Chapter 10.
Thermal properties of matter

G2 | Ji Yutong | 04/2024

New Words

Expansion/Contraction
Rivet invar ethanol brass petrol/gasoline
Metal plate Strip Alloy unscrew Thermostat paraffin draught damp

New Words

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

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)

The thermal expansion of solids

Applications:

Rivet

Metal lid

Steel tyre

Bimetallic strip

Consequence:

Metal bridges

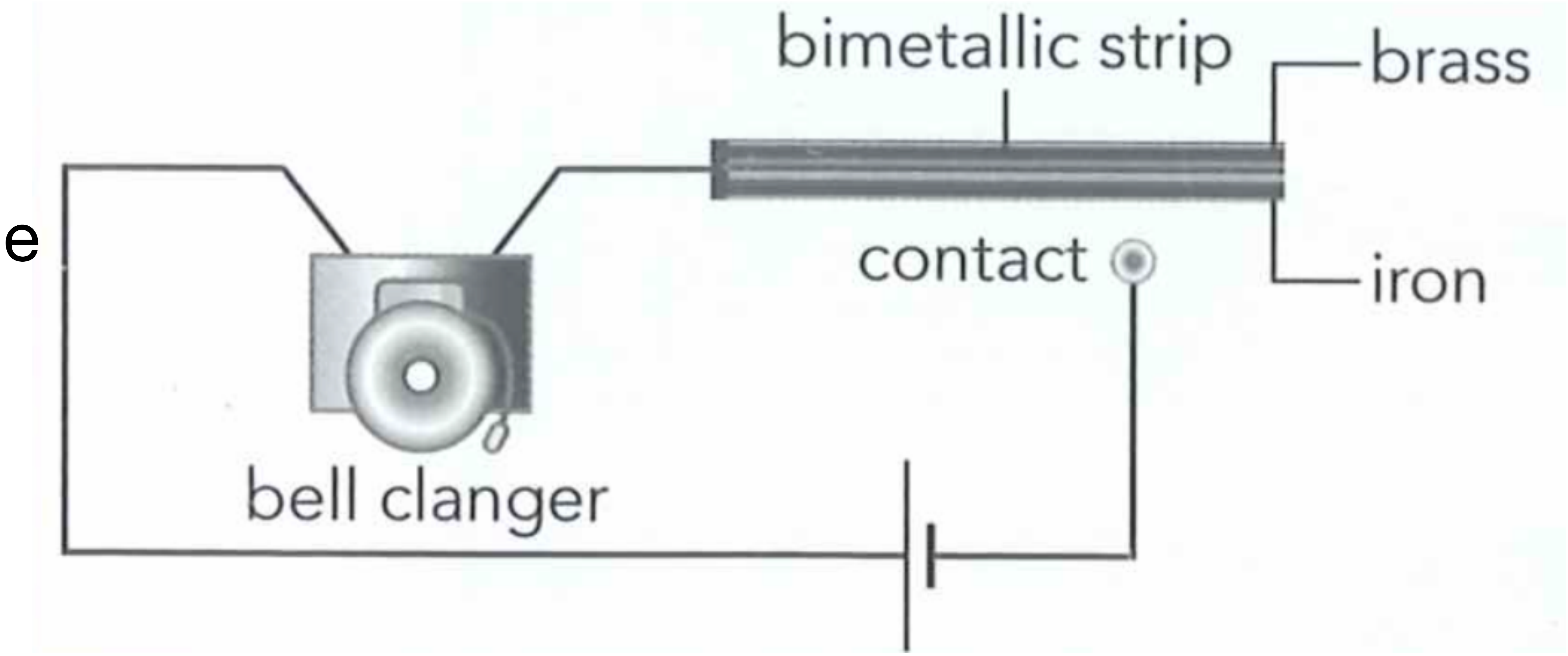
Concrete road

Exercise

The diagram shows the circuit for a fire alarm using a bimetallic strip.
Brass expands more than iron. Which metal should be at the top of the strip?
Describe what happens as the temperature raises in case of a fire?

Brass should be on the top

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

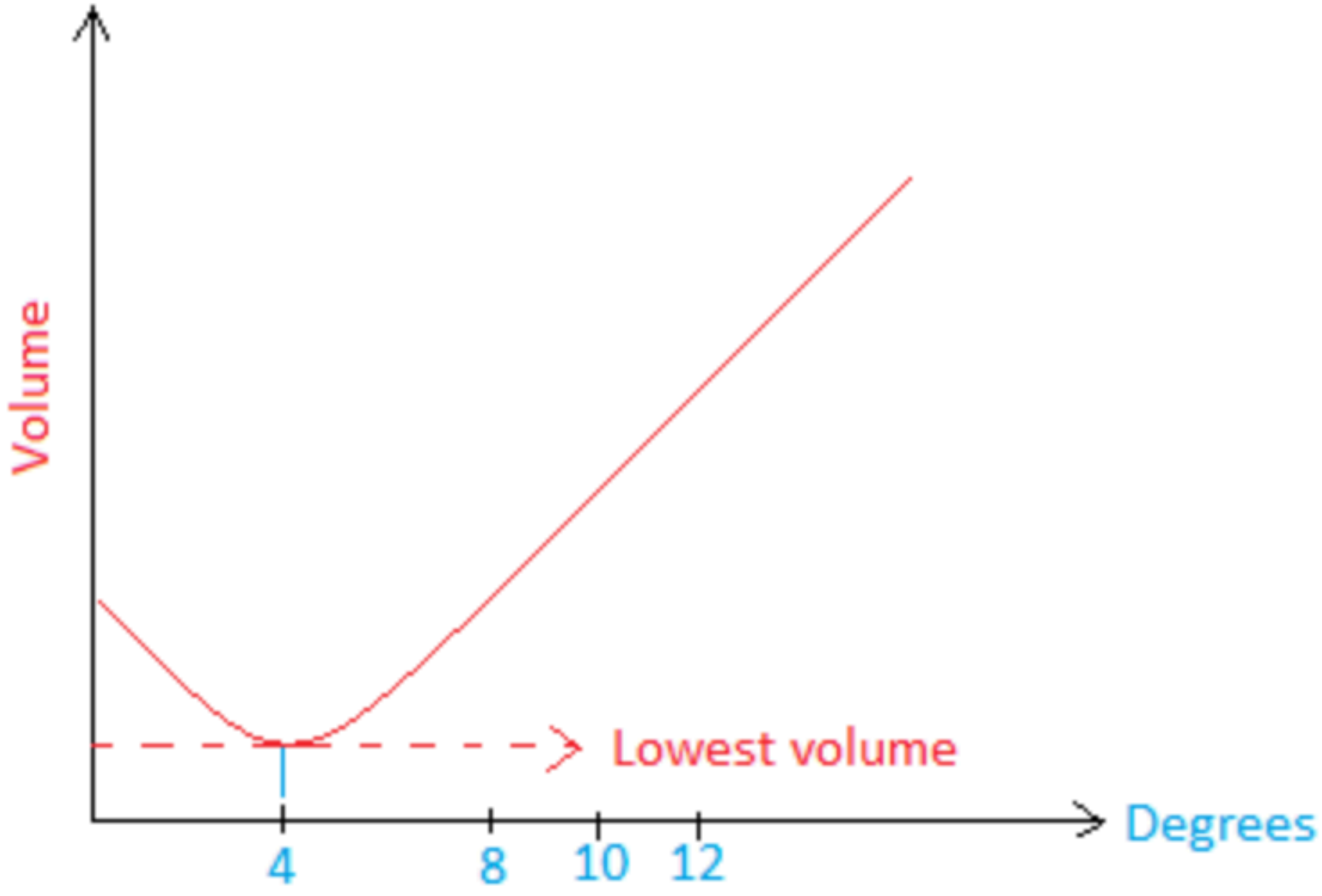


The thermal expansion of liquids

Applications:

Why not use water in the thermometer above?

