Section 1: Heat Transport

• What is the first law of thermodynamics?

Thermodynamics is the area of physics, which deals with how energy passes between systems. It deals with the macroscopic properties of a system like temperature and pressure.

The first law of thermodynamics tells us that energy cannot be created or destroyed. It states that the change in the internal energy of a system must be equal to the heat that passes into or out of the system or the work which is done on it.

A pan of boiling water on a stove is an example of convection heating

• Suggested Film

- Laws of Thermodynamics

Extension Questions

Q1. What is the second law of thermodynamics?

The first law of thermodynamics tells us that energy is always conserved but this alone is not enough to describe the way energy is transferred. For example, if a cold object like an ice cube passed heat to the air around it, became even colder and caused the air around it to heat up, this would not violate the first law. However, this does not happen because it would violate the second law of thermodynamics.

There are different ways to state the second law. One version states that heat will not pass spontaneously from a cold body to a hotter one. Work is always required for this to happen. The second law also says that it is impossible for any process to be 100% efficient, some energy is always lost to the surroundings.

Alternatively, the second law can be thought of as describing how the entropy of a system changes. It requires that the entropy, or disorder, of an isolated system must always increase (or stay the same). If the entropy of a system does decrease this must result in a greater or equal increase in entropy somewhere else.

Q2. What is the zeroth law of thermodynamics?

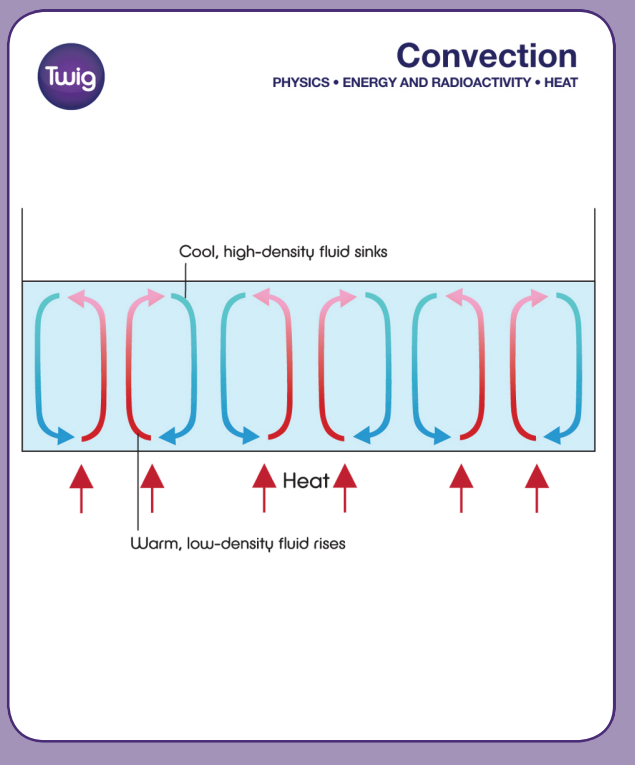
If two objects are in thermal equilibrium this means that they are at the same temperature and no heat will flow between them.

The zeroth law says that if two objects are in thermal equilibrium with a third object they must also be in thermal equilibrium with each other. This can provide a definition of temperature, the property which must be the same for each of these three objects.

Although formulated and accepted after the other laws of thermodynamics, it is generally agreed that the zeroth law is the most fundamental of the laws and so, instead of becoming the fourth law of thermodynamics, it was numbered zero and placed before the other laws.

• How is heat transported?

DIAGRAM 01:



There are three ways in which heat is transported: conduction, convection and radiation. In conduction, atoms or molecules that are in contact vibrate against each other, transferring energy and causing heat to flow from areas of high temperature to areas of low temperature.

Convection occurs because materials generally expand when heated. This reduces their density and means that in liquids and gases currents form, as hotter material rises and cooler material sinks. These currents transfer heat.

All objects emit electromagnetic radiation. The frequency of this radiation increases as the temperature of the object increases. This is why hot objects eventually glow red or yellow, although at temperatures under and around 500°C the radiation is mostly in the form of infrared light. This radiation transfers heat, as it can be absorbed by other objects, increasing their temperature. Heat from the Sun reaches the Earth through radiation.

• Suggested Film

- Heat Transport

Extension Question

Q3. How can we prevent heat transport?

We can insulate against heat transport. A thermos flask maintains its contents at a constant temperature by stopping or minimising conduction, convection and radiation. Conduction (and convection) is stopped by insulating the contents. The flask is made up of two containers, one nested inside the other. Between these is a vacuum and so no conduction can take place between the contents and the environment. The flask is also sealed tightly which, again, minimises conduction and stops convection.

