Delta Science Education

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HKDSE Physics

Core 1: Heat and Gases

Chapter 4: General Gas Law

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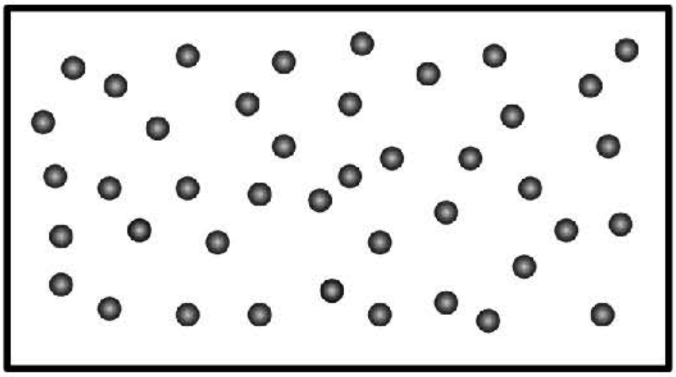
1. Macroscopic Physical Quantities of a gas

(1) Gas Pressure

- Pressure is defined as the normal force acting on a unit area.

- Gas exerts pressure on every single wall of the container that contains the gas.



- Pressure of a gas can be measured by a Bourdon Gauge:

- Air in the atmosphere consistently exerts a pressure on us. This pressure is called atmospheric pressure.
    - **The standard value of atmospheric pressure is about** $101,000$ Pa.
    - **Actual atmospheric pressure varies around** $101,000$ Pa**, depending mainly on the altitude and weather.**
    - **Another common unit for pressure is "atmospheric pressure"** (atm)**:**

Examples that you must fully understand

1. Which of the following can show the existence of air pressure?

   (1) A box of vita soy milk box collapses when air inside is being exhaled from it.

   (2) A can of coke will explode when being heated.

   (3) A balloon is inflated by blowing air into it.

   (4) Water would not fall down from a cup upside down if a plastic sheet placed beneath the water.

   (5) A vehicle tyre can run on road after it is filled with air.

2. A sucker sticking a hook to a vertical wall has a diameter of 4 cm. suppose all of the air inside is squeezed out from the sucker. Calculate the minimum force that is needed to pull the hanger away from the wall. Given that the atmospheric pressure is 101 kPa.

3. Explain why an iron nail can be easily hammered into a piece of wood. Explain also why a pair of scissors can cut a piece of cloth without much effort.

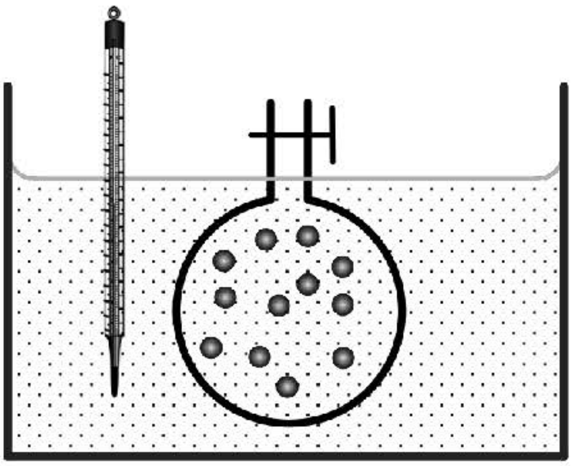
An iron nail has a very ______ and ______ end. Since the ______ exerted by the nail is ______ ______ to the contact surface ______, the pressure exerted on the piece of wood by the ______ end will be very ______.

A pair of scissors has two ______ ______ which exert a ______ ______ on the piece of cloth.

(2) Volume of a gas

- Gas does not have a specific volume.
- Volume of a gas is the volume of the container containing the gas.
- The SI unit of volume is cubic meter (m^3)
- Gas volume is usually measured by a syringe.

(3) Temperature of a gas

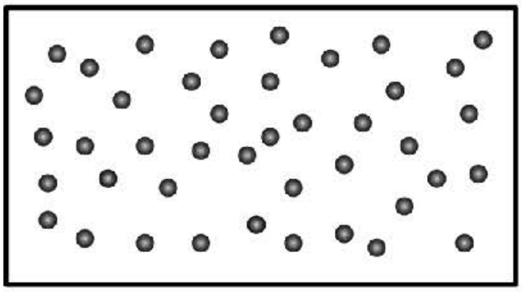


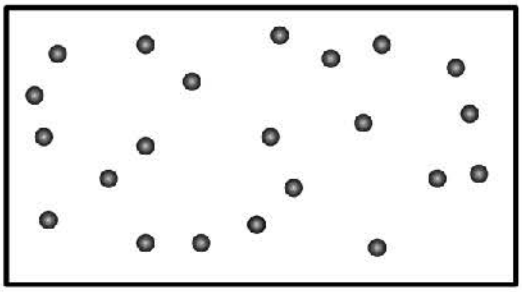
- Temperature of a gas inside a gas flask can be measured by placing the flask into a water bath. Then the temperature of water can be measured by a thermometer.
- The water should be well stirred before taking the temperature data.
- The temperature of the gas stored inside the gas flask is thus assumed to be the same as that of the water bath.

(4) Density of a gas

- Density of a gas can be found by

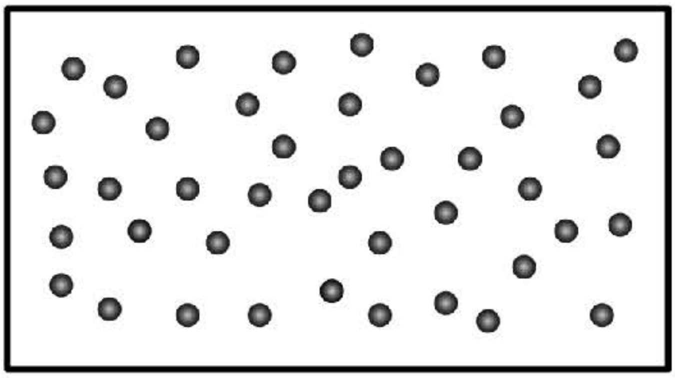
- Density of a gas is related to the separation s between gas molecules. For the same kind of gas, the greater the density, the smaller the separation:





(5) Amount of a gas

- To describe the amount of a gas, the following quantities are usually used:



Lxamplos that you must fully undorstand

1. Complete the following table:

	Number of particles	Number of mole		Number of particles	Number of mole
(1)	7.23×10^{29}		(2)	5.56×10^{11}	
(3)		0.012 mol	(4)		3.45 mol
(5)	9.02×10^{12}		(6)		6.71 mol

2. Fill in the blanks with a suitable number. Given that: **molar mass of hydrogen gas = 2 g mol^{-1}, molar mass of oxygen gas = 32 g mol^{-1}, molar mass of chlorine gas = 71 g mol^{-1}**

(a) Mass of 0.24 mol **of oxygen gas =**

(b) Mass of 1.45 mol **of chlorine gas =**

(c) Number of mole of 4 g **hydrogen gas =**

(d) Number of mole of 0.98 kg **of oxygen =**

(e) Mass of 4×10^{24} **hydrogen gas molecules =**

(f) Mass of 6.68×10^{-2} **chlorine gas molecules =**

(g) Mass (in kg**) of ONE oxygen gas molecule =**

(h) Mass (in kg**) of ONE chlorine gas molecule =**

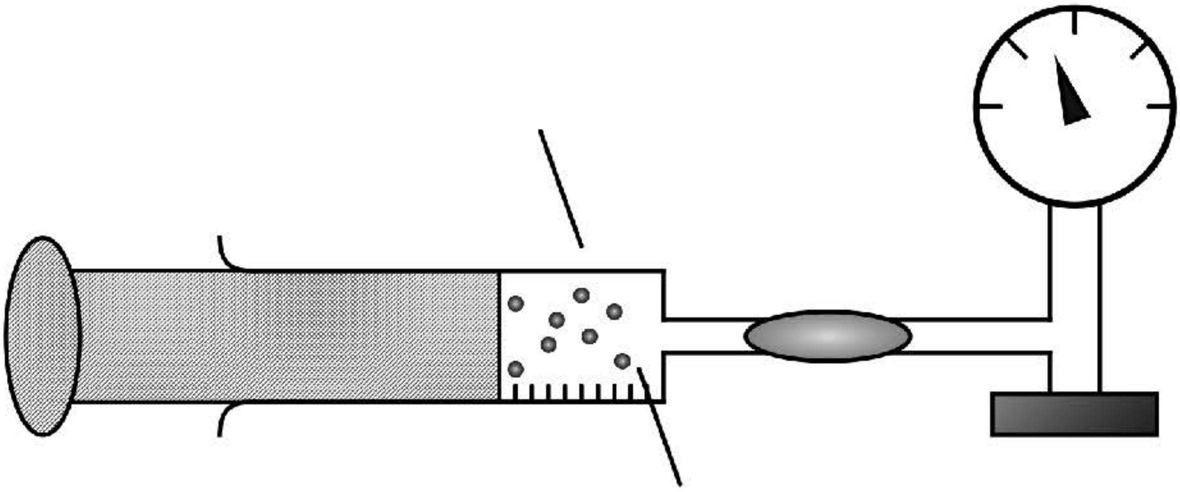
(i) Mass of 100 **oxygen gas molecules =**

(j) Mass of 1000 **chlorine gas molecules =**

(k) The average molar mass of a mixture of gas (0.24 mol **hydrogen gas,** 0.48 mol **chlorine gas and** 0.39 mol **oxygen gas) =**

