LESSON 3.3 - Understanding pressure in gas

Gas Pressure

The basic assumptions of kinetic molecular theory
1. Gases are made of tiny, individual particles. The volume of the particles themselves is insignificant compared with the volume occupied by the gas; therefore gases are mostly empty space.

2. Gas particles move rapidly and randomly in straight-line motion. Particles collide with one another and with the walls of the container in elastic collisions (no overall loss or gain of energy).

3. Individual particles are far apart and have very little attraction for each other. Particles are considered to move independently of each other.

4. The average kinetic energies of particles of different gasses are equal at given temperature.

5. The average kinetic energies of gas particles increase as the temperature increases.

Existence of Gas pressure based on the kinetic theory

Based on the kinetic molecular theory, gas molecules move freely and randomly. The gas molecules collide with one another and also collide with the walls of their container. The collision of gas molecules with one another is an elastic collision (no overall loss or gain of energy). The collision of gas molecules with the wall of the container produces change of momentum or impulsive force. So the gas molecules exert a pressure on the inside of the container because pressure is force per unit area \( P = \frac{F}{A} \)

The conclusion about gas pressure

Gas pressure is the force per unit area exerted by the gas molecules as they collide with the walls of their container.

What if the volume inside a container decreases?

1. The number of the gas molecules remains unchanged
2. The number of the gas molecules per unit volume increases
3. The volume of the gas molecules remains unchanged
4. The size of the gas molecules remains unchanged
5. The density of the gas molecules remains unchanged
6. The duration of the collision between the gas molecules with the walls of the container decreases
7. The frequency of collisions between the gas molecules with the walls of the container increases
8. The density of the gas increases
9. The pressure of the gas increases

What if the number of gas molecules in a container increases?

1. The collision rate between the gas molecules with the walls of the container increases
2. The pressure of the gas increases

What if the container is heated?

1. The average velocity of the gas molecules increases
2. The kinetic energy of the gas molecules increases
3. The collision rate between the gas molecules with the walls of the container increases
4. The force of collisions between the gas molecules with the walls of the container increases
5. The pressure of the gas increases
Measuring Gas Pressure

(i) **Manometer**

A manometer consists of a U-shaped glass tube filled with liquid—normally liquid. Water is used in a manometer to measure low gas pressure. One arm of the manometer is exposed to the atmosphere whereas another arm is connected to gas supply. There are three possible methods to read the pressure of a gas by using the manometer when the tap is opened.

(i) \[ P_{\text{gas}} = P_{\text{atmosfera}} + h \]

(ii) \[ P_{\text{gas}} = P_{\text{atmosfera}} - h \]

(iii) \[ P_{\text{gas}} = P_{\text{atmosfera}} \]

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**Example 1**

The figure shows a manometer containing mercury is connected to a gas supply.

![Manometer Diagram](image)

Calculate the pressure of the gas supply in the units (i) cm Hg (ii) Pa

[ Density of mercury = 1.36 \times 10^4 \text{ kg m}^{-3} and Atmospheric pressure = 76 \text{ cm Hg} ]

**Solution**

(ii) **Bourdon Gauge**

When the gas supply is connected to a Bourdon gauge, the pressure in the curved metallic tube will try to straighten it. Hence the pointer will rotate. The magnitude of the gas pressure can be read off the scale of the gauge.
The another use of U-Tube
The U-tube can also be used to determine the density of a liquid.

\[
\begin{align*}
\text{Pressure } P_1 &= \text{Pressure } P_2 \\
h_1 \rho_1 g &= h_2 \rho_2 g \\
h_1 \rho_1 &= h_2 \rho_2
\end{align*}
\]

Example 2
The figure shows a U-tube use to determine the density of a liquid K. When liquid K is poured into one arm, the water level in the other arm rises.

If the density of water is 1000 kg m\(^{-3}\), determine the density of liquid K.

Solution

Atmospheric pressure

Existance of Atmosheric

According to kinetic molecular theory, gases consist of molecules which are apart and in random motion at high speeds. The gas molecules possess mass and experience the pull of gravity. The result is that gases have weight. The weight of the gas molecules will produce force and as a result will exert pressure on you because pressure is force per area \( P = \frac{F}{A} \).

