Fundamental MECHANICS

Statics Fundamentals

CP6368
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Contents

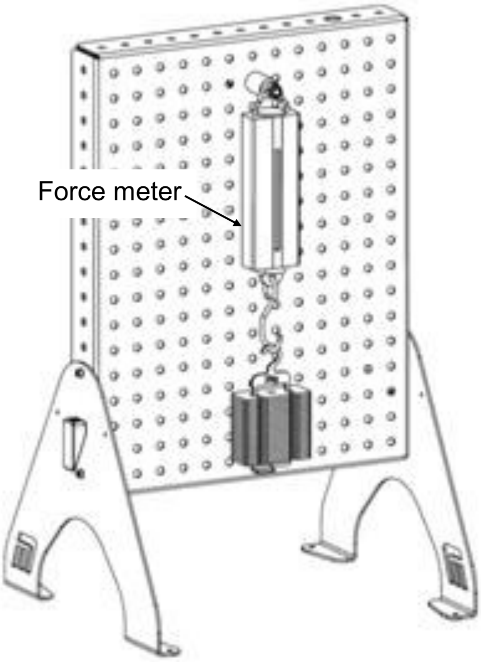
Worksheet 1

Mass, force and weight

How much do you *weigh*?
You might reply “80 kilograms”, but technically, you would be wrong! The reason - kilograms are units of *mass* ***not*** *weight*.

Mass, the amount of matter in a body, is measured in grams (g).
Your weight is the *force of gravity*, pulling your body towards the centre of the Earth. Forces are simply pushes and pulls, measured in newtons (N). Your bathroom scales measure your weight but display it in units of mass! Your mass is the same on Earth, on the Moon, and on Mars, but your weight in those three places is very different.

Over to you:



- Set up the force meter on the backplane and hang an empty mass hanger from it.
- Use the knurled wheel on top of the force meter to set the reading to zero.
- Add a 100g mass and notice the resulting reading.
- Add further 100g masses, one at a time, to a maximum of 500g, noting the force meter readings as you do so.
- Record all the readings in the Student Handout and complete the table.
- Use them to plot a graph of weight vs mass ***in kg***, as described in the Student Handout.

So what:

This graph shows the relationship between the mass of an object and its weight.

As it is a straight-line, it shows that a body’s mass and weight are directly proportional:

- double the mass and the weight doubles;
- halve the mass and the weight halves, etc.

Challenges!

- Use the graph to estimate the weight of an object having a mass of 380g.
- Find out what an object with a mass of 300g would weigh on the surface of the Moon.
- Why is this weight different from its weight on the Earth?
- Which would read correctly on the Moon, your bathroom scales or the force meter? Explain why.

Write all your answers in the Student Handout.

Worksheet 2

Combining forces

Combining masses is quite straightforward. Mass is a *scalar* quantity. The total mass is just the sum of the individual masses, always greater than the individual masses.

Combining forces is more complicated. Force is a *vector* quantity. It has size and direction and both need to be taken into account. The total force can have any value between zero and the arithmetic sum of their sizes. When forces act in the same straight line, we say that the system is in equilibrium when that sum is zero. If the sum is not zero, then the system will accelerate.

Some forces may not be obvious. In the system below, there are two obvious forces, the weights of the mass hangers, and two less obvious, the reaction forces at the pulleys.

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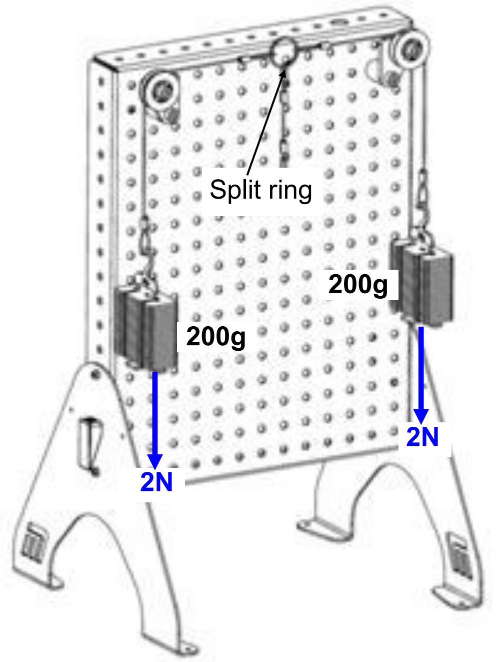


1. Equilibrium:

- Assemble the parts to the back panel as shown, using the split ring with three cords.
- Add equal masses of 200g to each long cord.
- You should be able to move the split ring horizontally to any position and it will stay put. The forces cancel out. The system is in equilibrium.

So what:

In the Student Handout:

- complete the free-body diagram for the split ring;
- answer the question about equilibrium.

Over to you .....

2. Unbalanced forces:

- Holding the split ring, add an additional mass of 50g to the left-hand hanger.
- Now, let go! (Be prepared to catch the left hand hanger!)
- Observe what happens to the split ring.

So what:

The system stops moving only when something comes into contact with the pulley, or when you catch the hanger. In either case, additional forces now restore equilibrium.

In the Student Handout, draw a free-body diagram to reflect this new scenario, when the split ring is midway between the two pulleys and accelerating.

Worksheet 3

Centre of gravity

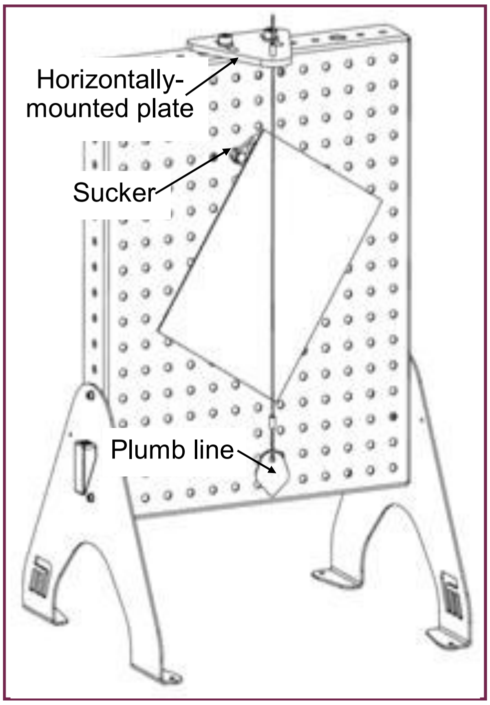
Every particle in a body is being pulled towards every particle in the Earth, by the force of gravity. The centre of gravity is the point where the weight of an object appears to act.

For the Earth, it is at its centre (give or take 42km.).
For a body, it is its “balance point”.

Why is this important? We need to know where this is when we want to lift an object from without it tipping, for example. Its full importance will become clear as you work through later worksheets.

Objects also have a *centre of mass*. In most situations, these are the same point.

Over to you:



- Set up the arrangement shown in the diagram.
- There are five different-shaped plastic samples in the kit.
  Suspend one from the backplane, using the sucker.
  (Hint - place it near one of the edges to reduce the effect of friction.)
  The sucker has a free-running bearing and so the shape should now hang with its centre of gravity below (or above) the centre of the sucker.
- Adjust the position of the plumb line so that it passes over the centre of the sucker and is close to, but not rubbing on, the surface of the plastic sample.

Worksheet 3

Centre of gravity

Over to you .....

- Use a fine **dry-wipe marker** to mark the positions of the plumb line where it crosses the edges of the shape.
- Remove the shape and draw a straight line between the two points. This recreates the position of the plumb line.
- Next, attach the sucker to a different point on the shape and repeat the process.

So what:

The centre of gravity of the shape lies at the intersection of the two lines.

Record your result by adding a cross to mark the centre of gravity on the shape shown in the Student Handout.

Test your result by carefully re-attaching the sucker where the lines cross and then hang the shape on the backplane.

When you nudge the shape, it does not rotate very far and then stays put, as its centre of gravity is now supported directly by the sucker.

Challenges!

Where do you think the centre of gravity of a ring-shaped sheet of plastic would be?

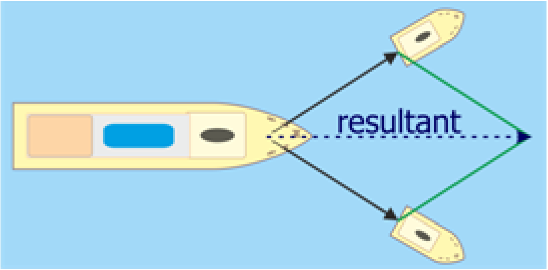
Mark it on the ring shape given in the Student Handout.

Worksheet 4

Parallelogram of forces

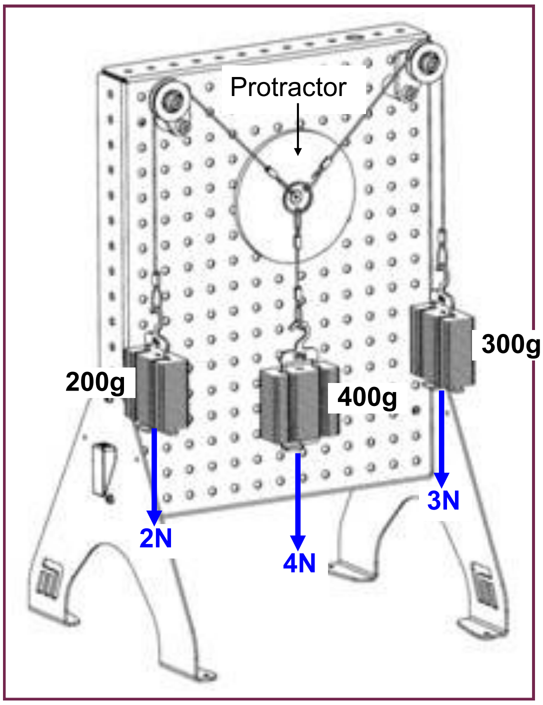
We have seen that forces acting in the same line are combined by simple adding or subtracting their sizes, depending on their relative directions.

When they are not in the same line, we have to use a more complicated process to find out their *resultant* ('sum'), such as the parallelogram of forces rule.



Over to you:

Resultant of a 2N and a 3N force:



- Assemble the system shown.
  Hold the split ring steady as you add each of the masses in turn.
  Once the masses are in place, carefully release the split ring and let it move to its natural position.
- Slide the protractor into position so that it is centred behind the split ring.
- Rotate it until the zero line points vertically downwards.
- Tap the back panel gently to reduce the effect of friction and readjust the protractor if needed.
- When the system has settled, measure the angles between the three forces acting on the split ring.
  (Make sure that you look at the protractor 'face on' to reduce reading errors.)
- Record these angles in the Student Handout.