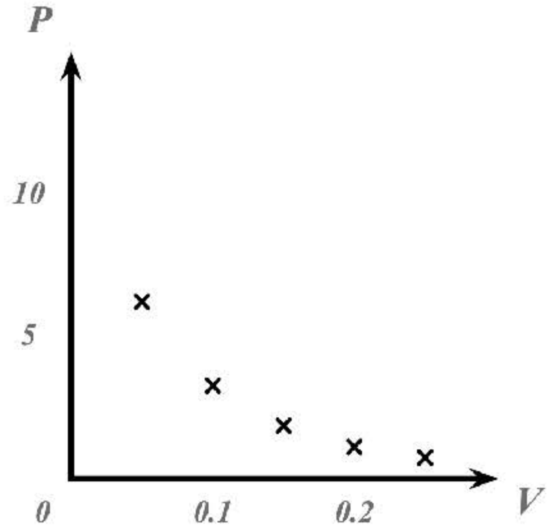
2. Boyle's Law (Pressure and Volume Relation)

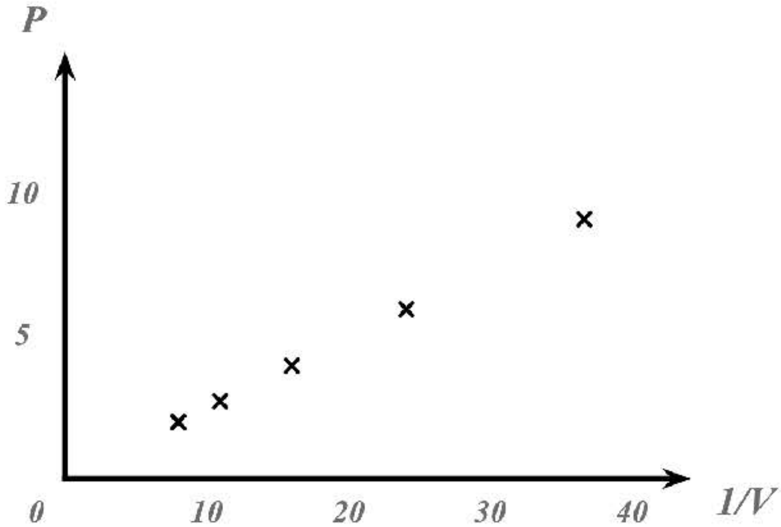
(1) Experimental procedure



- **A syringe containing a fixed amount of gas (n / M) is connected to a Bourdon gauge.**
- **The piston is pushed SLOWLY inwards (or outwards) to vary the volume of the gas V.**
- **The corresponding pressure P is then measured by the Bourdon gauge.**
- **Temperature of the gas must be kept constant throughout the experiment.**

(2) Experimental result





(3) Boyle's Law

The pressure P of a fixed mass of gas is inversely proportional to its volume V at constant temperature.

(4) Precautions of the experiment

- **The length of the rubber tubing should be short to reduce the volume of the gas inside the tubing**
- **The piston should be moved slowly so that the temperature can be kept constant.**
- **Do not take readings immediately after the piston is moved. Wait to ensure that the temperature becomes steady.**
- **Well lubricate the piston to reduce the friction between the piston and the wall.**

Examples that you must fully understand

1. In the experiment for finding the relation between the pressure and the volume of a gas at constant temperature, the initial readings of the syringe and the Bourdon Gauge are $26.8\ \text{cm}^3$ and $10^5\ \text{N m}^{-2}$ respectively.

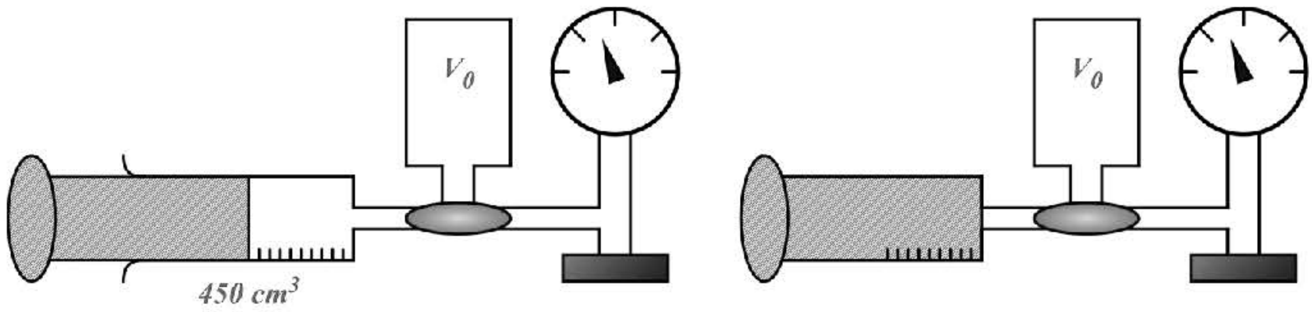
   (a) If the piston is pushed to compress the gas, the syringe reading is found to be $19.8\ \text{cm}^3$. What is the corresponding reading in the Bourdon Gauge?

   (b) The calculated reading of the Bourdon Gauge is found to be different from the observed reading. Give two reasons accounting for this deviation.

   The ______ of the gas inside the syringe may not be ______.
   The gas inside the ______ ______ has not been ______ into the ______.

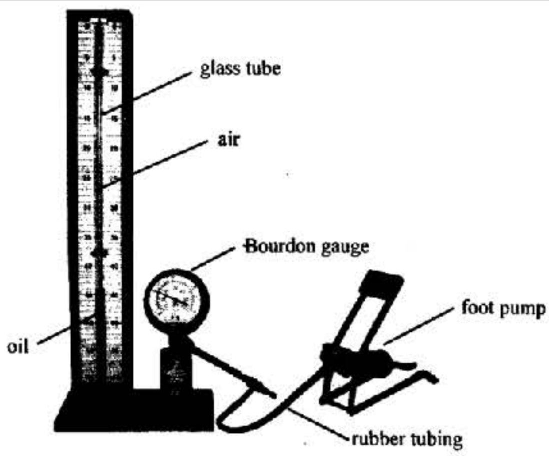
Examples that you must fully understand

2. The readings of the gas syringe and the Bourdon gauge as shown are $450\ cm^3$ and $175\ kPa$ respectively. When the piston is completely pushed in, the reading of the gauge becomes $325\ kPa$. Assume that the temperature remains constant throughout the whole process, calculate the volume of the container. State two more assumptions in the calculation.



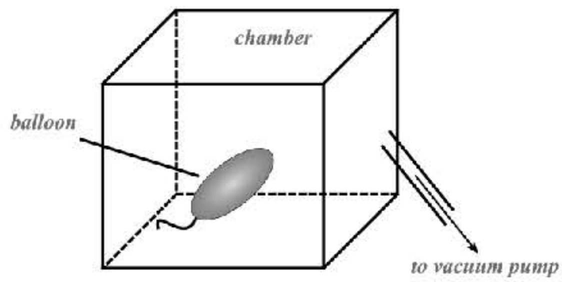
Assume that the [ ] of gas inside the connecting tubes is [ ].
Assume that [ ] [ ] of air so that the amount of gas [ ] is [ ].

3. The figure shows an experiment for studying the relationship between the pressure and volume of a fixed mass of gas at constant temperature. Which of the following can improve the accuracy of the experiment?



(1) Using a glass tube with greater volume.
(2) Pushing the piston quickly.
(3) Tap the Burdon Gauge before taking the reading.
(4) Taking the reading immediately after the piston is pushed.

4. A balloon containing a certain volume of gas at a pressure of $1\ atm$ is placed inside a chamber. Air is slowly pumped out from the chamber while the temperature remains unchanged for the whole process. Find the final pressure inside the chamber when the balloon has tripled its original volume.

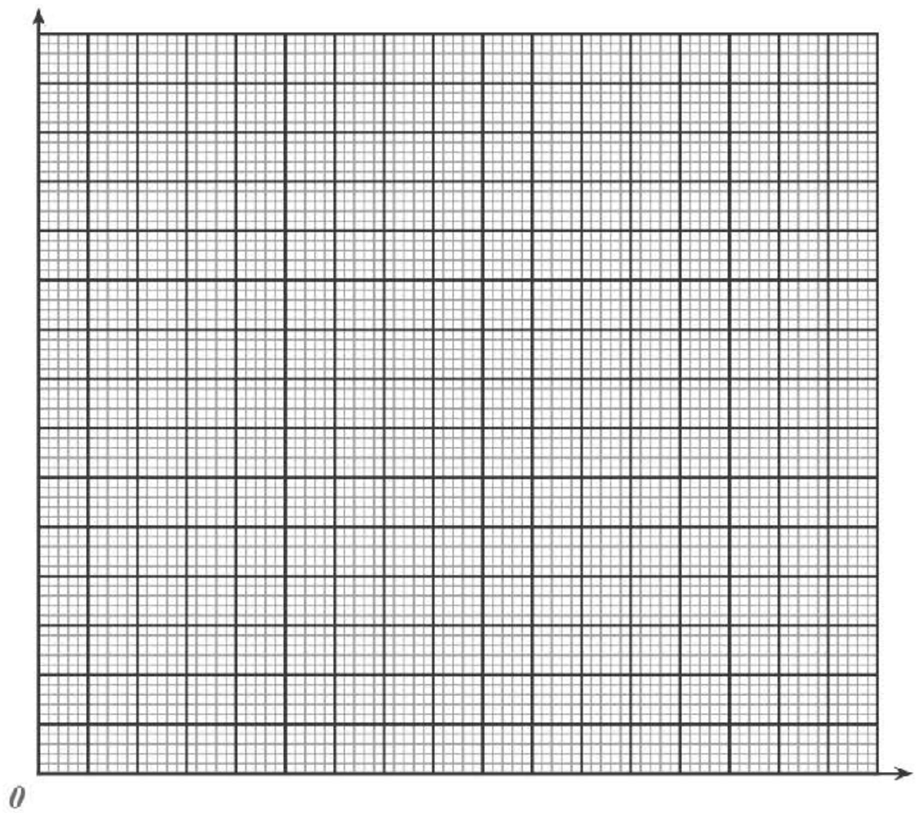


Examples that you must fully understand

5. Irma carries out an experiment to investigate the relationship between the pressure and volume of a fixed mass of gas at a constant temperature of 400 K. he varies the volume of gas and records the corresponding pressure in the table.