Water freezes under 0; unusual expansion of water;



Thermal expansion of water

The gas law

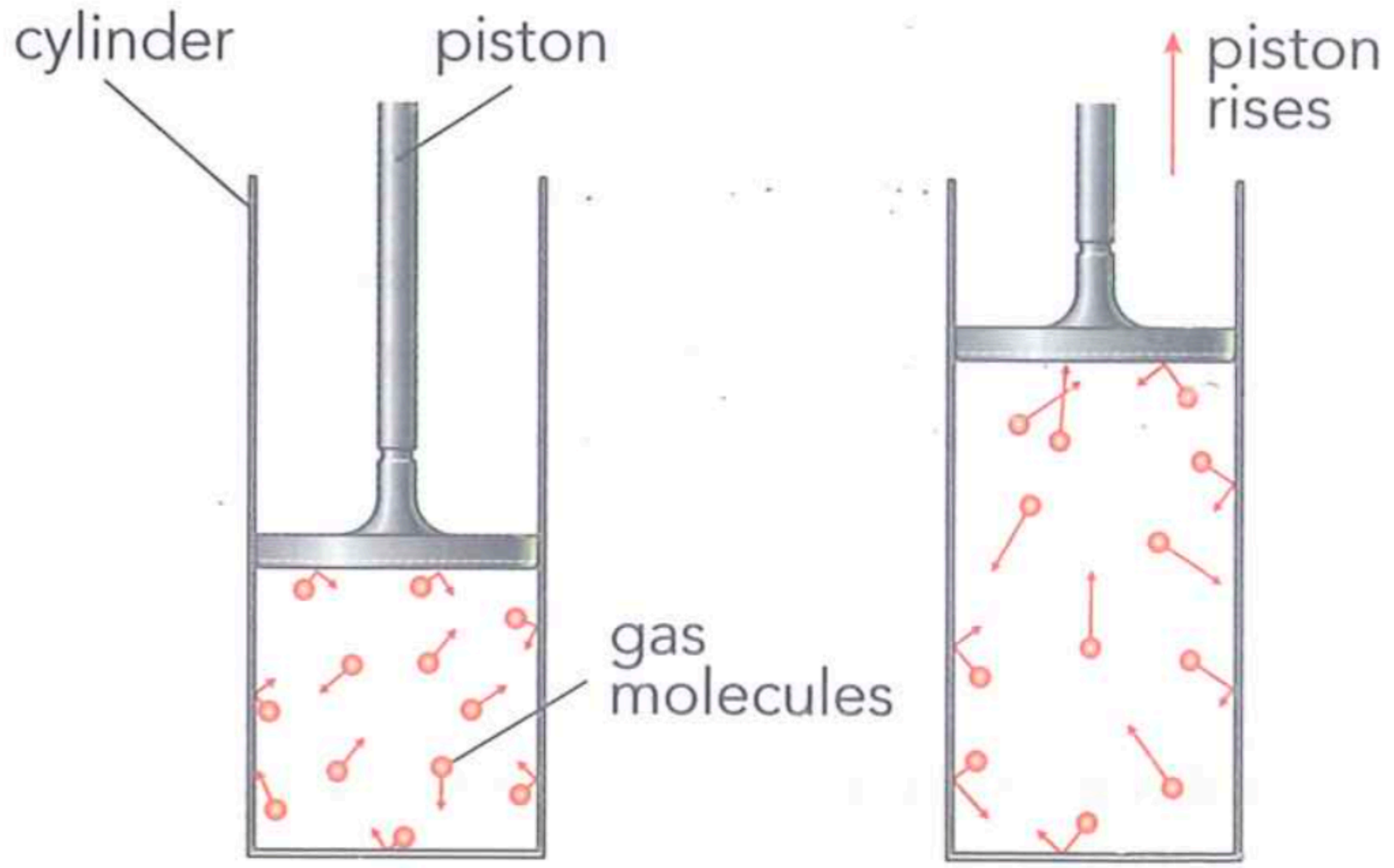
Heated: Charles's law

At constant pressure, constant ==> thermal expansion (热胀冷缩)

$$\frac{V}{T} = const$$

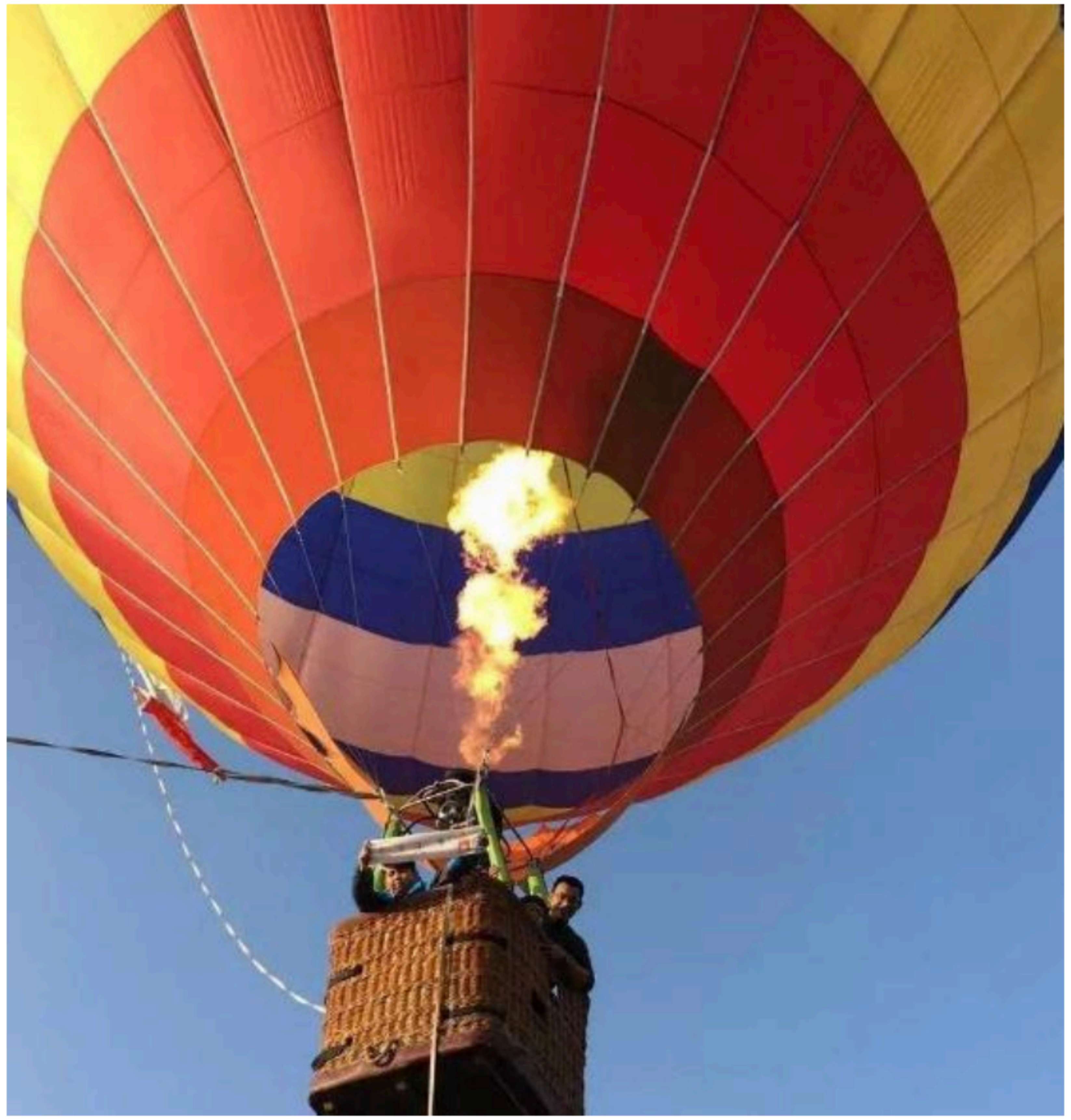
The thermal expansion of gases

Heat the gas



Gases expand -> density decreases -> hot air rises

Application:



