces is required. Identification of a suitable pivot point for the first calculation is a common problem. It is essential that learners have a sound knowledge of simple moments before tackling the more advanced work on systems with multiple pivots, and selection of a suitable second pivot point after the first one has been dealt with can be a significant issue. The mathematics of moments can be daunting at first, but learners can address this through successful tackling of problems involving a single pivot point before moving on to more complicated systems. However, a solid understanding of solving of simple simultaneous equations for two variables is expected, and should be firmly established in the learner's mathematical toolkit.

The correct units and terminology for the quantities introduced in a study of kinematics and dynamics can also present difficulties, especially in the difference between scalar and vector quantities (such as velocity and speed, and displacement and distance), the proper units for the quantities involved (especially acceleration, moment and pressure) and in the correct rearrangement of the equations of motion to find expressions for unknown quantities. The differences between displacement-time and velocity-time graphs can also prove problematic.

As in all parts of the course dealing with the collection and analysis of experimental data, the terms 'range', 'uncertainty' and 'percentage uncertainty' can cause confusion, as can the rules for the correct combination of percentage uncertainties from measured quantities into a single percentage figure for a calculated quantity. There may also be potential issues with the correct plotting of data, the correct calculation of the gradient of a graph, and the expression of the correct unit for the gradient of a graph. The OCR Practical Skills Handbook https://www.ocr.org.uk/Images/295483-practical-skills-handbook.pdf gives further guidance on these and many other matters.

The basic but abstract concepts of forces and energy are used frequently in Physics. It is important that the two areas are properly grasped by the student, and not confused or inappropriately overlapped.

Conceptual links to other areas of the specification – useful ways to approach this topic to set learners up for topics later in the course.

This theme gives much opportunity to develop an understanding of the difficulties in taking measurements of various physical quantities. It is possible that these have been introduced earlier in the course, but the range of measurement opportunities offered in this theme gives learners plenty of scope to develop their measurement and analytical skills. The methods of dealing with a spread of results, such as calculation of range, uncertainty and percentage uncertainty and the graphical representation of these, can be developed in this theme. The activities that support the material in this theme also offer plenty of opportunity to develop good practice in the identification of the largest uncertainty in an experiment, and the constructive criticism and analysis of the measurement methodologies used. Such methodologies include speed cameras (eg Gatso units), and the techniques used to gain position and time data for speed calculations. Criticism could include proper setting up and initial calibration of the equipment, and whether such equipment is maintained within calibration.

Determination of *g* using free fall methods could be compared with methods using pendulum motion (covered in A level physics Module 5) as a useful exercise in comparing and contrasting different experimental techniques.

Learner Activity 1

Learner Resource 1 is a simple introduction to the use of the Principle of Moments in determining the mass of a simple object. After completion, it could be developed by the Learners using two fingers to act as pivot points, and they can then qualitatively feel the difference in the support forces acting on the two pivot points. This should open the way to successfully tackling two support problems.

Learner Activity 2

Acceleration during linear motion (such as a trolley down an incline) can be measured using ticker-timers (eg https://spark.iop.org/collections/time-distance-and-speed) but video filming of acceleration can also be used. This can be related to sudden decelerations in vehicle impacts, and could form the basis of a student project on the acquisition and use of acceleration data. An understanding of acceleration and deceleration is fundamental to several parts of the course where forces are acting on objects, eg magnetic fields acting on moving charge-carrying particles and circular motion.

Learner Activity 3

The determination of g using free-fall apparatus is a well-established experiment (eg see measurement of g using an electronic timer resource at https://spark.iop.org/collections/acceleration-due-gravity.) but the free fall of a ball bearing in air could be compared against the fall of a ball bearing through a viscous fluid (eg PAG1.2 'Terminal Velocity'). This could lead to a comparison on terminal velocities in fluids of different viscosities, or to project work on the most suitable technique for spacecraft to achieve a 'soft' landing on other planetary bodies in the Solar System or beyond.

Thinking contextually

Activities

In order for the learner to gain a full understanding of the material covered in this Module, it is important that they have a good firm understanding of the basic terminology of kinematics and dynamics. Once this is complete, they can set out on their journey through the Forces and Motion areas described in the Specification.