Pressure P / kPa	60	80	100	120	140
Volume V / m^3	6.18×10^{-4}	4.63×10^{-4}	3.71×10^{-4}	3.08×10^{-4}	2.63×10^{-4}

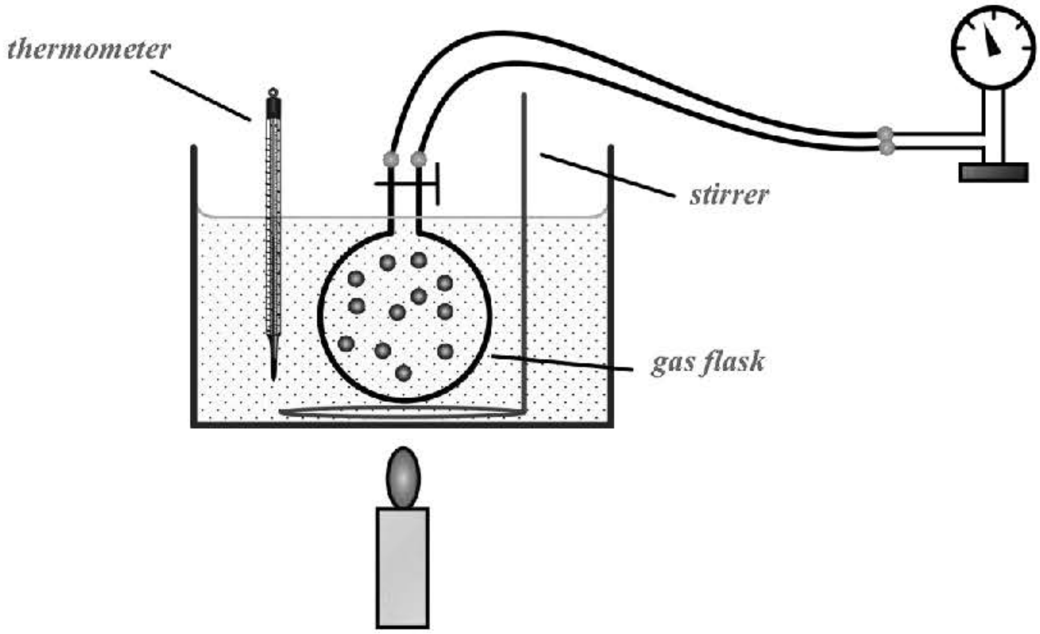
(a) Plot a suitable graph to verify Boyle's Law.



(b) What is the volume of the gas if the pressure is 40 kPa?

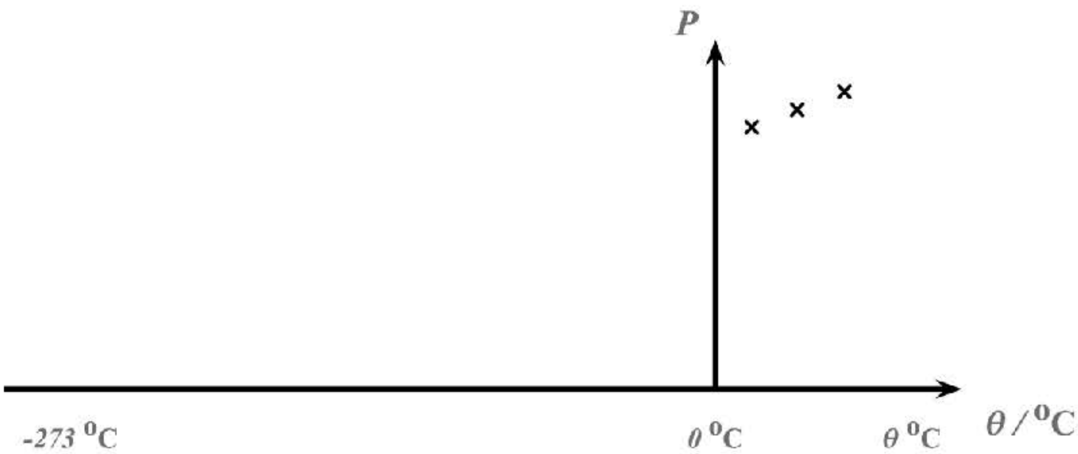
3. Pressure Law (Pressure and Temperature Relation)

(1) Experimental procedure



- **An air-tight gas flask being placed into a beaker of water bath is connected to a Bourdon gauge**
- **A thermometer is used to measure the temperature of the water bath (which is assumed to have the same temperature as the gas inside the flask).**
- **The water bath is then heated gently by a Bunsen burner.**
- **The pressure of the gas P and the temperature θ are then recorded at certain temperature interval.**

(2) Experimental result



(3) Pressure Law

The pressure P of a fixed mass of gas is directly proportional to its absolute temperature T at constant volume.

(4) Precautions of the experiment

- **The water should be well stirred to ensure uniform temperature distribution before taking a reading.**
- **The tube connecting the Bourdon gauge to the gas flask should be short.**
- **The gas flask should be wholly immersed in water.**
- **The thermometer should never touch the bottom of the beaker.**
- **Sufficient time should be allowed for the gas to reach thermal equilibrium with the water bath.**

Examples that you must fully understand

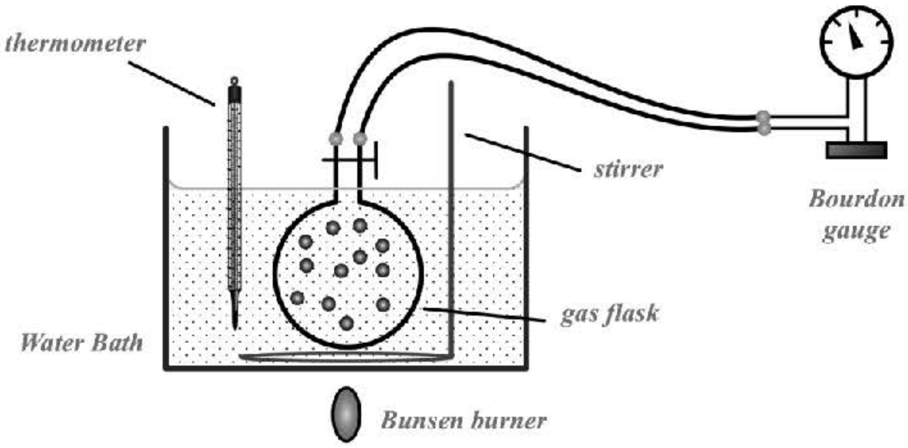
1. A certain amount of gas has a pressure of 150 kPa at 32°C.

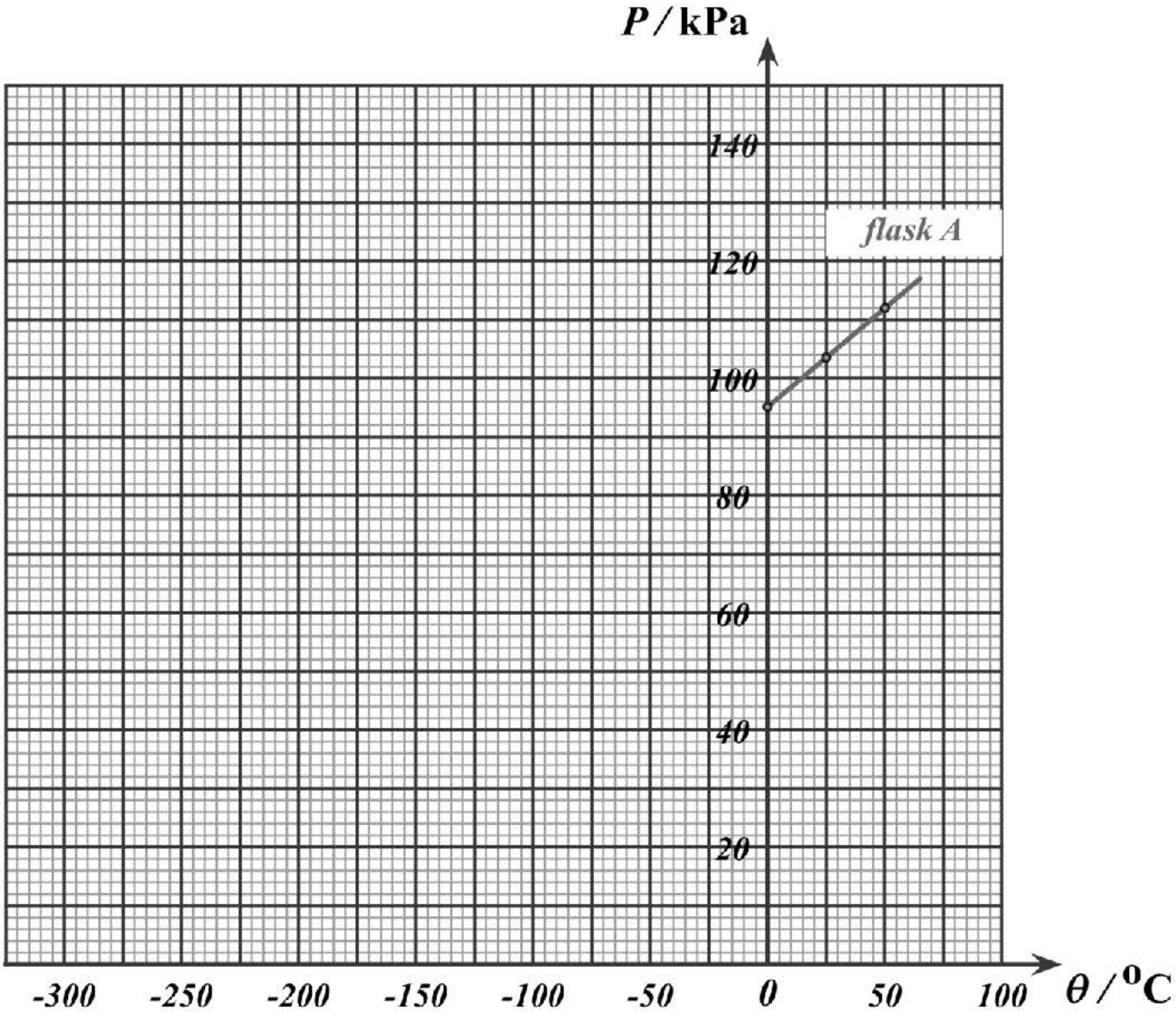
   (a) What would be its pressure if the gas is heated to a temperature of 234°C under constant volume?