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

Copy and complete theses sentences:

When an object is heated it ( ). When it cools it ( ). Liquids expand more than ( ), but less than ( )

Exercise

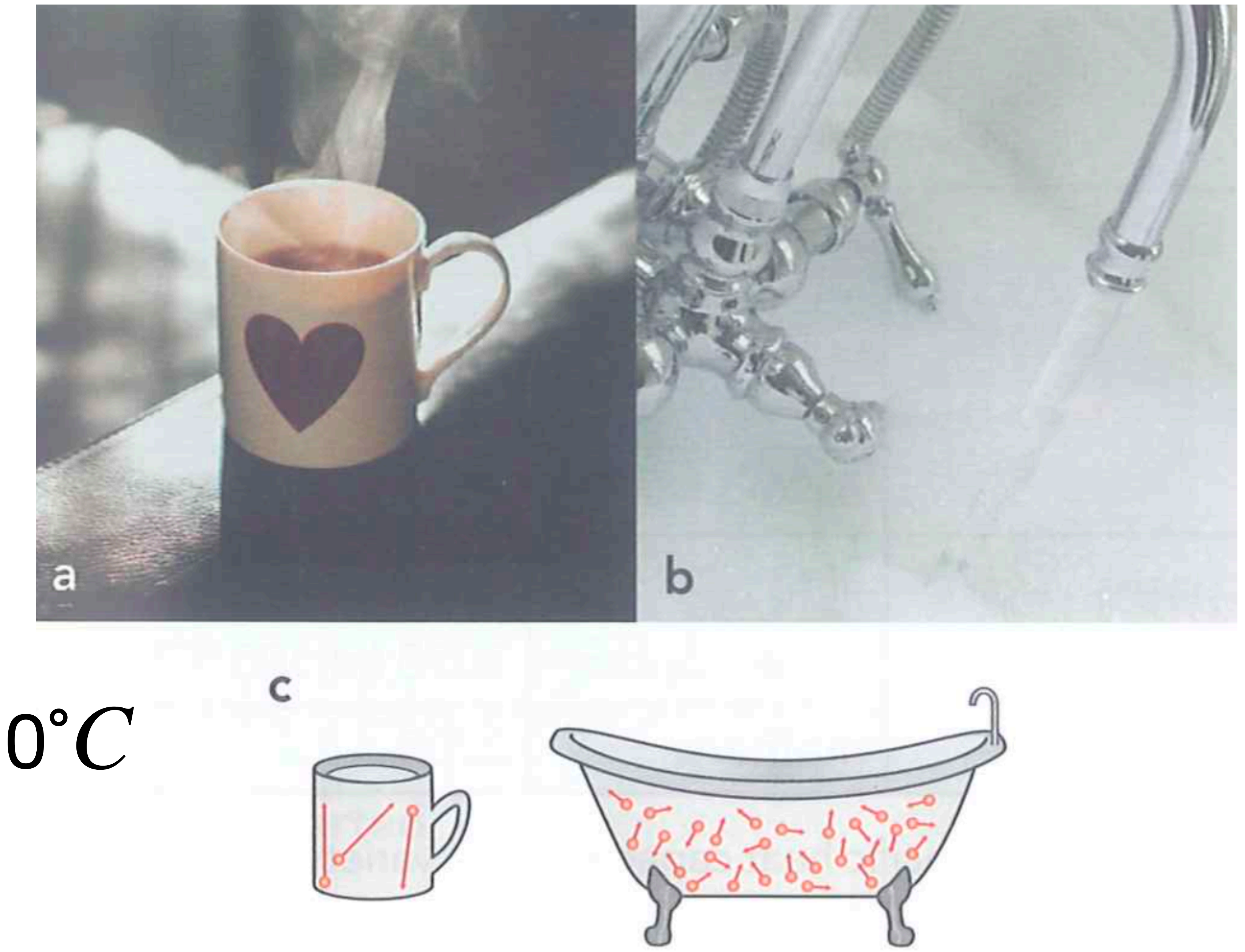
Copy and complete theses sentences:
When an object is heated it (expands). When it cools it (contracts). Liquids expand more than (solids), but less than (gases)

Specific heat capacity

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:

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

2. 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

Recap

Thermal expansion: when heated, particles don't get any bigger but have more energy => **move around faster/ vibrate more, take up more space**

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The amount of energy need to heat water depends on:

The mass of water

The increase in temperature

Specific heat capacity

Specific heat capacity of a substance: the energy needed to raise the temperature of 1kg of the substance by 1$^{\circ}C$.

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

$$specific\ heat\ capacity = \frac{energy\ required}{mass \times temperature\ increase}$$

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

A kettle heats 1.5kg of water. How much energy is needed to raise the temperature of water from 20°C to 60°C? from 20°C to 90°C?

Specific heat capacity

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

Different material has different specific heat capacities:

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

different material require different amount of energy to raise the same amount of substance by same amount of temperature

Specific heat capacity of water

water: ***high*** specific heat capacity

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

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

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

The specific heat capacities of aluminium, iron, ethanol and water are given.

substance	specific heat capacity J / kg °C
aluminium	900
iron	450
ethanol	2400
water	4200

1 kg of each metal is put into 5 kg of each liquid.

The starting temperature of each metal is 60 °C. The starting temperature of each liquid is 10 °C.