The inner flask has a reflective coating, which reflects any infrared or visible light. This stops heat being radiated away from the contents and stops heat, which has been radiated from outside affecting the contents.

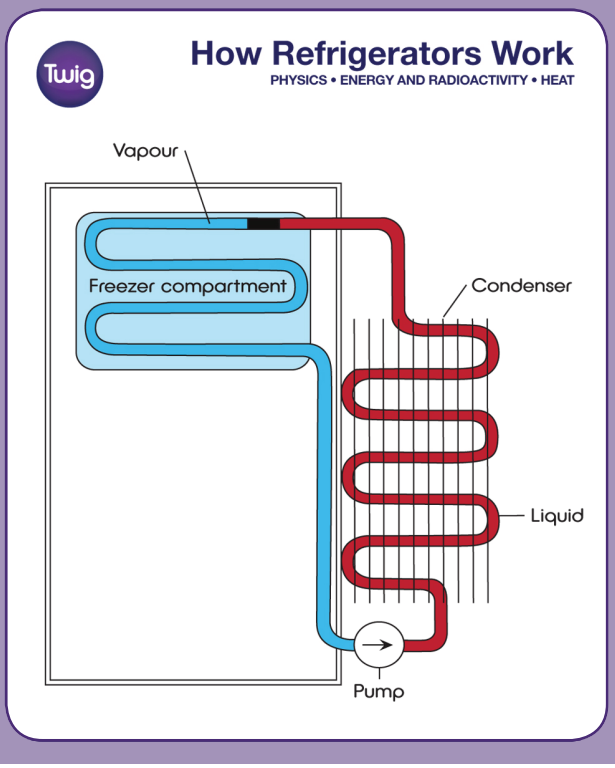
• How do fridges work?

Fridges use materials which are known as refrigerants. They have low boiling points, and so are normally gases at room temperature, but they can be changed into liquids through compression.

Fridges work by allowing an enclosed liquid to evaporate. As this requires energy it causes cooling. Heat then flows from the fridge into the cold material, cooling the contents of the fridge and heating the material. The material is then compressed, which heats it further and it is allowed to conduct heat to its surroundings, ready to be allowed to evaporate again.

Before refrigerators were widely available, ice was sometimes used for cooling

DIAGRAM 02:



Extension Questions

Q4. How did the ice industry work?

Before refrigerators were widely available, ice was sometimes used for cooling. This was first done by cutting ice from frozen lakes or ponds in winter and storing it in ice houses for use later in the year. To minimise melting, the ice was stored in large blocks and straw or sawdust was used for insulation.

Later, in the early 19th century, ice became more widely used and an ice industry developed. Where ice was not available locally it was cut from frozen lakes and transported, often across large distances, to the customer. This ice was expensive and the losses, as the ice melted during transport and storage, were large, but the industry existed well into the 20th century when freezers became more widely available and water could be frozen on demand to produce ice.

Q5. Why does salt melt ice on roads?

Water freezes at 0°C. However, saltwater has a much lower freezing point. Table salt is almost pure sodium chloride and a solution of sodium chloride in water can have a freezing point lower than -20°C. For this reason, when salt is put onto ice the ice melts. However, this will not work if the temperature is very low.

Section 2: Heating and Cooling

• Why do brakes heat up?

For a moving object to slow down a force must act on it and its kinetic energy must be decreased. When brakes are used to stop a vehicle they usually use friction to provide the required force and this causes the kinetic energy of the vehicle to be converted into heat. For this reason brake discs must be able to withstand very high temperatures.

• Suggested Film

- Red Hot: Emergency Stop

• What problems do expansion and contraction cause?

Almost all substances expand when their temperature increases and contract when their temperature decreases. This has to be accounted for when building large structures like bridges or even railway lines. The sections of the structure may expand significantly with heat and if sufficient space has not been left for this expansion the sections could push against each other and the structure could deform. Contraction can also cause problems and cables could contract and snap in cold weather unless they are made sufficiently slack.

• Suggested Films

- Expansion and Contraction

- Hot Air Balloons

Burners heat the air within hot air balloons, creating the lift they need to fly

Extension Questions

Q6. Why is the behaviour of water unusual?

As water cools down it contracts and the colder, denser water sinks leaving warmer, less dense water nearer the surface. However, below 4°C water begins to expand instead of contract, as the temperature decreases. This is very unusual and means that the cold water begins to rise to the surface. As the water freezes this behaviour continues.
The resultant ice is less dense than the water and floats on the surface. This means that water freezes from the top down. This is unusual and in cold weather means that large bodies of water do not freeze solid because the surface layer of ice insulates the water below. This allows fish and other organisms to survive cold winters. If water did not behave in this way, it is likely that life in lakes and oceans would be impossible. As the surface of the water froze it would sink to the bottom where it would be insulated by the water above and would be unlikely to melt. This could continue until all the water froze.

