Title

Investigating the relationship between pressure, volume and temperature of a gas

Objective

- To investigate, for a fixed amount of gas, the relationship between
  - volume and temperature at constant pressure, i.e. Charles's law
  - pressure and temperature at constant volume, i.e. Pressure law
  - pressure and volume at constant temperature, i.e. Boyle's law

Apparatus

Capillary tube (with silver thread)	x1	Thermometer	x1
500 mL round-bottomed flask	x1	Bourdon gauge	x1
100 mL syringe	x1	Hot plate with magnetic stirrer	x1
2500 mL beaker	x1	Jack	x1

Theory

Thermal behavior of gases is often described by sets of relationship among the common macroscopic quantities such as pressure P, volume V, temperature T and mass m. In this experiment, fixed amount of air is used as the gas for investigation. Since only two variables should be changed at one time, consequently there are three relationships to be explored: (I) V-T at constant P, (II) P-T at constant V, and (III) P-V at constant T.

(I) *V-T* at constant *P*

To establish a constant pressure environment while allowing volume and temperature to change, a small amount of air is trapped under a mercury thread in a capillary tube (uniform bore diameter) with the lower end closed and the upper end open to atmosphere. The capillary tube is immersed in a water bath of variable temperature. At equilibrium, the pressure of the trapped air is equal to the sum of the pressure due to the weight of the mercury thread P_{Hg} and the pressure due to atmosphere $P_{atm.}$ Both P_{Hg} and P_{atm} are independent of the trapped air which, hence, is conditioned to change its volume and temperature at constant pressure.

(II) *P-T* at constant *V*

To establish a constant volume environment while allowing pressure and temperature to change, a round-bottomed flask is used to contain a certain amount of air, and immersed in a water bath of variable temperature. The volume of the air inside is equal to the volume of the flask, which is rather fixed. Hence the air inside is conditioned to change its pressure and temperature at constant volume.

(III) P-V at constant T

To establish a constant temperature environment while allowing pressure and volume to change, a sealed syringe is used to contain a certain amount of air, which has a variable volume by moving the piston. At equilibrium, the temperature of the air inside is equal to the temperature of ambient air, which is rather fixed. Hence the air inside is conditioned to change its pressure and volume at constant temperature.

Procedure

(I)V-T at constant P and (II) P-T at constant V

As it takes time to heat up a large beaker of water, relationships (I) and (II) should be investigated together.

1. The apparatus was set up according to the figure below:
2. The initial set of readings was taken from the thermometer, Bourdon gauge and meter rule.
3. The hot plate and the magnetic stirrer were switched on. The rate of increase in temperature of water bath was monitored closely. The setting was adjusted accordingly to avoid heating the water bath at a rate too fast.
4. The same set of readings was taken whenever the temperature has increased by half of the smallest division, until the water boiled. The Bourdon gauge was tapped lightly before getting its reading as it might get stuck mechanically. The results

were tabulated.

(III) *P*-*V* at constant *T*

1. The apparatus was set up according to the figure below:
2. The initial set of readings was taken from the Bourdon gauge and the scale on the syringe. The water bath temperature was also recorded.
3. The piston was pulled slowly to increase the volume of air inside the syringe to a convenient value according to the syringe's scale. The Bourdon gauge was tapped lightly before taking the same set of readings. The results were tabulated.
4. Step 3 was repeated until the piston could not be pulled further. However, excessive force must be avoided as it might damage the syringe. The initial volume was reached finally.
5. The piston was pushed slowly to decrease the volume of air inside the syringe to a convenient value according to the syringe's scale. The results were tabulated.
6. Step 5 was repeated until the piston could not be pushed further. However, excessive force must be avoided as it might damage the syringe. The initial volume was reached finally.