The sequence described in this section is intended to steadily build the Learners' knowledge and skills in the areas described, so they may confidently move on to the next section.

However, the sequence described in this section is in no way a rigid framework and it does not need to be followed in this set order.

Activities

Learner Activity 1

Definition of quantities and units

The topic can start with Learners becoming familiar with the terminology of kinematics and the quantities used. An exercise in matching quantities and units in given in Learner Resource 2. An exercise in the correct use of prefixes, and the appreciation of the magnitude of quantities, is given in Learner Resource 3.

Learner Activity 2

Speed, velocity and acceleration

The topic can start with the Learners measuring simple motion of an object using distance and time data, eg https://spark.iop.org/collections/time-distance-and-speed. Measurements of instantaneous speed may be made using light gates or similar apparatus, eg https://spark.iop.org/episode-206-uniform-and-non-uniform-acceleration. Average speed may be measured using raw distance-time data, or by datalogging. Displacement-time data can be obtained using similar techniques. Velocity-time graphs can be obtained using datalogging techniques, and these can then be analysed to find acceleration. Alternatively, displacement-time data and acceleration may be derived from ticker timer data, eg https://spark.iop.org/collections/time-distance-and-speed.

Learner Activity 3

Linear Motion

The motion of objects may be studied using video capture techniques, eg the resource for multiflash photographs of free fall, and acceleration due to gravity may be calculated using data obtained from free fall experiments, eg the resource for investigating free fall with a light gate, or the resource for measurement of *g* using an electronic timer https://spark.iop.org/collections/acceleration-due-gravity.

Learner Activity 4

Reaction time data may be obtained using data logging techniques, and the effects of various factors on reaction time may be studied using simulation programmes freely available on the Web, eg https://www.stoppingdistances.org.uk/.

Learner Activity 5

Projectile motion may be studied using inclined plane experiments, or by video filming of projectiles in motion, eg https://spark.iop.org/episode-207-projectile-motion#gref. The separation of projectile motion into vertical and horizontal components is crucial to a successful understanding of projectile motion, and should be developed through practical work eg the resource on independent vertical and horizontal motions at https://spark.iop.org/collections/components-motion.

Learner Activity 6

Dynamics – this part of the course builds on the kinematics material to build a firm understanding of the underlying principles of dynamics. The introduction is through Newton's Second Law ($F=ma$) and experiments such as those found at https://spark.iop.org/collections/force-mass-and-acceleration-newtons-second-law and https://spark.iop.org/episode-211-newtons-second-law-motion. The differentiation between the terms "mass" and "weight" is important, eg https://spark.iop.org/mass-and-weight. The difference between scalar and vector quantities should also be clarified, eg http://www.schoolphysics.co.uk/age16-19/glance/Mechanics/Vectors_and_scalars/index.html.

Learner Activity 7

Non-linear motion – this topic area investigates concepts such as drag forces experienced by objects, and then moves on to consider terminal velocity, eg https://spark.iop.org/episode-209-drag-air-resistance-terminal-velocity.

Learner Activity 8

Equilibrium investigates the use of the simple concept of moments, eg https://spark.iop.org/episode-203-turning-effects, and then shows how this simple concept can be applied in a wide range of situations, eg https://spark.iop.org/collections/friction-turning-and-other-effects. Learner Resource 1 contains a simple experiment to introduce the concept of moments.

Simple techniques for determining the centre of mass of objects can be investigated, eg https://spark.iop.org/episode-203-turning-effects and www.schoolphysics.co.uk/age11-14/Mechanics/Statics/experiments/centre_of_mass.doc.

The triangle of forces is well-suited to experimental investigation, eg https://spark.iop.org/episode-202-forces-equilibrium and http://www.animatedscience.co.uk/ks5_physics/general/Mechanics/Forces.htm.