The pressure is called as at the atmospheric pressure.

Characteristics of Atmospheric Pressure

Atmospheric pressure acts equally in all directions. The atmospheric pressure on any object is not dependent on the surface area of the object. Atmospheric pressure is influenced by the height of an object above the sea level (altitude). Hence as the altitude increases, the atmospheric pressure decreases because the higher it is from the surface of the Earth, the lower is the density of air. We do not experience the atmospheric pressure at sea level because the pressure of body equal to the atmospheric pressure. The atmospheric pressure at sea level is approximately 1 atm = 1x10\(^5\) Pa = 76 cm Hg = 10 m of water.

Example 3
The atmospheric pressure is 76 cm Hg. Calculate the atmospheric pressure in the units Pa.

\[\text{Density of mercury} = 1.36 \times 10^4 \text{ kg m}^{-3}\]

Solution
Example 4

The atmospheric pressure at the sea level 760 mm Hg, while the atmospheric pressure on the top of a mountain is 600 mm Hg. If the density of mercury is $1.36 \times 10^4$ kg m$^{-3}$ and the average density of the air is 1.25 kg m$^{-3}$, estimate the height of the mountain.

Solution

Activities to show the existence of atmospheric pressure.

Activity 1

Fill the glass to the top with water and wet rim slightly. Lie the cardboard on the top of the glass. Hold the card firmly in place and turn the glass over. Take away your hand. The cardboard does not fall and the water remains in the glass. The explanation for this phenomenon is that the resultant force caused by the atmospheric pressure acts on the surface of the cardboard is greater than the weight of the water in the glass.

Activity 2

A metal can containing water is heated until the water in it vaporizes. Allow the steam to exit from the mouth of the can. The can is then capped and cooled down with tap water. As the result, the can is crushed and crumpled. The explanation for this phenomenon is that the pressure inside the metal can decrease and the external atmospheric pressure, which is higher compresses the metal can.

Measuring atmospheric pressure

(i) The Simple Fortin barometer

The simple barometer Fortin is along glass tube that has been filled with mercury and the inverted into a dish of mercury. The mercury column rises or falls according to the pressure of air on the mercury in the dish. The space above the mercury column is a vacuum so it exerts no pressure on the top of the mercury column.

If the vertical height of the mercury is $h$ cm, therefore the atmospheric pressure reading is $h$ cm mercury.
How does the height, \( h \), vary?

The height, \( h \), will remain unchanged when
(i) the diameter of the glass tube increases
(ii) the glass tube is tilted
(iii) the glass tube is lowered further into the dish
(iv) the glass tube is lifted up from the dish
(iv) the quantity of mercury in the dish is increased

The height, \( h \), will increase when the barometer is slowly submerged in water.

The height, \( h \), will decrease when
(i) the vacuum space in the glass tube is filled with gas
(ii) the barometer is carried out to a mountain

**Example 4**

The figure shows a mercury barometer is placed in a school laboratory where the atmospheric pressure is 75 cm Hg.

(a) What is the value of \( h \)
(b) What is the length of the vacuum space when the glass tube is
   (i) uplifted at height of 5 cm
   (ii) lowered further into the dish at a depth of 4 cm
(c) If the density of mercury is \( 1.36 \times 10^4 \text{ kgm}^{-3} \)
   and the density of water is \( 1 \times 10^3 \text{ kgm}^{-3} \),
   determine
   (i) the atmospheric pressure in the units Pa
   (ii) the value of \( h \) if the mercury is replaced by water.
   (iii) the value of \( h \) if the barometer is submerged in water at depth of 40.8 cm.

**Example 5**

The figure shows a barometer. The vacuum space is filled with a gas X.

What is the pressure of the gas X?
[Take atmospheric pressure = 76 cm Hg]

**Solution**
Aneroid Barometer

When the atmospheric pressure decreases, the container will expand. When the atmospheric pressure increases, the container will constrict. The slight movement of the box is magnified by a lever system which is connected to a pointer. The Aneroid barometer can be used as an altimeter by mountaineers or in an aeroplane to determine its altitude.