Results

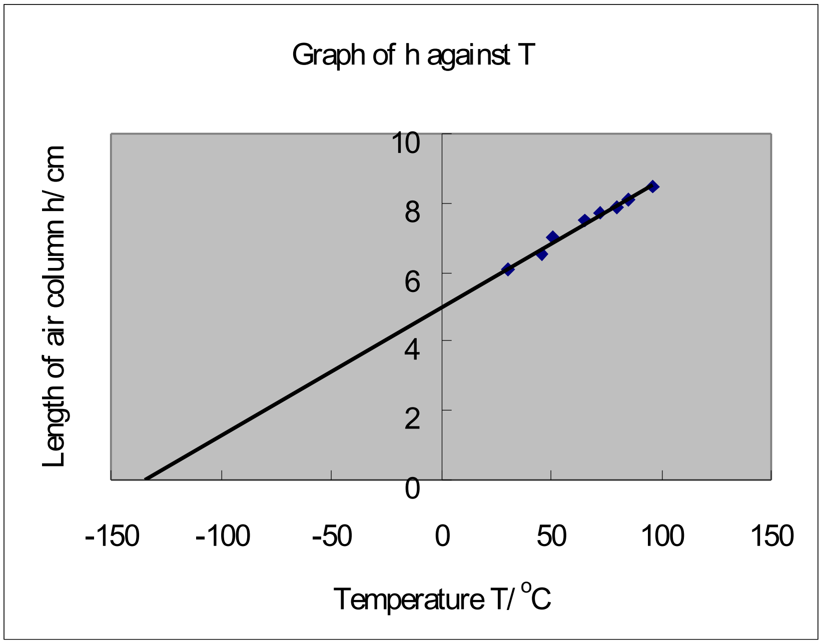
(I)*V*-*T* at constant *P* and (II) *P*-*T* at constant *V*

The temperature, the length of the air column and the pressure of the air inside the round-bottomed flask were tabulated in the table below:

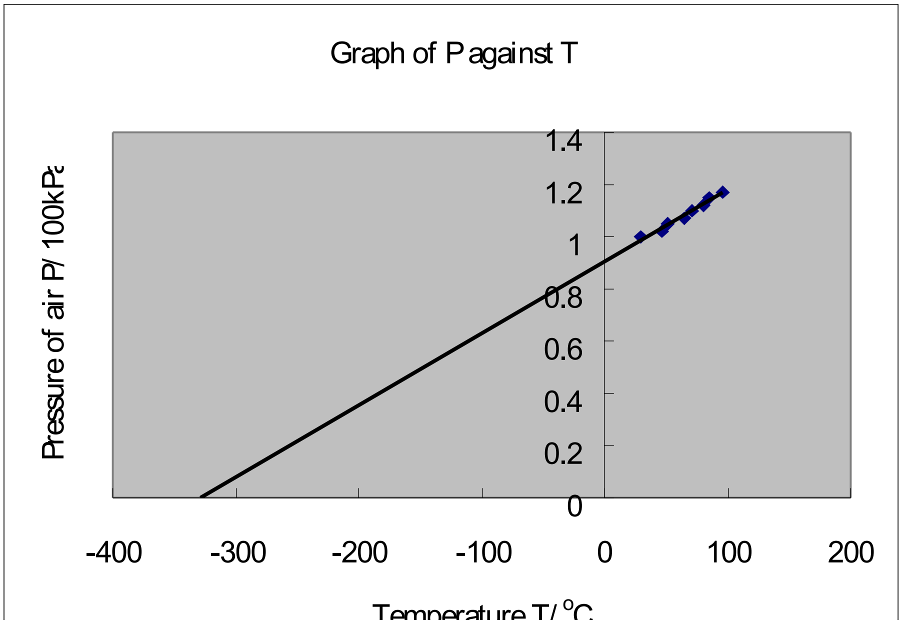
Temperature	(I) *V*–*T* at constant *P*	(ii) *P*–*T* at constant *V*
T / °C	Length of air column *h* / cm	Pressure of air *P* / 100 kPa

30	6.1	1
46	6.5	1.025
51	7.0	1.050
65	7.5	1.075
72	7.7	1.100
80	7.9	1.125
85	8.1	1.150
96	8.5	1.175

The graph of *h* against *T* was plotted below:



From the equation $y = 0.0369x + 4.9935$,
when $y = 0$, x-intercept $= -4.9935/\ 0.0369 = -135^{\circ}C$



The graph of *P* against *T* was plotted below:

From the equation $y = 0.0027x + 0.907$,

when $y = 0$, x-intercept $= -0.907/ 0.0027 = -336\ ^{o}\mathrm{C}$

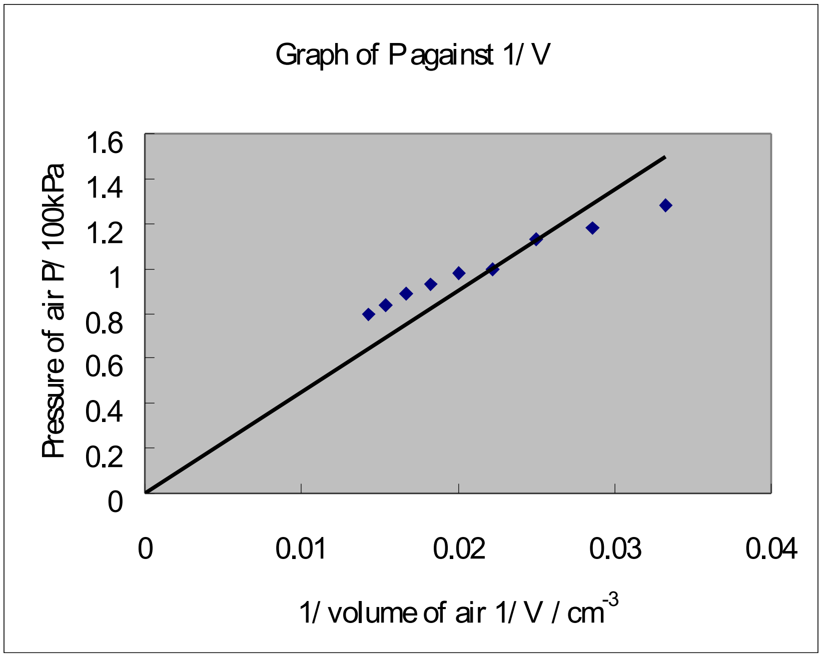
Slope of the graph $= 0.0027$

(III) *P-V* at constant *T*

The pressure and the volume of air inside the syringe under room temperature were tabulated in the table below:

At room temperature ($T = 25$ °C)		
Pressure of air P / 100 kPa	Volume of air V / cm^3	$1/V$ / cm^{-3}
0.80	70	0.0143
0.84	65	0.0154
0.89	60	0.0167
0.93	55	0.0182
0.98	50	0.02
1.00	45	0.0222
1.13	40	0.025
1.18	35	0.0286
1.28	30	0.0333

The graph of *P* against *1/V* was plotted below:



From the equation y = 45.055x, when y = 0, x-intercept = 0

Error

(I)*V-T* at constant *P* and (II) *P-T* at constant *V*

1. Air is not an ideal gas.
2. There are reading errors in measuring the temperature, the length of air column and the pressure of air.
3. Heat supplied to the water bath and that to the air inside round-bottomed flask and the capillary tube are not the same.
4. In (I), air in the rubber tubing connecting Bourdon gauge is neglected.
5. In (II), there may be leakage of air from the round- bottomed flask.

(III) *P-V* at constant *T*

1. Air is not an ideal gas.
2. There are reading errors in measuring the volume of air and the pressure of air.
3. Air in the rubber tubing connecting Bourdon gauge is neglected.

Improvement

1. The rubber tubing used should be as short as possible.
2. More accurate apparatus should be used.
3. For (II), vaseline is used to grease the junction in the round- bottomed flask.

Conclusion

In experiment (I), the length of air column *h* represents the volume of air *V* since *V* is equal to *h* x cross-sectional area of the column. The graph of *h* against *T* is plotted instead of *V* against *T* because volume of air *V* is difficult to measure. When the straight line is extrapolated, it cuts T-axis at -135^{o}C, which is far away from the expected result of -273 ^{o}C. However, by allowing the experimental errors, the volume of air *V* is still directly proportional to the temperature *T* measrued in K at constant pressure *P*, i.e. the results obey Charles' law.

In experiment (II), the slope of the graph depends on the number of moles of air *n* and the volume of air *V* by the equation $PV = nRT$. When the straight line is extrapolated, it cuts T-axis at -336^{o}C, which is away from the expected result of -273 ^{o}C. However, by allowing the experimental errors, the pressure of air *P* is still directly proportional to the temperature *T* measrued in K at constant volume *V*, i.e. the results obey Pressure law.

In experiment (III), the graph of *P* against *1/ V* is plotted instead of the graph of *P* against *V* because the line in the graph of *P* against *V* is a hyberbola which has no physical meaning for analysis. From the graph, the straight line passes the origin, indicating that the pressure of air *P* is directly proportional to 1/ the volume of air 1/ *V*. In other words, the pressure of air *P* is inversely proportional to the volume of air *V* at constant temperature *T*, i.e. the results obey Boyle's law.