Applications of Gas Laws in Anaesthesia delivery system- from source to alveoli.

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Anaesthesiologist will be dealing with many of the gases which are needed for anaesthetizing patients every day. These gases are delivered to the patient using anaesthesia work stations. Many of the gas laws are also applicable to these gases used by the anaesthesiologist using anaesthesia delivery system. A sound knowledge about the application of these gas laws is essential for every anaesthesia trainee for safe use of the anaesthesia delivery system and conduct of anaesthesia as well.

The common gas laws that are applicable are.

1. Boyles's Law
2. Charle's Law
3. Gay Lussac's Law
4. Avagadro's Law or Hypothesis
5. Dalton's Law of partial pressures
6. Universal gas law
7. Hegan-Poissuilles law for laminar flow
8. Graham's law for turbulent flow
9. Reynolds's number
10. Graham's law of diffusion.
11. Bernoulli's principle
12. Venturi's effect
13. Coanda effect
14. Critical temperature
15. Poynting effect
16. Henry's law
17. Raoult's law

<u>Definitions of the gas laws</u>

<u>1)Boyle's Law:</u> states that at constant temperature(T)the volume(V) of a given mass of a gas is inversely proportional to the absolute pressure(P).

$V \alpha 1/p$

The equation can also be written as-

PV = constant (if T is kept constant)

2) Charle's Law: States that at constant pressure, volume of a gas is directly proportional to the temperature.

V α T or

V / T = constant.

3)Gay Lussac's law: States that at constant volume pressure is directly proportional to the temperature

P α T or

P/T = constant

4) Avagadro's hypothesis: States that equal volume of gases contain equal number of molecules at standard temperature and pressure(STP).

Based on the above hypothesis-

One mole of a gas contains- 6.023×10^{23} molecules

This law can also be defined as -

One mole (molecular weight) of any gas at STP occupies ***22.4 litres*** of volume.

When mole (molecular weight) is expressed in grams it's called as **gram molecular weight**.

So 1 gram molecular weight of any gas at STP, will contain **6.023×10^{23} molecules and occupies *22.4 litres* of volume.**

Standard temperature is 273 K and standard pressure is 760 mm of Hg.

5) Universal gas constant : Concept of the gas laws(Boyle's law, Charle's law and Gay Lussac's law) can be combined with that of Avagadro's hypothesis and the mole as follows,

$PV = K_1$ (Boyle's law)

$V/T = K_2$ (Charle's law)

$P/T = K_3$ (Gay Lussac's law)

Using Avogadro's Hypothesis at constant pressure and temperature V= number of molecules (n).

So, combining the first 3 above gas laws, one can derive an equation - PV / T = Constant for a given quantity of any gas. The constants K1 K2 & K3 can be expressed as universal gas constant (R).

For one mole of any gas, PV /T = a unique constant **'universal gas constant'**(R) the more general applicable equation with slight modification can be written as PV=nRT. Where n is the number of molecules of the gas.

Universal gas constant is 1.987 joules/degree/mole in SI units.

6) Dalton's law of partial pressures: states that in a mixture of gases the pressure exerted by each gas is same as the pressure exerted as if it alone occupied the container.

It can also be defined as "in a mixture of gases the total pressure exerted by the mixture is equal to the sum of pressures exerted by the individual gases. The pressure exerted by each of the gases is called as the **partial pressure** of that gas. The partial pressure of the component gas must be proportionate to its percentage in the gas mixture.

Partial pressure= fractional concentration X total pressure.

7) **Hegan- Poissuilles' law:** is applied for laminar flow. It states that the flow through the tube is directly proportional to the pressure gradient and 4th power of radius and inversely proportional to the length of the tube and viscosity of the gas.

$$Q= \frac{\Pi r^4 (P_1 - P_2)}{8\eta L}$$

Where Q= flow of liquid
r= radius of the tubing
$P_1 - P_2$ = pressure gradient across the tubing
Ƞ (eta)= viscosity
L= length of the tubing.

8) **Reynolds number:** it is directly proportional to the velocity, density and diameter and inversely proportional to the viscosity.

