Chapter 10. Thermal properties of matter

Contents:

New word list:

Expansion/Contraction
Rivet铆钉 invar因瓦合金 ethanol乙醇 brass 黄铜 petrol/gasoline汽油
Shipbuilding 造船 Metal plate金属板 Strip条/带Alloy 合金 unscrew Thermostat恒温器
paraffin 石蜡 draught风 damp潮湿

2.2 Thermal properties and temperature

2.2.1 Thermal expansion of solids, liquids and gases

Core

1 Describe, qualitatively, the thermal expansion of solids, liquids and gases at constant pressure

2 Describe some of the everyday applications and consequences of thermal expansion

Supplement

3 Explain, in terms of the motion and arrangement of particles, the relative order of magnitudes of the expansion of solids, liquids and gases as their temperatures rise

2.2.2 Specific heat capacity

Core

1 Know that a rise in the temperature of an object increases its internal energy

Supplement

2 Describe an increase in temperature of an object in terms of an increase in the average kinetic energies of all of the particles in the object

3 Define specific heat capacity as the energy required per unit mass per unit temperature increase; recall and use the equation

$$c = \frac{\Delta E}{m\Delta\theta}$$

4 Describe experiments to measure the specific heat capacity of a solid and a liquid

2.2.3 Melting, boiling and evaporation

Core

1 Describe melting and boiling in terms of energy input without a change in temperature

2 Know the melting and boiling temperatures for water at standard atmospheric pressure

3 Describe condensation and solidification in terms of particles

4 Describe evaporation in terms of the escape of more energetic particles from the surface of a liquid

5 Know that evaporation causes cooling of a liquid

Supplement

6 Describe the differences between boiling and evaporation

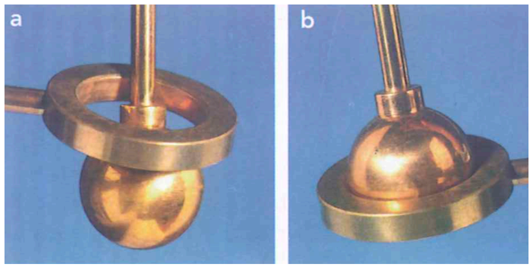
7 Describe how temperature, surface area and air movement over a surface affect evaporation

8 Explain the cooling of an object in contact with an evaporating liquid

10.1 Thermal expansion

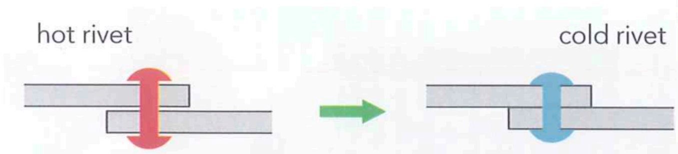
cause： particles gain energy, move faster/vibrate more, pushing each other further apart/take up more space (caution: particle size unchanged as temperature rise)

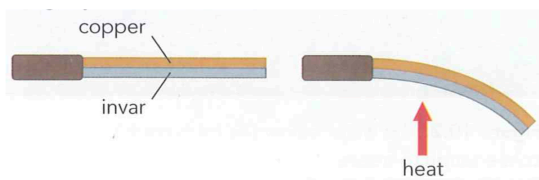
10.1.1 The thermal expansion of solids



Applications:

1. Rivet
2. Metal lid
3. Steel tyre
4. Bimetallic strip





Consequence:

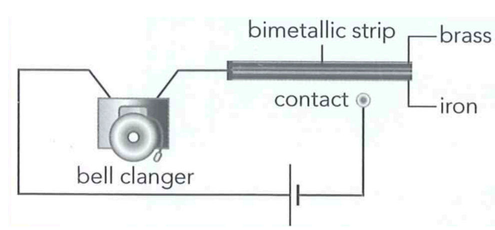
1. Metal bridges
2. Concrete road

Exercise 10.1

The diagram shows the circuit for a fire alarm using a bimetallic strip.

a. Brass expands more than iron. Which metal should be at the top of the strip?

b. Describe what happens as the temperature raises in case of a fire?

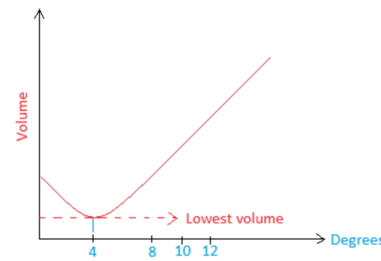


a. Brass should be on the top

b. The bar will bend downwards, the completing the circuit so that the bell rings

10.1.2 The thermal expansion of liquids

Applications:

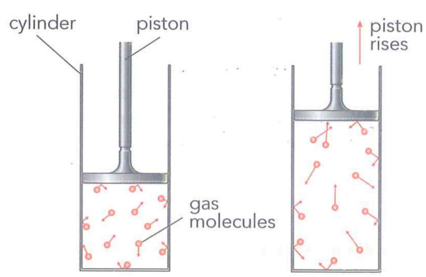


Thermal expansion of water

Why not use water in the thermometer above?

