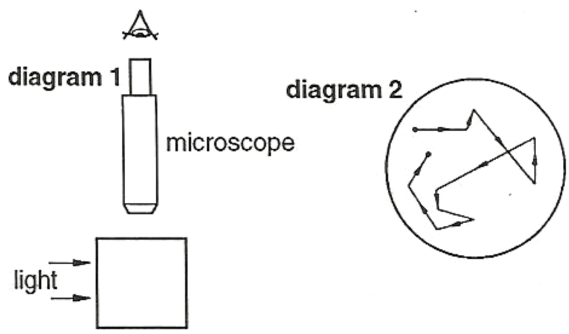
Name: ______________________________________ Class: __________ Date: ___________

Sec 3 Physics

Worksheet 11 Kinetic Model of Matter, Transfer of Thermal Energy, Temperature & Thermometry (suggested answers)

SECTION A: MULTIPLE CHOICE QUESTIONS

1. Diagram 1 shows smoke particles in a transparent box observed using a microscope. Small points of light are seen to move around, as shown in diagram 2.

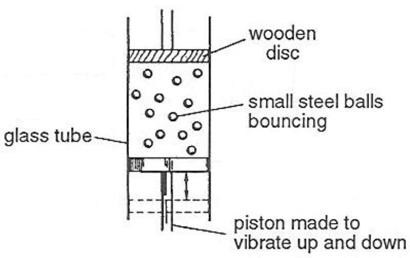


What does this experiment demonstrate about air molecules?

A They are in continuous random motion.
B They can be seen through a microscope.
C They move more quickly when they are heated.
D They move because of collisions with smoke particles.
E They give out light when they collide with smoke particles.

A

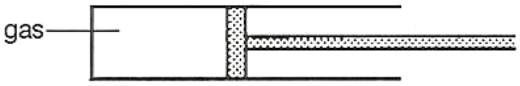
2. The diagram shows a model to demonstrate the behaviour of gas molecules. When the piston is vibrated more rapidly, the wooden disc is forced further up the tube. Weights have to be placed on the disc to return it to its original position. The model represents what happens to a gas when it is



A cooled, then compressed.
B cooled, then heated.
C heated, then compressed.
D heated, then cooled.
E expanded then cooled.

C

3. The volume of a constant mass of gas in a cylinder is reduced at a constant temperature.



The pressure exerted by the molecules of the gas increases because

A the gas molecules speed up.
B the density of the gas increases.
C the gas molecules collide with each other more often.
D the gas molecules strike the cylinder walls more often.
E there is a smaller area of the cylinder in contact with the gas. D

4. A student observes the Brownian motion of smoke particles in the air with a microscope. She sees moving points of light. These points of light come from

A air particles are only moving randomly.
B air particles are only vibrating.
C smoke particles are only moving randomly.
D smoke particles are only vibrating.
E both smoke and air particles moving randomly. C

5. Some gas is heated in a sealed container. Which of the following does not increase?

A The force due to the collisions between the gas molecules and the container walls.
B The number of collisions per second by the gas molecules on the container walls.
C The average kinetic energy of gas molecules.
D The average speed of the gas molecules.
E The average distance between gas molecules. E

6. Some gas trapped in a cylinder is compressed at constant temperature by a piston. Which of the following will not change?

A Density
B Mass
C Molecular spacing
D Pressure
E Volume B

7. When the temperature of a gas rises at a constant volume, its molecules

A move closer together.
B move with greater average speed.
C collide with one another less often.
D exert smaller forces on one another.
E expand. B

For an ideal gas, the temperature (in K) of a gas is directly proportional to the *average* kinetic energy of the gas molecules.

8. When a solid is heated, which of the following changes occurs?

A The density increases.
B The latent heat increases.
C The melting point increases.
D The molecules vibrate more rapidly.
E The number of molecules increases. D

9. Which states of matter are very difficult to compress?

A Gases only
B Gases and liquids only
C Gases, liquids and solids
D Liquids and solids only
E Solids only D

In primary schools, we have learnt that matter takes up space. In solids and liquids, the particles are packed at about 10^{-9} m apart. To force them closer, the electrons of atoms start to repel one another. Interestingly, the electrons are the ones that require the most space in an atom, not the heavy protons and neutrons.

10. A fixed mass of gas is heated while kept at a constant volume. How do the properties of the molecules of the gas change?