   (b) At which temperature (°C) would the pressure be halved if the volume of the gas remains unchanged?

Examples that you must fully understand

2. The figure below shows the apparatus to find the variation of the pressure P against the temperature θ of a fixed volume of gas inside a flask A. The results are plotted in the graph below.





(a) Estimate a value of absolute zero from the graph.

(b) From the graph, Dorothy concludes that

"The pressure P (in kPa) of the gas is directly proportional to its temperature θ (in °C)."

Comment on Dorothy's conclusion.

Dorothy's conclusion is [ ] since the graph [ ] [ ] [ ] through the [ ], the two quantities are not [ ] [ ] to each other.

(c) If the Celsius temperature (°C) is converted to a temperature in a new scale by adding the absolute value of the x-intercept of the graph, find the relation between the pressure and the new temperature from the graph.

(d) What is the pressure when the temperature becomes 250°C?

(e) Find the temperature in °C when the pressure becomes 460 kPa.

(f) What is the change of volume of the gas when the temperature increases during the experiment?

The [ ] of the gas is [ ] when the temperature increases.

(g) Suppose a larger flask B is now used to replace the flask A and the experiment is repeated. The volume of flask B is doubled that of A. Assume that the masses of the gas in both flasks are the same.

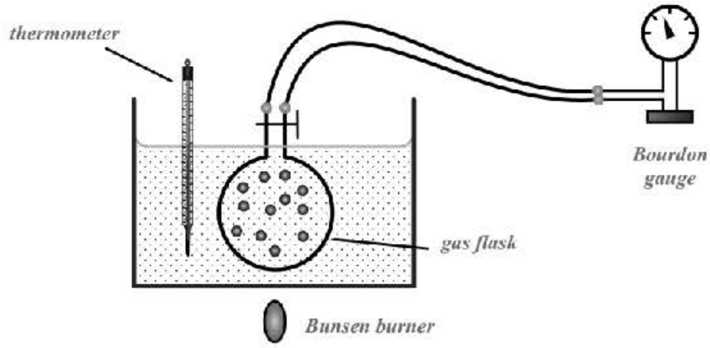
(1) What should be the gas pressure in flask B at 0°C?

(2) On the graph, draw the graph you expect to obtain for flask B in the experiment.

Examples that you must fully understand

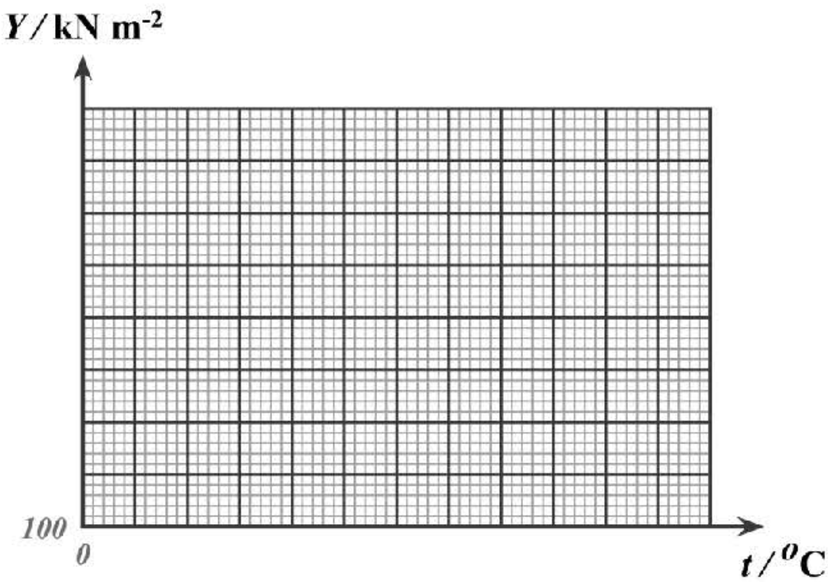
3. The figure below shows an experiment done by Natasha to find the variation of pressure of air inside a flask with temperature. The pressure Y and the temperature t are measured by Bourdon Gauge and a thermometer respectively. The experimental data are given below:

t / °C	Y / kN m^{-3}
20	107
35	113
45	116
60	122
78	128
90	133
100	136



(a) Using a scale that 2 cm **represents** 10 kN m^{-3} **and** 1 cm **represents** 10°C**, plot a graph of** Y **against** t **ranging from** *0°C* **to** *100°C*.

(b) Find the equation relating the pressure and temperature from the graph in (a). Hence find the temperature when the flask is being transferred into an oil bath. The gauge reading now is 92 kN m^{-2}**.**

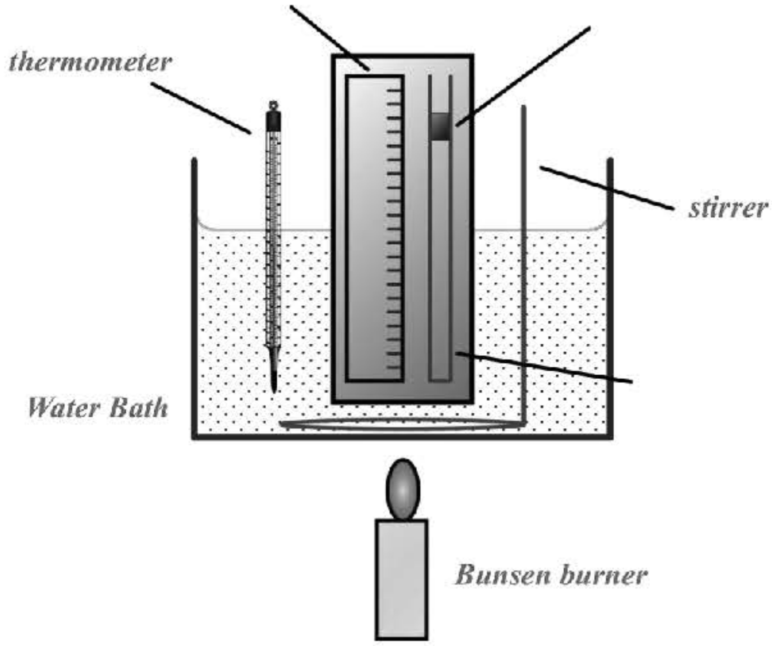


(c) Give THREE suggestions to improve the experimental setup as shown in the figure.

The [ ] should be [ ] [ ] in water.
The rubber [ ] joining the flask and the Bourdon gauge should be [ ].
A [ ] should be used to stir the water to ensure uniform [ ] distribution.

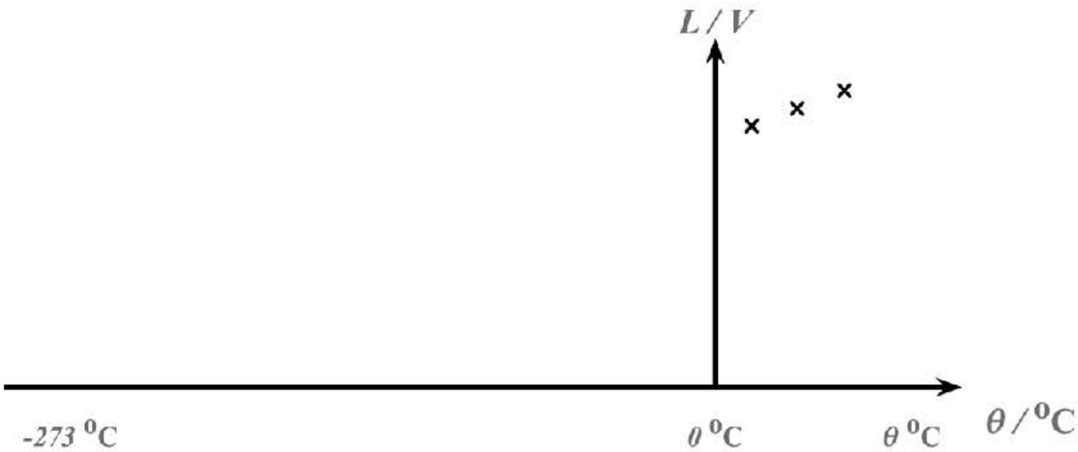
4. Charles' Law (Volume and Temperature Relation)

(1) Experimental procedure



- A column of gas under constant pressure is trapped by mercury thread inside a capillary tube.
- Together with a ruler and a thermometer, the tube is put into a water bath.
- The water bath is heated gently.
- The length of the gas column L (directly proportional to the volume V) and the temperature θ are then recorded at certain temperature interval.

