Pressure

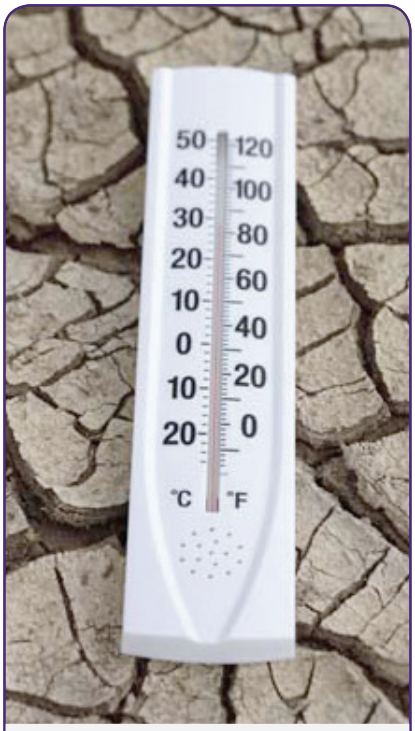
PHYSICS • FORCES • PRESSURE

Section 1: Gas Laws

• What is temperature?

Temperature is a measure of the average kinetic energy of the particles in a system. The faster the particles are moving, the greater the temperature.

The temperature is directly proportional to the kinetic energy of the particles, when the energy doubles the temperature doubles. However, the temperature is proportional to the square of the average speed of the particles, if the velocity doubles the temperature becomes four times larger.



A thermometer with a Celsius scale can be used in everyday life, but in physics it is not always suitable

- **Suggested Film**
  - **Gas Laws**

Extension Questions

Q1. What is absolute zero?

When the behaviour of gases with temperature is studied, it is clear that their volume decreases with temperature. If this behaviour continued as the temperature decreased we would expect there to be a temperature where the volume of the gas would become zero. This never happens as all gases turn into liquids when they reach a low enough temperature. However, as temperature is the measure of the average kinetic energy of the particles in a system, there must be a temperature at which this energy is zero. This temperature is -273.15ºC and is known as absolute zero. It is approximately the same as the temperature at which we would predict a gas would have zero volume.

Q2. What is the Kelvin scale?

Although the Celsius, or Centigrade, scale is commonly used in everyday life, it is not always suitable for use in physics. Zero on the Celsius scale is the melting point of ice but this is not the lowest temperature possible. This is absolute zero: -273.15ºC.

The Kelvin scale is similar to the Celsius scale because the size of a degree Celsius is the same as the size of a degree Kelvin. The only difference is that zero on the Kelvin scale is set at absolute zero. This means the scales are offset, so 20ºC is 293.15K.

The Kelvin scale is always used when dealing with the effect of temperature on pressure and volume.

• What is kinetic theory?

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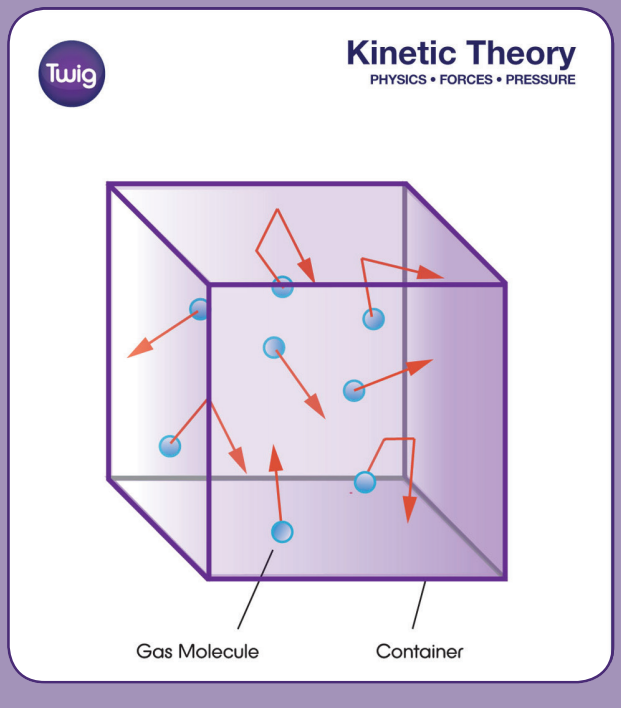


Kinetic theory explains the large-scale behaviour of gases in terms of large numbers of tiny particles which are in constant, random motion. It explains how collisions involving these particles are what causes pressure, and how the speed of these particles relates to measurements of temperature.