Worksheet 4

Parallelogram of forces

So what:

- In the Student Handout, draw a free-body diagram, showing these three forces acting on the split ring. Mark on the angles between them.
- As the system is in equilibrium, the 4N force is the equilibrant of the 2N and 3N forces.
- Use your results to find the resultant of the 2N and 3N forces by drawing a parallelogram of forces. A suitable grid is provided in the Student Handout. Write your answer in the space provided.

Over to you .....

- In the same way, find the resultant of a 2N and 5N force.
- Record your results in the Student Handout and give your answer in the space provided.

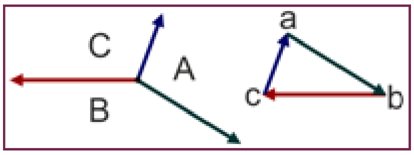
Challenge!

What is the effect on the equilibrant of doubling the 2N and 3N forces?

Worksheet 5

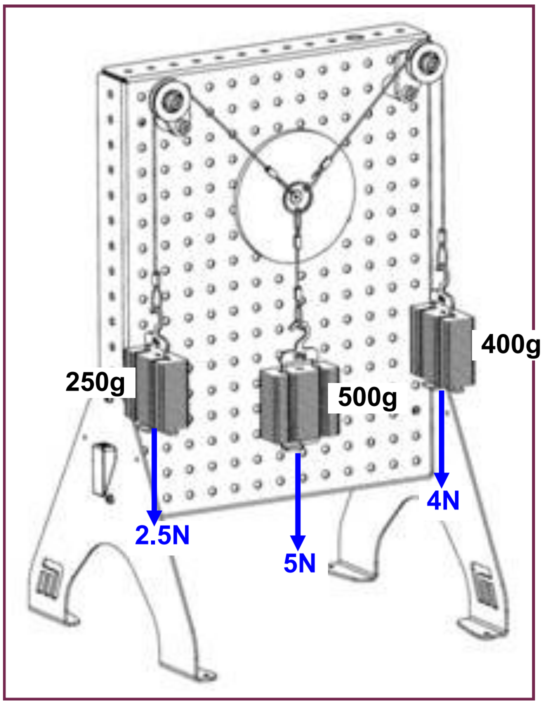
Triangle of forces

Another approach to combining forces is to use the triangle of forces rule.



It is often applied using Bow's notation to identify the forces. As shown in the diagram, the spaces between the forces in the left-hand diagram are labelled with capital letters. These advance in a clockwise direction. The forces are identified by the two letters that straddle them, so the red force can be called force **BC**. In the triangle of forces, lower case letters are used, so that the red force is known as force **bc**.

Over to you:



- The system is the same as in the previous worksheet, but uses different weights. As before, hold the split ring steady as you add each of the masses and then carefully release the split ring.
- Centre the protractor behind the split ring and then rotate it so that the zero line points vertically downwards.
- After tapping the back panel to reduce the effect of friction, measure the angles between the three forces acting on the split ring.
- Record them in the Student Handout.

Worksheet 5

Triangle of forces

So what:

- In the Student Handout, sketch a free-body diagram to show the forces acting on the split ring.
- Add Bow's notation letters running clockwise starting with **A** to the right of the 5N (vertical) force.
- Use your results to construct a triangle of forces, using the grid provided in the Student Handout. As the system is in equilibrium, the forces should form a closed triangle.

Bow's notation is a recognised way to label forces, allowing us to construct a triangle of forces without getting confused about the order in which the forces are placed.

The triangle of forces is an important tool in statics as it can cope with more complicated systems of forces.

It also allows easier processing by mathematical methods.

Equilibrant vs resultant:

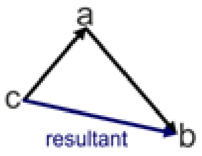
There are two versions of the triangle of force:

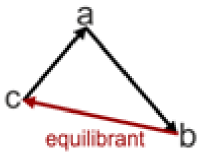
- the first allows us to determine the resultant of two forces;
- the second allows us to determine the equilibrant for a system that is in equilibrium.

The difference? The direction of the third force!

In the first case, the arrows on the two forces flow head-to-tail but the third arrow is in the opposite direction.

In the second case, all three arrows are head-to-tail.





Worksheet 6

Polygon of forces

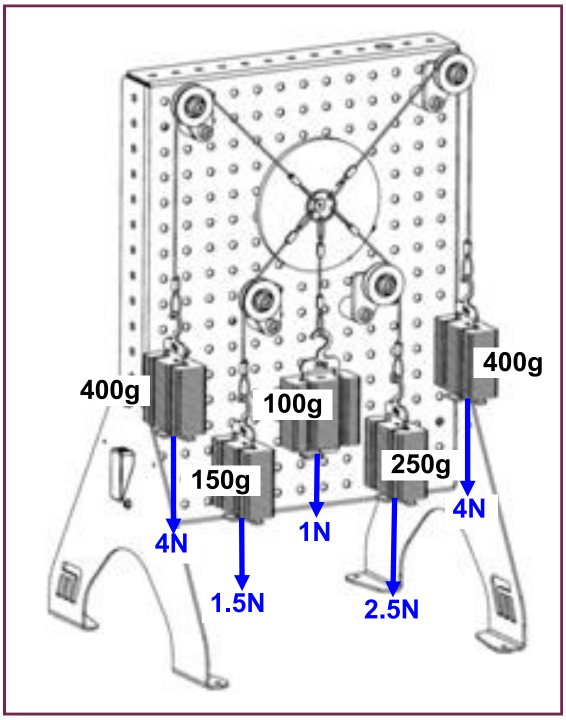
Worksheet 5 introduced the triangle of forces rule, as an alternative to the parallelogram of forces.

Why have two rules?

The parallelogram of forces is limited to finding the resultant and equilibrant of two forces, whereas the triangle of forces method can be applied to find the resultant and equilibrant for *any number of forces*.

To combine four forces, it is the quadrilateral of forces rule, for five forces, the pentagon of forces rule etc… Therefore, the general method is called the *polygon of forces*.

Over to you:



- The system is the same as in the previous worksheet, but this time uses the split ring with five cords (two long, two medium and one short.)
- As before, hold the split ring steady as you add each of the masses and then carefully release the split ring.
- Centre the protractor behind the split ring and rotate it until the zero line points vertically downwards.
- After tapping the back panel to reduce the effect of friction, measure the angles between the five forces acting on the split ring.
- Record them in the Student Handout.

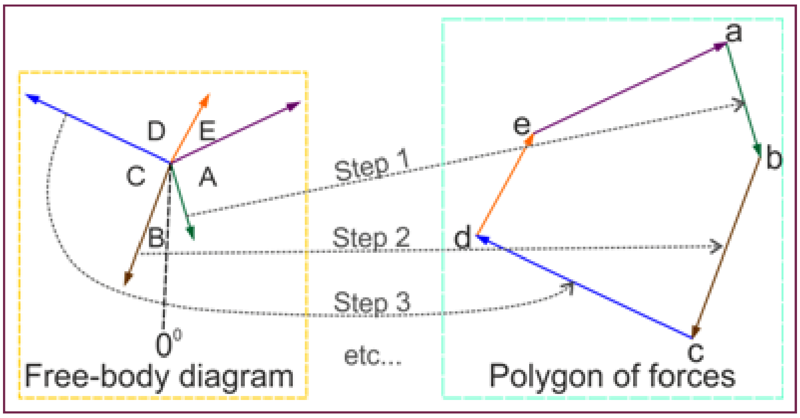
Worksheet 6

Polygon of forces

So what:

- In the Student Handout, sketch a free-body diagram to show the forces acting on the split ring. Add the sizes of the angles between each force.
- Add Bow's notation letters running clockwise starting with **A** to the right of the 2.5N force.
- Use this diagram to construct a polygon of forces, using the grid provided in the Student Handout. As the system is in equilibrium, the forces should form a closed pentagon.

The following diagram illustrates how to do this, from a free-body diagram:



A typical free-body diagram is shown on the left of the diagram (not the FBD for this investigation!)

- Choose a suitable scale for the polygon of forces diagram, e.g. 2cm represents 1N.
- Step 1 - draw a line representing the **AB** force using this scale, with the line pointing in the same direction as the original force.
- Step 2 - do the same for the **BC** force but starting the line on the end of the **ab** line.
- Step 3 - do the same for the **CD** force but starting the line on the end of the **bc** line.
  ⋮
- etc......

As the five lines create a closed pentagon, the system of forces is in equilibrium.

Worksheet 7

Principle of moments

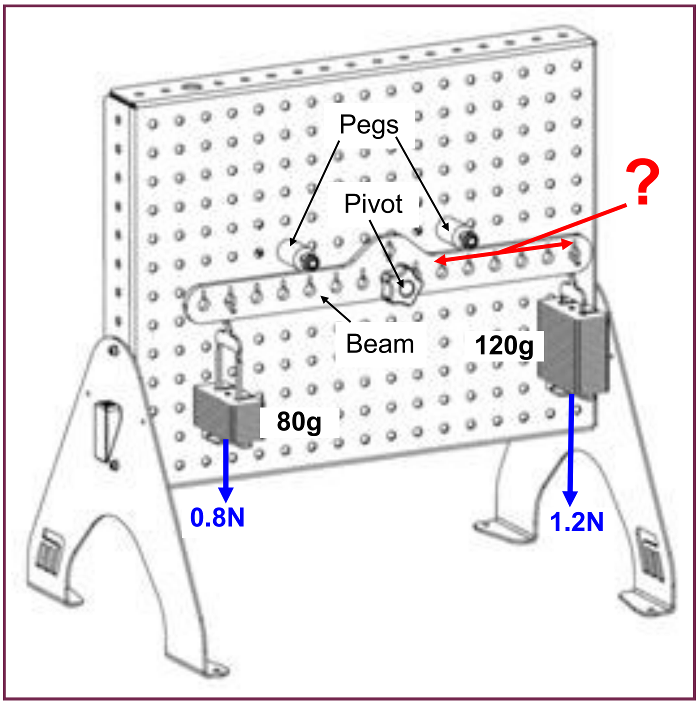
How to make the seesaw balance? The weight of the adult is much greater than that of the child, so how can they balance?

The answer, of course, is to move the adult nearer to the pivot (fulcrum) of the seesaw. The weights are unchanged, but their effects on the seesaw are now different.

A small force (the child's weight,) a long way from the pivot has the same effect as a large force, (the weight of the adult,) close to the pivot.

This illustrates the idea of the moment (turning effect) of a force.