Reynolds number = $\upsilon\rho d / \eta$

Where υ = linear velocity of fluid

ρ = density

d = diameter of tube

η = viscosity

Reynolds's number is a dimensionless number and if it exceeds 2000, then the flow becomes turbulent.

Laminar flow- is smooth, even, non-tumbling flow. The flow proceeds with a cone effect.

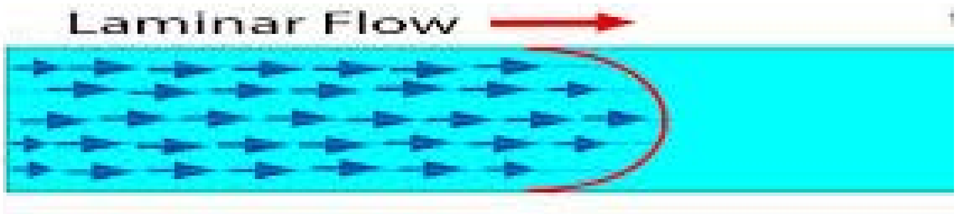


Figure 1 - laminar flow

The molecules of the gas in the centre of the system encounter lesser frictional resistance and move at a greater velocity than those at the sides of the system.

Turbulent flow- is a rough, tumbling and an uneven flow pattern.

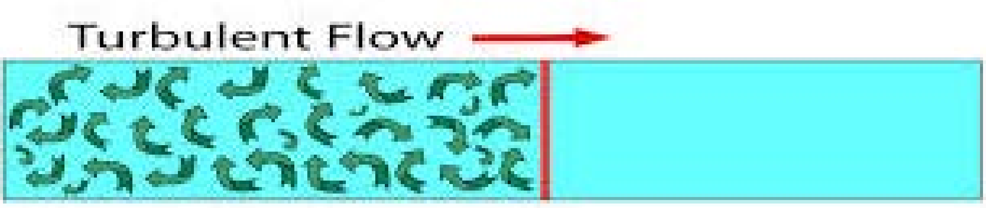


Figure 2 - turbulent flow

Turbulent flow moves with a blunt front. Due to tumbling effect all of the molecules in the system encounter the wall of the tube.

9) Graham's law for turbulent flow: states that the Flow rate is directly proportional to square root of pressure gradient on either side of the tube and inversely proportional to square root of density of the fluid.

$$\text{Flow} = \frac{\sqrt{P1-P2}}{\sqrt{density}}.$$

Where P1-P2 is pressure gradient across the tube.

Since flow α 1/ resistance, above equation can also be rewritten as

$$\text{Resistance} = \frac{\sqrt{density}.}{\sqrt{P1-P2}}$$

10) **Bernoulli's principle:** when a gas flowing through a tube encounters a constriction, at that point the pressure drops and the velocity increases i.e. kinetic energy increases and the potential energy decreases. This is called as Bernoulli's principle.

Venturi is a tube with a cross section gradually decreases and then increases.