There are other substances which expand on freezing instead of contracting, but water is the only known non-metal to have this property.

Q7. Why do water pipes burst in cold weather?

Because ice is less dense than water. If the water inside pipes turns into ice its volume increases (by around 10%). This can cause pipes to burst in cold weather, although the ice blocks the pipe and so prevents flooding. However, when the temperature increases again the ice melts and water flows out of the burst pipe, causing flooding.

• What is specific heat capacity?

As a substance is heated its temperature increases. The amount of energy required to increase the temperature of 1kg of a material by 1 degree Kelvin is known as the specific heat capacity and is measured in J/kgK.

Different materials have different specific heat capacities. Water has a high specific heat capacity (around 4200 J/kgK) and so relatively large amounts of energy are required to raise the temperature of water. For this reason, water can be used as a coolant as it can remove large amounts of heat before its temperature rises significantly. The high specific heat capacity of the water also means that it takes a long time to heat up and cool down, and this is why the sea can still be cold even though the Sun has been up for hours and can remain warm long after the Sun has set.

Extension Questions

Q8. What is latent heat?

If a substance is heated enough for it to change state it will require energy to melt or vaporise. This energy is required to overcome the attraction between atoms or molecules in the substance, and can be relatively large. For example, around 333,000J would be required to melt 1kg of ice and around 2,260,000J are required to turn the same amount of water into steam. By comparison, only around 4200J of energy is required to raise the temperature of 1kg of water by 1°C.

Q9. Why does sweating help us cool down?

It takes a large amount of energy to change a substance from a liquid to a gas and our bodies use this to keep us cool by sweating. When sweat, which is mostly water, is produced it evaporates from the surface of the skin, which requires large amounts of energy. This energy is taken from our body, which reduces our temperature. This mechanism allows us to maintain our normal temperature of 37°C indefinitely, even in very high hot conditions, as long as we are able to replace the water and minerals lost.

Section 3: Extreme Temperatures

• What is absolute zero?

A rubber ball that has been frozen to near absolute zero by liquid helium

Absolute zero is the lower limit to temperature. It occurs at -273.15°C. At this temperature the motion of the particles within a substance is almost zero and no more heat could be removed from it. It is not possible to cool anything to absolute zero, although the coldest temperature ever achieved is within a hundred trillionths of a degree of absolute zero.

• Suggested Films

- **The Race for Absolute Zero: Liquefying Gas**
- **The Race for Absolute Zero: Laser Cooling**
- **FactPack: Extreme Temperatures**

Extension Questions

Q10. 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, -273.15°C.

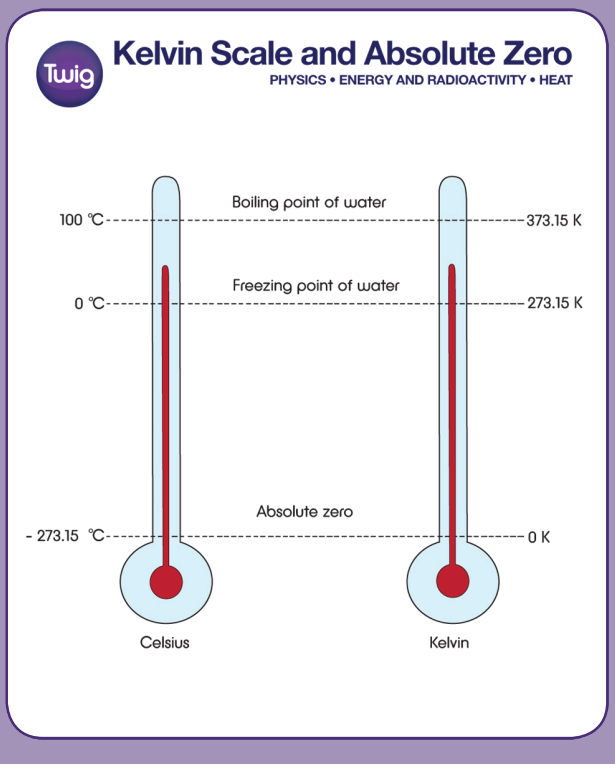
The Kelvin scale is similar to the Celsius scale because the size of a degree Celsius is the same as the size of a degree Kelvin (K). The only difference is that zero on the Kelvin scale is set at absolute zero. This means the scales are offset, so 20°C is 293.15K.

