

THE EFFECTS OF HEAT ON MATTER

Introduction

When heat is added to a body, various things can result:

- expansion
- increase in temperature
- change of state
- chemical change

The first three of these are physical changes which we will look at in more details

Expansion

When heat is added to a solid, the particles gain energy and vibrate more vigorously about their fixed positions, forcing each other further apart. As a result expansion takes place. Similarly, the particles in a liquid or gas gain energy and are forced further apart. The degree of **expansion** depends on the substance.

For a given rise in temperature a liquid will expand more than a solid. Gases expand enormously on heating, causing a possible explosion if the gas is in a confined space.

In a fire, the thermal expansion of steel beams, concrete and glass can cause considerable damage, especially if expansion takes place at different rates, setting up stresses in the material or structure.

Liquids in drums and pans may overflow when heated. This is due to the fact that liquids expand at a greater rate than solids.

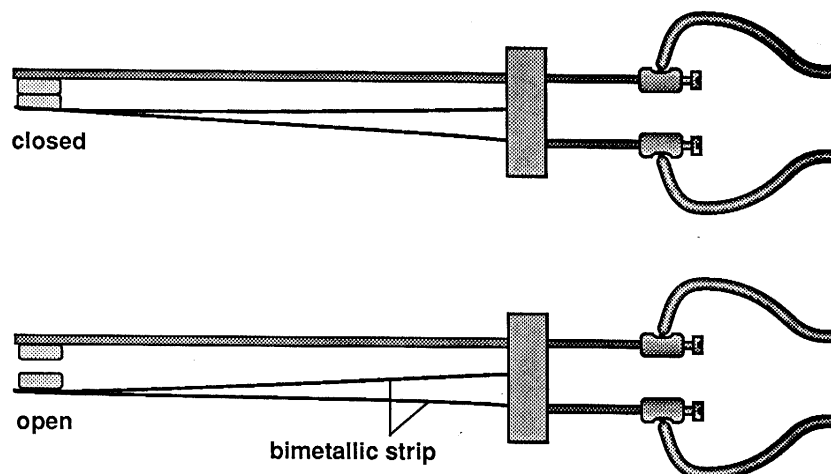
Thermostats

The fact that different substances can expand by different amounts is used in some heat detectors in fire alarm circuits, or as a switch in an electrical heating device.

A bimetallic strip is used which is made of two metals fixed together.

When the metals expand on heating, one expands more than the other causing the bar to curve. The curved bar touches on electric contact and sets off the alarm

This can also be used to break and make electrical contact as the temperature rises and falls in ovens, heater etc.,



Some automatic sprinkler heads operate when an expanding liquid breaks a bulb and releases the water jet. These can be designed to operate at different temperatures.

Allowances need to be made for expansion and contraction due to normal variation in temperatures, especially in large metal structures such as bridges, railway lines, power cables.

Solids expand in three dimensions, but very often only the change in length is important. To calculate the increase in length the **coefficient of linear expansion** for the material needs to be known.

Material	Coefficient of linear expansion (per K)
Aluminium	0.000 024
Copper	0.000 017
Steel	0.000 012
Concrete	0.000 012
Glass	0.000 009
Pyrex	0.000 003
Invar	0.000 000 1

For example:

A 100 m steel tape is correct at 5°C. What will be its length at 45°C?

$$\begin{aligned} \text{Increase in length} &= 100 \times 0.000012 \times 40 \\ &= 0.048\text{m (48 mm)} \end{aligned}$$

$$\text{Final length} = 100.048 \text{ m}$$

Invar is an alloy with a very low coefficient of expansion. It is used where a high degree of accuracy is needed over a wide range of temperatures such as for measuring rods and tapes, and in parts of clocks and watches

It is often used as one of the metals in a bi-metallic strip.

Temperature Increase

When heat energy is added to a substance, this results in an increase in the kinetic energy of its particles, that is, the particles move at higher speeds. Since temperature is a measure of the average kinetic energy, the temperature increases.

The amount of temperature increase for a given body will depend on the amount of heat added, the mass of the body and the material it is made of.

The specific heat (of a material) is the amount of heat required to raise the temperature of one kilogram of the substance by one degree (°C or K).

Water is an efficient cooling agent because it has a high specific heat.

Material	Specific heat (kJ/kg°C)
water	4.2
steam	2.0
ice	2.12
iron	0.46
aluminium	0.90
copper	0.40
glass	0.79
rock, earth, sand	0.84 (approx)

The specific heat can be used to calculate the amount of heat absorbed as a given mass of substance

$$\boxed{\text{Heat absorbed (or released)}} = \boxed{\text{Mass (kg) of material}} \times \boxed{\text{Specific Heat}} \times \boxed{\text{Change in temperature}}$$

rises in temperature.