Over to you:



- Assemble the beam as shown. Make sure that it can rotate freely until it hits the pegs.
- Place a 80g mass in the sixth hole from the pivot on the right hand side, i.e. at a distance of 120mm from the pivot, since the holes on the beam are 20mm apart.
- Decide where to place a 120g mass so that the beam is balanced.
- Nudge the beam a little to overcome friction and check your prediction.
- Remove the 80g mass and decide where a 240g mass needs to be placed on the left of the beam to make it balance.
- Record your findings in the Student Handout and complete the calculations for the moments of the forces.

Worksheet 7

Principle of moments

So what:

To decide whether an object is in equilibrium, it is not enough to check whether all the forces cancel out.

In addition, all the turning effects (moments) of the forces must cancel too, as otherwise the object will rotate.

This investigation shows that small forces can have big effects when applied at a large distance from the pivot.

This has great significance when we look at levers later in the module.

Challenge!

Use the apparatus to measure the weight of the unknown object.

One drawback of the experiment you just carried out is that distances must increase in steps of 200mm (i.e. by a ‘hole’ in the beam,) making the distance measurement easier.

The unknown object has a loop of thread attached to make the distance measurement more sensitive. You can slide the loop along the beam to locate an exact balance point. However, the downside of this approach is that you then have to measure the distance from the loop to the pivot with a ruler.

Record your finding in the Student Handout.

Worksheet 8

Non-concurrent forces

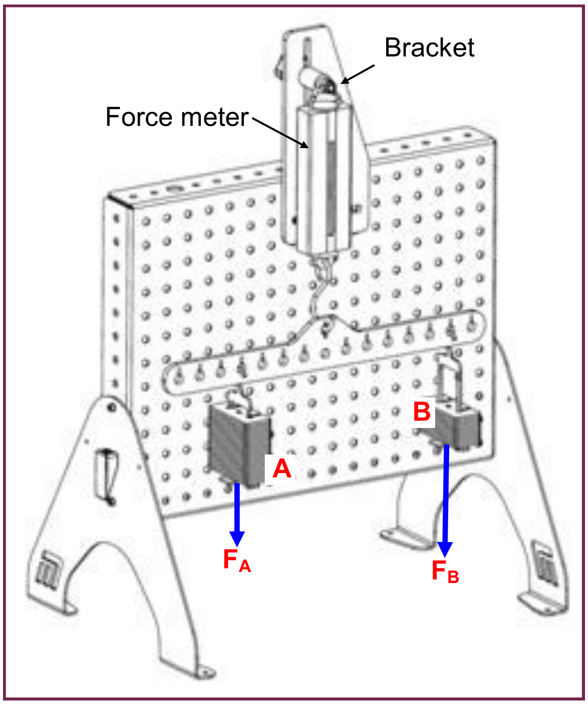
Concurrent forces all act through a single point. As a result, they do not generate a moment, a twisting effect. All situations prior to worksheet 7 involved concurrent forces.

The beam system in worksheet 7 contains non-concurrent forces, having a number of vertical forces at different distances from the pivot.

The photograph shows part of a crane lifting a load . The forces in the cables are non-concurrent.

Over to you:

1. Parallel forces:



- Assemble the beam and ‘zero’ the force meter to cancel out its weight, as before.
- Place two masses, labelled **A** and **B** in the diagram, in positions on the beam so that it is balanced horizontally. (Don’t forget to nudge the beam slightly to overcome friction.)
- Read the force shown by the force meter and record results in the table in the Student Handout. Complete the ‘Sum ...’ column.
- Repeat the process for two further combinations of different masses, completing the table in the Student Handout as you do so. (Don’t overload the force meter!)

Worksheet 8

Non-concurrent forces

So what:

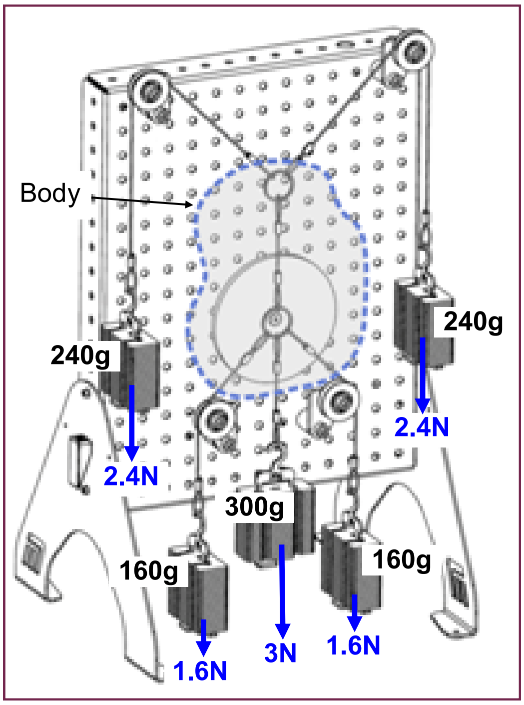
When the forces are in parallel, the magnitude of the resultant (and equilibrant) is simply the sum of the forces.

The beam, in the experiment just completed, is in equilibrium and so the resultant force on it is zero. The total moment of the forces acting on it must also be zero. In this case, this means that the line of action of the resultant must pass through the point of support (hook).

2. Skewed (non-parallel) forces:

Over to you:

- A set of five non-concurrent forces act on a body, (shown on the diagram purely for illustration). Assemble the system, using the two connected split rings. The top one has the two longer cords, the bottom one the medium length cords.
  The forces within short cord connecting the split rings can be ignored as they occur within the body.
- Centre the protractor behind the lower split ring and rotate it until the zero line points vertically downwards.
- After tapping the back panel to reduce the effect of friction, measure the directions of the three lower forces acting on the body.
- Move the protractor behind the upper split ring and repeat the procedure for the two upper forces.
- Record them in the Student Handout.



So what:

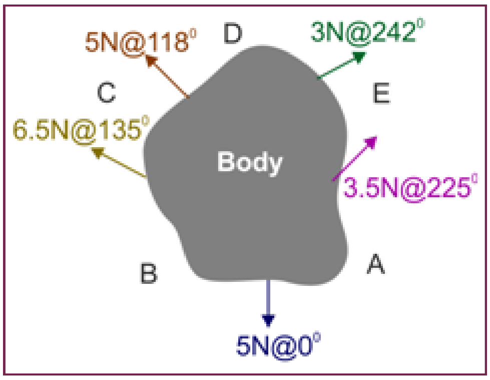
The diagram shows a set of five non-concurrent and skewed forces, acting on a body.

If it is in equilibrium, the resultant of the forces **and** the sum of their moments about any point is zero.

The polygon of forces technique, used earlier, can find the resultant force and direction but cannot find the sum of the moments.

Instead, a construction method called a *link polygon* is used.

Use the link polygon method to confirm that the five forces used in the experiment hold the body in equilibrium.



Worksheet 9

Stability

Why is it difficult to balance a bottle on its neck? The slightest nudge and it falls over!

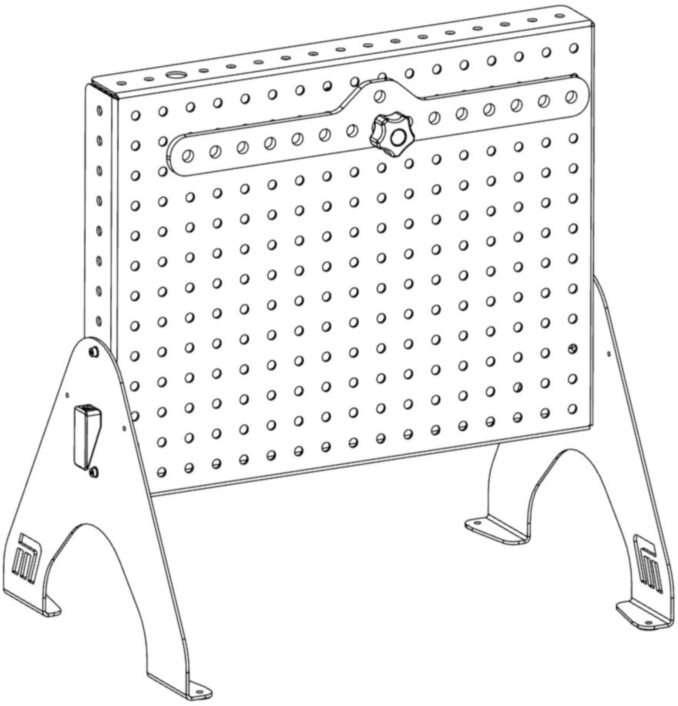
Standing it on its base is easy and it takes quite a shove to make it topple.

Now a ball! That never tips over! It just rolls.

Here's one way to view this:

Over to you:

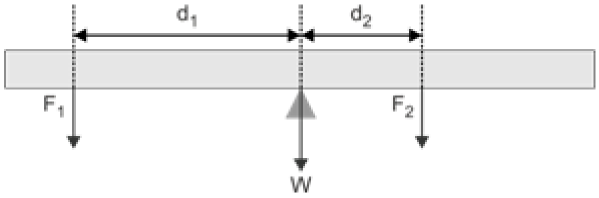
1. Pivot in centre line:



- Assemble the beam as before but with *the pivot on the centre line of the beam*. Make sure that the plastic bushing is in place in the pivot and that the beam can rotate freely.
- Add a combination of masses that make the beam balance.
- Raise one end of the beam slightly and notice what happens.
- Move it still further - any difference?
- Record your observations in the Student Handout.

So what:

When the beam is horizontal:



- the weight **W** of the beam acts through the pivot and so causes no moment;
- force $\mathbf{F_1}$, at distance $\mathbf{d_1}$ from the pivot, produces an anticlockwise moment of

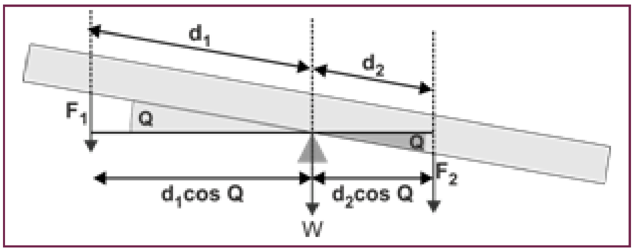
  $\mathbf{F_1} \times \mathbf{d_1}$;
- force $\mathbf{F_2}$, at distance $\mathbf{d_2}$ from the pivot, produces a clockwise moment of

  $\mathbf{F_2} \times \mathbf{d_2}$.