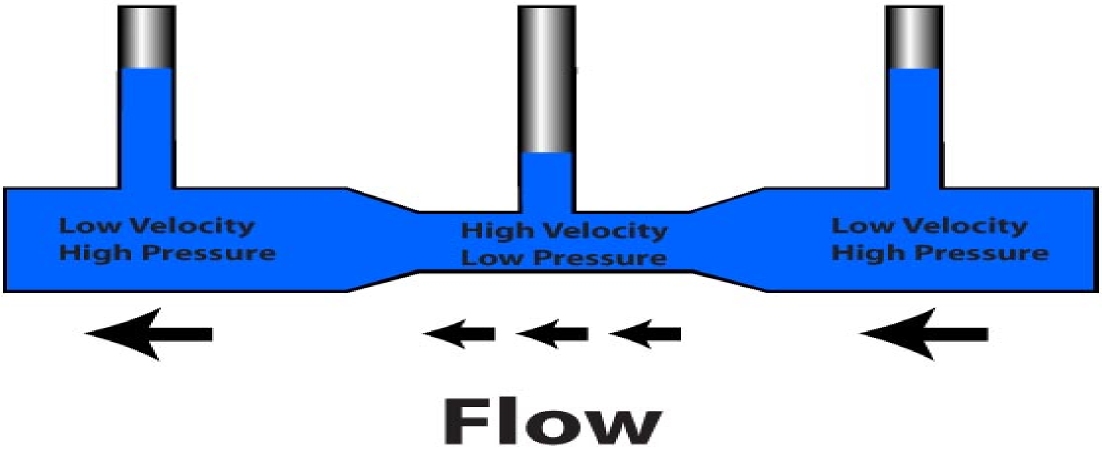


Figure 3 - Bernoulli's principle

Entrainment of air from the surrounding due to fall in pressure at the point of constriction is called as **VENTURI'S EFFECT.**

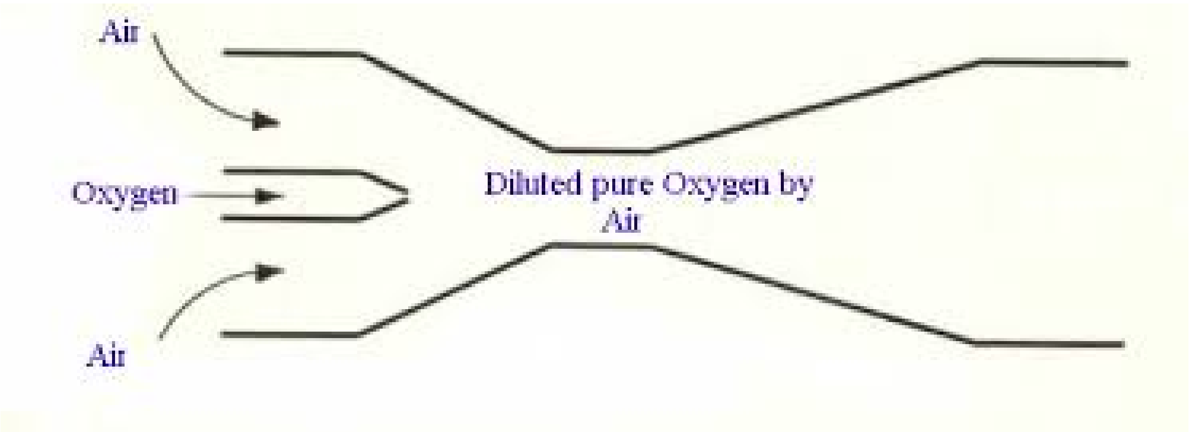


Figure 4 - Venturi effect

<u>11) Coanda effect:</u> is the tendency of the fluid jet to be attached to a nearby surface. This phenomenon is also called as wall attachment. When a narrow tube encounters a Y junction of the wide bore, because the flow tends to cling to one side, the flow will not evenly divide between the two outlets, but flows through only one limb of the Y piece. This behavior is called **COANDA EFFECT.**

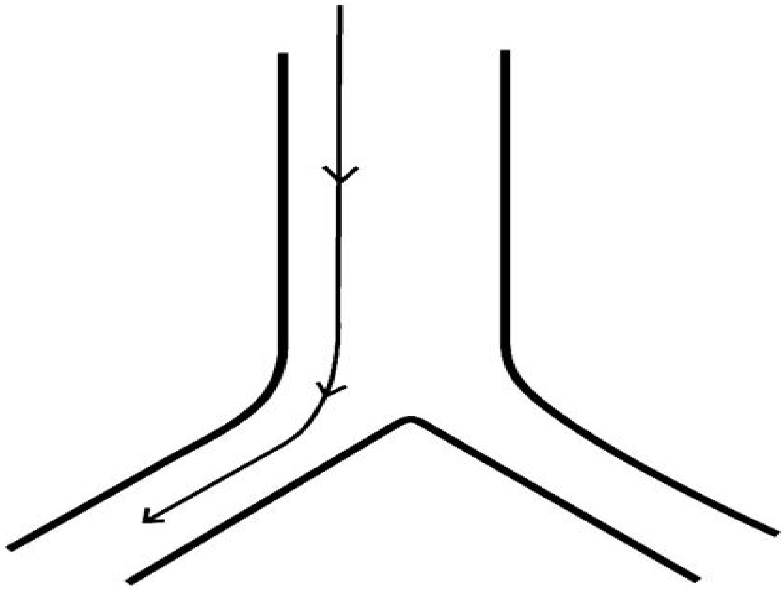


Figure 5 - Coanda effect

12) Critical Temperature: this is the temperature above which the gas cannot be compressed to its liquid state with any amount of pressure. So a gas can remain in a liquid state below its critical temperature.