Water freezes under 0; unusual expansion of water;

10.1.3 The thermal expansion of gases



Heat the gas

Gases expand -> density decreases -> hot air rises

Application:

10.1.4 Comparison of expansion in solids, liquids and gases

When heated, particles don't get any bigger but have more energy => move around faster/ vibrate more, take up more space

States	Thermal expansion	Explanation
Solid	*Least*	*Vibrate more about a fixed point, tightly bonded, so separate little*
Liquid	*More than solid*	*vibrate more, and move a bit faster, not so tightly bonded, a small separation*
Gas	*Even more than liquid*	*Move faster and further apart, not bonded, separate most*

Exceptions:

Liquid paraffin, petrol(gasoline) expands very rapidly on heating.

Exercise 10.2:

Copy and complete theses sentences:

When an object is heated it (expands). When it cools it (contracts).

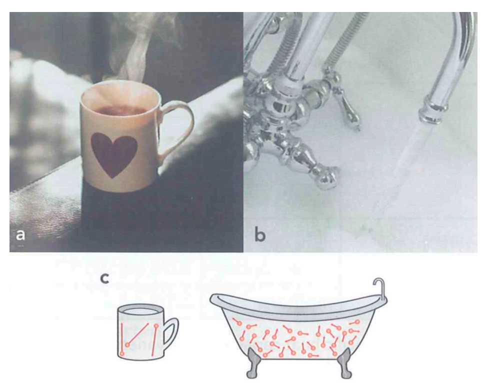
Liquids expand more than (solids), but less than (gases)

10.2 Specific heat capacity

10.2.1 Energy and temperature

Energy vs temperature: internal energy is different from temperature. Internal energy is the total energy of all molecules in the object; temperature is the average kinetic energy of all molecules in the object.

Relation: it takes energy to raise temperature



Compare the heat needed to raise temperature in following two scenarios:

A. Raise a bottle of water from $10^\circ C$ to $20^\circ C$, or from $10^\circ C$ to $100^\circ C$;

B. Raise a bottle of water from $10^\circ C$ to $20^\circ C$, or a tank of water from $10^\circ C$ to $20^\circ C$;

So, the amount of energy need to heat water depends on:

The mass of water

The increase in temperature

10.2.2 Specific heat capacity

Specific heat capacity of a substance: the energy needed to raise the temperature of 1kg of the substance by 1 degree.

Equation: $c = \frac{\Delta E}{m\Delta\theta}$

Equation in word: $specific\ heat\ capacity = \frac{energy\ required}{mass \times temperature\ increase}$

Unit: J/(kg $\cdot^{\circ} C$)
Delta: change in

Example: it takes 4200 J to raise the temperature of 1kg water by 1$^{\circ}C$, the specific capacity of water is (4200 J/(kg $\cdot^{\circ} C$)

Exercise 10.3:
A kettle heats 1.5kg of water. How much energy is needed to raise the temperature of water from 20$^{\circ}C$ to 60$^{\circ}C$? from 20$^{\circ}C$ to 90$^{\circ}C$?

Different material has different specific heat capacities
: different material require different amount of energy to raise the same amount of substance by same amount of temperature

Type of material	Material	Specific heat capacity / J/(kg °C)
metals	steel	420
	aluminium	910
	copper	385
	gold	300
	lead	130
non-metals	glass	670
	nylon	1700
	polythene	2300
	ice	2100
liquids	water	4200
	sea water	3900
	ethanol	2500
	olive oil	1970
gases	air	1000
	water vapour	2020 (at 100 °C)
	methane	2200

Energy transfers to make solid molecules vibrate more and gas molecules move faster.

10.2.3 The specific heat capacity of water

water: high specific heat capacity

So,

It takes a lot of energy to heat up water

Hot water takes a long time to cool down.

Can you think of any phenomena relating to this fact?

Exercise 10.4

A cook heats 500g of olive oil in a steel pan which has a mass of 300g, the oil needs to be heated form 20˚C to 190˚C. Using the data from previous table to calculate the thermal energy needed:

To heat the pan

To heat the oil

In total

Exercise 10.5

The electric kettle has a power rating of 2000 W. It takes 90s to heat 500g water from 20˚C to boiling. Use this information to calculate an approximate value for specific heat capacity of water.