The beam is in equilibrium, so:

$$\mathbf{F_1} \times \mathbf{d_1} = \mathbf{F_2} \times \mathbf{d_2}$$

When the beam is tilted at angle **Q**:



- the weight **W** of the beam still acts through the pivot and so causes no moment;
- force $\mathbf{F_1}$ acts at a distance of $\mathbf{d_1.cosQ}$ from the pivot, producing an anticlockwise moment of

  $\mathbf{F_1} \times \mathbf{d_1.cosQ}$
- force $\mathbf{F_2}$, at distance $\mathbf{d_2.cosQ}$ from the pivot, produces a clockwise moment of

  $\mathbf{F_2} \times \mathbf{d_2.cosQ}$

Equating these:

$$\mathbf{F_1} \times \mathbf{d_1.cosQ} = \mathbf{F_2} \times \mathbf{d_2.cosQ}$$

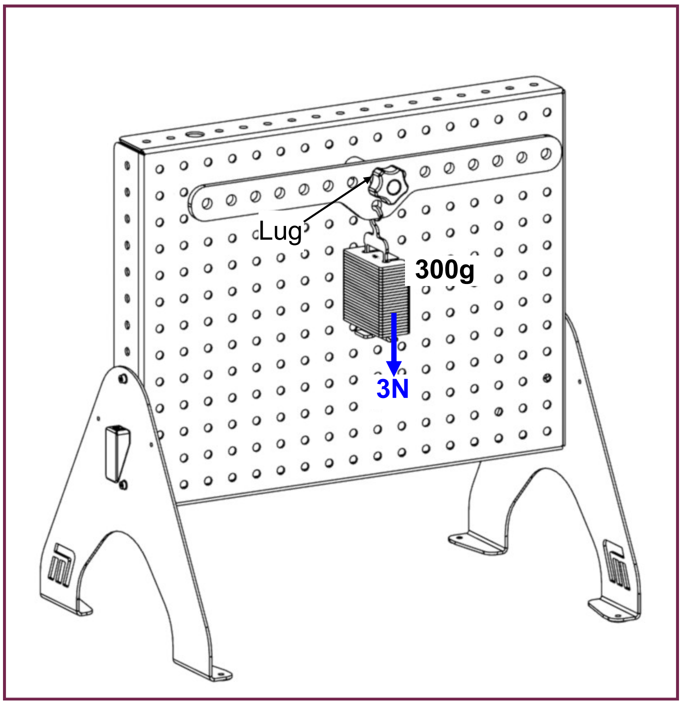
The beam ~~is~~ still in ~~equilibrium~~.

Worksheet 9

Stability

Over to you:

2. Pivot in centre line with lug below it:



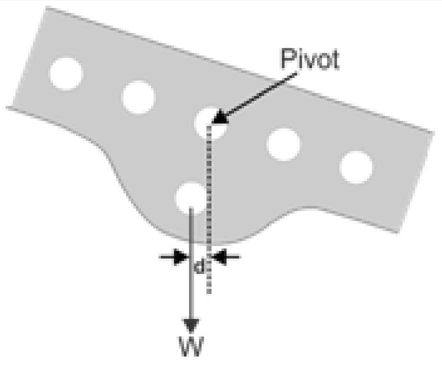
- Assemble the beam with the pivot on the centre line of the beam but this time with the lug at the bottom. Check that the beam can rotate freely.
- Add a 300g mass, hanging from the lug, as shown.
- Now, add a combination of masses that make the beam balance.
- Raise one end of the beam slightly and notice what happens.
- Move it still further - any difference?
- Record your observations in the Student Handout and answer the questions.

So what:

The difference now is that when the beam is tilted, its centre of gravity rises and provides a restoring moment to return the beam to its horizontal position.

The role of the 300g mass is to increase the weight of the beam and the restoring moment it produces.

The diagram illustrates this:



The restoring moment is **W** x **d**,

where **W** is the weight of the beam plus 300g mass
and **d** is the horizontal distance between **W** and the pivot.

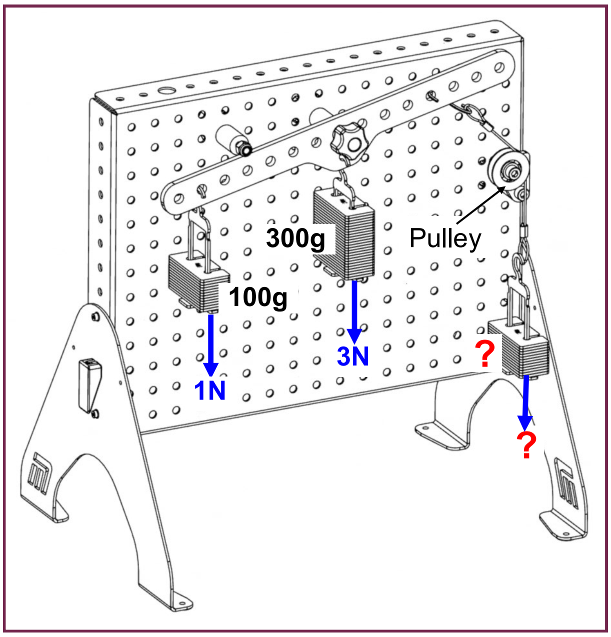
Worksheet 10

Oblique forces

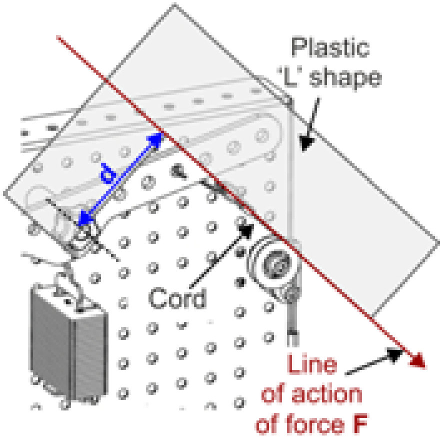
So far, the forces applied to the beam have been purely vertical. This is not always the case.

In this worksheet, an oblique force is applied to the beam by hanging a weight from a pulley.

Over to you:



- Assemble the beam as shown with the pivot on the beam centre line and the lug at the bottom. Check that it can rotate freely.
- Add a 300g mass, hanging from the lug, as before, to increase stability.
- Add a 100g mass in the position shown, on the left-hand side of the beam.
- Now, increase the mass on the other hanger until the beam is horizontal. To 'fine tune' this, change the angle of the cord by rotating the arm attached to the pulley.
- Use the plastic "L" shape as an *engineer's square* to find the perpendicular distance **d** from the pivot to the line of action of this force, **F**, as shown. (Mark it with the dry wipe marker and then measure it.)
- Record your observations in the Student Handout. (Notice the units used for these measurements!)



Worksheet 10

Oblique forces

So what:

Forces not at right angles to the beam are often called *oblique forces*. When dealing with oblique forces on beams the distance to the pivot is **not** the distance along it, rather it is the **distance at right angles to the line of action of the force to the pivot**.

Worksheet 11

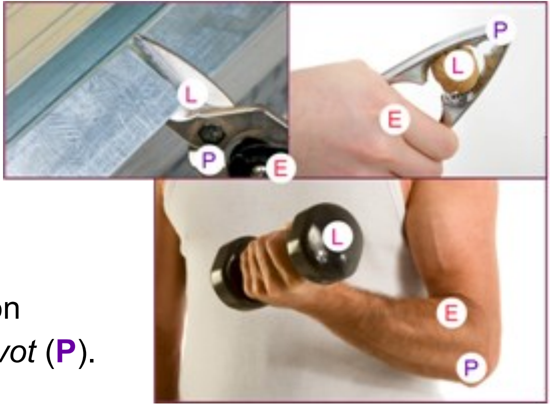
Levers

Levers are widely used in many routine applications.

The forces in them are known as the *load* (**L**) and the *effort* (**E**).

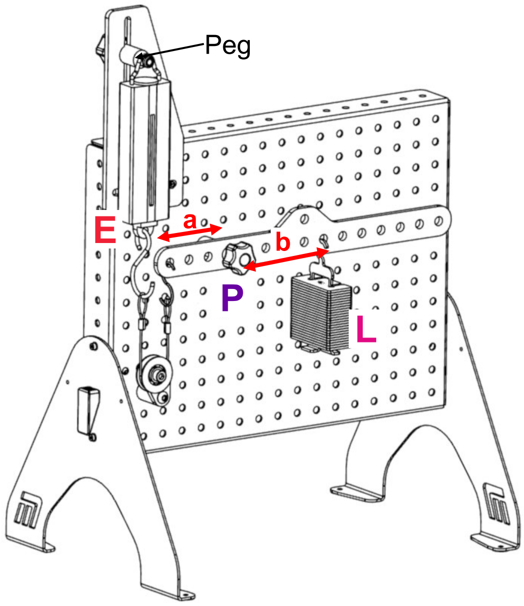
The load is the force which we are trying to lift or overcome, and the effort is the force required to do so.

There are three classes (orders,) of lever, depending on where the load and effort are applied, relative to the *pivot* (**P**).



Over to you:

First-order lever:



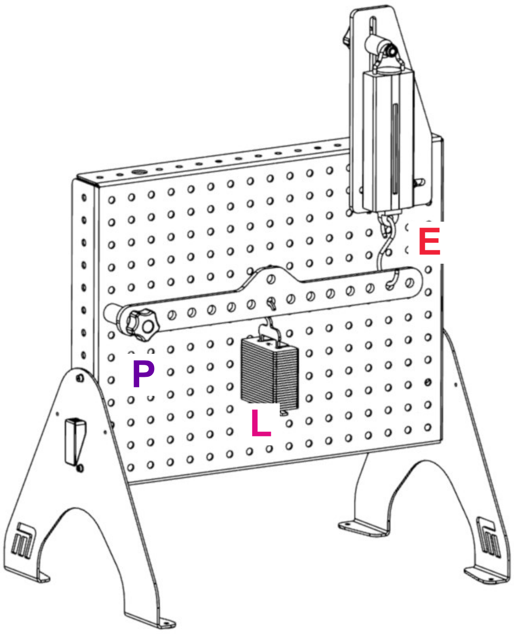
- Assemble the beam as shown and check that it can rotate freely. This arrangement is an example of a first-order lever with pivot **P** positioned between the load **L** and the effort **E**.
- Adjust the position of the peg until the beam is horizontal.
- Next, zero the meter, tapping it and the back panel to reduce the effects of friction.
- Add a 40g mass positioned 100mm (in the fifth hole,) to the right of the pivot.
- Which moves further as you do so - the effort or the load?
  Roughly how many times further? Write a comment in the Student Handout.
- Measure the distances from load to pivot, **a**, and effort to pivot, **b**. Record them in the Student Handout and calculate **b** / **a**.
- Adjust the peg again until the beam becomes horizontal. Take a reading from the force meter, (taking the usual steps to reduce the effects of friction.)
- Add further masses, 40g at a time until you reach a maximum of 240g, taking readings of load and effort in the same way, as you do so.
- Record the results and complete table 1 in the Student Handout.

