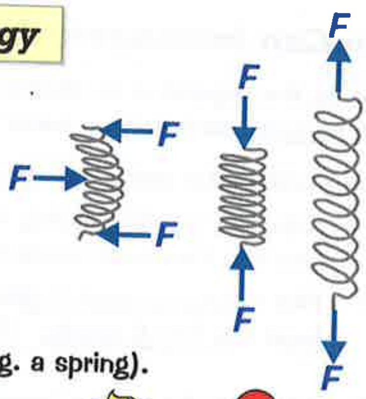
Forces and Elasticity

And now for something a bit more fun — squishing, stretching and bending stuff.

Stretching, Compressing or Bending Transfers Energy



1) When you apply a force to an object you may cause it to stretch, compress or bend.
2) To do this, you need more than one force acting on the object (otherwise the object would simply move in the direction of the applied force, instead of changing shape).
3) An object has been elastically distorted if it can go back to its original shape and length after the force has been removed.
4) Objects that can be elastically distorted are called elastic objects (e.g. a spring).
5) An object has been inelastically distorted if it doesn't return to its original shape and length after the force has been removed.
6) The elastic limit is the point where an object stops distorting elastically and begins to distort inelastically.
7) Work is done when a force stretches or compresses an object and causes energy to be transferred to the elastic potential energy store of the object. If it is elastically distorted, ALL this energy is transferred to the object's elastic potential energy store (see p.100).

Elastic objects — useful for passing exams and scaring small children

Extension is Directly Proportional to Force...

If a spring is supported at the top and then a weight is attached to the bottom, it stretches.

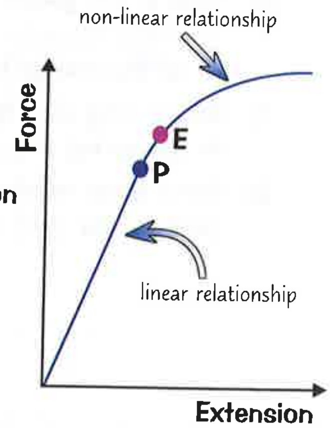
1) The extension of a stretched spring (or other elastic object) is directly proportional to the load or force applied — so $F \propto x$.
2) This means that there is a linear relationship between force and extension. (If you plotted a force-extension graph for the spring, it would be a straight line.)
3) This is the equation: $\boxed{F = k \times x}$ where F is the applied force in N, k is the spring constant in N/m and x is the extension in m.
4) The spring constant depends on the material that you are stretching — a stiffer spring has a greater spring constant.
5) The equation also works for compression (where x is just the difference between the natural and compressed lengths — the compression).

For a linear relationship, the gradient of an object's force-extension graph is equal to its spring constant.

...but this Stops Working when the Force is Great Enough

There's a limit to the amount of force you can apply to an object for the extension to keep on increasing proportionally.

1) The graph shows force against extension for an elastic object.
2) There is a maximum force above which the graph curves, showing that extension is no longer proportional to force. The relationship is now non-linear — the object stretches more for each unit increase in force. This point is known as the limit of proportionality and is shown on the graph at the point marked P.
3) The elastic limit (see above) is marked as E. Past this point, the object is permanently stretched.



I could make a joke, but I don't want to stretch myself...

That equation is pretty simple, but that doesn't mean you can skip over it. Have a go at the question below.

Q1 A spring is fixed at one end and a force of 1 N is applied to the other end, causing it to stretch. The spring extends by 2 cm. Calculate the spring constant of the spring. [2 marks]

Investigating Elasticity

You can do an easy experiment to see exactly how adding masses to a spring causes it to stretch.

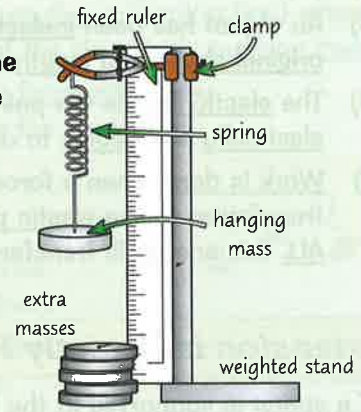
You Can Investigate the Link Between Force and Extension

PRACTICAL

Set up the apparatus as shown in the diagram. Make sure you have plenty of extra masses, then measure the mass of each (with a mass balance) and calculate its weight (the force applied) using $W = mg$ (p.17).

You could do a quick pilot experiment first to find out what size masses to use.

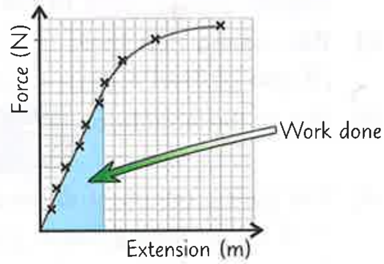
- Using an identical spring to the one you will be testing, load it with masses one at a time and record the force (weight) and extension each time.
- Plot a force-extension graph and check that you get a nice straight line for at least the first 6 points. If it curves too early, you need to use smaller masses.