	Average speed	Frequency of collision with walls	Average distance apart
A	Increases	Increases	Unchanged
B	Increases	Increases	Decreases
C	Increases	Unchanged	Unchanged
D	Unchanged	Increases	Increases
E	Unchanged	Unchanged	Decreases

A

11. Why does the pressure of a fixed mass of gas increase when it is heated at constant volume?

A More molecules are created by heating.
B The average mass of the molecules increases.
C The average speed of the molecules increases.
D The molecular collisions become more elastic. C

12. The Brownian motion of smoke particles is caused by

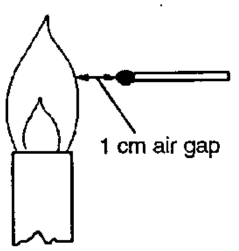
A collisions between air molecules.
B collisions between smoke particles.
C collisions between smoke particles and air molecules.
D convection currents in the air. C

13. If heat is removed from an object, its temperature will normally

A fall. **C** rise.
B fall, then rise. **D** rise then fall. A

Unless a chemical reaction ensues and starts producing heat.

14. An unlit match is held near to a scorching bunsen flame.



The match does not get hot enough to light because

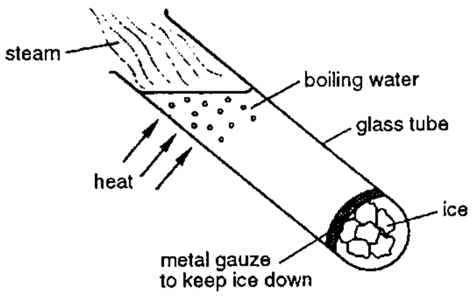
A the flame is not hot enough.
B air is a bad conductor of heat.
C the match head reflects radiation.
D the flame does not radiate any heat sideways. B

Technically, option A is not wrong; if the flame is very hot, it can ignite the matchstick by radiation. Option B is the default answer.

15. How may heat be transferred through a vacuum?

A by convection only
B by radiation only
C by conduction only
D by conduction and convection only B

16. Boiling water and ice can exist at the same time in a test tube.



What does this experiment show?

A Ice conducts heat well.
B Metal gauze conducts heat poorly.
C Water conducts heat well.
D Water conducts heat poorly. D

17. A copper plate is heated to 100 °C. It cools by emitting

A electrons.
B γ -radiation.
C infra-red radiation.
D ultraviolet radiation. C

According to Wien's law (not in the syllabus), all types of electromagnetic waves can be radiated by an object above absolute zero. However, the different wavelengths do not radiate with the same intensity. The dominant wavelength emitted at ~ 373 K is infra-red.

18. By what process does a beaker of hot water lose energy?

A conduction, convection and evaporation only
B conduction, convection and radiation only
C conduction, convection, evaporation and radiation
D evaporation and radiation only C

Evaporation removes the *latent heat of vaporization* from the hot water. Some energy is needed to change water from the liquid phase to the gaseous phase.

19. Which types of surface are the best absorbers and the best emitters of infra-red radiation?

	Best absorber	**Best emitter**
A	black and dull	black and dull
B	black and shiny	white and dull
C	white and dull	black and shiny
D	white and shiny	white and shiny

A

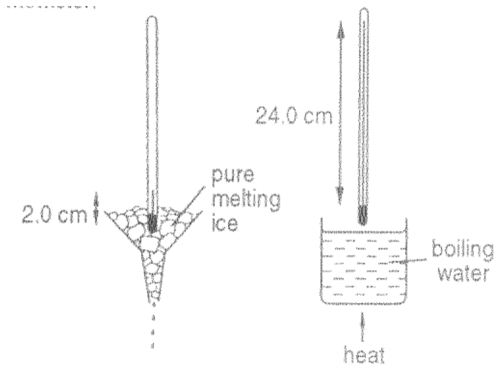
Note: a good absorber must also be a good emitter. We can use the following example to illustrate this concept: a hot object placed in a room will eventually be cooled down to reach thermal equilibrium with the room. At thermal equilibrium, the rate of absorption and emission rate is the same for the object. If the absorption coefficient is higher than the emission coefficient, then the object can absorb net heat from the room even when it is at a higher temperature. Such a situation will violate the Second Law of Thermodynamics.

In the molecular sense, Einstein showed that the probability of absorption for all radiation is the same as the probability of emission.