- **Suggested Film**
  - **Gas Laws**

• What is pressure?

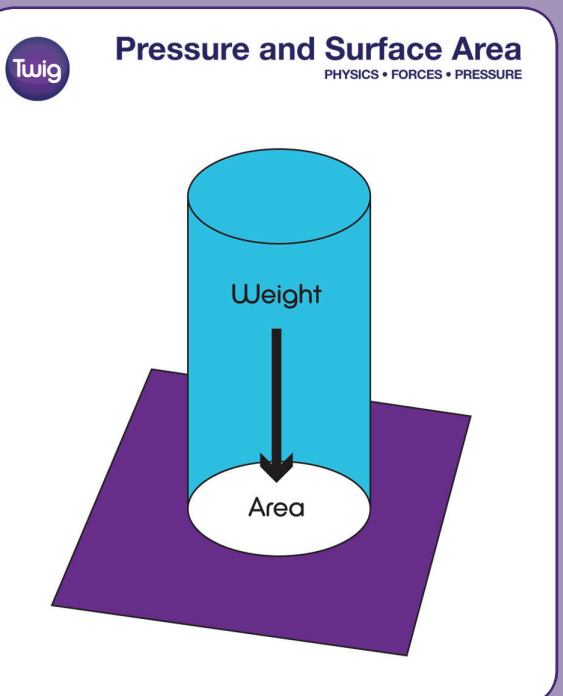
Pressure is a measure of how much force is acting on a given area. It is measured in pascals (Pa), or newtons per square metre (N/m^2). The same force can produce very different effects when applied over different areas. For example, blades or pins apply force over a very small area. This produces a large pressure and allows us to cut into or pierce objects in a way which would be impossible if we used a flat object.

Snow shoes work through the same principle, except they are designed to reduce the pressure due to the weight of the wearer. These ensure that the weight of the wearer is spread over a larger area and the lower pressure means they are less likely to sink into snow when walking.

- **Suggested Films**
  - **Pressure and Surface Area**
  - **FactPack: Pressure and Altitude**

Applying force to a drawing pin, which has a small surface area, produces a large pressure

DIAGRAM 02:



Extension Questions

Q3, What is air pressure?

The surface of the Earth has to support the weight of the atmosphere above it. The force per unit area, due to this large downward force, is known as the air pressure. At the surface of the Earth air pressure is around 100,000Pa, or 1 bar. This is equivalent to 10 tonnes on every square metre. This amount of pressure is also known as 1 atmosphere.

Q4. Why are gas cylinders dangerous in fires?

Gas cylinders contain gas which has been compressed so it can be stored in a very small volume. This means the pressure of the gas is very high, sometimes hundreds of times higher than atmospheric pressure.

In a fire the temperature of the gas inside the cylinder increases, which means the pressure increases further. Eventually the cylinder may fail because of the high pressure and this could result in an explosion. This is particularly dangerous if the cylinder contains flammable material. If this ignites in the fire there can be a very large explosion. For this reason firefighters have to be especially careful whenever they are dealing with a fire, which is thought to involve gas cylinders.

Section 2: Buoyancy

• What causes buoyancy?

An object in a liquid will experience an upward force equal to the weight of the liquid it has displaced. If this upward force is greater than the weight of the object it will float.