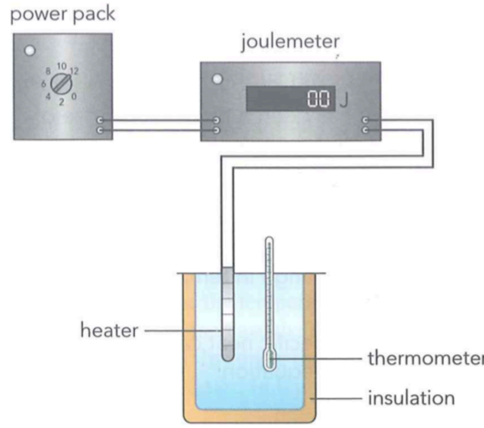
Compare your answer to the specific heat capacity of water given in the table before.

Comment on why it is different

10.2.4 Measuring the specific heat capacity of water:

You will need:

- a beaker of water with a lid with holes for the thermometer and heater
- insulation for the beaker
- electric heater
- power pack
- joulemeter (your teacher may show you an alternative way to find the energy used)
- thermometer
- access to balance.



1. Put 0.25 kg of water into the beaker.
2. Set up the experiment as shown in Figure 10.15.
3. Measure and record the initial temperature (θ_1) of the block.
4. Turn on the power supply and leave until the temperature changes by about 50 °C.
5. Turn off the power supply. Record the final temperature (θ_2).
6. Calculate the change in temperature using $\Delta\theta = \theta_2 - \theta_1$.
7. Record the joulemeter reading.
8. Calculate the specific heat capacity of the metal using the equation:

$$c = \frac{\Delta E}{m\Delta\theta}$$

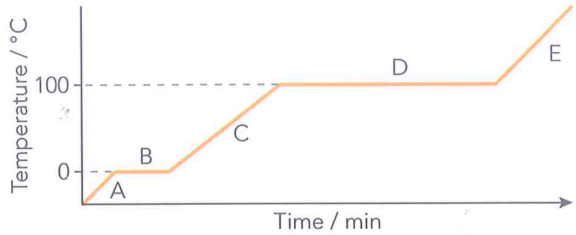
Compare your answers with the value of specific heat capacity given in table before, are they higher or lower? explain the difference.

The thermal energy supplied by the heater heats the heater itself, the thermometer and the surrounding air as well as the beaker. Explain what effect this will have on the accuracy of your answer.

Part of energy used to increase the temperature of heater, thermometer, beaker and surrounding air.

10.3 Changing state

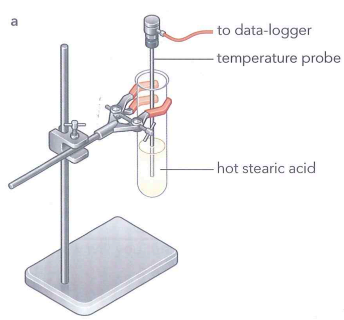
10.3.1 Temperature change during state changing
Keep heating ice:



During change of states,
from liquid to gas (i.e. water -> steam)
the temperature (stays the same). Energy is taken in and used to (overcome attraction among molecules).
from solid to liquid (i.e. ice -> water)
the temperature (stays the same). Energy is taken in and used to (break bonds among molecules).

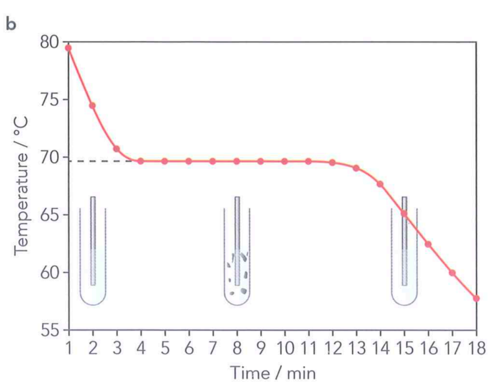
When changes are reversed, energy (is given out).

10.3.2 Investigating a change of state
Settings:



Stearic acid: waxy substance, warm: clear, colorless liquid

Results:



Hotter than surrounding: energy transfer from wax;
At first, liquid wax cools down, its temperature drops gradually;
As the temperature drops, the temperature difference btw wax and surroundings gets smaller, it cools more slowly, the graph slightly curved;

Clear liquid; mixture of clear liquid and white solid; white solid

Explanations:
Hotter than surrounding: energy transfer from wax;
At first, liquid wax cools down, its temperature drops gradually;As the temperature drops, the temperature difference btw wax and surroundings gets smaller, it cools more slowly, the graph slightly curved;
Temperature stays the same for a few minutes but energy still transferred from wax to surroundings, wax is solidifying.
The wax's temperature drops again, all wax is now solid and it keeps cooling down until reaches the temperature of surroundings.