Worksheet 11

Levers

Over to you:

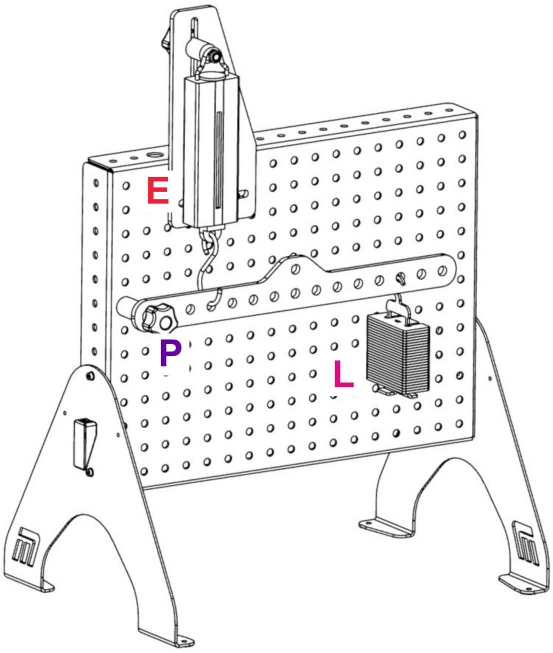
Second-order lever:



- Modify the arrangement as shown and check that the beam can rotate freely.
  This new arrangement is an example of a second-order lever with load **L** positioned between the effort **E** and the pivot **P**.
- As before, adjust the peg so that the beam is horizontal and zero the meter.
- This time, hang the 40g load 140mm to the right of the pivot (i.e. in the seventh hole).
- Again, notice how much the load and effort move and write a comment in the Student Handout.
- Measure the distances from load to pivot, **c**, and effort to pivot, **d**.
  Record them in the Student Handout and calculate **d** / **c**.
- Using the same procedure as before, increase the load in steps of 40g to a maximum of 240g, recording readings of load and effort in table 2 in the Student Handout as you do so.

Over to you:

Third-order lever:



- Modify the arrangement as shown and check that the beam can rotate freely.
  This new arrangement is an example of a third-order lever with effort **E** positioned between the load **L** and the pivot **P**.
- As before, adjust the peg so that the beam is horizontal and zero the meter.
- This time, hang the 40g load 200mm to the right of the pivot (i.e. in the tenth hole).
- Again, notice how much the load and effort move and write a comment in the Student Handout.
- Measure the distances from load to pivot, **e**, and effort to pivot, **f**.
  Record them in the Student Handout and calculate **e** / **f**.
- Using the same procedure again, increase the load in steps of 40g to a maximum of 240g, recording readings of load and effort in table 3 in the Student Handout as you do so.
- Comment on the results of these investigations.

Worksheet 12

Supported beam

Beams are a common solution where loads must span a gap.

Examples include bridges over rivers, or supports across building entrances.

The pillars supporting the beam exert upward forces, called *reactions.*

Over to you:

1. A quick 'demo':

- Suspend a 30cm plastic or steel rule on your hands, as shown
- Get a colleague to press down, gently, in the centre of the rule.
- What do you feel?

So what:

- Your hands are acting as pillars, providing vertical reaction forces balancing the weight of the rule and the force applied by your colleague.

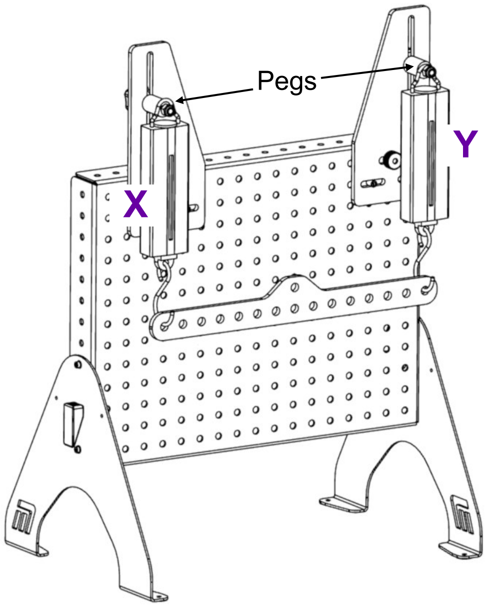
  The distance between your hands is called the *span*.

Worksheet 12

Supported beam

Over to you:

2. In more detail:



- Assemble the beam as shown so that it is horizontal (with the pegs near the bottom of the slots to allow them to be raised during the experiment.)
- Zero the force meters, tapping them and the back panel to reduce the effects of friction.

A. Centred load:

- Add a 100g mass, positioned at the centre of the beam.
- Record the readings of force meters **X** and **Y** in table 1 in the Student Handout.
- Add further masses, 100g at a time to a maximum of 500g and complete the table in the Student Handout with the force meter readings as you do so.
- Comment on these results.

B. Off-centre load:

- Remove the 100g mass and instead hang a 500g mass at 80mm (4th hole) from the left hand support.
- Adjust the pegs holding the force meters to level the beam.
- Measure:
    - the distance, **g**, from load to pivot;
    - the distance, **h**, from effort to pivot;
    - the readings on force meters **X** and **Y.**
- Record these readings in the Student Handout and carry out the calculations mentioned.

So what:

The beam is in equilibrium. Hence:

- the sum of the support reactions, (from the force meters,) must equal the applied load;
- the sum of their moments about any point must be zero

When the load is half-way between the two force meters, they share it equally.

When the load is not in the centre, as we known the distance between the supports and the distances between them and the load, we can use these relationships to calculate the reactions at the supporting pillars, (force meters).

Worksheet 13

Uniformly distributed load

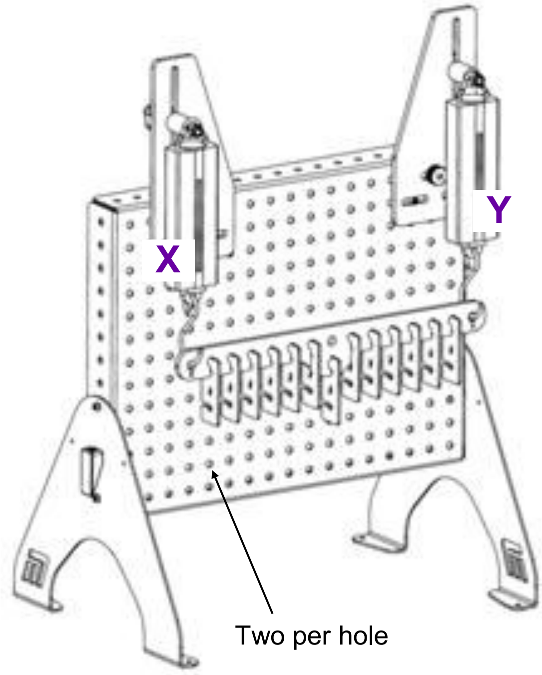
Loads that are concentrated at a single point, like the ones used so far, are called *point loads*.

However, beams can also carry loads that are spread over the length of the beam. These are called *uniformly distributed loads*, (UDLs).

For example a set of books on a bookshelf could be considered to be a UDL.

Over to you:

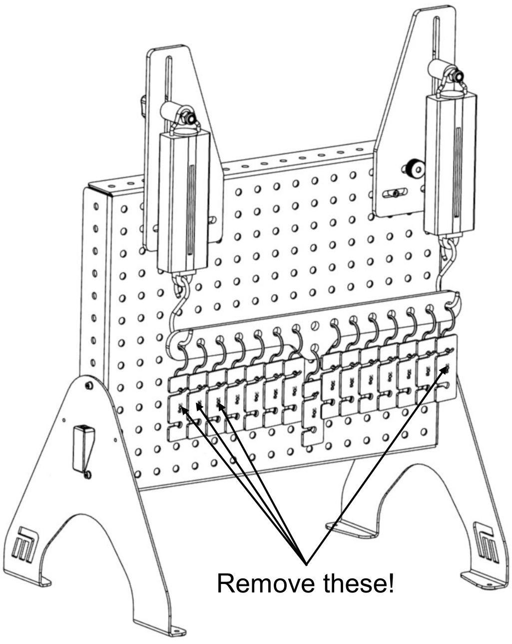
UDL 1:



- Assemble the beam as shown so that it is horizontal (with the pegs near the bottom of the slots to allow them to be raised during the experiment.)
- Zero the force meters, tapping them and the back panel to reduce the effects of friction.
- Add two 20g masses in each hole to give a total added mass of 13 x 40 = 520g (=0.52kg). Ignoring the weight of the beam, the distributed load totals 0.52 x 10 = 5.2N.
  The points of support provided by the force meters are 280mm (= 0.28m) apart, producing a UDL of 5.2 / 0.28 = 18.6Nm^{-1}
- Take a reading from each force meter.
- Record these in the Student Handout and comment on why you think these readings are correct.

Over to you:

UDL 2:



- Next, remove the 20g masses from the four positions shown.
- Calculate the resulting UDL and note it in the Student Handout.
- Ensure that the beam is horizontal by adjusting the pegs holding the force meters.
- Take a reading from each force meter and record it in the Student Handout.
- Comment on whether these readings seem to be correct.

So what:

- As far as the support reactions are concerned, the UDL acts as a single-point load, located at *its* centre, (not necessarily at the middle of the beam).
- So far we have ignored the mass of the beam by initially zeroing the force meters. This allows us to assume that it is ‘light’.
  Otherwise, what sort of load should it be considered to be?
  Write your answer in the Student Handout.

Worksheet 14

Horizontal reactions

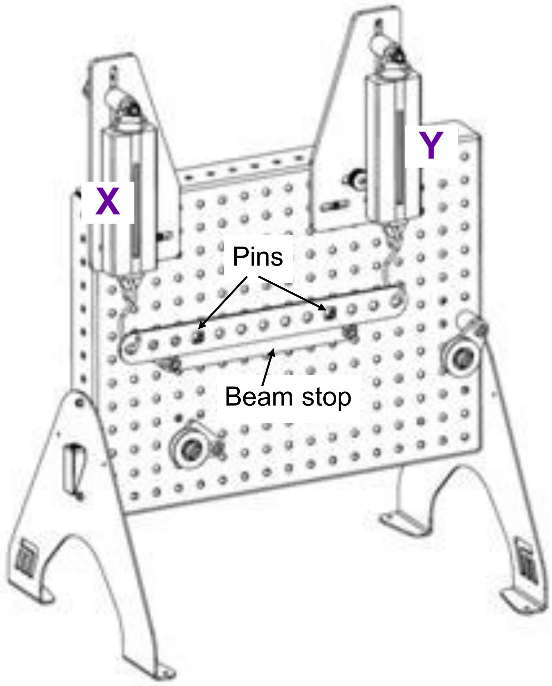
In Worksheet 13, the beam was supported by two *pinned-roller supports*. These allowed the beam to move sideways (*roller* - a little) and rotate (*pin* - a little).