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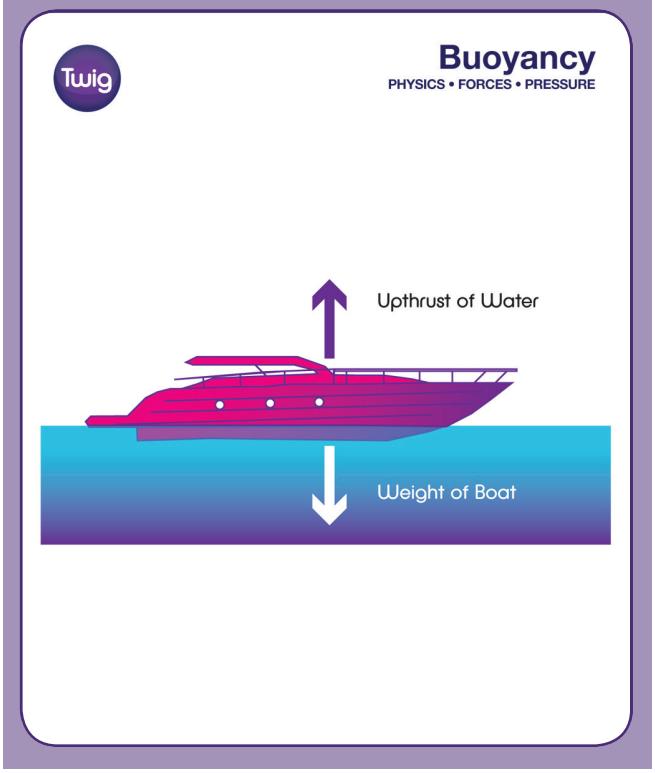


This upward force occurs because the displaced liquid would have been supported by a force opposing its weight. The weight of the top layer of the liquid means that it exerts a force on the liquid beneath it. As this bottom layer liquid cannot be compressed indefinitely it ‘pushes back’, exerting a force upwards until the two forces become equal.

If liquid in the top layer is removed or displaced the water below will still be exerting an upward force. This is the source of buoyancy.

• Suggested Film

- Buoyancy

Extension Question

Q5. Why is buoyancy different in saltwater and freshwater?

Saltwater is denser than freshwater. This means that an object in saltwater has a greater buoyancy because the weight of the water it has displaced is greater. Because of this, ships float higher in the water when they pass from freshwater into seawater.

Extension Questions

Q6. How do submarines control their buoyancy?

Submarines control their buoyancy using ballast tanks. To increase their overall density and allow them to sink, submarines fill these tanks with water. When at neutral buoyancy (when the submarine will neither rise nor sink as its overall density is the same as the water surrounding it) the submarine will dive or rise using dive planes. These are 'fins' on the submarine, which can be adjusted so that passing water pushes the submarine upwards or downwards. At any time the water can be forced out of the ballast tanks using compressed air. This would cause the submarine to rise in the water.

Q7. How do fish control their buoyancy?

Some fish use a gas-filled organ called the swim bladder to control their buoyancy in much the same way as submarines use their ballast tanks.

Problems with the swim bladder can affect a fish's stability. This is the reason why ill aquarium fish are sometimes seen floating upside down at the surface of the tank.

Not all fish have a swim bladder; sharks do not control their buoyancy in this way. Instead, as they force their way through the water they use their fins to generate lift, like the diving planes of a submarine. This upward force balances their weight and allows them to move through the water without sinking. However, this also means that if they stop swimming they will not generate lift and will begin to sink.

• What is density?

Different materials have different densities. The density of a material is the mass that is present in a given volume and is usually measured in kilograms per cubic metre.

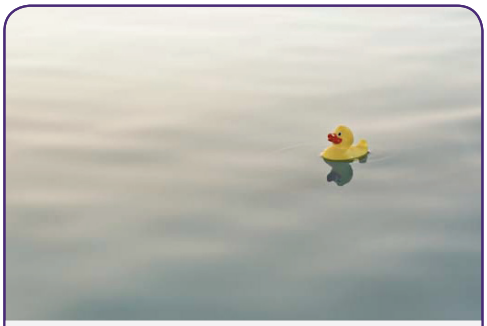
Air has a density of approximately 1kg per cubic metre and water has a density of around 1000kg per cubic metre. Metals would be about ten times denser than water. Lead has a particularly high density; a cubic metre of lead would have a mass of around 10,000kg (10 tonnes).

The density of an object can vary with temperature. As the temperature increases and the object expands, it has the same mass but takes up more volume and so the density decreases. Density can also be increased by compression, using pressure to force the same mass to occupy a smaller volume.

Liquids and solids tend to have densities, which are not strongly affected by changing temperature or compression, but the density of gases can be changed relatively easily.

• Suggested Film

- Buoyancy



A rubber duck floats as the upward acting buoyant force is greater than the weight

Extension Questions

Q8. Is lead the densest element?