20. When you stand bare feet with one foot on a stone floor and the other on a carpet, the stone floor feels colder than the carpet. The most likely explanation is that

A air is unable to circulate through the carpet fibres.
B more energy flows from the carpet to your foot than from the stone floor to your foot.
C more energy flows from your foot to the stone floor than to the carpet.
D the stone floor is at a lower temperature than the carpet. C

21. The diagram shows the positions of the mercury threads in a thermometer.

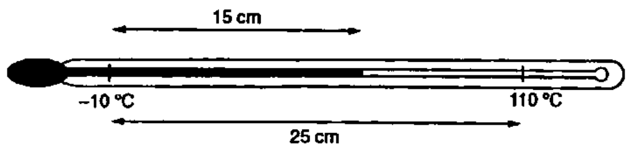


What is the distance between each 1 °C mark on the thermometer?

A 0.22 cm
B 0.24 cm
C 2.0 cm
D 2.2 cm A

The difference in length is 22.0 cm. If 100 °C represents 22.0 cm, then 1 °C is represented by 0.22 cm.

22. The diagram shows a mercury-in-glass thermometer. The distance between the –10 °C and the 110 °C markings is 25 cm.



At which temperature is the end of the mercury thread 15 cm from the –10 °C mark?

A 50 °C
B 60 °C
C 62 °C
D 72 °C C

The starting temperature is –10 °C.

23. The lengths of mercury thread in the uniform tube above the bulb of a mercury thermometer are:
20 mm when the bulb is in melting ice;
170 mm when the bulb is in the steam above boiling water;
50 mm when the bulb is in a liquid X.

What is the temperature of liquid X?

A 20 °C
B 25 °C
C 30 °C
D 33.3 °C A

24. A thermometer reads 1 °C in pure melting ice and 101 °C in the steam above boiling water. It is used to measure the temperature of the water before and after it is heated.

What is the error when the temperature rise is calculated?

A 2 °C too low
B 1 °C too low
C zero
D 1 °C too high C

While there is a systematic error in the thermometer, the error is cancelled when the temperature difference is taken.

(Final temperature + error) – (initial temperature + error)

25. How can the sensitivity of a liquid-in-glass thermometer be increased?

A use a liquid that is a better conductor of heat
B use a thinner-walled bulb
C use a longer tube
D use a liquid of higher boiling point
E use a tube with a narrower bore E

Using a thinner-wall bulb will allow heat exchange to be faster, increasing the responsiveness of the thermometer. Using a thinner-wall glass is also desirable because this reduces the heat capacity of the thermometer itself. Remember, to measure the correct temperature, the thermometer should be as close to thermal equilibrium with the object it is measuring. If the thermometer has a high heat capacity, then instead of heating the mercury and causing it to expand, some heat is wasted in increasing the temperature of the glass.

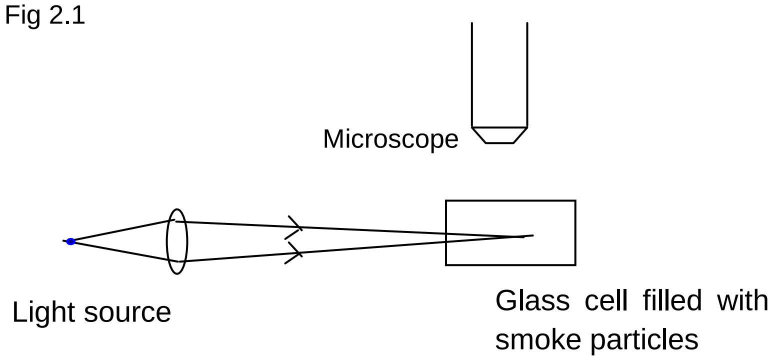
SECTION B: STRUCTURED QUESTIONS

1. **(a)** State the kinetic theory of matter.

Matter is made up of tiny particles;
particles are in continuous and random motion. [2]

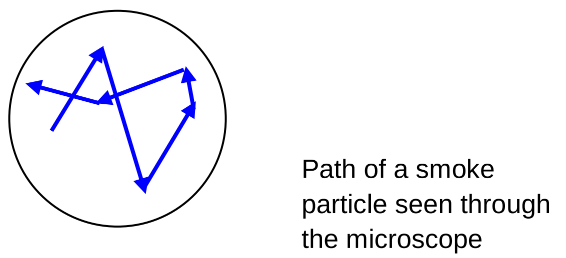
(b) The apparatus below is used to view the Brownian motion exhibited by smoke particles.

Fig 2.1



(i) Sketch the path of one smoke particle seen through the microscope in Fig 2.2 below. [2]

Fig 2.2



(ii) Describe what is seen through the microscope.