(2) Experimental result



(3) Charles' Law

The volume V of a fixed mass of gas is directly proportional to its absolute temperature T at constant pressure.

(4) Precautions of the experiment

- **The water should be well stirred to ensure uniform temperature distribution before taking a reading.**
- **The gas column should be wholly immersed in water.**
- **The thermometer and the gas column should never touch the bottom of the beaker.**
- **The capillary tube should have an open end to ensure that the pressure of the trapped gas is constant and always equal to the atmospheric pressure.**

Examples that you must fully understand

1. A fixed mass of gas at 50°C is heated at constant pressure until the temperature reaches 324°C. What is the percentage increase of the volume?

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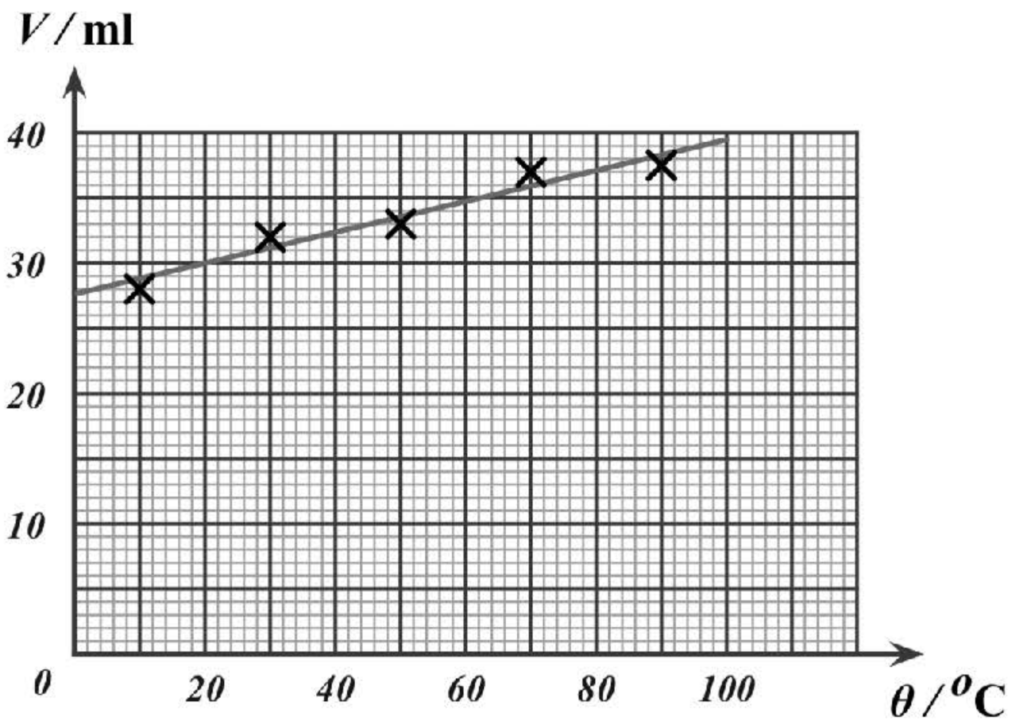
2. The variation of volume V of a trapped air inside an air column with its temperature θ under constant pressure is shown.



(a) Write down the equation relating V and θ.

(b) Find the absolute zero of temperature.

(c) Calculate the volume of the trapped air if the temperature is increased to 800°C.

(d) How does the pressure of the trapped air change with temperature?

The ______ of the ______ air would be ______.

Examples that you must fully understand

3. In an experiment to investigate the relation between the volume and temperature of a gas, which of the following is / are the necessary precautions for an accurate result?

(1) Stealing the capillary tube at both ends.

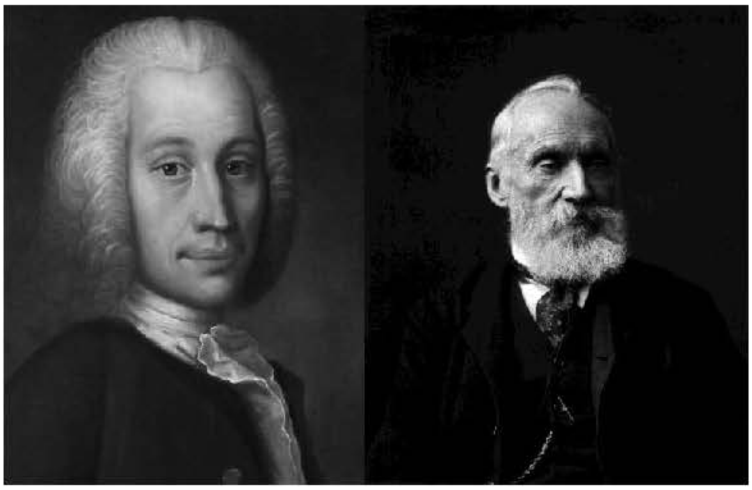
(2) Stir the water continuously.

(3) A lid should be used to cover the beaker.

(4) Some cotton wool should be used to warp the beaker in order to reduce heat loss to the surroundings.

5. Absolute temperature

■ Relation of the Kelvin (absolute) temperature T and the Celsius temperature θ:



■ The SI unit of temperature is kelvin (K).

Examples that you must fully understand

1. A certain amount of gas is at a temperature of -79°C.

(a) What is the temperature of the gas in kelvin scale?

(b) If the gas is heated to 800°C, express the increase of temperature in kelvin.

6. The General Gas Law (The Ideal Gas Law)

(1) Origin of the General Gas Law

- The state of a gas can be described by the following macroscopic quantities:

Quantities				
Unit				

- The General Gas Law relates the macroscopic quantities:

General Gas Law	Constant Kept	Relationships	
	n, T		Boyle's Law
	V, n		Pressure Law
	P, n		Charles' Law
	P, T		Avogadro's Law

- Putting the proportional constant as the Universal Gas Constant (also called Molar gas constant), $\boldsymbol{R}$, we can obtain the equation of the General Gas Law:

R : Universal Gas Constant $= 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

Examples that you must fully understand

1. If the volume of a fixed mass of gas of initial pressure $\boldsymbol{P}$ is halved and its absolute temperature is doubled, what would be the new pressure?

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2. A cylinder of volume 45 cm^3 contains a gas at a pressure of 400 kPa and a temperature of 20°C.

   (a) If the gas is compressed to one third of its original volume and the temperature is increased to 80°C, **what is the final pressure of the gas?**

   (b) If the pressure of the gas is increased to 550 kPa **and the temperature is decreased to** -120°C, **what is the volume of the gas now?**

3. A tyre of a car is filled with air at a temperature of 34°C and a pressure of 400 kPa. After driving for some time, the temperature of the air inside the tyre increases to 45°C and the capacity of the tyre increases by 9%. Find the pressure inside the tyre.

4. 14×10^{-3} m^3 of a gas is contained in a vessel at 191°C and a pressure of 45×10^5 Pa.

   (a) Find the volume of the gas at s.t.p. (standard temperature and pressure) of 0°C **and** 100 kPa.

   (b) If the density of the gas at s.t.p. is 1.2 kg m^{-3}, **what is the mass of the gas?**

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5. Which of the following can increase the pressure of the gas inside a container?

(1) Increase the temperature of the container.

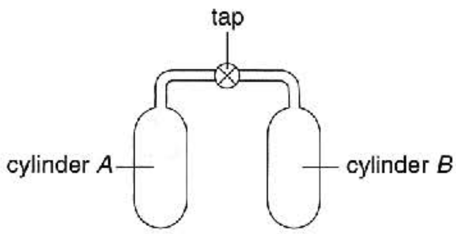
(2) Increase the volume of the container.

(3) Increase the amount of gas inside the container.

6. A balloon contains helium gas at the room temperature of $25^{o}C$. If the pressure of the gas is $175\ kPa$ and the volume of the balloon is $1000\ cm^3$, what is the amount of the helium gas inside the balloon?

7. A gas in a vessel of fixed volume has a pressure p and absolute temperature T initially. After some time, the pressure of the gas is increased to $3.99p$ and the absolute temperature is increased to $9T$. find the percentage of the original mass of the gas that has been leaked out from the vessel during this process.

8. Two insulated gas cylinders A and B are connected by a tube of negligible volume, as shown in the figure. Each cylinder has an internal volume of $2.0 \times 10^{-2}\ m^3$. Initially, the tap is closed and cylinder A contains $1.2\ mol$ of an ideal gas at a temperature of $37\ °C$. Cylinder B contains the same ideal gas at pressure $1.2 \times 10^5\ Pa$ and temperature $37\ °C$.



(a) Calculate the amount, in mol, of the gas in cylinder B.

(b) The tap is opened and some gas flows from cylinder A to cylinder B. Using the fact that the total amount of gas is constant, determine the final pressure of the gas in the cylinders.

(2) Variation of the General Gas Law

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Examples that you must fully understand

1. An open inexpansible vessel contains 36 g of a certain gas at 330 K. What is the mass of gas remained inside the vessel if it is heated from 330 K to 550 K under constant pressure? Find also the percentage of gas remaining inside the vessel.

2. Find the number of molecules in 24000 cm^3 of air in an atmospheric pressure of 10^5 Pa and at room temperature (25^oC)?