Applications of Atmospheric Pressure

(i) Drinking straw

When we suck through a straw, the air pressure in the straw is lowered. Then the pressure of the atmosphere acting on the surface of the drink in the glass pushes the water up the straw and into our mouth.

(ii) Rubber sucker

When the sucker is pressed into place, most of the air behind it is squeezed out. The sucker is held in position by the pressure of atmosphere on the outside surface of the rubber. If the seal between the sucker and the surface is airtight, the sucker will stick permanently.

(iii) Syringe

Pulling up the piston reduces the atmospheric pressure inside the cyclinder. The atmospheric pressure on the liquid surface then pushes the liquid up into the syringe. If we then hold the plunger in place and lift the syringe out of liquid, none will fall out. This is again due to atmospheric pressure.

(iv) Vacuum cleaner

A vacuum cleaner produces only a partial vacuum. The fan inside the cyclinder blows air out of the vents. Which less air inside, the air pressure there drops. The atmospheric pressure outside then pushes air up the cleaner hose, carrying dust and dirt with it.
(v) Lift pump

When the plunger is lifted, valve A closes and valve B opens. The atmospheric pressure acting on the surface of the water causes water to flow past valve B into the cylinder.

When the plunger is pushed down, valve B closes and valve A opens. Water flows above the plunger.

When the plunger is next lifted, valve A closes and valve B opens. The atmospheric pressure, acting on the surface of the water, forces water past valve B into the cylinder. Simultaneously, the water above the plunger is lifted and flows out through the mouth.

1. Gas pressure exits because the gas molecules
   A. move randomly and freely
   B. move at the same velocity
   C. collide with one another in elastic collisions and with the walls of the container in
   D. collides with the wall of the container produces change of momentum

2. The figure shows an air-tight container.

   Why does the pressure of the gas increase?
   A. The molecules gas expand
   B. The number of molecules of gas increases
   C. The molecules move faster and hit the walls more often
   D. The molecules move at the same speed, but hit the walls more often

3. Some gas trapped in a cylinder is compressed at a constant temperature by a piston. Which of the following does not increase?
   A. Mass
   B. Density
   C. Pressure
   D. Molecular spacing

4. The figure shows a cylinder contains gas. The piston is held fixed and the cylinder is heated.

   When the temperature of a gas rises at constant volume, its molecules
   A. move close together
   B. move with greater average speed
   C. collide with one another less often
   D. exert smaller forces on one another

5. When the temperature of a gas rises at constant volume, its molecules
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   B. move with greater average speed
   C. collide with one another less often
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6. The figure shows a cylinder contains air.
When the piston is pulled upwards, which of the following is true?

A. The density of the gas molecules increase
B. The distance between molecules increase
C. The number of the gas molecules per unit volume increase
D. The frequency of collisions between the gas molecules with the walls of the container increase

Which one of the following pairs of measuring instruments to measure gas pressure is true?

A. Bourdon gauge and manometer
B. Manometer and Fortin’s barometer
C. Bourdon gauge and Fortin’s barometer
D. Fortin’s barometer Fortin and Aneroid barometer

The figure shows a manometer used to determine pressure in a gas tank. Which comparison is correct about pressure in the gas tank with the atmospheric pressure?

A. Pressure in the gas tank is equal to the atmospheric pressure
B. Pressure in the gas tank is greater than the atmospheric pressure
C. Pressure in the gas tank is less than the atmospheric pressure

The figure shows a manometer is connected to a gas supply. If the atmospheric pressure is 76 cm Hg determine the pressure of the gas.

A. 30 cm Hg  B. 46 cm Hg  C. 76 cm Hg  D. 86 cm Hg  E. 106 cm Hg

The figure shows a U-tube filled with two liquids X and Y which are incompatible. If the density of liquid Y adalah 0.9 g cm\(^{-3}\), what is the density of liquid X?