1) Measure the natural length of the spring (when no load is applied) with a millimetre ruler clamped to the stand. Make sure you take the reading at eye level and add markers (e.g. thin strips of tape) to the top and bottom of the spring to make the reading more accurate.
2) Add a mass to the spring and allow the spring to come to rest. Record the mass and measure the new length of the spring. The extension is the change in length.
3) Repeat this process until you have enough measurements (no fewer than 6).
4) Plot a force-extension graph of your results. It will only start to curve if you exceed the limit of proportionality, but don't worry if yours doesn't (as long as you've got the straight line bit).

You should find that a larger force causes a bigger extension. You can also think of this as more work needing to be done to cause a larger extension. The force doing work is the gravitational force and for elastic distortions, this force is equal to $F = kx$.

You can find the work done for a particular forces (or energy stored — see below) by calculating the area under the linear section of your force-extension graph up to that value of force.



You Can Calculate Work Done for Linear Relationships

1) Look at the graph on the previous page. The elastic limit is always at or beyond the limit of proportionality. This means that for a linear relationship, the distortion is always elastic — all the energy being transferred is stored in the spring's elastic potential energy store.
2) So, as long as a spring is not stretched past its limit of proportionality, work done to the spring is equal to the energy stored in its elastic potential energy store.
3) For a linear relationship, the energy in the elastic potential energy store (and so the work done) can be found using:

Spring constant (N/m)

Energy transferred in stretching (J)

$$E = \tfrac{1}{2} \times k \times x^2$$

Extension² (m²)

Time to spring into action and learn all this...

Remember that you can only use the gradient to find the spring constant if the graph is linear (a straight line).

Q1 A spring with a spring constant of 40 N/m extends elastically by 2.5 cm. Calculate the amount of energy stored in its elastic potential energy store. [2 marks]

Fluid Pressure

Hopefully reading this page will make you feel a little less pressured about your physics exam.

Pressure is the Force per Unit Area

1) Pressure is the force per unit area.
The following equation can be used for solids, liquids and gases:

$$P = \frac{F}{A}$$

Pressure in pascals (Pa)
Force normal to a surface (N)
Area of that surface (m^2)

The soles of high-heeled shoes have a small area, so they exert a large pressure on the ground, which can damage some types of flooring. The soles of snowshoes have very large areas, which 'spread out' your weight (the force) and stop you sinking into snow as you walk.

2) Gases and liquids are both fluids (their particles are free to move, or 'flow').
3) Fluid pressure is the pressure caused by the collisions of gas or liquid particles on a given surface.
4) Fluid pressure always exerts a force at right angles (normal) to any surface in contact with the fluid (p.98).
5) The force on a surface due to fluid pressure depends on the area of the object the fluid is in contact with.
6) The properties of a fluid and the atmospheric pressure surrounding the fluid affect fluid pressure (see next page).

Fluid Pressure Depends on Depth and Density

1) Density can be thought of as a measure of the 'compactness' of a substance, i.e. how close together the particles in a substance are. For a given liquid, the density is uniform (the same everywhere) and it doesn't vary with shape or size. The density of a gas can vary though.

Liquids can actually be squashed slightly under very large pressures, but because the change is so small you can assume the density of a liquid is uniform.

2) Assuming their particles have the same mass, a denser fluid has more particles in a certain space than a less dense one. This means there are more particles that are able to collide so the pressure is higher at a given depth in the denser fluid.

3) As the depth of a fluid increases, the number of particles above that point increases. The weight of these particles adds to the pressure felt at that point, so fluid pressure increases with depth.
4) You can calculate the pressure due to the column of liquid above a certain depth using:

$$P = h \times \rho \times g$$

Pressure due to a column of liquid (Pa)
Height of the column (the depth) in m
Density of the liquid (kg/m^3) (the symbol is the Greek letter 'rho')
Gravitational field strength (N/kg)

EXAMPLE:

Calculate the change in pressure between a point 20 m below the surface of water and a point 40 m below the surface. The density of water is 1000 kg/m^3. The gravitational field strength of the Earth is 10 N/kg.

1) Calculate the pressure caused by the water at a depth of 20 m.
$P = h\rho g = 20 \times 1000 \times 10$
$= 200\,000$ Pa

2) Do the same for a depth of 40 m.
$P = h\rho g = 40 \times 1000 \times 10$
$= 400\,000$ Pa

3) Take away the pressure at 20 m from the pressure at 40 m.
$400\,000 - 200\,000 = 200\,000$ Pa (200 kPa)

Check your answer makes sense (you can't get negative pressure).