Smoke particles scatter light and appear as bright points;
The bright points move about in straight lines punctuated by numerous deflections.

[2]

(iii) How do the observations provide evidence for the kinetic model of matter?

The deflections can only be caused by a force according to Newton's laws;
the smoke particles must be bombarded by some smaller particles which are moving continuously at high speeds.

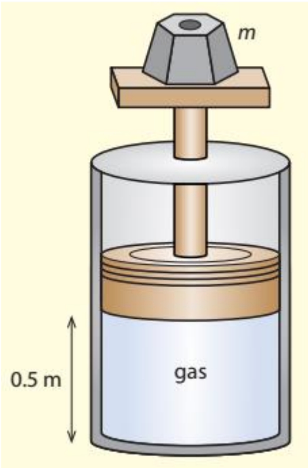
[2]

(iv) If the experiment is conducted at a lower temperature, how would the observations be different?

At a lower temperature, the speeds of the bright spots will decrease.

[1]

2. The diagram shows a cylinder in a vacuum, which has a movable, frictionless piston at the top. An ideal gas is kept in the cylinder. The piston is at a distance of 0.500 m from the bottom of the cylinder, and the volume of the cylinder is 0.050 m^3. The weight on top of the cylinder has a mass of 10.0 kg. The temperature of the gas is 19.0 °C.



(a) Calculate the pressure of the gas. [3]

$$\text{pressure from weight of mass} = \frac{F}{A} = \frac{\text{weight}}{\text{cross sectional area}}$$

$$= \frac{mg}{\left(volume/height\right)}$$

$$= \frac{10.0 \times 9.81}{\left(0.050/0.500\right)}$$

$$= 9.8 \times 10^2 \text{ Pa}$$

Since the external environment is vacuum, there will be no contribution from atmospheric pressure. The effect of pressure arises solely due to the mass weighing down in the gas.

(b) (SMTP) Determine how many molecules there are in the gas. [3]

$$\text{ideal gas equation: } pV = NkT \quad \Rightarrow \quad N = \frac{pV}{kT}$$

$$N = \frac{9.8 \times 10^2 \times (0.050)}{1.38 \times 10^{-23} \times (273.15 + 19.0)} = 1.2 \times 10^{22} \text{ molecules}$$

(c) The temperature is increased to $152\ ^\circ\text{C}$. Calculate the new volume of the gas. [3]

The weight of the mass exerts constant pressure on the gas (isobaric expansion).

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \Rightarrow \quad \frac{0.050}{273.15 + 19.0} = \frac{V_2}{273.15 + 152}$$

$$V_2 = 0.073\ \text{m}^3$$

3. Four main types of processes involve gases: *isothermal*, *isobaric*, *isochoric* and *adiabatic*.
Are these processes quick or slow?

(a) Isothermal: Slow. As the temperature is constant, any work done on the gas must be equal to the heat loss from gas. Losing heat from the system requires time.

(b) Isobaric: Slow. Constant pressure implies that there is no net force on the "piston", which implies no acceleration. So the piston is inching its way out; slow process.

(c) Isochoric: Constant volume implies no work is done on the gas. (If there is work done on/by gas, then there must be compression or expansion.) Hence, the speed of an isochoric process depends on entirely how fast heat is supplied to the system.

(d) Adiabatic: Fast. An adiabatic process is one which does not allow heat transfer into or out of the gas. Only when the process happens very fast will there be no time for heat transfer.

4. Using the kinetic particle theory, explain the following:

(a) The pressure of an ideal gas increases when the volume is decreased at a constant temperature,

Volume decrease $\Rightarrow$ frequency of collisions increases;

Total force acting on the wall increases;

Pressure which is $\frac{force}{area}$ increases [3]

(b) The pressure of an ideal gas increases when the temperature is increased at constant volume,

Temperature increases $\Rightarrow$ average KE or average velocity of molecules increases;

Frequency of collisions and the force of collisions increases;

Total force increases;

Pressure which is $\frac{force}{area}$ increases [3]

(c) The volume of an ideal gas increases when the temperature is increased at constant pressure.