Another example of this type of support is that in a skateboard. It is all too easy for the skateboard to slide out from under you, because it offers very little resistance to horizontal forces, just friction in the wheels, and between the wheels and the ground.

In real life, care is taken to make sure that any horizontal forces are opposed by horizontal reactions at the supports.

Over to you:

Step 1:



- Assemble the system shown above.
  First of all, fix the beam-stop in position on the back panel. Then rest the beam on it so that the two square holes sit on the two beam-stop pins. Next, add the force meters and pulleys.
- Adjust the positions of the force meters so that the beam ‘floats’ over the pins on the beam-stop, i.e. so that the pins are centred in the square holes on the beam.
  The bottom of the beam should be level with the engraved line on the beam-stop.

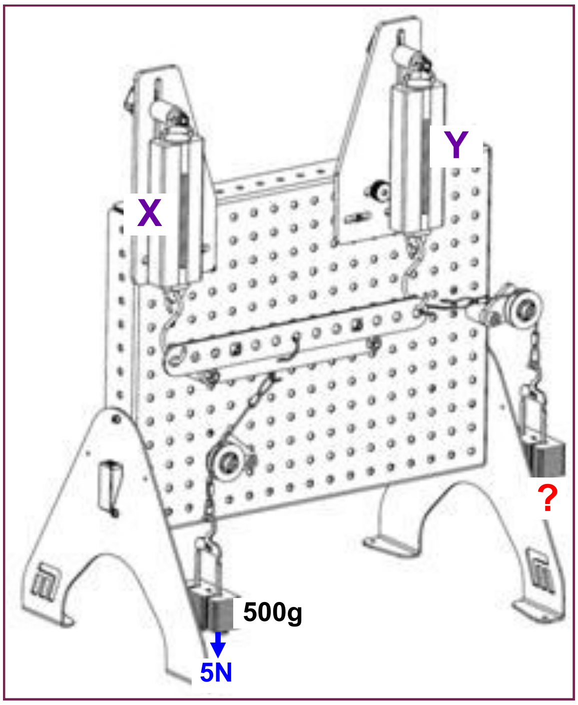
Worksheet 14

Horizontal reactions

Over to you .....

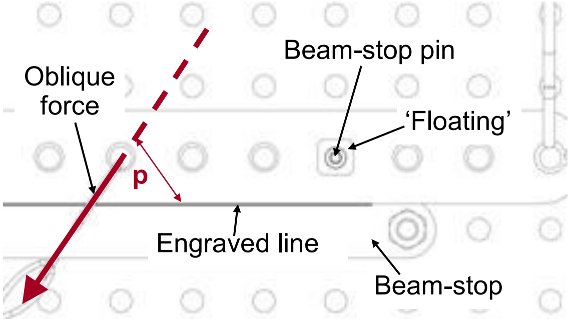
Step 2:

- Hang a 500g mass on the left-hand pulley to create an oblique load.
- Add an empty hanger to the right-hand pulley to complete the set up.
- Starting with a mass of 160g on the right-hand pulley, adjust the heights of the force meters and the mass on the right-hand pulley until the original ‘floating’ position is restored.
- Measure the angle **p** between the line of action of the oblique force and the beam.
- Observe the readings on the two force meters.
- Record all results in the Student Handout.



So what:

- In the Student Handout, draw a free-body diagram of the system, labelling all forces and the angle **p** of the oblique load.
- The beam is in equilibrium because:
  - the load on the right-hand pulley provides a horizontal force to balance the horizontal component of the oblique load;
  - the force meters provide an upward vertical force to balance the downward vertical component of the oblique load;
  - the moments of all forces cancel out.
- In the Student Handout, complete the calculations and explanation.

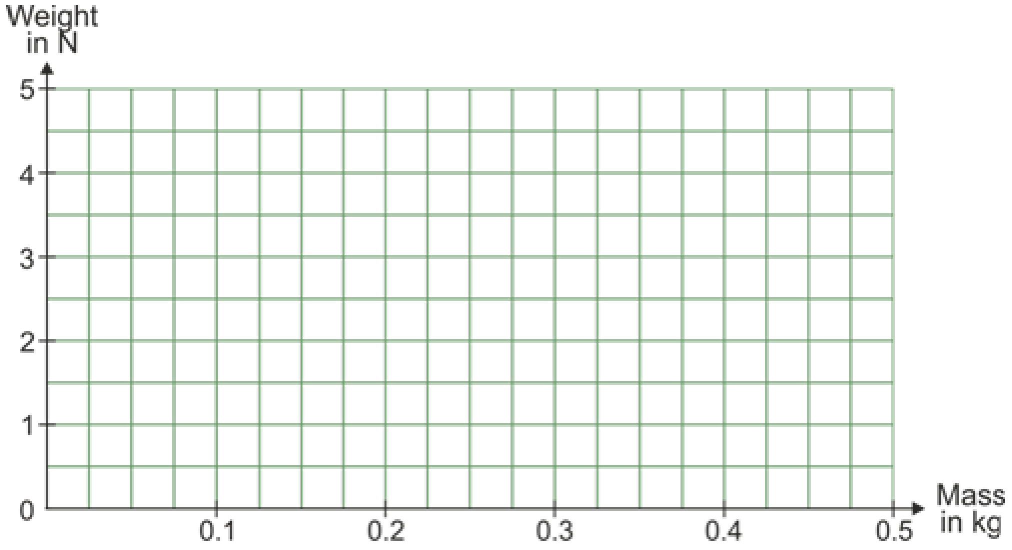


Student
Handout

Worksheet 1 - Mass, force and weight

Mass in g	Mass in kg	Force meter reading in N
100		
200		
300		
400		
500		

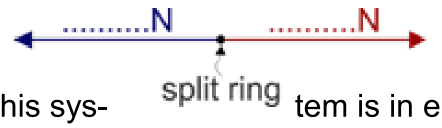
Use your results to plot a graph using the axes and scales given below. Show your measurements as small crosses. Your results should suggest a straight line relationship. Calculate its gradient.



Gradient of graph = ...N/kg

Worksheet 2 - Combining forces

1. Free-body diagram for equilibrium:



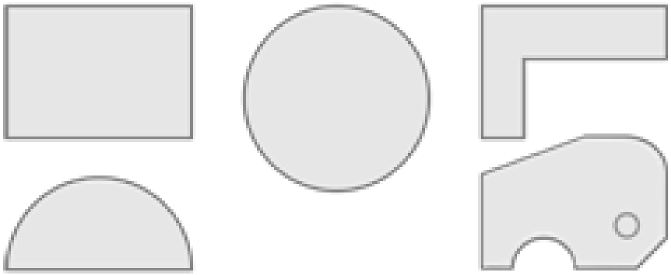
What does it mean to say that this system is in equilibrium?

....

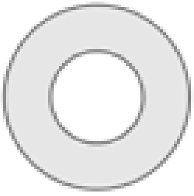
....

2. Free-body diagram for unbalanced forces:

Worksheet 3 - Centre of gravity



Challenge:Mark the centre of gravity on the ring.



Worksheet 4 - Parallelogram of forces

Resultant of a 2N and a 3N force:

Angle between 2N force and 3N force = ...^{0}
Angle between 3N force and 4N force = ...^{0}
Angle between 2N force and 4N force = ...^{0}

Free-body diagram:

Parallelogram of forces:

Resultant of the 2N and 3N forces = ...N at an angle of ....^{0} to the vertical.

Worksheet 4 .....

Resultant of a 2N and a 5N force:

Angle between 2N force and 5N force = ...^{0}
Angle between 5N force and 4N force = ...^{0}
Angle between 2N force and 4N force = ...^{0}

Parallelogram of forces:

Resultant of the 2N and 5N forces = ...N at an angle of ....^{0} to the vertical.

Challenge!

The effect on the equilibrant of doubling the 2N and 3N forces:

....
....
....
....
....
....

Worksheet 5 - Triangle of forces

Angle between 2.5N force and 4N force = ...^{0}
Angle between 4N force and 5N force = ...^{0}
Angle between 2.5N force and 5N force = ...^{0}

Free-body diagram:

Triangle of forces:

Worksheet 6 - Polygon of forces

Angle between 2.5N force and 1N force = ...^{0}
Angle between 1N force and 1.5N force = ...^{0}
Angle between 1.5N force and 4N force = ...^{0}
Angle between the two 4N forces = ...^{0}
Angle between 4N force and 2.5N force = ...^{0}

Free-body diagram:

Worksheet 6 ......

Polygon of forces:

Worksheet 7 - Principle of moments

Left-hand side			Right-hand side		
Weight in N	Distance from pivot in cm	Anticlockwise moment in N.cm	Weight in N	Distance from pivot in cm	Clockwise moment in N.cm
0.8	12	9.6	1.2		
2.4			1.2		

Challenge!

Weight of the unknown object = ...N

Student Handout

Worksheet 8 - Non-concurrent forces

1. Parallel forces:

Mass A in g	Weight F_A of mass A in N	Mass B in g	Weight F_B of mass B in N	Total downward force (F_A+F_B) in N	Force meter reading (Equilibrant) in N

2.

Skewed (non-parallel) forces:

Force in N	Direction
3	0^0
2.4	
2.4	
1.6	
1.6	

Free-body diagram:

Worksheet 8 - Non-concurrent forces

2. Skewed (non-parallel) forces:

Link polygon of forces:

Worksheet 9 - Stability

With the pivot in the centre line of the beam and the lug above it, what happens when you tip the beam slightly?

....

....

....

With the pivot in the centre line of the beam and the lug below it, what happens when you tip the beam slightly?

....

....

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Worksheet 9 - Stability .....

There are three types of stability:

- stable equilibrium;
- neutral equilibrium;
- unstable equilibrium.

With the pivot in the centre line and the lug above it, which type is represented?

....

With the pivot in the centre line and the lug below it, which type is represented?

....

Worksheet 10 - Oblique forces

When the beam is horizontal:

anticlockwise moment due to 100g mass = ...Nm
mass needed to provide oblique force = ...kg
resulting oblique force = ...N
perpendicular distance **d** from pivot
to line of action of force = ...m
clockwise moment of oblique force = ...Nm

Comment on these results:

....