More about melting point & boiling point
Melting point: temperature at which a solid melts to become a liquid.
Boiling point: the temperature at which a liquid changes to a gas (at constant pressure) 液化气
pressure affects boiling point of a substance, for example, at the top of mount Everest water boils at 71$^{\circ}C$, 高压锅

Does air has a fixed boiling point?
A pure substance: fixed boiling/melting point
A mixture of substances: over a range of temperatures

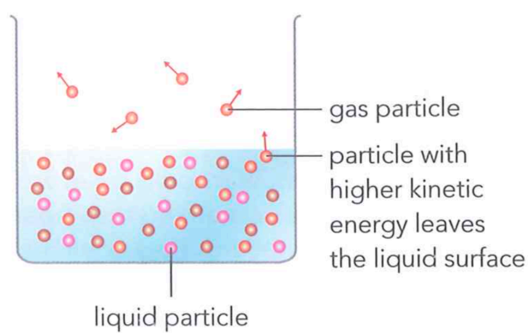
Do all substances melt or boil when they are heated?
No, some burn some break down before having a chance to change state.

10.3.3 Evaporation
Liquid -> gas (water => water vapor)

After it rains, the puddles dry up even though the temperature is much lower than 100$^{\circ}C$. Why?
evaporation happens at any temperature

But on a hot day the puddles disappear quickly than on a cold
A liquid evaporates more quickly as its temperature approaches its boiling point.

How to explain evaporation using kinetic model of matter?



The water particles are moving around, some are moving faster enough to overcome attraction and escape from the surface of the water. And become water vapor in the air.
If temperature of liquid is higher, more of its particles will have enough energy to escape
The hottest particles are most likely to escape as they have most energy, when they escape the average energy of remaining particles is less. So the liquid cools down.(**cooling by evaporation**)
Transfer Thermal energy
E,g, sweat: from skin to surroundings ; help us regulate body temperature in hot condition

Comparing evaporation and boiling

Boiling: only happens at the boiling point of a substance. Evaporation occurs at all temperatures.

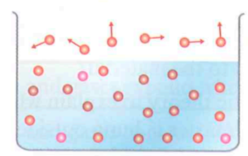
Boiling happens throughout the liquid. Evaporation only happens at the surface

A boiling liquid bubbles. A liquid can evaporate without bubbles

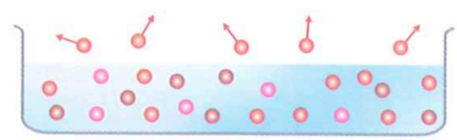
Boiling requires heat, evaporation provides cooling. For a liquid to boil, it has to be heated=the kinetic energy of its particles must be increased. Evaporation happens when the most energetic particles escape, so evaporation takes energy from the substance

Speeding up evaporation

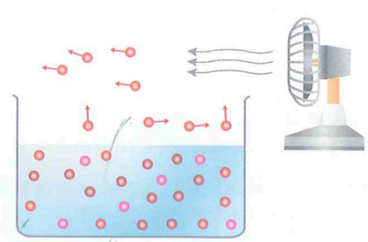
Increasing the temperature
The particles on average have more kinetic energy;
More of particles will have enough energy to escape;
Liquid evaporates more quickly



Increasing the surface area
More of the particles are close to the surface,
They can escape more easily.
Liquid evaporates more quickly



Blowing air across the surface
When particles escape from the water, they are blown away so that they cannot fall back into water
Helps the liquid evaporate quickly



Exercise 10.6

Explain in terms of movement and position particles what happens to an ice cube as it is heated and melts.

Initially the particles are in fixed positions and they vibrate sound these positions. As the ice is heated, they vibrate more until they reach the melting point. At this point they have enough energy ti break free and move freely, although attractive forces still hold them together.

Exercise 10.7

Tungsten melts at a much higher temperature than iron. What can you say about the forces between the tungsten atoms, compared to the forces between the iron atoms

Forces between tungsten atoms are stronger than forces between iron atoms.

Exercise 10.8

A solid is heated but its temperature does not rise.
What is happening to the solid: it is melting
What happens to the energy that is being supplied to the material:
Energy required to break bonds between particles(it increases their potential energy)

Exercise 10.9

Explain how covering a bottle of milk with a damp cloth will help to cool the milk.

The water from the damp cloth will evaporate and will take energy away from milk.