There are several elements which are denser than lead. Iridium and osmium are both approximately twice as dense as lead, although they are very rare. Gold and platinum are almost as dense as these elements. Tungsten is also very dense and this is the origin of its name, which means 'heavy stone'.

Uranium is also very dense, about 70% more dense than lead. In the nuclear industry, many of the radioactive isotopes present in uranium are removed and depleted uranium is produced as a by-product. Depleted uranium is relatively cheap for this reason and has sometimes been used in counterweights in commercial aircraft and in radioactive shielding.

Q9. Why is water special?

Most substances expand with increasing temperature and their liquid forms are less dense than their solid forms. Water does not behave in this way, because of the special way in which molecules bond within ice, and this is why ice forms on the top of lakes or rivers instead of the bottom. This partly insulates the water below from the cold and prevents the water from freezing completely. If ice sank in water it would not only expose the top of the water to the cold, but it would also be far less likely to thaw as, even when the temperature rose, the water would insulate the ice at the bottom from the heat above. We could expect much more of the water on Earth to be frozen solid.

• What is ballast?

Ballast is used on ships to control buoyancy

If a ship is too light its buoyancy could mean that it sits too high in the water. This could result in the ship becoming unstable and more likely to tip over. This is an issue after a ship has unloaded its cargo. For this reason ships will take on extra weight, known as ballast. This can take different forms, but water is commonly used as it can easily be loaded and unloaded. This can present environmental problems, as water from one place is transported to another before being dumped, along with any microbes or foreign species it contains. It is not unknown for cholera to be transported between countries through ships' ballast.

• Suggested Film

- Buoyancy

Extension Question

Q10. What is a ship's displacement?

The displacement of a ship is a measurement of the mass of water it displaces. This is always equal to the mass of the ship. Obviously the displacement of a ship will change as it is loaded and unloaded, but the displacement can be measured by looking at how deep the ship sits in the water. This is indicated by markings on the hull of the ship.

Displacement is measured in tonnes but should not be confused with measurements like gross tonnage or net tonnage, which are based on a separate definition of 'ton' and are actually measurements of the volume of a ship.

Section 3: Humans and Pressure

• How does pressure help fighter pilots?

G-suits help fighter pilots to tolerate intense forces

Fighter pilots have to tolerate large accelerations. This could cause them to lose consciousness as blood is forced into the lower parts of the body instead of the brain. The effects of this can be reduced by wearing G-suits. These are tightly fitting and use pressure from inflatable bladders within the suit to prevent the blood pooling in these parts of the body, therefore allowing the pilots to tolerate large accelerations.

- **Suggested Film**
  - **Fighter Pilots: G-Force**

Extension Question

Q11. What is altitude sickness?

The proportion of oxygen in the air stays constant, at around 21%, up to altitudes far beyond those reached by mountain climbers or commercial aircraft. However, the decrease in air pressure can cause problems. Altitude sickness can result in headaches, tiredness and dizziness. Mountain climbers have to be aware of the effects of altitude sickness, and although the air pressure in a commercial aircraft should be high enough to prevent most people experiencing altitude sickness, it is not unknown for some passengers to have symptoms.

• Why do aircraft have to be pressurised?

As altitude increases the air pressure decreases. This is because at the increased height, the weight of the air above is less than it would be at ground level. Even at a height of a few thousand metres humans find it difficult to breathe due to the reduced air pressure.

For this reason, commercial aircraft which usually fly at a height of around 10,000m, have to pressurise the inside of the aircraft, maintaining a higher pressure inside the aircraft than is found outside.

Extension Question

Q12. Why isn't atmospheric pressure used in aircraft?

The air pressure in aircraft is not the same as that found at ground level. Instead, the air pressure is equivalent to that found at a height of around 2500m. This avoids most ill effects of low air pressure although it is still possible that some passengers may experience pain in their ears or sinuses.

These problems could be avoided if the cabin used the same air pressure that is found at ground level. However, this would mean the pressure inside the aircraft would be far higher than the pressure outside and this would put enormous stress on the structure of the aircraft.

Extension Question

Q13. Where does the air on board an aircraft come from?