Critical pressure is the pressure of the gas at its critical temperature.

13) Poynting effect: when two gases, one of high and another of low critical temperature are mixed in a container,the critical temperature of the gas with a high critical temperature will decrease to a lower level**(pseudo critical temperature)**and the mixture will remain as a gas above this pseudo critical temperature. This effect is called as Poynting effect.

14) Adiabatic Changes: the three gas laws describe the behaviour of the gas when one of the three variables, pressure, temperature or volume is constant. For these conditions to be applied, heat energy is to be takenoff or added to the gas as the changes occurs. The state of the gas can also be attended without allowing the gas to exchange heat with the surroundings, and this is called **ADIABATIC CHANGE.** When the energy is neither gained from or lost to the atmosphere the process is called as **ADIABATIC PROCESS.** This is also called as **JOULE THOMSON EFFECT.**

15) Raoult's law states that the reduction of vapour pressure of a solvent is proportional to the molar concentration of the solute. This law is useful during calculation of concentrations of volatile anaesthetics in azeotropic mixtures.

Applications of gas laws in the anaesthesia delivery system

1. **What is the gas law applied to know the volume of oxygen in a full "E" type of cylinder available for use at 15 psig(pressure at common gas outlet)?**

To know the volume of oxygen available one has to apply **BOYLE'S LAW**.

As we know the volume of an E type of cylinder is approximately 5 Litres.

The service pressure at which the cylinder is filled is 2000 psig

BOYLE'S LAW states that pressure × volume is constant at constant temperature OR PV = constant.

Considering the pressure in cylinder as P1(2000 psig) and volume of the cylinder as V1(5L) and volume of oxygen available(V2) at a pressure of P2 (15 psig),

The equation will be

P1V1= constant, and

P2V2= constant

Hence the equation will be P1V1= P2V2

2000 X 5= 15 X V2

V2=2000 x 5/15=665 litres

So if we use 3 litres of oxygen, the E type full cylinder will last for about 220 mins(5 liters of oxygen will remain in the cylinder and cannot be used).

2. **How Bourdon's pressure gauge will indicate the content of the oxygen cylinder?**

The gas law applicable is **UNIVERSAL GAS CONSTANT** and the equation used is

PV= nRT.

Where P=pressure

n=number of molecules

R=universal gas constant and

T= temperature

Since in this cylinder volume is constant, temperature is constant and R is already a constant P = n, i.e. pressure shown in the Bourdon's gauge is proportional to the number of molecules which is the amount of gas in the cylinder. Hence the pressure gauge acts as a content gauge.

If the gauge pressure in E type cylinder is showing 1000 PSI(half full), then the volume of gas one can use will be 330 litres at 15 PSI.

3. **How do you know how much of nitrous oxide is present in an E type of cylinder for use?**

Nitrous oxide has a **critical temperature of 36.5^{o} C**. Hence at room of temperature of 20^{o} C it remains as liquid. Since it is in liquid form one cannot use Boyle's law to calculate the volume available and also the pressure gauge will not show the content of the cylinder. To calculate the amount of nitrous oxide to be used, one has to weigh the cylinder and deduct the tare weight (weight of the empty cylinder) to know the actual weight of liquid nitrous oxide in kgs. If the weight of the liquid nitrous oxide is 3.3 kgs, then using Avagadro's Hypothesis 1 gram molecular weight of any substance will occupy 22.4 litres; the molecular weight of N_2O is 14 × 2 + 16= 44 (molecular weight of Nitrogen is 14 and oxygen is 16.)