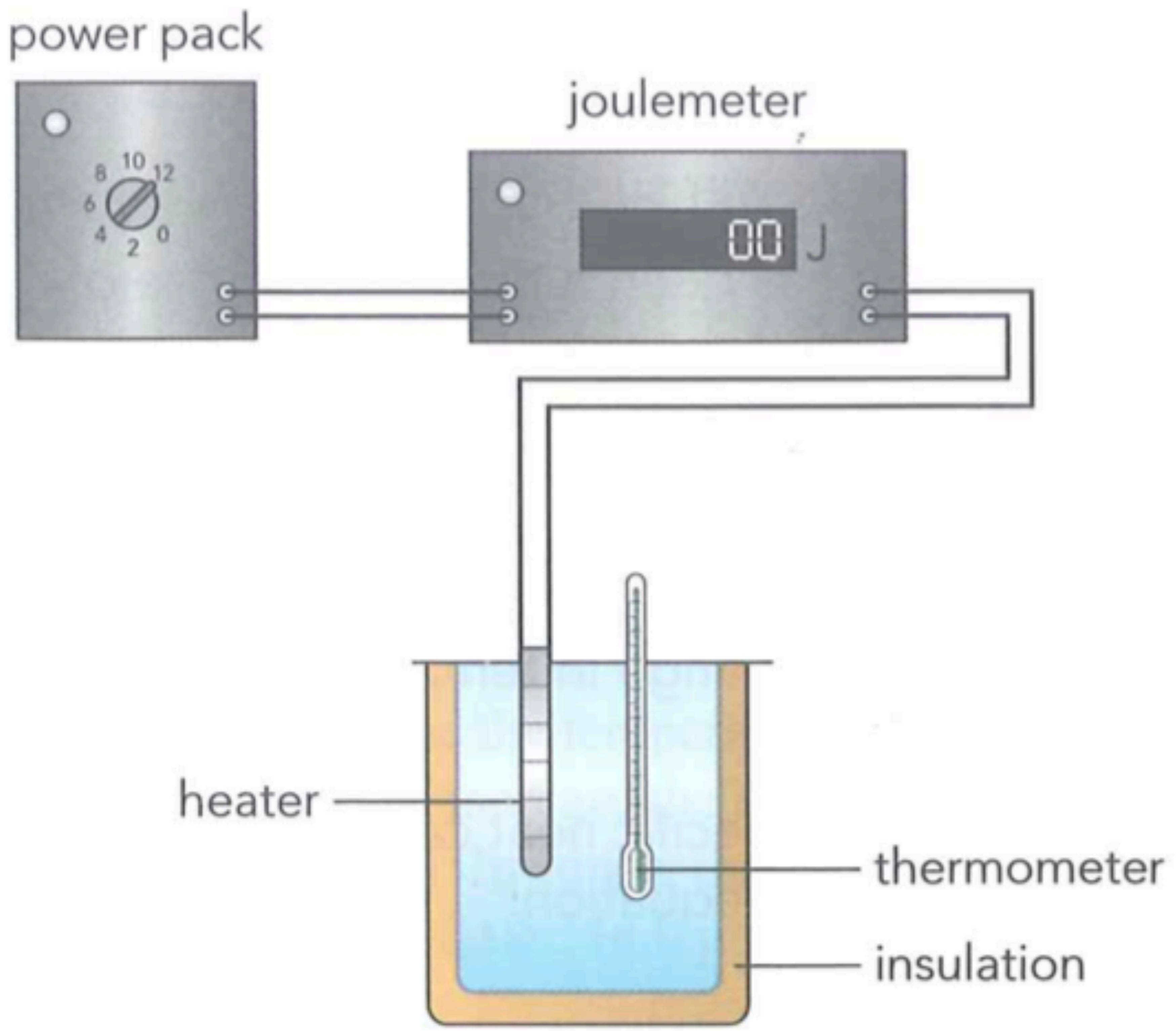
Which example has the highest final temperature?

	metal	liquid
A	aluminium	ethanol
B	iron	ethanol
C	aluminium	water
D	iron	water

Measuring the specific heat capacity of water

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:

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



Measuring the specific heat capacity of water

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

The answer will be higher. Because part of thermal energy supplied by the heater **heats the heater itself, the thermometer and the surrounding air as well as the beaker.**

Exercise

A chef heats some water in a pan on a hotplate.

The temperature of the water rises by 10 °C in time t.

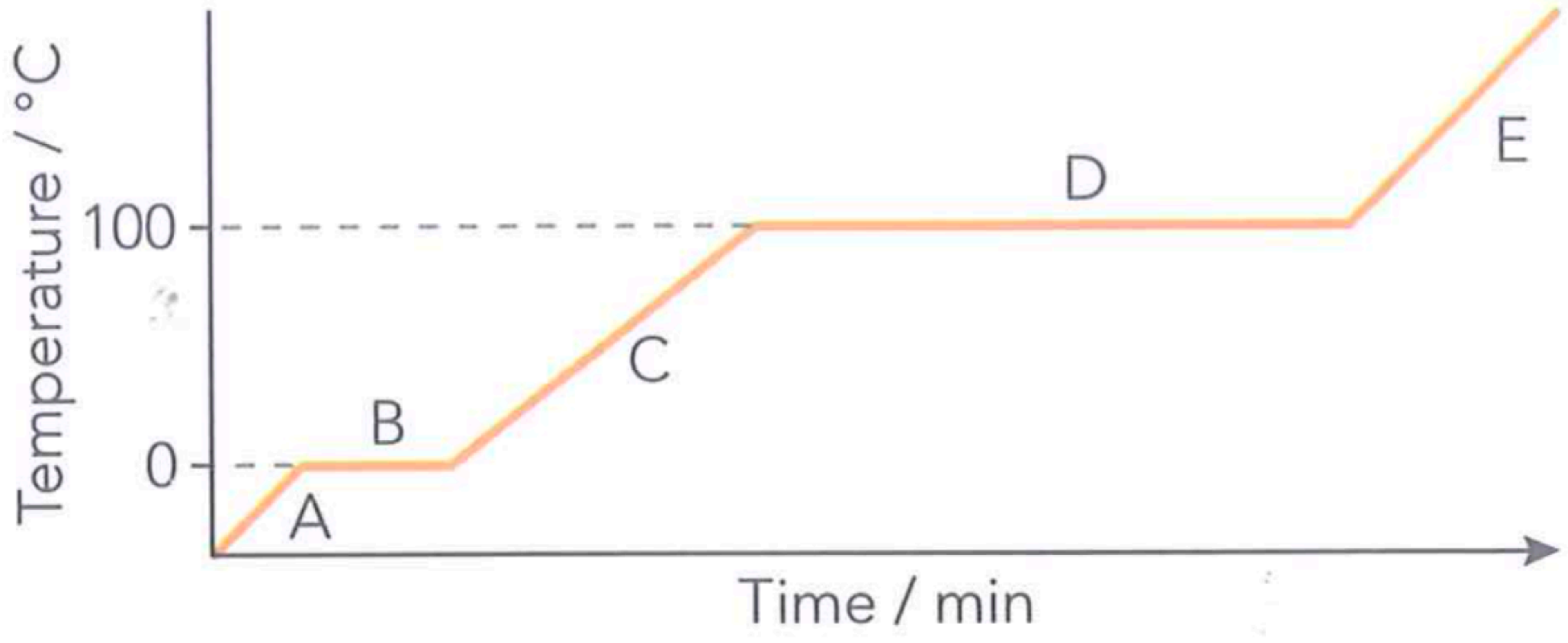
She then puts the same volume of oil in an identical pan on the same hotplate.

The specific heat capacity of water is 2.5 times that of oil and water is 1.1 times denser than oil.

What is the time for the temperature of the oil to rise by 10 °C?