To maintain a high pressure in the cabin, an aircraft has to take in air from the outside. This is commonly done by taking 'bleed air' from the engines. As the engines draw in air, it is compressed, which causes its temperature to rise. This hot air is then cooled and passed into the cabin. The exhaust air from inside the cabin is vented through valves at the rear of the aircraft. This helps to maintain the correct pressure.

Some modern aircraft do not use bleed air from the engines. Instead they use electrical compressors to provide air at the correct pressure.

• Why does pressure affect divers?

When divers go underwater, as well as coping with the normal effects of air pressure due to the weight of the air above them, they also have to cope with the pressure due to the weight of the water above them. As water is much denser than air, this pressure increases very quickly. At a depth of only 10m the diver will experience a pressure twice that at ground level. For every 10m the diver descends the pressure will increase by 100,000Pa (1 atmosphere).

The pressure increases significantly as a diver goes deeper underwater

- **Suggested Film**
  - **The Bends**

Extension Question

Q14. What are the bends?

Decompression sickness, also known as 'the bends' occurs when divers ascend too quickly. At depth, under increased pressure, gases like nitrogen dissolve in the body. If a diver ascends too quickly then, as the pressure drops, these come out of solution and form bubbles. Symptoms can vary depending on where these bubbles appear, but can include headaches, joint pain, fatigue and unconsciousness. Decompression sickness can be fatal and divers take great care to control their ascent, rising slowly with regular stops to allow excess gas to be eliminated from the body.

Divers also have to be careful if they are planning to fly soon after they have been diving. As the cabin pressure in commercial aircraft is less than air pressure at ground level this can be equivalent to an ascent and this can cause problems if there is still excess gas in the diver's body.

• Quizzes

Gas Laws

Basic

• Which of the following gases is not usually found in the air we breathe?

A – nitrogen

B – ammonia

C – carbon dioxide

D – oxygen

• What causes air pressure?

A – the weight of particles in the air

B – it is caused by friction when objects pass through the air

C – particles of gas striking surfaces

D – the force of attraction between air particles

• Why do divers need special apparatus to breathe from cylinders?

A – the gas is under pressure and when it is released it rushes out

B – it is difficult to get air to leave the cylinder

C – the gas has to be heated before the diver breathes it in

D – when the air comes out of the cylinder it is very hot

Advanced

• What happens when more gas molecules are added to a fixed volume?

A – pressure decreases as the particles have less space to move

B – pressure decreases for some gases but increases for others

C – pressure increases as more molecules are striking the container

D – pressure increases as the particles will collide with each other more often

• How does temperature of a gas affect the pressure?

A – as temperature increases pressure decreases

B – there is no effect

C – whether pressure increases or decreases depends on the gas used

D – as temperature increases pressure increases

• How does temperature relate to the speed of the particles in a gas?

A – the higher the temperature, the higher the speed of the particles

B – whether the speed increases or decreases depends on the gas used

C – the higher the temperature, the lower the speed of the particles

D – the temperature has no effect on the speed of the particles

Buoyancy

Basic

• Why can some objects float in water?

A – they are not affected by the gravitational force

B – there is a force, buoyancy, which acts upwards

C – they are repelled by water

D – they have no mass

• What is the "displaced water"?

A – the water beneath a floating object

B – the water an object has moved out of the way

C – the water above a sunken object

D – the water absorbed by an object

• What is the buoyant force equal to?

A – the weight of the displaced water

B – the mass of the displaced water

C – the weight of the water beneath a floating object

D – the weight of the air inside a hollow object

Advanced

• What happens when an object is less dense than water?

A – the object will sink as there will be a large buoyancy force

B – the object will float as there will be a small buoyancy force

C – the object will float as there will be a large buoyancy force

D – the object will sink as there will be a small buoyancy force

• Why is it easy for people to float in the Dead Sea?

A – its high salt content means it has a low density

B – its high salt content means it is very dense

C – its low salt content means it has a low density

D – its low salt content means it is very dense

• Why do heavy metal ships float?

A – the ship and the air in the hull combined are denser than water

B – they are hollow and all hollow objects float

C – they displace a small amount of water

D – the ship and the air in the hull combined are less dense than water

• Answers

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