So a gas is a fluid — next they'll be telling me custard is a solid...

Have another read through and make sure you can explain how pressure changes with depth.

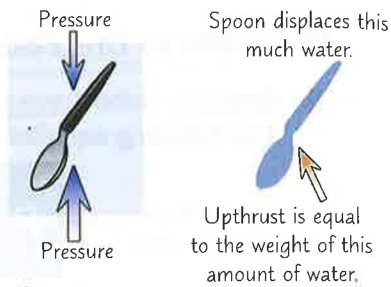
Q1 Calculate the force exerted on a 10 m^2 area by a pressure of 200 kPa. [2 marks]

Q2 At a point 5 cm below the surface of a jug of olive oil, the pressure is 450 Pa.
Calculate the density of olive oil. The gravitational field strength of Earth is 10 N/kg. [2 marks]

Upthrust and Atmospheric Pressure

Fluid pressure can explain why potatoes sink and apples float. Because you've been dying to know...

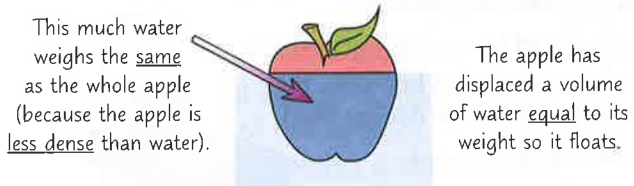
Objects in Fluids Experience Upthrust

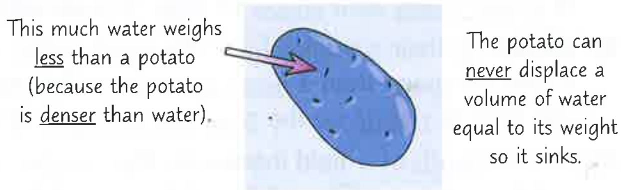


1) When an object is submerged in a fluid (either partially or completely), the pressure of the fluid exerts a force on it from every direction.
2) Pressure increases with depth, so the force exerted on the bottom of the object is larger than the force acting on the top of the object.
3) This causes a resultant force (p.67) upwards, known as upthrust.
4) The upthrust is equal to the weight of fluid that has been displaced by the object (e.g. the upthrust on an old boot in water is equal to the weight of a boot-shaped volume of water).

An Object Floats if its Weight = Upthrust

1) If the upthrust on an object is equal to the object's weight, then the forces balance and the object floats.
2) If an object's weight is more than the upthrust, the object sinks.
3) This means that whether or not an object will float depends on its density.
4) An object that is less dense than the fluid it is placed in displaces (pushes out of the way) a volume of fluid that is equal to its weight before it is completely submerged.
5) At this point, the object's weight is equal to the upthrust, so the object floats.
6) An object that is denser than the fluid it is placed in is unable to displace enough fluid to equal its weight. This means that its weight is always larger than the upthrust, so it sinks.

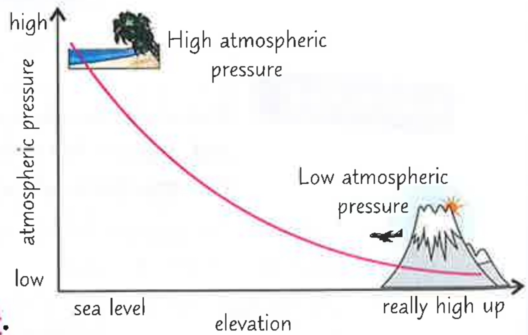




Submarines make use of upthrust. To sink, large tanks are filled with water to increase the weight of the submarine so that it is more than the upthrust. To rise to the surface, the tanks are filled with compressed air to reduce the weight so that it's less than the upthrust.

Atmospheric Pressure Decreases with Height

1) The atmosphere is a layer of air that surrounds Earth. It is thin compared to the size of the Earth.
2) Atmospheric pressure is created on a surface by air molecules colliding with the surface.
3) As the altitude (height above Earth) increases, atmospheric pressure decreases — as shown on the graph. The graph is curved because atmospheric pressure is affected by the density of the atmosphere, which also varies with height.



4) As the altitude increases, the atmosphere gets less dense, so there are fewer air molecules that are able to collide with the surface.
5) There are also fewer air molecules above a surface as the height increases. This means that the weight of the air above it, which contributes to atmospheric pressure, decreases with altitude.

Next time you're feeling pressured, go on a hike...

Atmospheric pressure and liquid pressure are similar — but the density of the atmosphere changes (unlike liquids).

Q1 Explain why a wooden object ($\rho = 700$ kg/m^3) floats in water ($\rho = 1000$ kg/m^3). [3 marks]