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

Q11. What is the third law of thermodynamics?

The third law of thermodynamics states that the entropy (or disorder) of a substance approaches zero at absolute zero (although this would only apply to a perfect crystal). The third law also means that it is impossible to cool something to absolute zero (-273.15°C) in a finite number of steps.

DIAGRAM 03:



• Why do kettles go quiet just before they boil?

When a kettle is used to heat water, the water at the bottom of the kettle is heated first. This water changes to steam and bubbles form, which rise through the water. As they pass through the cooler water the steam cools down and condenses back into water. The bubbles then collapse, making a loud noise. This continues until all the water in the kettle is hot enough that the bubbles no longer collapse and reach the surface of the water.

• Suggested Film

- Cavitation

• Quizzes

Heat Transport

Basic

• Which of these is not a form of heat transport?

A – conduction

B – diffusion

C – convection

D – radiation

• What happens when atoms get hotter?

A – they begin to break apart

B – their vibrations decrease

C – the bonds between them become stronger

D – their vibrations increase

• What is the name of the most direct method of transferring heat between two objects?

A – conduction

B – diffusion

C – convection

D – radiation

• Which of these is likely to be a good conductor of heat?

A – wood

B – glass

C – iron

D – rubber

Advanced

• What is conduction?

A – when hot liquid or gas expands and rises

B – when infrared radiation is emitted by a hot object

C – the transfer of thermal energy between neighbouring molecules or atoms

D – the spread of particles through random motion

• What is convection?

A – when hot liquid or gas expands and rises

B – when infrared radiation is emitted by a hot object

C – the transfer of thermal energy between neighbouring molecules or atoms

D – the spread of particles through random motion

• When do objects usually radiate heat?

A – when they are moving at high speed

B – when they are in contact with hotter objects

C – when they collide with other objects

D – when they are hotter than their surroundings

Heat Transport

Basic

• What do vibrating atoms emit which is detected as heat?

A – sound

B – electromagnetic waves

C – particles

D – ultraviolet light

Advanced

• Is infrared radiation able to reach us from the Sun?

A – yes, because it can travel through the vacuum of space

B – no, because it cannot travel through a vacuum

C – no, because it does not contain particles

D – yes, but only because convection occurs in space

• What is thermal radiation?

A – when hot liquid or gas expands and rises

B – when infrared radiation is emitted by a hot object

C – the transfer of thermal energy between neighbouring molecules or atoms

D – the spread of particles through random motion

1st and 2nd Laws of Thermodynamics

Basic

• How long ago was the Earth struck by an enormous asteroid?

A – 10 million years ago

B – 35 million years ago

C – 65 million years ago

D – 120 million years ago

• What was the energy released when the asteroid struck Earth equivalent to?

A – the energy released by a nuclear bomb

B – the energy released by a hundred nuclear bombs

C – the energy released by all the world's nuclear bombs

D – more energy than all the world's nuclear weapons combined

• How much energy is in the Universe?

A – an infinite amount

B – the amount constantly varies

C – a fixed amount

D – the amount is gradually increasing

Advanced

• What does the first law of thermodynamics say about energy?

A – heat energy cannot be converted into other forms of energy

B – some energy is always destroyed during any conversion process

C – energy cannot be created or destroyed

D – no process which changes the form of energy can be 100% efficient

• What does the second law of thermodynamics say about energy?

A – heat energy cannot be converted into other forms of energy

B – some energy is always destroyed during any conversion process

C – energy cannot be created or destroyed

D – no process which changes the form of energy can be 100% efficient

• What is the efficiency of a machine?

A – the ratio of the output of useful work to the total input

B – the ratio of the input of energy to the total energy output

C – the ratio of the input of energy to the output of useful work

D – the ratio of the total energy output to the input of energy

Expansion and Contraction

Basic

• What is it called when an object occupies more space?

A – expansion

B – radiation

C – contraction

D – diffusion

• What is it called when an object takes up less space?

A – expansion

B – radiation

C – contraction

D – diffusion

• When do objects usually contract?

A – when they lose heat energy

B – when their temperature increases

C – when their molecules begin to move more quickly

D – when they gain heat energy

• Why do balloons expand when heated?

A – because the mass of the air inside increases

B – because the skin of the balloon expands

C – because the air inside expands

D – because the skin of the balloon becomes weaker

Advanced

• How does temperature not usually affect objects?

A – by changing their weight

B – by changing their size

C – by changing their shape

D – by changing their density

• What does not usually happen when heat is applied to a substance?

A – it occupies more space

B – its molecules move faster

C – its molecules gain energy

D – its molecules move closer together

• How do solids usually behave when heated?