A $0.36t$ **B** $0.44t$ **C** $2.3t$ **D** $2.8t$

Changing state



heating ice

B: from **solid** to **liquid** (i.e. ice -> water)

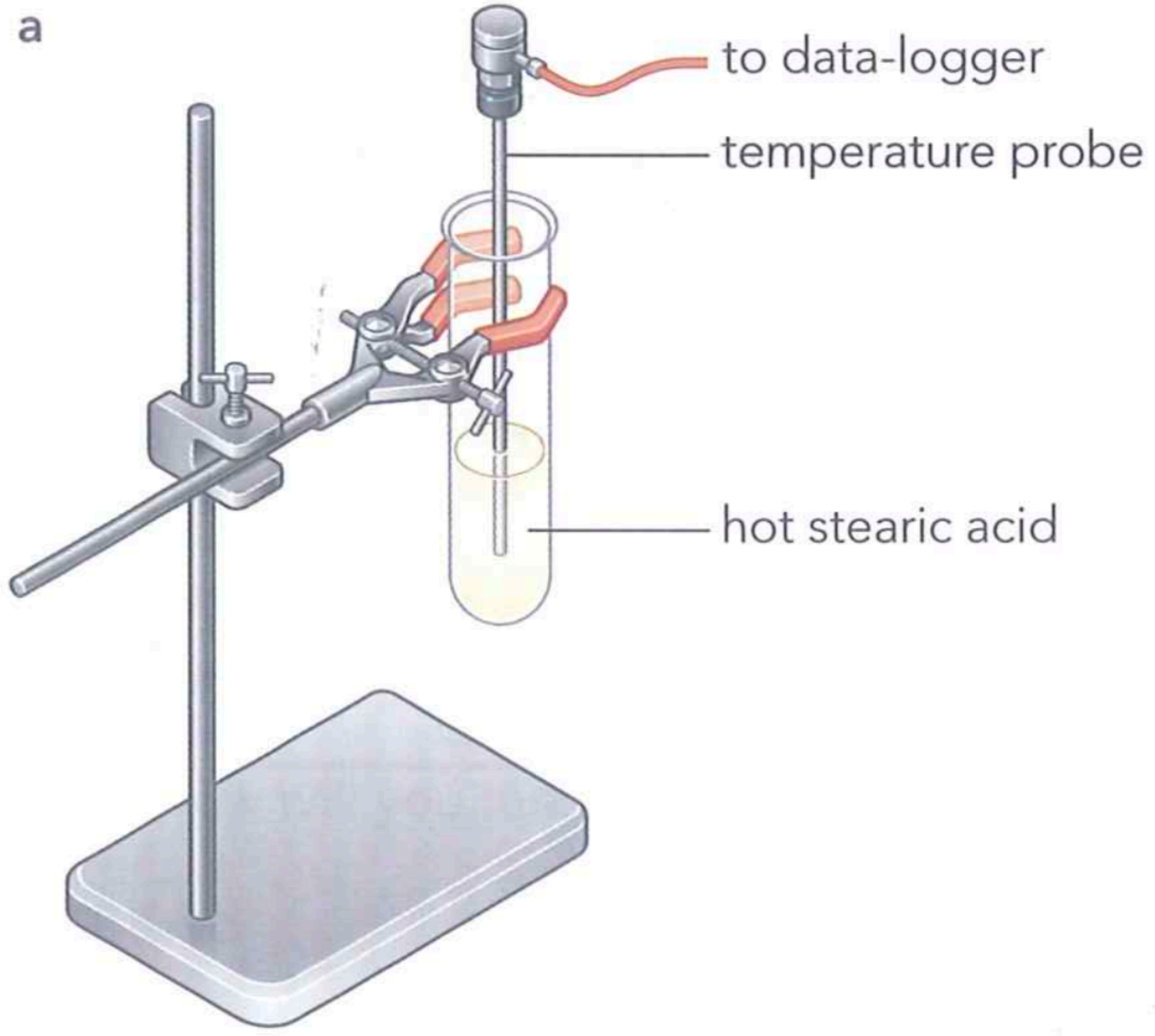
the temperature ***stays the same***. Energy is taken in and used to ***break bonds*** among molecules.

D: from **liquid** to **gas** (i.e. water -> steam)

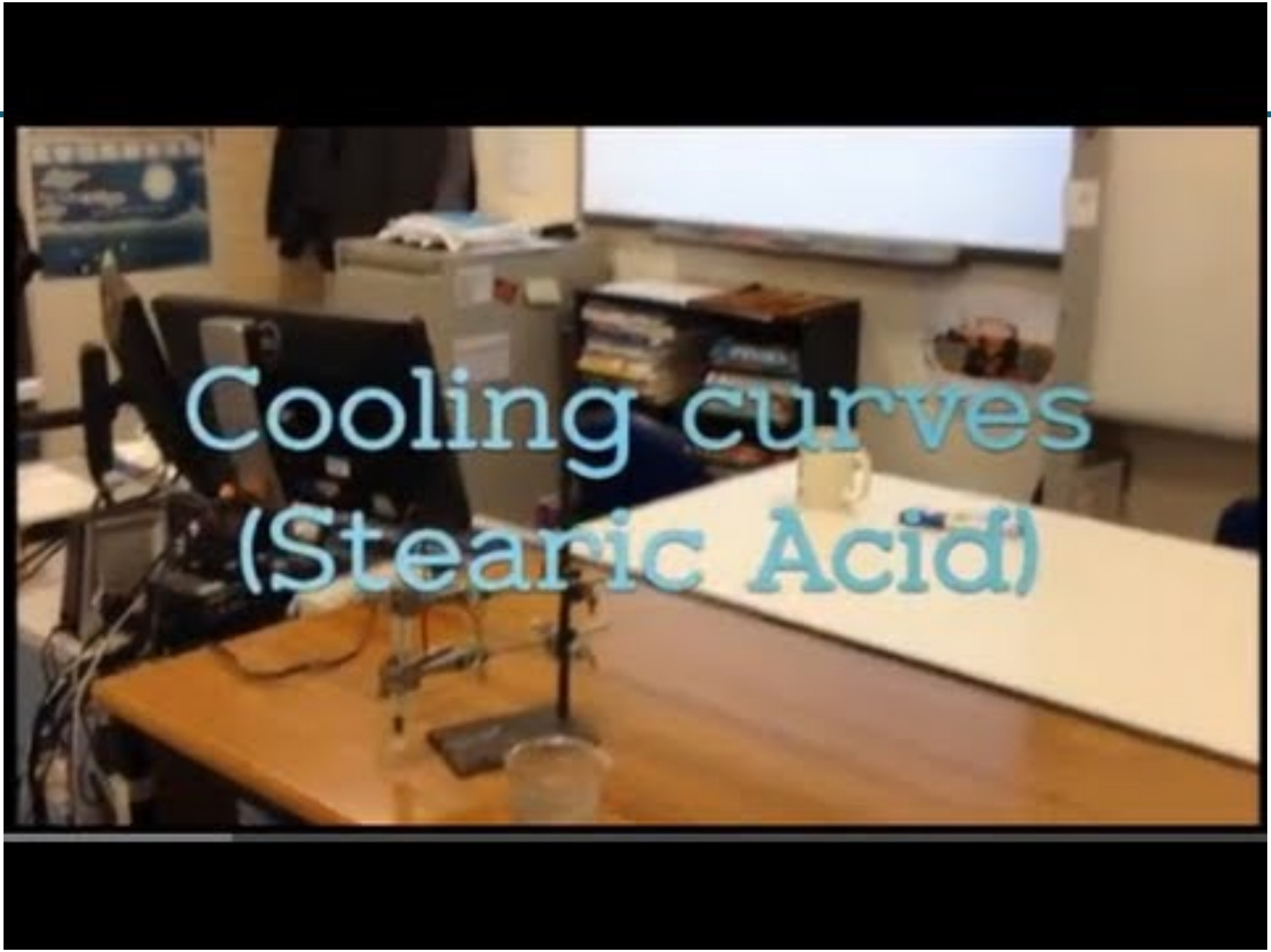
the temperature ***stays the same***. Energy is taken in and used to ***overcome attraction*** among molecules.

When changes are reversed, energy is given out.