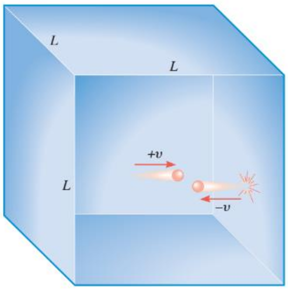
Temperature increases $\Rightarrow$ average KE or average velocity of molecules increases;

The total force acting on a movable wall will initially increase; (slow process)

The pressure on the inner wall > the pressure from the external wall; (slight difference)

Difference in pressure will create a resultant force pushing the wall outwards [3]

Explanation for an constant pressure in an isobaric expansion



For a single molecule,

$$F_{average} = \frac{-mv-(+mv)}{2L/v} = \frac{-mv^2}{L}$$

For N molecules in 3-D, one-third will be striking the wall during the time *t*,

$$F_{total} = \left(\frac{N}{3}\right)\left(\frac{mv_{rms}^2}{L}\right)$$

Note this step: a lot of local reference books says mentioned about "average force per unit area" instead of the total force. That is not correct according to the equations. (JC syllabus)

$$P = \frac{F_{total}}{L^2} = \left(\frac{N}{3}\right)\left(\frac{mv_{rms}^2}{L^3}\right) = \left(\frac{N}{3}\right)\left(\frac{mv_{rms}^2}{V}\right) \Rightarrow \boxed{PV = \frac{2}{3}N\left(\frac{1}{2}mv_{rms}^2\right)}$$

This step is not necessary, but I just want to show you that *PV* has units of energy. *PV* is the work done on the gas. (JC syllabus)

Also, $\frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$

k: Boltzmann constant; *T*: temperature in kelvin. This equation is based on the *Equipartition Theorem* (university syllabus).

Suppose during an isobaric expansion T increases to $2T$, then V must increase to $2V$. (Charles' Law)

For $2T$, the v_{rms} will increase by a factor of $\sqrt{2}$

For $2V$, the L will increase by a factor of $\sqrt[3]{2}$ (since $L^3 = V$)

Then F_{total} will increase by a factor of $\frac{2}{\sqrt[3]{2}} = 2^{\frac{2}{3}}$

And area which depends on L^2 will also increase by a factor of $2^{\frac{2}{3}}$,

Hence in an isobaric process a change in F_{total} will be accompanied by a corresponding proportional change in L^2.

In word explanation, a Sec student may write the following:

- As T increases, KE or v_{rms} (of molecules) increases.
- F_{total} (total molecular force) on the wall of the piston will increase by a certain factor
- Surface area of the wall of piston *A* will increase by the same factor as F_{total}
- Since $P = \frac{F_{total}}{A}$, the pressure will be constant.

  (basically writing the steps of equations in words)

5. A Bunsen burner is used to heat a beaker full of water.

(a) Explain how energy is transferred through the bottom of the beaker.

Glass particles at the near side of the flame gain energy and vibrate more vigorously; these particles collide with their neighbouring particles and transfer energy to them. The process carries on to reach the far side.

(*The vibrations are random in a direction, so heat also spread sideways*.) [2]

(b) Explain how energy is transferred through the water.

Hot water at the bottom of the beaker expands and becomes less dense, and rises to the top;
cool denser water from the top sinks to the bottom and, in turn, gets heated up.

[2]

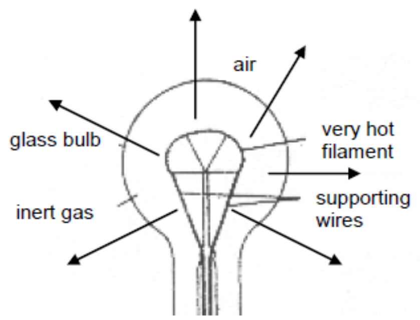
(*A circulating convection current is set up; the precise manner of circulation depends on the position at the bottom of the beaker heated up. Also, the convection current is more visible when the temperature difference is greater. As the heating carries on, the temperature difference between the bottom and the top gets smaller, and the convection current weakens*.)

(c) Several centimetres to one side of the Bunsen burner, a student's hand starts to feel hot. Explain the process by which energy is transferred from the burner to the student's hand.

The dominant transfer process is radiation.
Convection currents from the side of the flame push the air upwards (not sideways). The upward airflow also greatly diminishes sideway conduction.

[2]

6. The figure on the right shows a filament lamp standing upright in the air.



(a) On the figure, draw arrows to represent radiation from the filament. [1]

(b) State two places where thermal *conduction* takes place.
through the glass bulb;
along the supporting wires.

(c) Describe briefly the two convection currents which are set up.

1. convection of the inert gas in the glass bulb
2. convection of the environmental air surrounding the hot glass bulb. [2]

7. A saucepan with a thick copper base contains water and is placed on a flat electric hot plate.

(a) State and describe the process by which energy is

(i) transferred from the hot plate to the water;

Conduction from the surface atoms of the hot plate to the water molecules in contact with the metal surface atoms.
Strongly vibrating metallic surface atoms transfer energy to slower moving water molecules that collide with them. [2]

(ii) spread through the water.