For example: how much heat would be absorbed when 50kg of water is heated from 10°C to 100°C?

$$\text{Heat absorbed} = 50 \times 4.2 \times 90$$

$$= 18.900 \text{ kJ}$$

Change in State

When a solid changes to a liquid or a liquid changes to a gas, the temperature does not change while the change of state is taking place. The heat absorbed is being used to separate the particles and there is no rise in temperature. When the change is reversed exactly the same amount of heat is released.

The heat energy involved in a change of state is called the **latent heat**.

The latent **heat of vaporisation** is the amount of heat required to change one kilogram of a liquid to its gas (or vapour) at its boiling point.

Experiments have shown that it takes approximately 2260 k Joules of heat to evaporate one kilogram of water at 100°C. That is, the latent heat of vaporisation of water is 2260 kJ/kg.

Compare this with 860 kJ/kg for alcohol.

The very high latent heat of vaporisation of water contributes to its cooling effect, even more than its high specific heat.

The latent heat of fusion for the change from solid (ice) to liquid (water) is 336 kJ/kg.

The effects of latent heat can be seen in the following examples:

- Steam burns are much worse than boiling water burns. Steam contains additional latent heat energy which is given out as the steam changes back to water.
- Vaporisation of a liquid removes heat from its surroundings. This can be observed in:
 - Release of L.P.G., causing icing-up of valves etc.,
 - Cooling by sweating, or wearing wet clothing

This will be more noticeable if there is a wind blowing which increases the rate of evaporation.

- evaporation of volatile liquids e.g. meths or ether, on the skin which causes “freezing”
- Refrigeration systems make use of the evaporation of volatile liquids to remove heat from the contents of the refrigerator. This latent heat is later released at the cooling fins on the back, as the vapour is condensed back to a liquid by the compressor

The amount of heat absorbed (or released) as a substance changes state can be calculated:

$$\boxed{\text{Heat absorbed (or released)}} = \boxed{\text{Latent heat (kJ/kg)}} \times \boxed{\text{Mass}}$$

For example:

1000 kg of water (at 100°C) is changed to steam by a fire. How much heat does this remove from the fire?

$$\begin{aligned} \text{Heat absorbed} &= 2260 \times 1000 \\ &\quad \text{(by the water as it changes to steam)} \\ &= 2,260,000 \text{ k Joules (or 2260 M Joules)} \end{aligned}$$

Compare this to the amount of heat that was required to heat the water from 10°C to 100°C)
= 378,000 k Joules

It can be seen that more than 80% of the total heat absorbed by the water is removed from the fire as the water turns to steam.

Note: The boiling point, or temperature at which boiling occurs, will vary according to the pressure the liquid is subject to. Boiling points are usually given at one atmosphere (101.3kPa).

The boiling point will increase at higher pressures, for example, pressure cookers, autoclaves, car radiators. The boiling point will decrease at lower pressures, for example, high altitudes, low pressure evaporation of milk.

Summary

1. On heating, a substance may

- expand

- increase in temperature
- change state
- undergo chemical change

2. Solids expand less than liquids, liquids expand less than gases

3. Thermal expansion is due to the increased energy of movement of the particles in a substance, forcing the particles further apart

4. Thermostats which contain a bimetallic strips, use the fact that different metals expand at different rates.

5. Thermal expansion of parts of a building during a fire can cause considerable damage.

6. The coefficient of linear expansion for a material gives the amount that each unit of length will increase, for a one degree temperature rise.

7. For thermal expansion: change in length = original length x coefficient of linear expansion x temperature change.

8. Increase in temperature, results from the increase in kinetic energy of the particles, when heat is added.

9. The specific heat of a material is the amount of heat required to raise the temperature of 1 kilogram of a substance by one degree (°C or K).

10. Water is a very good cooling agent because of its high specific heat.

11. For a change in temperature:

$$\text{Heat absorbed} = \text{mass (kg)} \times \text{specific heat} \times \text{temperature change}$$

12. When a substance changes state, the temperature does not change while the change of state is taking place.

13. The energy absorbed during a change of state is called "latent heat".

14. During a change of state, the latent heat energy is used to overcome the forces holding the particles together in a liquid or solid.

15. The latent heat of vaporisation is the amount of heat required to change 1 kilogram of a liquid to a gas (or vapour) at its boiling point.

16. The latent heat of fusion is the amount of heat required to change one kilogram of a solid to its liquid state.

17. For a change of state:

$$\text{Heat absorbed} = \text{mass (kg)} \times \text{latent heat}$$

18. The units for measuring specific heat are $\text{kJ/kg}^\circ\text{C}$. and the units for measuring latent heat are kJ/kg
19. Water has a very high latent heat of vaporisation.
20. The boiling point of a liquid may change if the surrounding pressure is changed.