Investigating a change of state

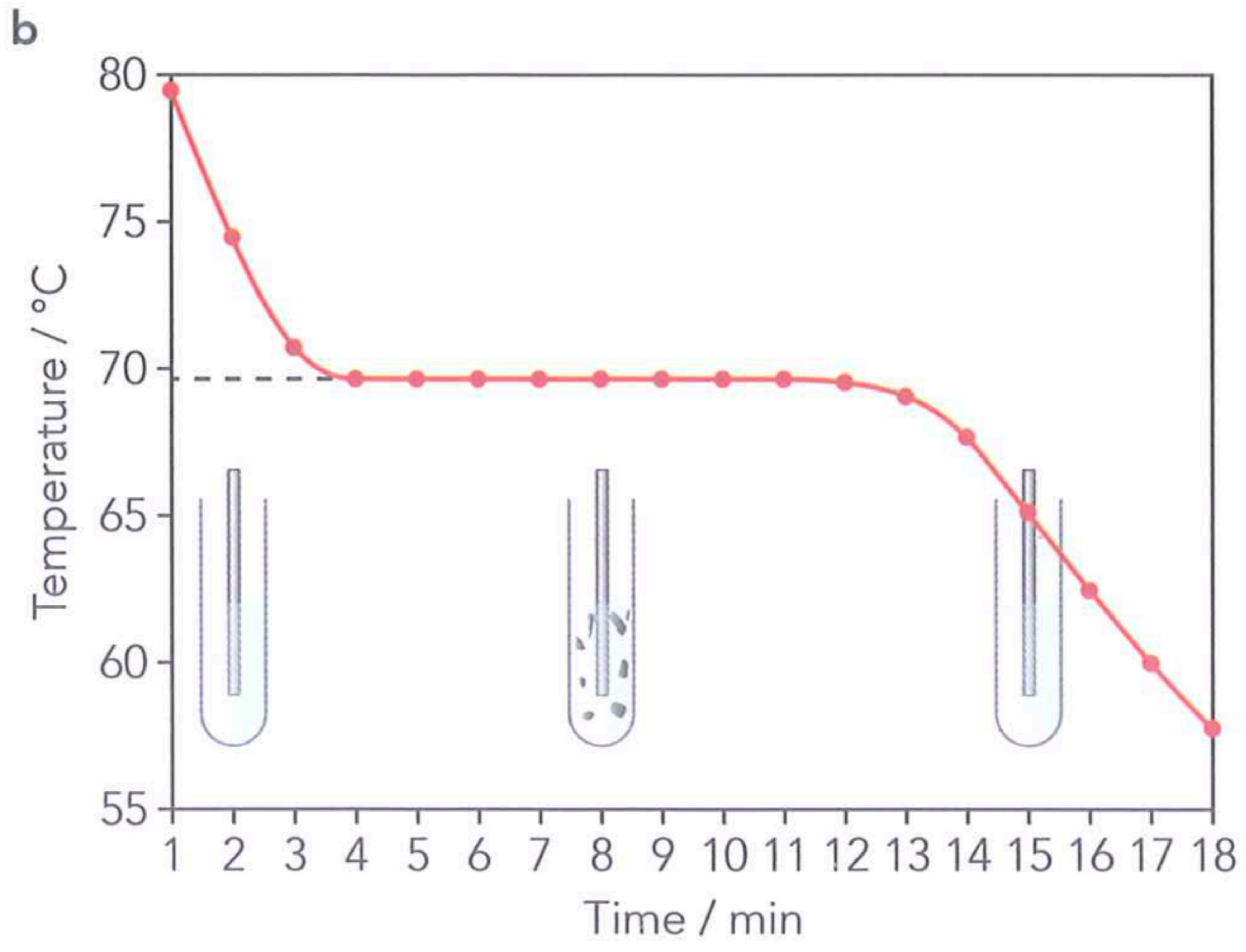


Stearic acid: waxy substance,
warm: clear, colorless liquid


Cooling curves
(Stearic Acid)

Investigating a change of state

Clear liquid => mixture of clear liquid and white solid=> white solid



- 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

★**Water**

0$^{\circ}C$: the melting point of pure ice at standard atmospheric pressure
100$^{\circ}C$: the boiling point of pure water at standard atmospheric pressure

More about melting point & boiling point

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.

Evaporation

Liquid -> gas (e.g. 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 more quickly than on a cold day?

A liquid evaporates more quickly as its temperature approaches its boiling point.

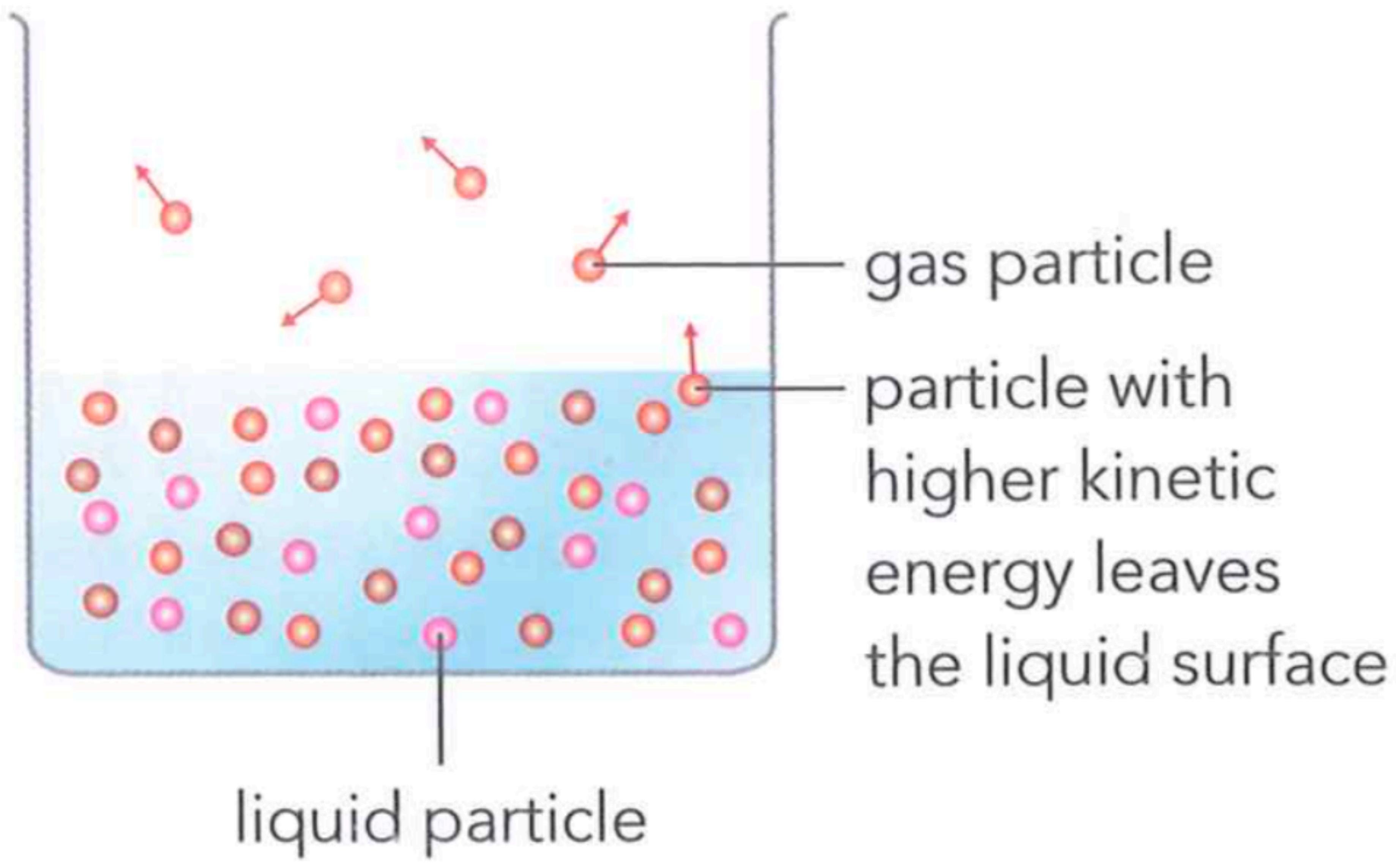
But why?