....

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Student Handout

Worksheet 11 - Levers

First-order lever:

Which moves further - the effort or the load? Roughly how many times further?

....

....

....

Distance from load to pivot, **a** = ...mm
Distance from effort to pivot, **b** = ...mm
Ratio of distances **b** / **a** = ...

Table 1:

Load in g	**Weight of load, L in N**	**Effort, E in N**	**Mechanical advantage (L / E)**

Second-order lever:

Which moves further - the effort or the load? Roughly how many times further?

....

....

....

Distance from load to pivot, **c** = ...mm
Distance from effort to pivot, **d** = ...mm
Ratio of distances **d** / **c** = ...

Table 2:

Load in g	**Weight of load, L in N**	**Effort, E in N**	**Mechanical advantage (L / E)**

Worksheet 11 - Levers .....

Third-order lever:

Which moves further - the effort or the load? Roughly how many times further?

....

....

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Distance from load to pivot, **e** = ...mm
Distance from effort to pivot, **f** = ...mm
Ratio of distances **f** / **e** = ...

Table 3:

Load in g	**Weight of load, L in N**	**Effort, E in N**	**Mechanical advantage (L / E)**

Comment on the results of the investigations in Worksheet 11:

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Student Handout

Worksheet 12 - Supported beam

A. Centred load:

Load in g	**Weight of load, L in N**	**Force meter X in N**	**Force meter Y in N**
100			
200			
300			
400			
500			

Table 1:

B. Off-centre load:

Distance from load to pivot, g = ...mm

Distance from effort to pivot, h = ...mm

Reading on force meter **X** = ...N

Reading on force meter **Y** = ...N

Calculate:

- the total force on the beam;

....

....

- the total moment trying to rotate the beam.

....

....

Hence justify the statement that the beam is in equilibrium.

....

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Worksheet 13 - Uniformly distributed load

UDL 1:

Reading on force meter **X** = ...N

Reading on force meter **Y** = ...N

Comment on why you think these readings are correct:

....

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UDL 2:

New value of UDL = ...Nm

Reading on force meter **X** = ...N

Reading on force meter **Y** = ...N

Comment on why you think these readings are correct:

....

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....

If we cannot ignore it, what kind of load is the weight of the beam?

....

....

....

Worksheet 14 - Horizontal reactions

Reading on force meter **X** = ...N

Reading on force meter **Y** = ...N

Mass on right-hand pulley = ...g = = ...kg

Weight on right-hand pulley = ...N

Oblique load, **F** = 5N

Angle **p** between oblique load and beam = ...^{0}

Vertical component of oblique force = **F . sin p** = ...N

Horizontal component of oblique force = **F . cos p** = ...N

Free-body diagram:

Explain how these measurements suggest that the beam is in equilibrium:

....

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Notes for the Instructor

Notes for the instructor

About this course

Introduction

Using the Fundamental Mechanics module, students investigate effects of forces in simple systems through a series of practical investigations.

The kit consists of a number of parts that students can assemble and use with minimum supervision to complete a series of worksheets that illustrate a number of topics in the area of statics for BTEC level xxxx courses.

Aim

The course teaches students how to recognise the effects of forces and combinations of forces on simple structures.

Prior Knowledge

It is expected that students have followed an introductory science course, enabling them to take, record and analyse scientific observations. Some mathematical capability is required - ability to measure angles using a protractor, familiarity with the trigonometric functions sine and cosine and ability to use a calculator to evaluate them.

Using this course:

It is expected that the Worksheets and Student Handout are printed / photocopied, preferably in colour, for the students' use.

Each worksheet has:

- an introduction to the topic under investigation;
- step-by-step instructions for the investigation that follows.

The Student Handout is a record of measurements taken in each worksheet and questions relating to them. Students do not need a permanent copy of the worksheets but do require their own copy of the Student Handout

This format encourages self-study, with students working at a rate that suits their ability. It is for the instructor to monitor that their understanding is keeping pace with progress through the worksheets. One way to do this is to 'sign off' each worksheet, as the student completes it, and in the process have a brief chat to assess the student's grasp of the ideas involved in the exercises it contains.

We realise that you as a subject area practitioner are the lead in determining how and what students learn. The worksheets are not meant to supplant this or any other supporting underpinning knowledge you choose to deliver. For subject experts, the 'Notes for Instructors' are provided simply to reveal the thinking behind the approach taken.

For staff whose core subject knowledge is not in the field covered by the course, these notes can both illuminate and offer guidance.

Mathematics has been kept to a minimum. There are no derivations and any equations are stated in simple terms. For example statements such as $\Sigma M = 0$ is stated simply as "the sum of the moments is zero" etc.

Time:

It will take students between six and ten hours to complete the worksheets. It is expected that a similar length of time will be needed to support the learning that takes place as a result.

Notes for the instructor

What the student will need:

To complete the Fundamental Mechanics course, the student will need the following equipment:

Bom Structure	Description	Quantity
FM1883	Statics Fundamentals Kit	
FM2522	Work Panel for Fundamentals	1
FM1759	Magnetic Protractor Assembly	1
FM6508	RH Adjustable Pulley Assembly for FM1883	2
FM2915	Hanging Weights	5
FM1955	Looped String kit for FM1883	1
FM2222	Balance Slider Plate Assembly	2
FM9626	Peg Bar Assembly	1
FM6737	Spring Balance Pillar	2
FM5923	Equilibruim Beam Pillar Assembly	1
FM7938	Plumb Bob Assembly	1
FM7197	Suction Cup Assembly	1
COM2817-00	Pulley Hook	15
LAS1599	Short beam for FM1883	1
COM7488	Salter 12 spring balance 10N x 0.1N	2
LAS1499	Spring balance mounting plate for FM1883	2
LAS1733	Beam for FM1883	1
COM8599	Extra fine tip blakc marker pen	1
LAS1655	Centre of gravity shape (rectangle) for FM1883	1
LAS1455	Centre of gravity shape (circle) for FM1883	1
LAS1544	Centre of gravity shape (L) for FM1883	1
LAS1433	Centre of gravity shape (semi-circle) for FM1883	1
LAS1333	Centre of gravity shape (irregular) for FM1883	1
LAS1322	Centre of gravity shape (triangle) for the FM1883	1
FM6908	LH adjustable pulley assembly for the FM1883	2
FM7966	Looped String kit Setup 1 for FM1883	1
FM8522	Looped String Kit Setup 2 for FM1883	1
FM1499	Looped String Setup 3 for FM1883	1
FM2666	5g hanging weights pack of 5	5

Notes for the instructor

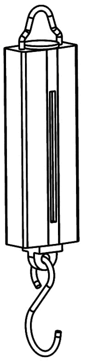
What the student will need, worksheet by worksheet:

Worksheet	Item
1	work panel
	force meter
	force meter pillar
	mass hanger
2	work panel
	two adjustable pulleys
	two mass hangers
	split ring with three cords
3	work panel
	plumb line
	suction cup assembly
	plastic centre of gravity sheets
4	work panel
	magnetic protractor assembly
	two adjustable pulleys
	three mass hangers
	split ring with three cords
5	work panel
	magnetic protractor assembly
	two adjustable pulleys
	three mass hangers
	split ring with three cords
6	work panel
	magnetic protractor assembly
	four adjustable pulleys
	five mass hangers
	split ring with five cords
7	work panel
	beam balance pillar
	balance beam
	two mass hangers
8	work panel
	force meter
	force meter plate
	force meter plate holder
	force meter pillar
	beam balance pillar
	balance beam
	five mass hangers
	magnetic protractor assembly
	four adjustable pulleys
	split ring with five cords

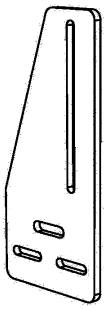
Worksheet	Item
9	work panel
	balance beam
	three mass hangers
10	work panel
	beam balance pillar
	balance beam
	three mass hangers
	adjustable pulley
11	work panel
	force meter
	force meter plate
	force meter plate holder
	force meter pillar
	beam balance pillar
	balance beam
	adjustable pulley
	mass hanger
12	work panel
	two force meters
	two force meter plates
	two force meter plate holders
	two force meter pillars
	beam balance pillar
	balance beam
	mass hanger
13	work panel
	two force meters
	two force meter plates
	two force meter plate holders
	two force meter pillars
	beam balance pillar
	balance beam
	mass hanger
14	work panel
	two force meters
	two force meter plates
	two force meter plate holders
	two force meter pillars
	beam balance pillar
	Short balance beam
	two adjustable pulleys
	two mass hangers
	peg bar assembly

Notes for the instructor

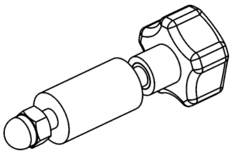
Identity parade:



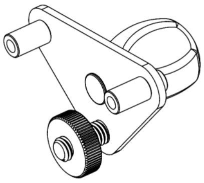
force meter



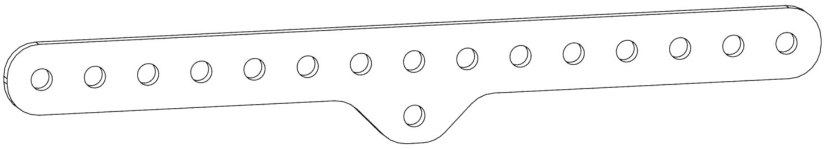
force meter plate



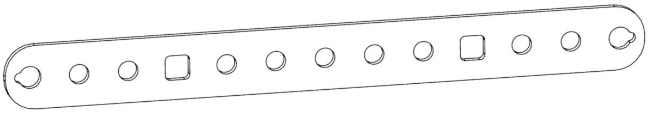
force meter pillar



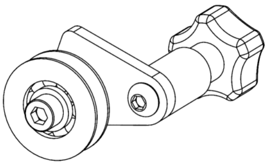
force meter plate holder



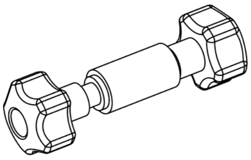
beam balance



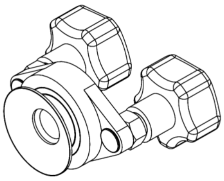
Short beam



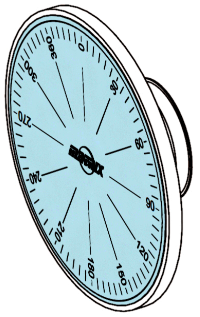
adjustable pulley
(left hand and right hand)