Learner Activity 9

The calculation of the density of a regularly shaped object is relatively straightforward, eg https://spark.iop.org/collections/measuring-density. Measuring the density of irregularly shaped objects by the displacement method is also straightforward, eg http://www.youtube.com/watch?v=ovdE_-FCWpc. The concept of pressure exerted by solids, liquids and gases can be investigated using many methods, eg https://spark.iop.org/collections/pressure. Upthrust is sometimes a difficult concept for learners, but its presence and effect (and introduction to $p = h\rho g$) can be investigated using fluids of varying viscosity, eg https://spark.iop.org/falling-through-high-viscosity-liquid.

Determining the mass of a metre rule using the Principle of Moments

Introduction

In this experiment, you will determine the mass of a metre rule using a 1 N weight, a single pivot point and the Principle of Moments. As an extension task, you could introduce more pivot points and more weights to use the Principle of Moments to determine the value of unknown quantities in equilibrium systems with more than one pivot point.

Equipment required:

- Uniform metre rule with graduated scale
- A loop of light string or cotton
- A 1 N weight Hanger. (preferably one with a hook on the end to attach to the loop of light string or cotton)
- A clamp stand with a clamp attached (the metal bar on the stand acts as the pivot point)
- Laboratory scales (to check your value for the weight of the ruler)

Method

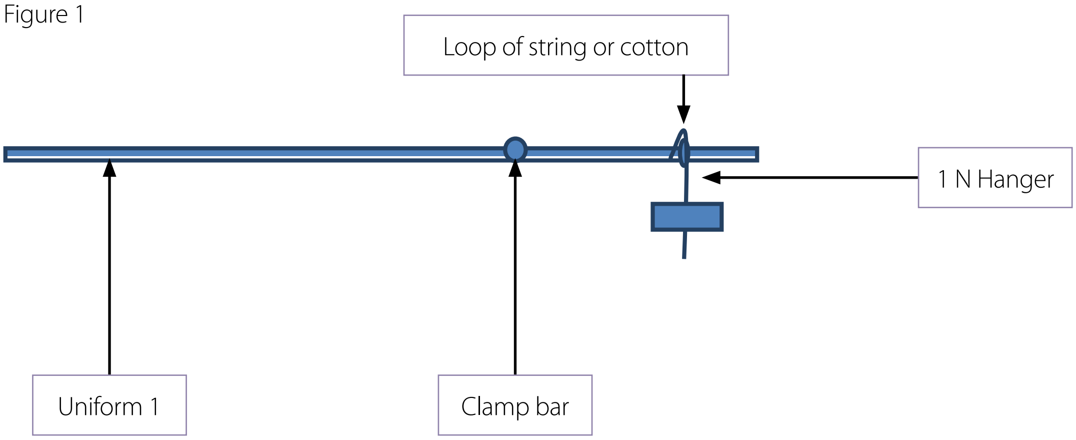
- Attach the 1 N weight to the metre rule by tying it to the rule using the loop of string. Locate the loop at the 90 cm mark on the rule.
- Then balance the metre rule on the metal bar protruding from the boss on the clamp stand. You will need to take care to ensure that the clamp stand is clamped to the bench, be careful not to overbalance the ruler, or to drop the weight. The setup is shown in Figure 1 next page.
- Record the location of the pivot point on the ruler.
- Now calculate the weight of the ruler using the Principle of Moments. You may assume that the centre of mass of the ruler is at the 50 cm point.
- You should find the anticlockwise moment around the pivot point by measuring the distance from the loop of string to the pivot, and multiplying it by the weight of the Hanger?
- You should find the clockwise moment by measuring the distance between the pivot point and the 50 cm mark on the ruler, and multiplying it by the unknown weight of the ruler.
- The Principle of Moments states that for a system in equilibrium, the total anticlockwise moment around a pivot point should equal the total clockwise moment.
- Use the Principle of Moments to calculate the weight of the ruler.
- Use the laboratory scales to check your answer.
- What is the main cause of uncertainty in your answer?

Determining the mass of a metre rule using the Principle of Moments

Extension

- Use more than one Hanger with different weights, and more than one pivot point. Can you use the Principle of Moments to predict the location of pivot points with different arrangements of weights, and could you use it to find unknown weights?