Evaporation

How to ***explain evaporation*** using kinetic model of matter?

★**More energetic particles escape from the surface of a liquid**

e.g. 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.



Higher Temperature → More evaporation

If temperature of liquid is higher, ***more*** of its particles will have enough energy to escape

Evaporation

Why do we sweat when feel hot? ★**cooling by evaporation**

The fastest particles are most likely to escape as they have most energy.
When they escape, less energetic molecules left behind, the average energy of remaining particles is less.
So the liquid cools down. Temperature decreases
Thermal energy transfer from skin to surroundings.

sweat helps us regulate body temperature in hot condition

Evaporation vs 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*

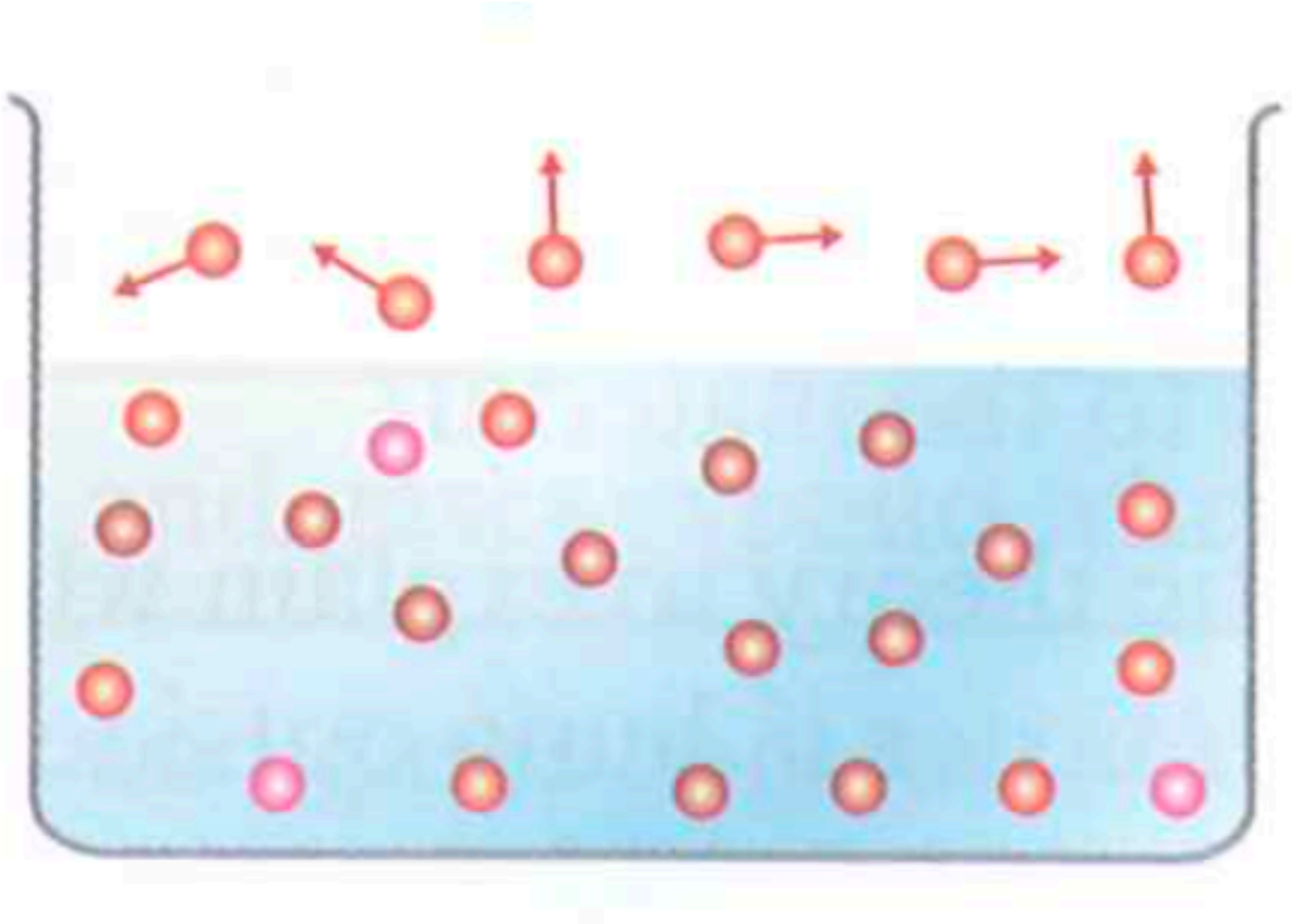
Boiling requires *heat*, evaporation provides *cooling*.

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

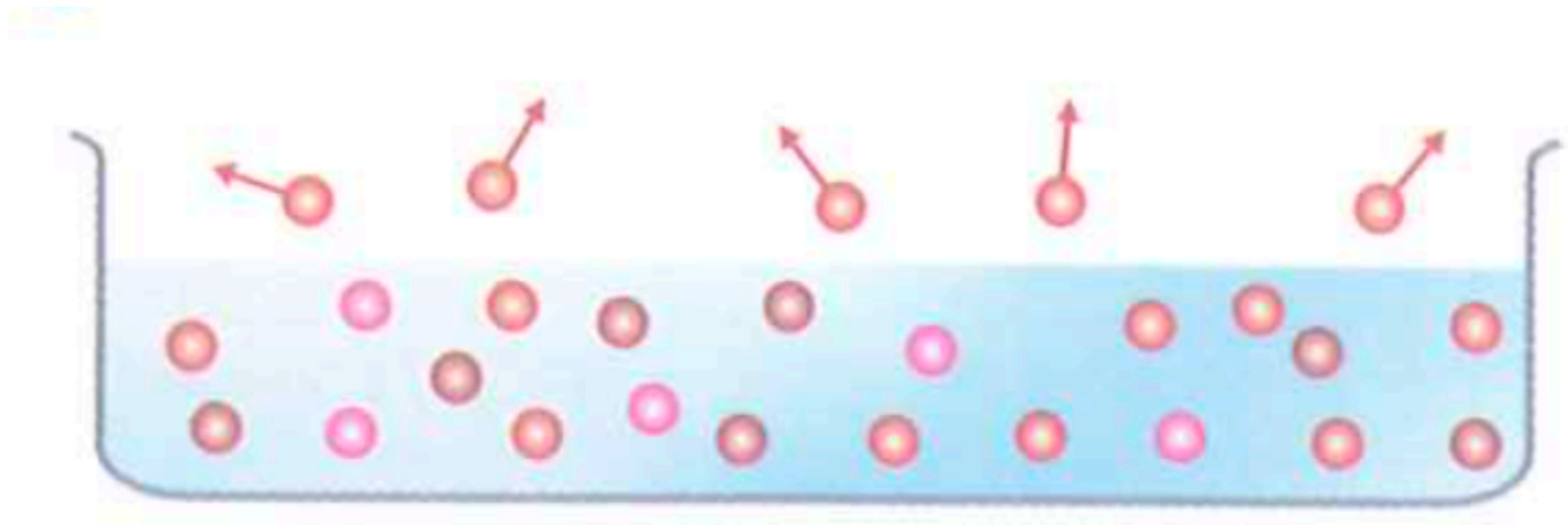
The particles on average have *more kinetic energy*;
More of particles will have enough energy to escape;
Liquid evaporates more quickly