Hot water from the bottom of the pan expands and becomes less dense, and rises; cooler, denser water from the top sinks and, in turn, heats up. This process creates a convection current that circulates water in the pan. [2]

(b) Suggest **three** reasons why the water would reach boiling point more rapidly with a lid on the pan.

Heat loss by the following paths are reduced:

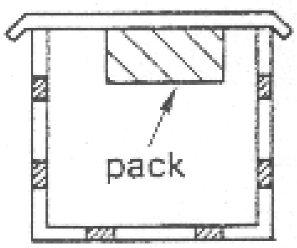
1. By convection of the air above the water (air gap between water surface and lid is small).
2. By conduction through the air above the water (air gap is a good insulator)
3. By evaporation of water from the surface (relative humidity reaches 100%) [3]

(c) The sides of saucepans are often polished. How does this reduce heat loss?

Polished surfaces are poor emitters (radiators) of heat.

[1]

8. As shown in the diagram, a pack of frozen liquid is placed in a holder under the box's lid. The box is then used to keep food cold.



(a) Suggest why the frozen pack is placed at the top of the box rather than at the bottom.

Air at the top is cooled, becomes denser and sinks;
warmer air from the bottom rises to the frozen pack. The circulation of cold air keeps the interior cold.

[2]

(In reality, the cold pack is placed at the bottom in direct contact with the food. There is no need to set up a convection current. We merely need to make sure the food at the bottom is cold. Nobody cares for the warm air at the top.
Also, if food is present in the box, the irregular spacing between food does not allow convection currents to pass through easily.
Lastly, a cold pack at the lid makes the lid heavy to lift, not a clever design in the first place.)

(b) Why does the food keep cold longer if the walls

(i) are made of rigid plastic rather than of metal,

Plastics are poor conductors of heat

[1]

(ii) have a layer of lagging on the outside?

The air trapped in the lagging and the material of the lagging are poor conductors of heat. Heat gain from surroundings is reduced. [1]

9. Explain why a mercury-in-glass laboratory thermometer has

(a) a narrow capillary bore,

To be more sensitive to small changes in temperature;
Given the exact change in volume, the thermometer with a smaller cross-sectional area capillary bore would register a longer (more noticeable) change in length. [2]

(b) a bulb made of very thin glass?

To increase the responsiveness of the thermometer;
the thin glass allows rapid transfer of heat from through the glass to the mercury.

[2]

10.

The diagram (not to scale) shows two mercury thermometers, A and B, identical in every respect except that the bulb of A is much larger than that of B.

State, giving a reason for your answer in each case, which thermometer

(a) will cover the larger range of temperature,

Thermometer B.
With more mercury in the bulb of A, it will take up more space when it expands upon heating. Hence, for every degree rise in temperature, the mercury thread of thermometer A lengthens more than B and will reach the end of the stem at a lower temperature than B. [2]

(b) will indicate more quickly a small temperature rise.

Thermometer B.
The smaller amount of mercury takes less time to be heated up to a higher temperature by the same amount of heat supplied. [2]

11. A mercury-in-glass thermometer has a scale starting at $-10\ °C$ and finishing at $110\ °C$. The length of the scale is 240 mm.

(a) What is the range of the thermometer?

$\text{range} = 110 - (-10) = 120\ °C$
OR
Range = -10 ^{0}C to 110 ^{0}C range: $-10\ °C$ to $110\ °C$ [1]

(b) Determine the sensitivity of the thermometer in mm K^{-1} (or $\text{mm }°C^{-1}$).

Sensitivity = 240 / 120 = 2.0 mm K^{-1} [mm K^{-1} and mm$^{o}C^{-1}$ will give similar answers] (2 sf)

[1]

A second thermometer has a bulb with twice the volume of the thermometer in part (a). Its length and bore are just the same as those of the thermometer in part (a).

State, justifying your answer in each case,

(c) the range of the second thermometer,

$60\ °C$
Double the amount of mercury will expand twice as much into the bore for the same temperature change. The mercury thread will reach the end of the stem at a temperature $50\ °C$. ($60\ °C$ above the minimum temperature on the scale, assuming the minimum value is still $-10\ °C$) [2]

(d) the sensitivity of the second thermometer.