Examples that you must fully understand

3. Given that the Ideal gas constant is $8.31\ \text{J K}^{-1}\ \text{mol}^{-1}$, the Avogadro constant is $6 \times 10^{23}\ \text{mol}^{-1}$, and the molar mass of oxygen is $32\ \text{g mol}^{-1}$. A gas vessel contains $10\ \text{g}$ of oxygen kept at $120\ \text{kPa}$ and 100°C.

   (a) Find the number of mole of oxygen molecules inside the vessel. Hence find the number of oxygen molecules inside the vessel.

   (b) Find the mass of one oxygen molecule.

   (c) Calculate the volume of the gas vessel.

4. A certain amount of gas particles in a vessel has a pressure of $1 \times 10^{5}\ \text{Pa}$ and the temperature is T. If the number of gas particles per cubic meter in the vessel is $2.47 \times 10^{25}\ \text{m}^{-3}$, calculate the value of T.

5. Given that the standard atmospheric pressure = $10^{5}\ \text{Pa}$ and room temperature = 25°C.

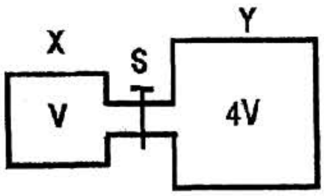
   (a) Find the density of air at r.t.p. if the average molar mass of air is $29\ \text{g mol}^{-1}$.

   (b) What would be the density of air at s.t.p.?

Examples that you must fully understand

6. Two vessels of equal volume both contain an ideal gas and are connected by a tube of negligible volume. Initially both vessels are at temperature T_0 and pressure P_0. One vessel is maintained at T_0, while the temperature of the other is raised to T. The new pressure is then given by

7. Two metallic containers X and Y of volume V and $4V$ respectively are connected by a narrow tube as shown. Initially the tap S is closed and ideal gas is contained in X at a pressure of 400 kPa while container Y is evacuated. The tap S is then opened and when equilibrium is finally reached,



***(1) the gas pressure in X is* 100 kPa.**

(2) there are still gas molecules moving through the tap S.

(3) the product of pressure and volume of the gas in X is equal to that in Y.

(4) the density of gas molecules in X is greater than that in Y.

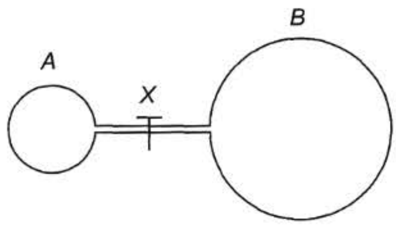
(5) the gas molecules in Y on average move faster than those in X.

8. A tank having a volume of $0.15\ \text{m}^3$ contains helium gas at 1×10^7 Pa. How many balloons can be blown up if the diameter of each filled balloon is 0.25 m at 1.2×10^5 Pa? State the assumption in your calculation.

[ ] is assumed to be [ ] for the whole process.

Examples that you must fully understand

9. Two containers A and B with volumes $100\ cm^3$ and $500\ cm^3$ respectively are connected by a tube of negligible volume as shown in the figure below. The tap X for controlling gas flow is closed initially. Container A contains an ideal gas at a pressure of 12×10^5 Pa while there is a vacuum in container B. The temperature of the two containers is maintained at 0°C by two separate water baths with melting ice.



(Given: Universal gas constant = $8.31\ J\ K^{-1}\ mol^{-1}$;
Avogadro number = $6.02 \times 10^{23}\ mol^{-1}$;
Mass of a molecule of the ideal gas = 4.52×10^{-26} kg)

(a) Find the number of moles of oxygen in container A, and

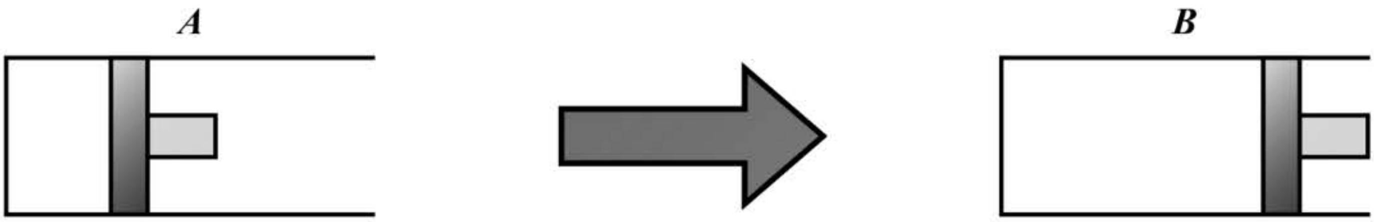
(b) Now tap X is opened, calculate the number of mole of gas remained in container A.

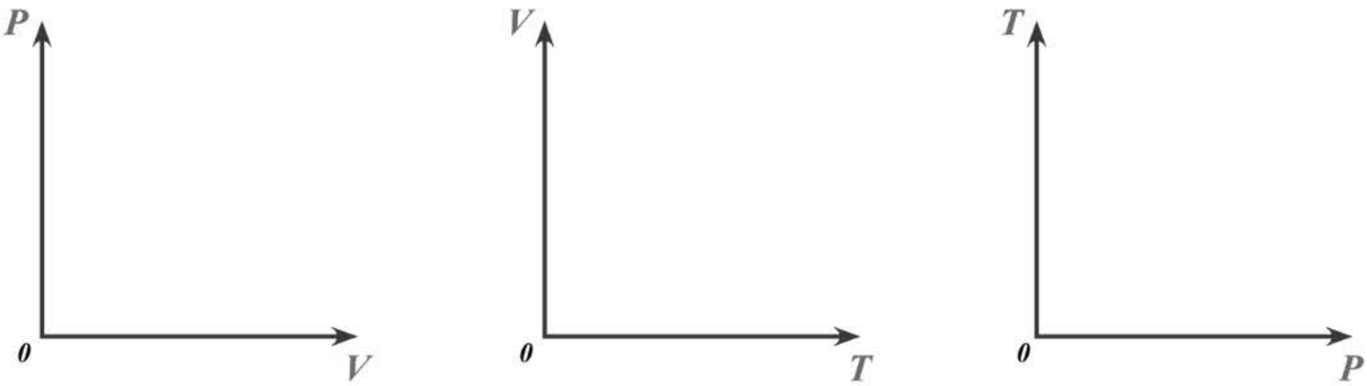
(c) Container B is now heated to 100°C while the temperature of container A is maintained at 0°C, find the pressure in both containers. Hence, calculate the net amount of gas, in moles, that passed through the connecting tube during the heating process.

7. Gas processes

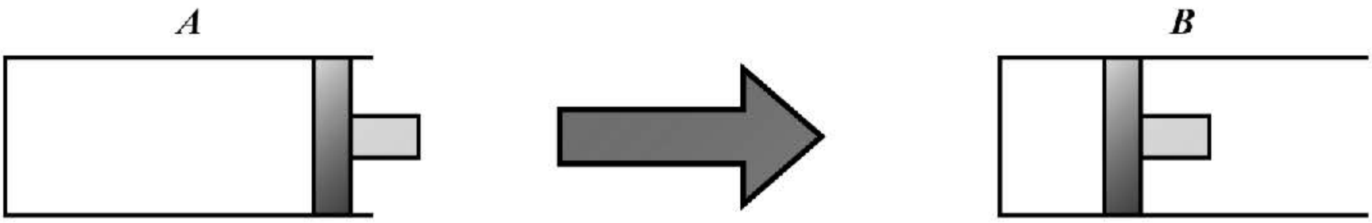
(1) To expand or to compress a gas of fixed mass under constant temperature

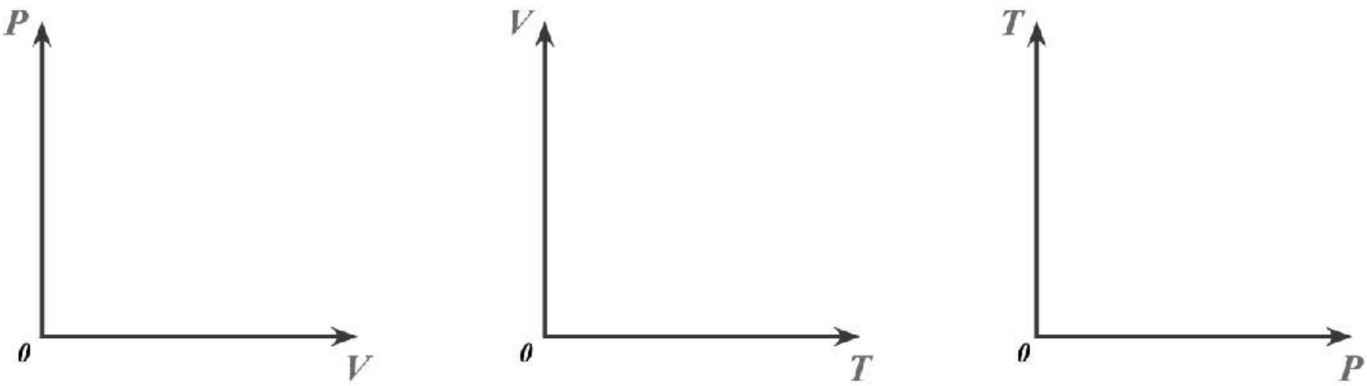
- Expansion of a gas at constant temperature from state *A* to state *B*:





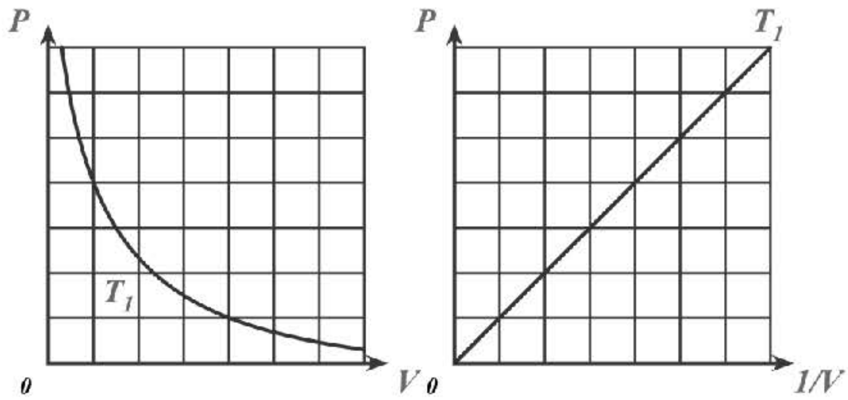
- Compression of a gas at constant temperature from state *A* to state *B*:





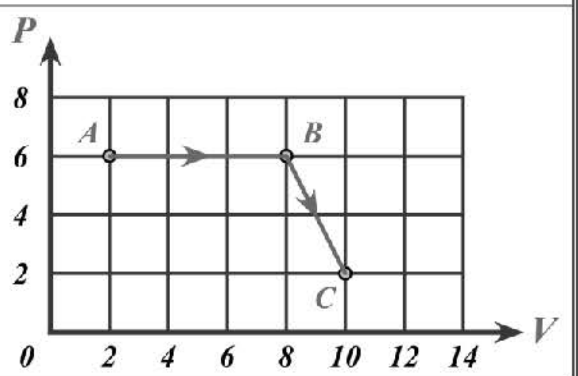
- Boyle's Law can be applied during this process:

- Physical meaning of the slope of the *P-1/V* graph:

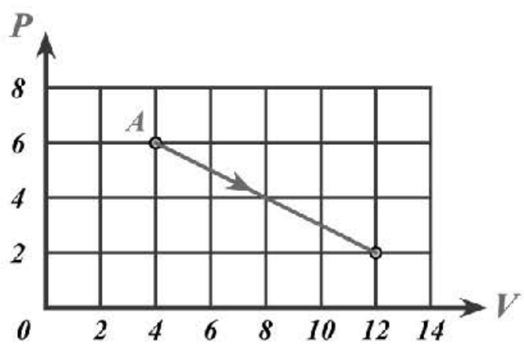


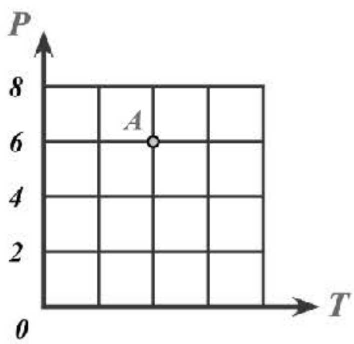
Examples that you must fully understand

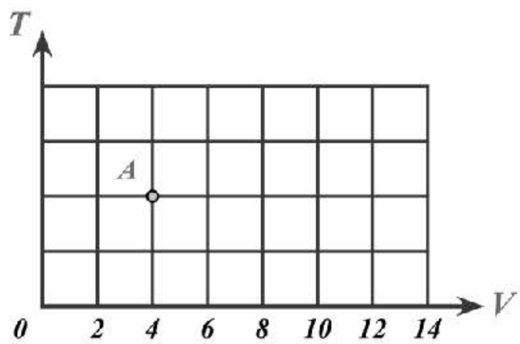
1. An ideal gas changes from state *A* to *B*, and then to *C* along the path shown. Arrange the temperatures for the three states in ascending order:



2. The pressure *P* of a fixed mass of ideal gas varies with its volume *V* is shown in the above figure with arbitrary units. Sketch the corresponding *P-T* graph and *V-T* graph for the same process.

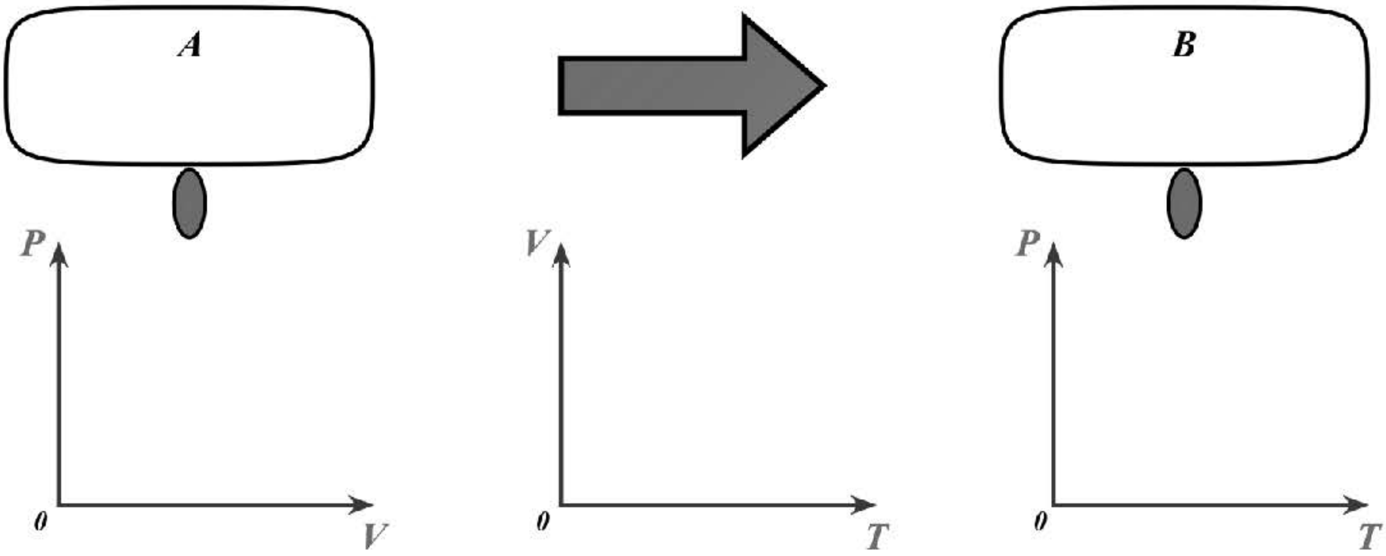




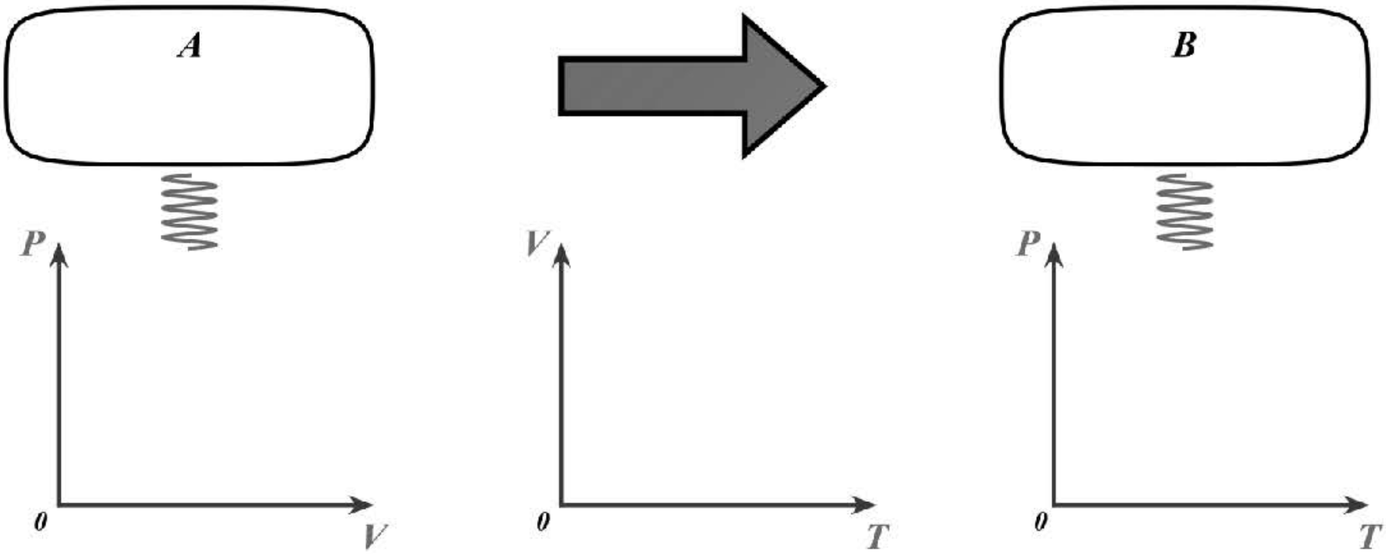


(2) To heat or cool a gas under constant volume

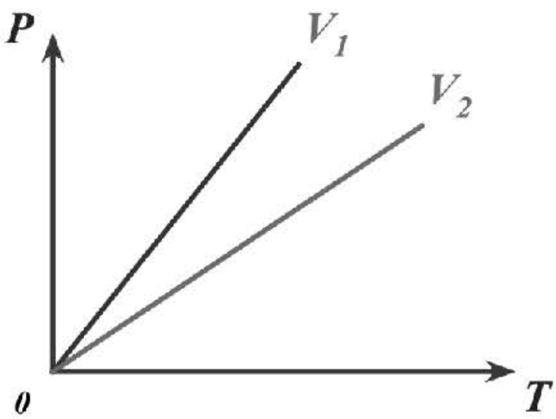
- Heating a gas at constant volume from state *A* to state *B*:



- Cooling a gas at constant volume from state *A* to state *B*:



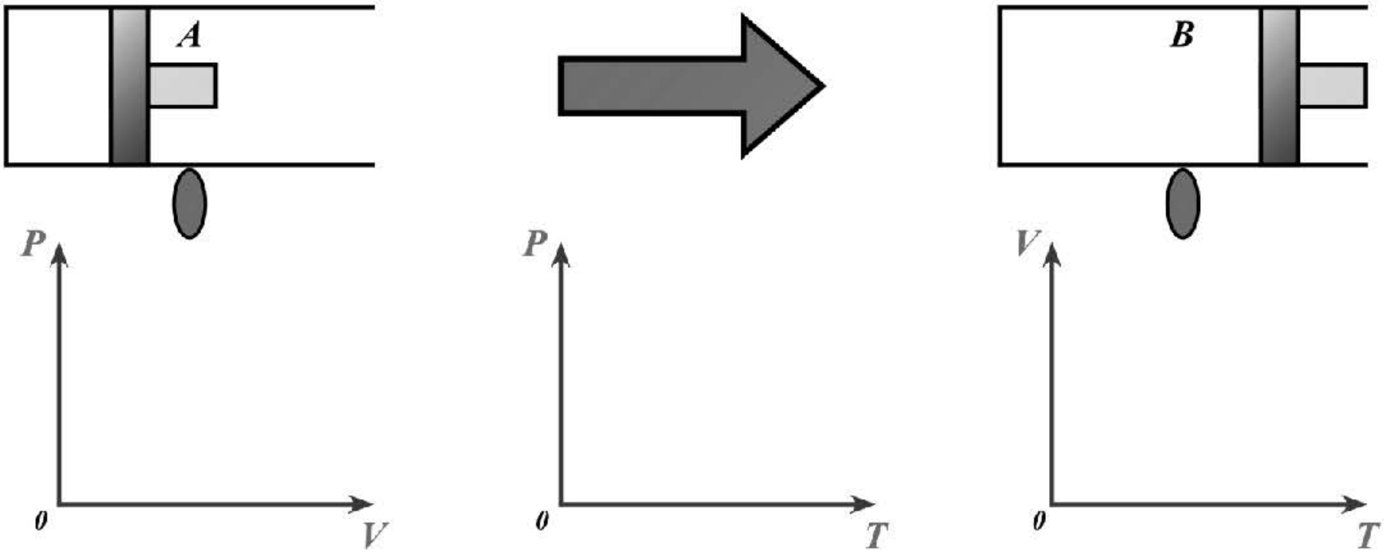
- Pressure Law can be applied during this process:



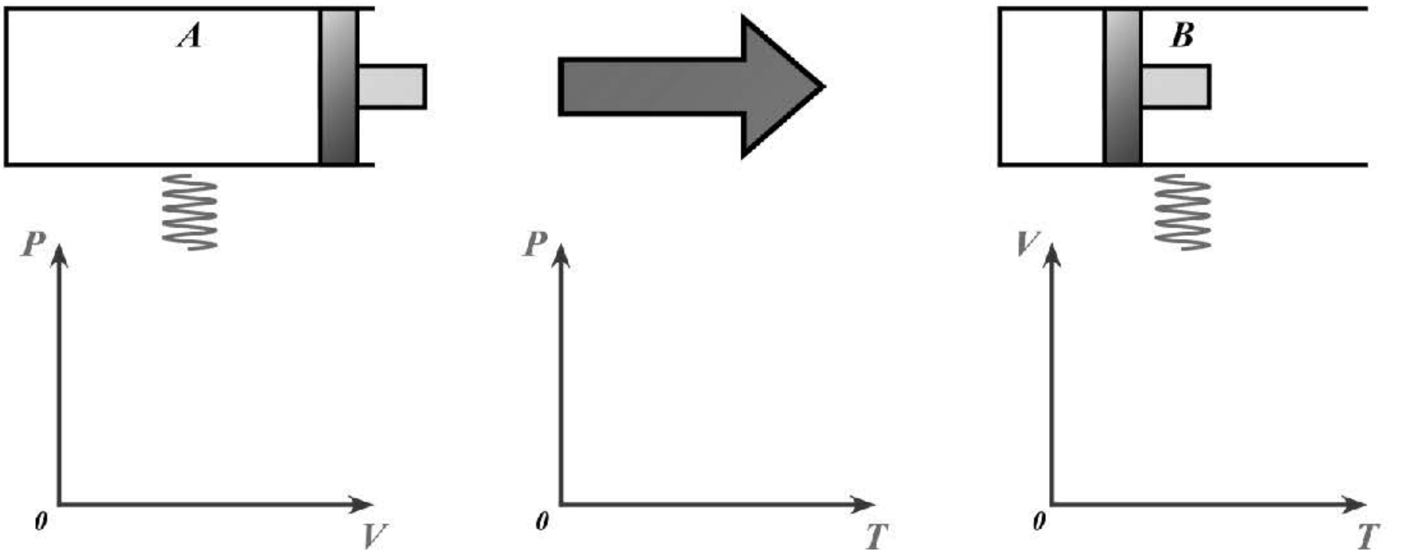
- Physical meaning of the slope of the *P-T* graph:

(3) To heat or cool a gas under constant pressure

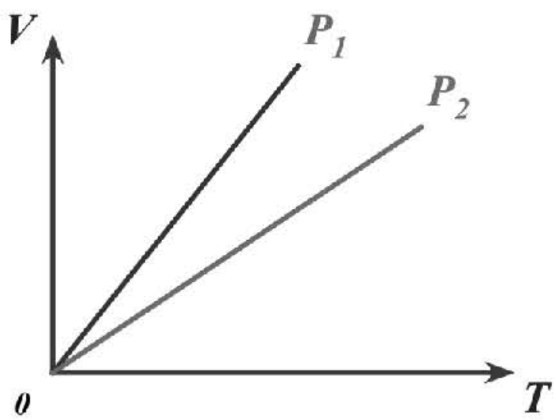
- Heating a gas at constant pressure from state *A* to state *B*:



- Cooling a gas at constant pressure from state *A* to state *B*:



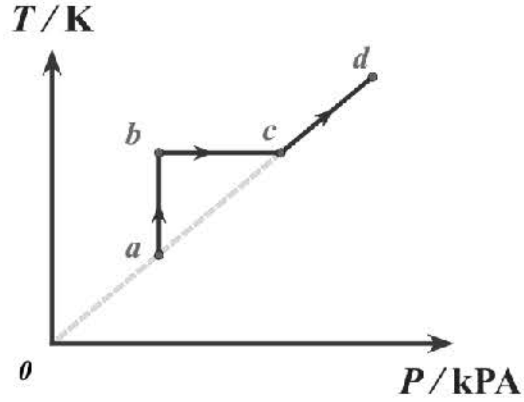
- Charles' Law can be applied during this process:



- Physical meaning of the slope of the *V-T* graph:

Examples that you must fully understand

1. A fixed mass of mass of an ideal gas undergoes the 3 processes changing from *a* to *d* as shown in the *T-P* diagram below. Which of the following statements is / are correct?

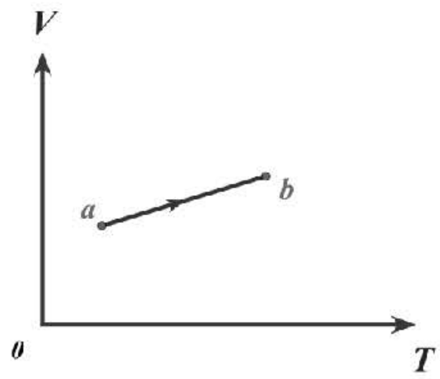


(1) From state *a* to *b*, the volume of the gas increases.

(2) From state *b* to *c*, the volume of the gas decreases.

(3) From state *c* to *d*, the volume of the gas remains unchanged.

2. The graph shows the relation between volume *V* and the absolute temperature *T* of a fixed mass of an ideal gas, which changes from state *A* to state *B* along the path *AB*. Which of the following statements is / are correct?



(1) The graph shows that *V* is directly proportional to *T*.

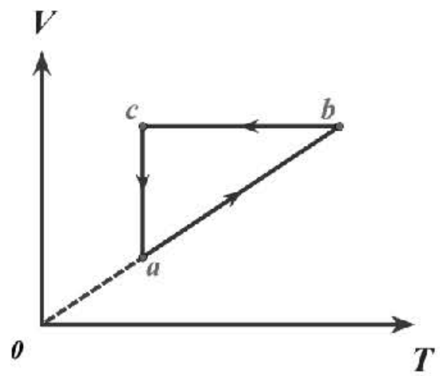
(2) The graph shows that the gas is real gas.

(3) The temperature is measured in degree Celsius.

(4) The slope of the graph represents the pressure of the gas.

(5) The pressure of the gas at state *A* is greater than that at state *B*.

3. The graph shows the *V-T* relation of a fixed mass of ideal gas. The gas changes its state from *a* to *b*, then from *b* to *c* and finally from *c* back to *a* as shown. Which of the following statements about the pressure of the gas is / are correct?



(1) The pressure remains constant in the process from *a* to *b*.

(2) The pressure decreases in the process from *b* to *c*.

(3) The pressure decreases in the process from *c* to *a*.

Examples that you must fully understand

4. The following 3 processes are carried out for an ideal gas inside a cylinder.

   (1) ***a*** to ***b***: The gas is being heated under constant volume.

   (2) ***b*** to ***c***: The gas is being expanded under constant temperature.

   (3) ***c*** to ***a***: The gas is being cooled under constant pressure.

   (a) The table below shows part of the data of the gas at the three states *a*, *b* and *c*. Complete the table.

	P / kPa	V / l	T / K
a	**150**		**300**
b		**120**	**400**
c	**150**		

   (b) Sketch the above 3 processes in the following 2 graphs.