So 44g of N_2O will give 22.4 litres

3300 g will give $\frac{3300 \times 22.4}{44}$= **1680 litres.**

A full E type nitrous oxide cylinder will give 1680 liters of gas at STP(273 K and 760 mm of Hg)

As per **CHARLE'S LAW**, volume is directly proportional to temperature,

Room temperature is 273+ 20= 293K.

Hence at room temperature (293 K) a full E type nitrous oxide cylinder will give $\frac{1680 \times 293}{273}$ = 1803 litres.

A full E type nitrous oxide cylinder will give 1803 liters of gas at room temperature.

4. **Why the Bourdon's pressure gauge of N_2O does not show the contents of the cylinder?**

N_2O is a liquid at room temperature and hence it will not follow the universal gas constant equation. The pressure in the N_2O Bourdon pressure gauge always shows 750 psig till all the liquid N_2O becomes vapour. 750psig is the saturated vapour pressure of N_2O at 20^{o}C. When all the liquid nitrous oxide converts into the vapor state, the Bourdon's pressure gauge will act as the content gauge and BOYLE'S LAW will be applicable.

5. **What is filling density and how it is used to fill** N_2O?

Filling density = $\frac{\text{Weight of liquid } N_2O}{\text{Weight of water}}$

The filling density or filling ratio of N_2O in the tropical climate is 0.67. So in an "E" type of cylinder which has a volume of 5 litres and 5 liters of water will weigh 5 kgs., since the density of water is 1, 1 liter of water weighs 1 kg, the filling ratio represents the mass of N2O in kilograms divided by the internal volume of the cylinder in liters.

$$0.67 = \frac{\text{weight of } N_2O}{5 \text{ kgs}}$$

Wight of the liquid N_2O in an E type cylinder = 0.67 x 5= 3.35 kgs.

So weight of liquid N_2O that can be filled in an E type cylinder is 3.35 kgs.

6. **Why oxygen cylinder should not be kept under the sun?**

If oxygen cylinder is kept under the sun its temperature increases and according to **GAY LUSSAC's law** pressure is directly proportional to temperature, volume being constant, Pressure increases inside the cylinder so much that the cylinder may even explode. Hence the oxygen cylinders should be stored in a cooler place. In order to prevent accidental explosion safety valves are incorporated in the cylinder valves.

7. **How is the safety valve of the cylinder works?**

There are 3 types of safety valves in the cylinder

a) Fusible plug. b) Frangible disc. and c) Safety relief valve.

Safety valves are present just below the conical depression of the cylinder valve.

a) FUSIBLE PLUGS are made up of Woods metal(an alloy of cadmium, bismuth, tin and lead) and the metal melts at a temperature of 212 ^{o} F. If the temperature inside the cylinder increases when the cylinder is accidentally kept under the sun, the Woods metal in the fusible plug melts and gives vent for oxygen and prevents explosion.
b) FRANGIBLE DISC has a diaphragm that breaks at a particular pressure. As the temperature inside the cylinder increases, the pressure also increases (**GAY LUSSAC'S LAW**), the diaphragm in the frangible disc breaks and gives vent to the gas and prevents explosion.
c) SAFETY RELIEF VALVE opens at a particular pressure and closes once the pressure inside the cylinder decreases. Pressure inside the cylinder can increase as a result of

increase in temperature **(GAY LUSSAC'S LAW)**if accidentally the cylinder is heated up.

8. Why should you open the cylinder slowly?

Cylinder should be opened slowly as rapid opening of the valve will produce a rapid flow of oxygen into the space in the tubing of the yoke assembly and the pressure regulator, producing to an **ADIABATIC PROCESS** as rapid compression of oxygen in the narrow tube produces a vey high temperature leading to possible explosion. Hence oxygen cylinder should be opened slowly to prevent adiabatic process.

9. Why liquid oxygen should be stored below -118 ^{o} C?

Critical temperature of oxygen is -118 ^{o}C and boiling point is -183 ^{o}C. Hence in order to maintain liquid state, oxygen should be stored between -118 ^{o}C to -183 ^{o}C.