Speeding up Evaporation

Increasing the surface area

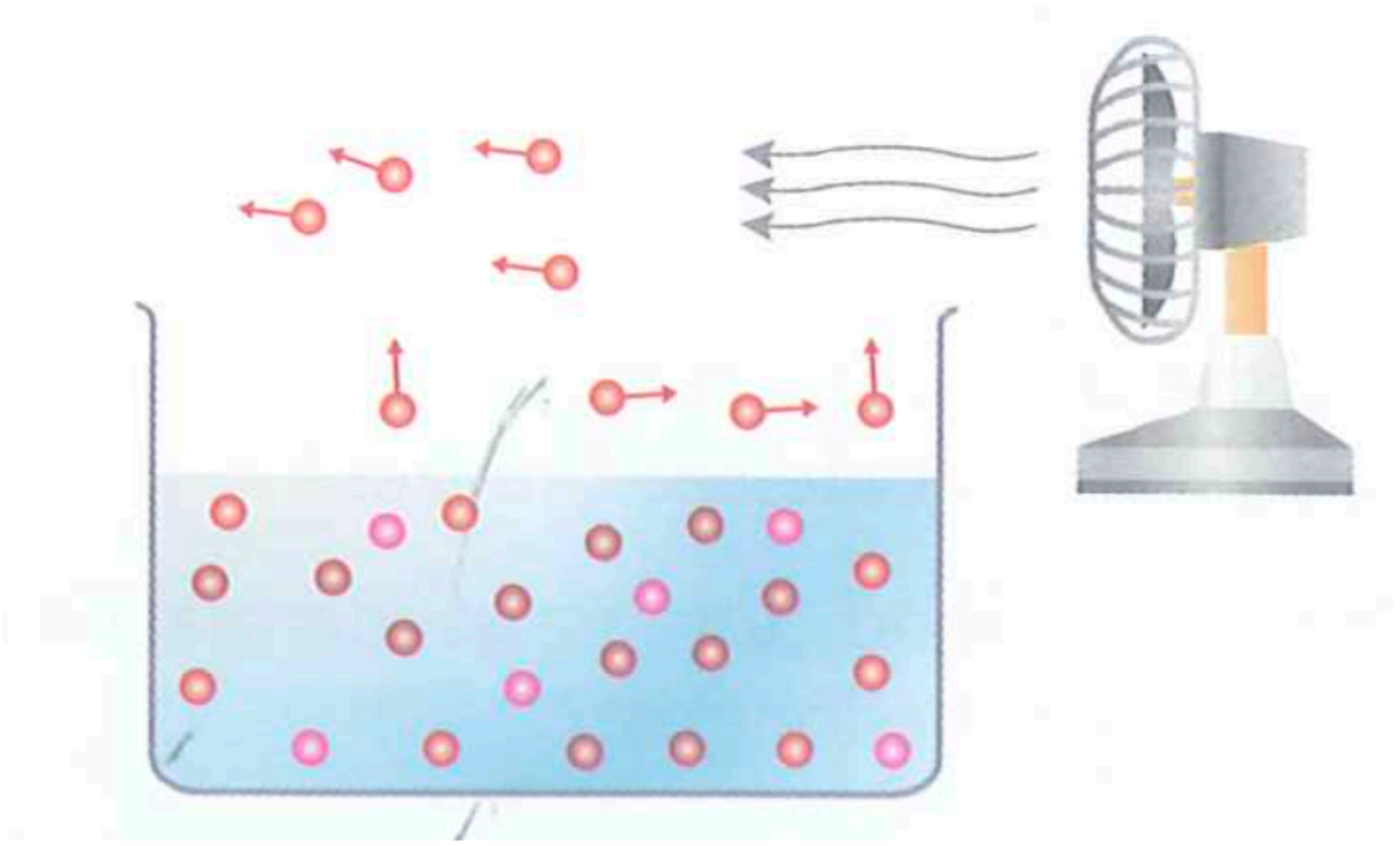
More of the particles are *close* to the surface,
They can escape *more easily*.
Liquid evaporates more quickly



Speeding up Evaporation

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

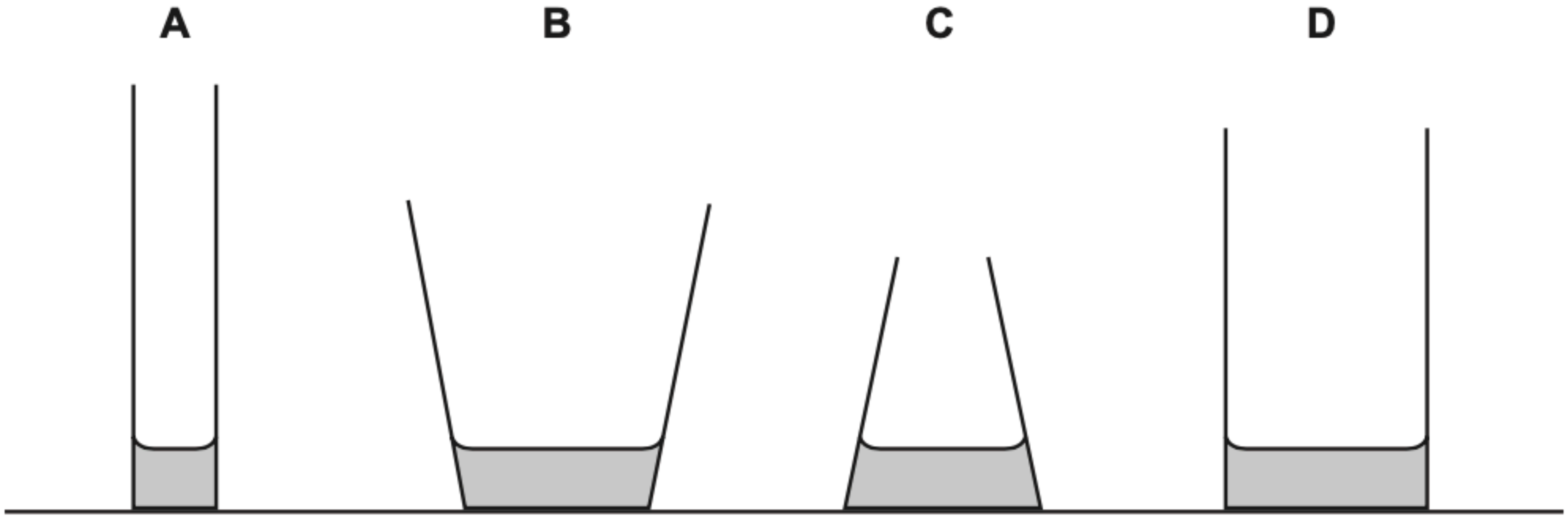


Exercise

Four containers each contain water.

More water at the same temperature is added to each container.

From which container does water now evaporate more slowly than it did before?



Exercise

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 around these positions. As the ice is heated, they vibrate more until they reach the melting point. At this point they have enough energy to break free and move freely, although attractive forces still hold them together.

Exercise

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

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

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. （2'）

More energetic molecules escape from damp cloth;
less energetic molecules left behind, average k.e. of cloth decreases;
temperature of damp cloth drops;
energy transfer from milk to damp cloth(4').

HW: sq 215-219

2.c thermal couple 不做