A. 0.3 g cm\(^{-3}\)  B. 0.6 g cm\(^{-3}\)  C. 1.2 g cm\(^{-3}\)  D. 2.7 g cm\(^{-3}\)  E. 2.7 g cm\(^{-3}\)

The figure shows an apparatus is to be used to compare the density of two liquids. If the density of liquid A and liquid B is 800 kg m\(^{-3}\) and 600 kg m\(^{-3}\) respectively, what is the ratio of \(h_1\) and \(h_2\)?
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12 We do not experience the atmospheric pressure at sea level because

A the atmospheric is very light
B the density of atmospheric is less than the density of our body
C the force exerted by the atmospheric pressure is zero
D the pressure of our body equal to the atmospheric pressure

13 The figures show a simple mercury barometer. Which one shows the height, h, to be measure to find atmospheric pressure?

14 The figure shows a mercury barometer.

What happen to the height of h if the glass tube is tilted?

A decreases
B increases
C remains unchanged

15 The height of mercury in a barometer will be decreased if
10

What is the pressure at point X?
[ The atmospheric pressure = 75 cm Hg ]

A 0 cm Hg  B 65 cm Hg  
C 75 cm Hg  D 85 cm Hg  
E 100 cm Hg

22 The figure shows a mercury barometer is added with water to it in a container.

What is the height of water, h.
[ The atmospheric pressure = 75 cm Hg ]

A 5 cm  B 37 cm  
C 68 cm  D 75 cm  
E 85 cm

23 The figure shows a mercury barometer.

If the vacuum space in the tube is filled with gas X, what is the pressure of gas X?
[ The atmospheric pressure = 75 cm Hg ]

A 0 cm Hg  B 20 cm Hg  
C 55 cm Hg  D 75 cm Hg  
E 95 cm Hg

24 Which of the following not involving the applications of the atmospheric pressure?

A Syringe  B Drinking straw  
C Rubber sucker  D Bunsen Burner

25 The figure shows a suction pump being pressed against a smooth wall. The pump sticks to the wall when released.

The pump sticks to the wall because

A the atmospheric pressure is equal to the pressure inside the pump  
B the atmospheric pressure is less than the pressure inside the pump  
C the atmospheric pressure is more than the pressure inside the pump

26 Figure shows an apparatus is used to determine the density a liquid.

(a) In figure (a), the atmospheric pressure is $1 \times 10^5$ Pa. What is the pressure of the air in tubes P and Q?

(b) The air in tubes P and Q is sucked out through tube R which is then clipped. Figure (b) shows the level of the water and the oil after the air is sucked out.
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(i) Explain why do the water and the oil rise through the tubes P and Q?

(ii) Why is the height of the water column is lower than that of the oil column?

(c) If the density of water is 1000 kg m\(^{-3}\).
   (i) Determine the pressure at point X due to the water column only.
   (ii) Calculate the pressure of the air that is still trapped in tubes P and Q.
   (iii) Compare the pressure at point X and Z.
   (iv) Determine is the density of the oil.

(a) Berdasarkan rajah A dan rajah B,
   (i) Observe the figures and state the similarity between the situations of the glasses.
   (b) Name the pressure involved in Figure (a) and Figure(b).
   (c) Explain why the situations in (a) happen?
   (d) (i) Based on the Figure B, without removes the plastic glass from the container, suggest one method how to flow the water from the plastic glass to the container.
   (ii) Give the reason for your answer in d(i).
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(e) **State two applications that use the above principle.**

(ii) **Give one reason why don’t the mercury column drops until it reaches the level of the mercury in the dish?**

(d) **Determine the pressure in units cm Hg at point**

(i) **J**

(ii) **K**

(e) **What will happen to the value of h if**

(i) **the tube is raised through a height 10 cm**

(ii) **the tube is lowered through a depth of 5 cm**

(iii) **the glass tube is inclined about 5° from the vertical line.**

(iv) **the surrounding temperature increases.**

(v) **the apparatus is placed on the top of a mountain.**

(vi) **the space P in the tube is filled with the little of water.**

(f) **Given that the density of water is 1000 kgm⁻³ and the density of mercury is 13600 kgm⁻³. Determine**

(i) **the atmospheric pressure in units Pa**

(ii) **the value of h if the mercury is replaced by water.**