$\text{sensitivity} = 2 \times 2.0 = 4.0\ \text{mm K}^{-1}$

[2]

12. When the hot end of a thermocouple thermometer is placed in a bath of liquid at $0\ °C$, its e.m.f. reading is found to be 22 mV. When the liquid bath is heated to $100\ °C$, the e.m.f. reading becomes 50 mV. After that, the bath is cooled until the e.m.f. reading is 42 mV. The cold end of the thermocouple remains in melting ice throughout.

(a) What is the temperature of the bath as measured using the thermocouple when the e.m.f. reading is 42 mV?

$$\theta_{bath} = \frac{42-22}{50-22} \times 100\ °C = 71\ °C$$

[2]

(b) The reading taken at the same time on a mercury-in-glass thermometer placed in the bath is 40 °C.

(i) Suggest a reason for the difference between this reading and the value calculated in part (a).

It is not possible to find a temperature-dependent property that varies linearly between the fixed points;
all physical properties vary differently with temperature in a non-linear way.

[2]

(The example in the question is exaggerated. Laboratory thermocouple thermometers do not differ in their readings by such a large value. If the thermocouple and mercury thermometers are well-calibrated, they should be reading the same temperature.)

(ii) Will there be any value(s) where the thermometers give a similar reading? State the reason.

0 °C and 100 °C.
Different thermometric properties agree at the fixed points (ice point and steam point).

[2]

(c) Name the physical property which varies with temperature in
(i) a mercury-in-glass thermometer;
(ii) a thermocouple thermometer.

(i) Volume (ii) Electromotive force (e.m.f)

(d) State
(i) two advantages of a mercury-in-glass thermometer;
(ii) two advantages of a thermocouple thermometer.

(i) Mercury-in-glass thermometer is able to give temperature reading directly. The expansion of mercury is very linear around the human usage temperature range (around 0 ºC to 100 ºC).
(ii) Thermocouple is able to measure a wide range of temperature about -200 ºC to 1700 ºC and very high temperature even beyond 1000 ºC. It is also very useful in measuring rapidly changing temperature. (It can be used to measure temperature at a point.)

[4]

13. If deep-sea divers rise to the surface too quickly, nitrogen bubbles in their blood can expand and prove fatal. This phenomenon is known as **the *bends***. If a scuba diver rises quickly from a depth of 25 m in Lake Michigan (which is fresh water and the pressure at that depth is 3.46×10^5 Pa)

(a) what will be the volume of an N_2 bubble that occupied 1.0 mm^3 in his blood at the lower depth?

$$p_1V_1 = p_2V_2$$
$$(3.46 \times 10^5)(1.0) = (1.01 \times 10^5)V_2$$
$$V_2 = 3.43 \text{ mm}^3$$

A volume of 3.43 mm^3 implies that the diameter is about 1.87 mm. In contrast, the original diameter is about 1.24 mm.

[3]

(b) Does it seem that the difference is large enough to be a problem?

(*Assume that the pressure difference is due only to the changing water pressure and not to any temperature difference. This assumption is reasonable since we are warm-blooded creatures.*)

A volume of 3.43 mm^3 implies that the diameter is about 1.87 mm. In contrast, the original diameter is about 1.24 mm. Possibility of clogging blood vessels.

[2]

14. The gas inside a balloon will always have a pressure nearly equal to atmospheric pressure, since that is the pressure applied to the outside of the balloon. You fill a balloon with helium (a nearly ideal gas) to a volume of 0.600 L at a temperature of 20.0 °C. What is the volume of the balloon if you cool it to the boiling point of liquid nitrogen (77.3 K)?

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
$$\Rightarrow \quad \frac{0.600}{(273.15 + 20.0)} = \frac{V_2}{77.3}$$
$$\Rightarrow \quad V_2 = 0.158 \text{ L}$$

[3]

15. (SMTP) The giant hornet *Vespa mandarinia japonica* preys on Japanese bees. However, of one of the hornets attempts to invade a beehive, several hundred of the bees quickly form a compact ball around the hornet to stop it. They don't sting, bite, crush or suffocate it. Instead, they overheat it by quickly raising their body temperatures from the normal 35 °C to 47 °C or 48 °C, which is lethal to the hornet but not the bees.