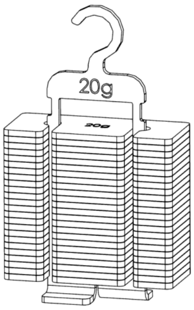
beam balance pillar



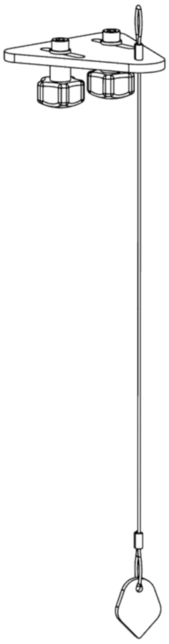
suction cup assembly



magnetic protractor assembly



mass hanger



plum bob assembly

Notes for the instructor

Learning Objectives

On successful completion of this course, the student will be able to:

- distinguish between mass and weight;
- explain the terms *vector* quantity and *scalar* quantity;
- state the units of measurement for weight and mass;
- explain the meaning of the term *centre of gravity*;
- obtain experimentally the location of the centre of gravity of a lamina;
- represent a force vector as a line, drawn to scale;.
- state the conditions for the forces acting on a body that is in equilibrium;
- draw a free-body diagram for a body subject to a number of coplanar forces;
- explain the terms *resultant* and *equilibrant* of a set of forces;
- sum two force vectors using a parallelogram of forces;
- interpret a triangle of forces diagram;
- explain the use of Bow's notation to label clearly a system of forces;
- use a triangle of forces diagram to find the resultant and equilibrant for a number of forces;
- define the term *moment of a force* and state its unit of measurement;
- distinguish between the terms *moment* and *torque*;
- state that a moment of a force is a vector, and that it can be represented by a clockwise or anti-clockwise arrow dependent on its direction and the reference point;
- state that when a body is in equilibrium, the sum of the clockwise moments is equal to the sum of the anticlockwise moments about any point;
- use a beam balance to weigh an object;
- use a link polygon to describe a system of forces acting on a body in equilibrium;
- distinguish between *neutral* and *stable* equilibrium;
- calculate the moment of an oblique force about a given point on a beam;
- distinguish between the three classes of levers and give examples of each;.
- explain what is meant by the term *mechanical advantage*;
  explain what is meant by the term *uniform distributed load, UDL* ;
- use the principle of moments and equilibrium of forces to find the support reactions for both point loads and UDLs;
- distinguish between the two different types of pinned supports and show how they are drawn;
- resolve a given force into two perpendicular components;
- use given information on horizontal, vertical and oblique forces to determine whether a beam is in equilibrium.

Notes for the instructor

Worksheet	Notes
1 Mass, force and weight Timing 20 - 30 mins	Concepts involved: mass weight gravitational field strength acceleration due to gravity Students may need help to set up the apparatus and ‘zero’ the force meter initially. Some may make mistakes in converting the mass in g to kg. The graph should be drawn as a straight line. Its gradient gives a measure of the gravitational field strength, ‘g’, which should be around 10N/kg. Some sources link mass and weight using the formula F=ma, where the ‘a’ is the acceleration due to gravity. One issue with this is that the students need to realise that, even sitting in a chair, they are accelerating towards the centre of the Earth. Using the concept of gravitational field strength avoids this. This could be a time to talk about accuracy and tolerance in measurements. On the surface of the Moon, ‘g’ is around 1.6N/kg, because the Moon has a much smaller mass than the Earth. This means that an object with mass of 300g would weigh around 0.5 (0.48) N on the Moon. On the Moon, the force meter reads correctly. The bigger the force, the greater the extension of the spring in the force meter and the greater the reading, no matter where the reading takes place. The bathroom scales measure force, but then convert the reading into kg assuming a ‘g’ of 10N/kg, the value correct on Earth, but not on the Moon.
2 Combining forces Timing 20 - 30 mins	Concepts involved: scalar quantity vector quantity free-body diagram equilibrium acceleration This could be a good point to distinguish between free-body diagrams (FBD) and space diagrams. The pulleys and cords in the kit can be considered to be “ideal” - i.e. have zero mass and friction. Again, it is a good idea to tap the panel to remove the effect of “stiction”. There could be class discussion as to why the acceleration caused by the unbalanced forces is only short-lived.
3 Centre of gravity Timing 20 - 40 mins	Concepts involved: centre of gravity centre of mass static friction Again, students may need help to set up the apparatus. It isn’t necessary for each group to investigate every shape. Different groups can be given different shapes, with the results later shared. To extend the life of the suckers, students should be told to ‘peel’ at the edge of the sucker to release the shape rather than simply pulling it. The bearing should be tapped gently to overcome static friction (stiction). It may not be obvious why this method works. Some may not realise that when the lamina is at rest, the centre of gravity is vertically beneath the point of support, somewhere along the line they draw. When they test their result, the centre of gravity sits at the point of support, at the sucker, and so it stays put when they nudge it. The centre of gravity of a ring is at the centre of the circle, i.e. in mid air.

Notes for the instructor

Worksheet	Notes
4 Parallelogram of forces Timing 30 - 50 mins	Concepts involved: resultant force equilibrant force parallelogram of forces In many situations, both static and dynamic, students need to obtain the total of a number of forces. The instructor could introduce this topic by discussing some of these. It is important that students understand what is going on in this system. The weight in the centre is balancing the effects of the left-hand and right-hand weights and so the force it exerts is the equilibrant of the other two forces. The outcome depends on how accurately the students measure the angles between the forces and then reproduce them on the parallelogram of forces diagram and on their choice of scale. There is plenty of scope and need for practising these skills beforehand. Two further exercises on this worksheet allow further practice.
5 Triangle of forces Timing 20 - 30 mins	Concepts involved: triangle of forces Bow's notation One challenge here is to explain why both the triangle and parallelogram of forces rules exist! The reality is that the diagram using one rule can be obtained from the diagram using the other. The instructor should check that students have drawn the free-body diagram and applied Bow's notation correctly. The text shows the difference between using this rule to obtain the resultant of two forces and using it to obtain the equilibrant. Students should be clear about which is which.
6 Polygon of forces Timing 20 - 40 mins	Concepts involved: polygon of forces The procedure is similar to that in the previous worksheet but is applied to a more complex situation. Correct use of Bow's notation is vital here. The instructor should check that the free-body diagram is correct. The worksheet outlines the process of constructing the polygon step-by-step. Some may require help in applying it.
7 Principle of moments Timing 20 - 40 mins	Concepts involved: moment of a force principle of moments Some preliminary work on moments is essential if students are to get full benefit from what they do here. The student is challenged to decide where to place the 120g mass. The more able might attempt to calculate a solution whereas others might use trial-and-error. This is a good opportunity to address accuracy in measurement since distances are 'quantised' into 200mm lumps. The weighing challenge could be done as a class competition.

Notes for the instructor

Worksheet	Notes
8 Non-concurrent forces Timing 20 - 30 mins	Concepts involved: concurrent forces non-concurrent forces link polygon line of action 1. Parallel forces The aim is to demonstrate that the equilibrant is simply the sum of the two weights. The investigation should be straightforward for all students. By now, they should be able to calculate the weights of A and B using gravitational field strength (10N/kg) or the F = m . a equation. These weights are non-concurrent and create moments which the student cancel out through appropriate choice of location. 2. Skewed forces The first hurdle for students is to visualise a body subject to five non-concurrent, skewed forces. The diagram indicates where the body is in relation to the forces. A slight concern is that students go looking for a body to attach to the equipment! The second hurdle is to measure the direction of the forces. One way is to move the protractor up to centre it on the top split ring. That's fine so long as they keep 0^0 pointing vertically downwards. Finally, when the results are complete, the students are asked to draw a link polygon to determine the resultant (both in magnitude and direction). This is a fairly complex procedure and will require extensive preparation and practice.
9 Stability Timing 40 - 60 mins	Concepts involved: stable equilibrium neutral equilibrium unstable equilibrium 1. Pivot in centre line / lug above: The practical work should be straightforward. It gives another chance for students to decide on a pair of balancing moments. The 'So what' section shows why tipping the beam has no effect. Some students may need help in understanding the argument given there. This arrangement is an example of neutral equilibrium. 2. Pivot in centre line / lug below: Similar concerns arise here. They may no understand the purpose of the 300g mass. The argument is the same, whether the 300g is there or not. The effect is better seen with the added mass since the weight of the beam by itself, and the resulting restoring moment, is small. This arrangement is an example of stable equilibrium.
10 Oblique forces Timing 20 - 30 mins	Concepts involved: oblique force perpendicular distance The main difficulty here is the measurement of the perpendicular distance from the line of action of the force to the pivot. Preliminary practice using trigonometry to calculate perpendicular distances for oblique forces in examples on applying the principle of moments could help.

Notes for the instructor

Worksheet	Notes
11 Levers Timing 30 - 50 mins	Concepts involved: load effort three classes of levers mechanical advantage Students could be shown everyday examples of levers and asked to decide which class they belong to. The significance of mechanical advantage could be explored in terms of these examples. The worksheets then explore the three classes experimentally. The same procedure is used with all three classes. Students measure the ratio of distances between load and pivot and effort and pivot without any explanation of its significance. It is hoped that they make the connection between this ratio and mechanical advantage. Instructors may need to prompt them towards this. Although velocity ratio is not mentioned specifically, it is implied in the questions about distances, asked of students during the practical work. It could be discussed to complete the study of levers.
12 Supported beam Timing 30 - 40 mins	Concepts involved: reaction forces conditions for equilibrium This starts with a simple but direct demonstration of the meaning of reaction forces. The main experiment brings in no new ideas but applies the conditions for equilibrium - total force is zero, total moment is zero. Further examples with calculations would cement these ideas.
13 Uniformly distributed load Timing 30 - 40 mins	Concepts involved: uniform distributed load The instructor could focus on the significance of each of the words ‘uniform’ and ‘distributed’, in this context. UDL could be contrasted with point load and uniform varying load. The students could calculate the UDL value for a number of situations to drive home the concept. In both examples studied, the UDL behaves like a point load as far as reaction forces in the supports are concerned. The instructor may need to expand on this for some students.
14 Horizontal reactions Timing 30 - 40 mins	Concepts involved: pin support roller support resolution of forces In advance of the investigation, the instructor should give the students plenty of practice in resolving a force into vertical and horizontal components. Construction of the system is complicated and so is broken down into two stages. The challenge is to measure the forces needed for equilibrium in both the vertical and horizontal directions. The expanded diagram aims to show that we want the beam to ‘float’, unsupported by the beam stop pegs in both directions. Some may find it difficult to measure the angle between the line of action of the force and the beam directly. They may prefer to project the lines onto a piece of paper and measure the angle that way. The instructor may wish to check the free-body diagrams.