A – different solids contract at different rates when heated

B – different solids expand at different rates when heated

C – all solids expand at the same rate when heated

D – all solids contract at the same rate when heated

• Why do liquids expand at different rates when heated?

A – the rate of expansion depends on the shape of the object

B – the rate of expansion depends on the exact nature of their bonds

C – they have different densities

D – the rate of expansion depends on the method of heating

• Answers

Heat Transport

Basic

• Which of these is not a form of heat transport?

A – conduction

B – diffusion

C – convection

D – radiation

• What happens when atoms get hotter?

A – they begin to break apart

B – their vibrations decrease

C – the bonds between them become stronger

D – their vibrations increase

• What is the name of the most direct method of transferring heat between two objects?

A – conduction

B – diffusion

C – convection

D – radiation

• Which of these is likely to be a good conductor of heat?

A – wood

B – glass

C – iron

D – rubber

Advanced

• What is conduction?

A – when hot liquid or gas expands and rises

B – when infrared radiation is emitted by a hot object

C – the transfer of thermal energy between neighbouring molecules or atoms

D – the spread of particles through random motion

• What is convection?

A – when hot liquid or gas expands and rises

B – when infrared radiation is emitted by a hot object

C – the transfer of thermal energy between neighbouring molecules or atoms

D – the spread of particles through random motion

• When do objects usually radiate heat?

A – when they are moving at high speed

B – when they are in contact with hotter objects

C – when they collide with other objects

D – when they are hotter than their surroundings

Heat Transport

Basic

• What do vibrating atoms emit which is detected as heat?

A – sound

B – electromagnetic waves

C – particles

D – ultraviolet light

Advanced

• Is infrared radiation able to reach us from the Sun?

A – yes, because it can travel through the vacuum of space

B – no, because it cannot travel through a vacuum

C – no, because it does not contain particles

D – yes, but only because convection occurs in space

• What is thermal radiation?

A – when hot liquid or gas expands and rises

B – when infrared radiation is emitted by a hot object

C – the transfer of thermal energy between neighbouring molecules or atoms

D – the spread of particles through random motion

1st and 2nd Laws of Thermodynamics

Basic

• How long ago was the Earth struck by an enormous asteroid?

A – 10 million years ago

B – 35 million years ago

C – 65 million years ago

D – 120 million years ago

• What was the energy released when the asteroid struck Earth equivalent to?

A – the energy released by a nuclear bomb

B – the energy released by a hundred nuclear bombs

C – the energy released by all the world's nuclear bombs

D – more energy than all the world's nuclear weapons combined

• How much energy is in the Universe?

A – an infinite amount

B – the amount constantly varies

C – a fixed amount

D – the amount is gradually increasing

Advanced

• What does the first law of thermodynamics say about energy?

A – heat energy cannot be converted into other forms of energy

B – some energy is always destroyed during any conversion process

C – energy cannot be created or destroyed

D – no process which changes the form of energy can be 100% efficient

• What does the second law of thermodynamics say about energy?

A – heat energy cannot be converted into other forms of energy

B – some energy is always destroyed during any conversion process

C – energy cannot be created or destroyed

D – no process which changes the form of energy can be 100% efficient

• What is the efficiency of a machine?

A – the ratio of the output of useful work to the total input

B – the ratio of the input of energy to the total energy output

C – the ratio of the input of energy to the output of useful work

D – the ratio of the total energy output to the input of energy

Expansion and Contraction

Basic

• What is it called when an object occupies more space?

A – expansion

B – radiation

C – contraction

D – diffusion

• What is it called when an object takes up less space?

A – expansion

B – radiation

C – contraction

D – diffusion

• When do objects usually contract?

A – when they lose heat energy

B – when their temperature increases

C – when their molecules begin to move more quickly

D – when they gain heat energy

A – because the mass of the air inside increases

B – because the skin of the balloon expands

C – because the air inside expands

D – because the skin of the balloon becomes weaker

Advanced

• How does temperature not usually affect objects?

A – by changing their weight

B – by changing their size

C – by changing their shape

D – by changing their density

• What does not usually happen when heat is applied to a substance?

A – it occupies more space

B – its molecules move faster

C – its molecules gain energy

D – its molecules move closer together

• How do solids usually behave when heated?

A – different solids contract at different rates when heated

B – different solids expand at different rates when heated

C – all solids expand at the same rate when heated

D – all solids contract at the same rate when heated

• Why do liquids expand at different rates when heated?

A – the rate of expansion depends on the shape of the object

B – the rate of expansion depends on the exact nature of their bonds

C – they have different densities

D – the rate of expansion depends on the method of heating