Assume the following: 500 bees form a ball of radius $R = 2.0$ cm for a time $t = 20$ min. The primary loss of energy by the ball is by thermal radiation. The ball's surface has emissivity $e = 0.80$, and the ball has a uniform temperature. On average, how much *additional* energy must each bee produce during the 20 min to maintain 47 °C?

$$Q = e\sigma T^4 At$$
$$= (0.80)(5.67\times10^{-8})\left[(47+273)^4-(35+273)^4\right](4\pi(0.020)^2)(20\times60)$$
$$= 407 \text{ J}$$

Hence, each bee must produce $\frac{407}{500} = 0.814$ J of energy during the 20 min.

16. (SMTP) Water standing in the open at 32.0 °C evaporates because of the escape of some of the surface molecules. The heat of vaporization (2255 J/g) is approximately equal to εn, where ε is the average energy of the escaping molecules and n is the number of molecules per gram.

(a) Determine the value of ε.

1 mole of water contains 6.02×10^{23} water molecules. 1 mole of water weighs 18 grams.

$\therefore$ 1 g of water has $\frac{6.02\times10^{23}}{18} = 3.344\times10^{22}$ molecules

$$\therefore \varepsilon = \frac{2255}{3.344\times10^{22}} = 6.74\times10^{-20} \text{ J/molecule}$$

(b) What is the ratio of ε to the average kinetic energy of H_2O molecules, assuming the latter is related to temperature in the same way for gases?

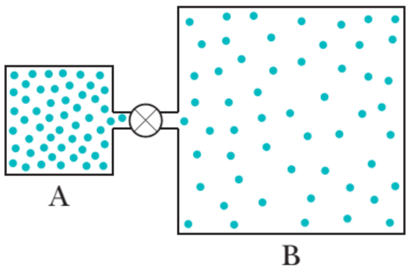
If the liquid molecules are related in the same way to vapour molecules, then we can use

$$KE_{average} = \frac{3}{2}kT = \frac{3}{2}\left(1.38\times10^{-23}\right)\left(32.0+273.15\right)$$
$$= 6.31\times10^{-21} \text{ J/molecule}$$

$$\frac{\varepsilon}{KE_{average}} = \frac{6.74\times10^{-20}}{6.31\times10^{-21}} = 10.7$$

17. (SMTP) This is a hard question on ideal gas.

Container A in the figure shown holds an ideal gas at a pressure of 5.0×10^5 Pa and a temperature of 300 K. It is connected by a thin tube (and a closed valve) to container B, with four times the volume of A. Container B holds the same ideal gas at a pressure of 1.0×10^5 Pa and a temperature of 400 K. The valve is opened to allow the pressures to equalize, but the temperature of each container is maintained. What then is the pressure?



$$p_AV_A = n_ART_A \quad \Rightarrow \quad 5.0\times10^5 V_A = 300n_AR$$
$$p_BV_B = n_BRT_B \quad \Rightarrow \quad 10\times10^5\left(4V_A\right) = 400n_BR$$
$$\therefore \frac{5.0}{4.0} = \frac{3}{4}\frac{n_A}{n_B} \quad \Rightarrow \quad n_A = \frac{5}{3}n_B$$

Let $n_A = \frac{5}{3}$ mol and $n_B = 1$ mol (as long as the ratio holds)

After equalizing pressure, the equations for the two containers are:

$$p_{A'}V_{A'} = n_{A'}RT_{A'} \quad \Rightarrow \quad p_{A'}V_A = 300n_{A'}R$$ (V_A remains the same since the container does not expand)

$$p_{B'}V_{B'} = n_{B'}RT_{B'} \quad \Rightarrow \quad p_{B'}\left(4V_A\right) = 400n_{B'}R$$
$$\Rightarrow 4p_{A'}V_A = 400n_{B'}R$$
$$\Rightarrow p_{A'}V_A = 100n_{B'}R$$

You should see that the RHS of both equations are identical, so their LHS must balance too.

$\therefore 300n_{A'} = 100n_{B'} \qquad \Rightarrow \qquad n_{A'} = \dfrac{1}{3}n_{B'}$

But $n_{A'} + n_{B'} = 2\dfrac{2}{3}$ mol (since the total number of particles remains unchanged)

$\therefore \; n_{A'} + 3n_{A'} = \dfrac{8}{3}$ mol

$\Rightarrow \; n_{A'} = \dfrac{2}{3}$ mol

Since $n_A = \dfrac{5}{3}$ mol drops to $n_{A'} = \dfrac{2}{3}$ mol, it means that the pressure must drop by a factor of $\dfrac{2}{5}$. (since V_A and T_A do not change.)

Hence, the new pressure in the containers is $\dfrac{2}{5}\left(5.0\times10^5\right)$ Pa $= 2.0\times10^5$ Pa.