Figure 1



Learner Resource 2

Quantities and units

Match the quantity (red) and unit (blue), then state whether it is a scalar or vector quantity (green).

Velocity	m	Vector
Speed	$m\,s^{-2}$	Vector
Distance	N	Vector
Time	kg	Vector
Displacement	$m\,s^{-1}$	Vector
Acceleration	$m\,s^{-1}$	Vector

Quantities and units

Match the quantity (red) and unit (blue), then state whether it is a scalar or vector quantity (green).

Mass	N	Vector
Weight	N m	Scalar
Force	m	Scalar
Moment	kg m^{-3}	Scalar
Density	N m^{-2}, Pa	Scalar
Pressure	s	Scalar

Quantities and units

Below are the answers to the Learner Resource 2 card sort activity.

Velocity	$m\,s^{-1}$	Vector
Speed	$m\,s^{-1}$	Scalar
Distance	m	Scalar
Time	s	Scalar
Displacement	m	Vector
Acceleration	$m\,s^{-2}$	Vector
Mass	kg	Scalar
Weight	N	Vector
Force	N	Vector
Moment	N m	Vector
Density	$kg\,m^{-3}$	Scalar
Pressure	$N\,m^{-2}$, Pa	Vector

Powers of ten and prefixes

Match the measured quantity in the left-hand column (red) with the correct statement in the centre column (blue), and the type of quantity in the right-hand column (green).

320 km h^{-1}	5.5 x 10^3 m (5.5km)	Displacement (lap of average Formula 1 track)
0.001 N	88.9 m s^{-1}	Time (length of senior hockey match)
5 500 m	1 × 10^{-3} N (1 mN)	Maximum speed of Formula 1 car
70 minutes	1.134 × 10^4 kg m^{-3}	Force (very small)
400 ms	4.4 × 10^4 kg	Moment (wheel nut torque on car)
11.34 gcm^{-3}	4.2 × 10^3 s (4200 s)	Time for complete blink of human eye

Powers of ten and prefixes

Match the measured quantity in the left-hand column (red) with the correct statement in the centre column (blue), and the type of quantity in the right-hand column (green).

0.000000000165 m	1.3×10^{2} Nm	Pressure (normal room pressure)
44 000 kg	6.770×10^{3} N (6.77 kN)	Distance (radius of silver atom)
6770 N	1.65×10^{-10} m (165 pm)	Density of lead at room temperature
1400 ms^{-2}	1×10^{5} Pa (100 kPa)	Weight of Formula 1 car (minimum)
100 000 Nm^{-2}	1.4×10^{3} m s^{-2}	Mass of loaded articulated lorry
130 Nm	4.0×10^{-1} s	Acceleration of cat flea when jumping

Powers of ten and prefixes

Below are the correct matches for the Learner Resource 3 card sort activity.

0.001 N	$1 \times x\, 10^{-3}$ N (1 mN)	Force (very small)
5 500 m	5.5×10^{3} m (5.5 km)	Displacement (lap of average Formula 1 track)
70 minutes	4.2×10^{3} s (4200 s)	Time (length of senior hockey match)
320 kmh^{-1}	88.9 ms^{-1}	Maximum speed of Formula 1 car
130 Nm	1.3×10^{2} Nm	Moment (wheel nut torque on car)
44 000 kg	4.4×10^{4} kg	Mass of loaded articulated lorry

Powers of ten and prefixes

Below are the correct matches for the Learner Resource 3 card sort activity.

11.34 g cm^{-3}	1.134 × 10^4 KGM^{-3}	Density of lead at room temperature
100 000 N m^{-2}	1 × 10^5 Pa (100 kPa)	Pressure (normal room pressure)
400 ms	4.0 × 10^{-1} s	Time for complete blink of human eye
0.000000000165 m	1.65 × 10^{-10} m (165 pm)	Distance (radius of silver atom)
6770 N	6.770 × 10^3 N (6.77 kN)	Weight of Formula 1 car (minimum)
1400 ms^{-2}	1.4 × 10^3 m s^{-2}	Acceleration of cat flea when jumping

Did you know?

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