10. How Joule Thomson's effect is used in the manufacture of oxygen from air?

When air is compressed suddenly, it gets heated up as a result of **adiabatic process.** When this air is cooled by external cooling and is made to suddenly expand, it loses further temperature as energy is spent in order to hold the molecules together i.e. the Vander Waal forces. This sudden loss of temperature is due to **JOULE THOMSON'S EFFECT.** When this is repeated many times the temperature reduces to less than -183 ^{o} C and through fractional distillation, liquid oxygen collected in the lower part is separated from nitrogen with a boiling point of -197 ^{o} C which collects at the top of the container.

11. What is pressure and what is the principle adopted in the construction of pressure regulators?

Pressure is defined as force per unit area i.e. P= F/ A. This can be rearranged to **F=PxA**. When we keep the force constant and increase the area, then automatically the pressure decreases. This is the principle adopted in the construction of pressure regulators where in high pressured gases from the cylinders are exposed to larger area of the diaphragm inside the regulator , where the force is kept constant by the spring, and the output pressure from the pressure regulator decreases.

12. **How pressure is reduced in the DRAGER machines from the pressure regulators to flow meter assembly?**

In Ohmeda machines, there will be a second stage pressure regulators which reduces the out put pressures of O2 to 14 PSI and N2O to 26 PSI. Where as in Drager machines there is no second stage regulator. As the gases from the pressure regulators at a pressure of 45 to 60 psig move towards the flow meter assembly they have to flow through the "Flow restrictors" which are nothing but sudden narrowing of the tubes. According to **BERNOULLI'S PRINCIPLE** here the pressure is further reduced, but flow is increased before reaching the flow meter assembly.

13. **What is the importance of viscosity and density regarding the accuracy of flow in the flow meters at different atmospheric pressures?**

Density is defined as mass per unit volume i.e. D= m/v.

Density of the gas can be obtained from Avagadro's hypothesis, as we know that 1 gram molecular weight of any gas occupies 22.4 litres of volume at STP,

Gram molecular weight divided by 22.4 litres will give the density of the gas.

e.g. N_2O- molecular weight is 44 hence 44/22.4 = 1.96

Since the viscosity and density of each gas is different, the flow meters are calibrated for that particular gas and hence should not be interchanged.

Flow meters are tapered glass tubes. The internal diameter is narrower in the lower part and wider in the upper part. In the lower part flow of the gas is laminar and in the upper part the flow is orificial or turbulent, as the diameter of the tube is more than the vertical length of the float or the bobbin. So for lower flows it is laminar flow and for higher flows it is turbulent. The flow meters are always calibrated at 760 mm of Hg. If the anaesthesia machine is used in a high altitude area, where the atmospheric pressure is very low, the density of the gas decreases, but viscosity will not change. As higher flows depend on density and as per **GRAHAM'S LAW FOR TURBULENT FLOW,** flow is inversely proportional to square root of density i.e. FLOW ά 1/√ density

Flow will be higher than the actual flows that are set in the flow meters. The opposite will occur under hyperbaric conditions.

14. **How Avagadro's Hypothesis is used to calculate the amount of volatile liquid needed to make a known percentage of vapors?**

Let us take sevoflurane as example. Molecular weight of sevoflurane is 200. Density of sevoflurane is 1.5

According to **AVAGADRO'S HYPOTHESIS,** 200g of sevoflurane gives 22400ml of vapor.

So 1g of sevoflurane will give - 22400/200= 112 ml of vapors.

Since the density is 1.5, 1.5 g is equal to 1 ml.

So 1ml of sevoflurane liquid =112 x 1.5 = 168 ml.

Since this 168 ml of sevoflurane vapour is at standard temperature of 273 K, one has to calculate at room temperature i.e. 293 K

Based on **CHARLE'S LAW**, the volume of a liquid anaesthetic is directly proportional to temperature i.e. V/T= constant

$V1/T1 = V2/T2$ $V1 = 168$ ml $T1 = 273$ K $V2 = ?$ $T2 = 293$ K

$$V2 = \frac{V1 \times T1}{T2}$$

$$V2 = \frac{168 \times 293}{273} = 180 \text{ ml}$$

Thus 1 ml of sevoflurane at room temperature gives 180 ml of sevoflurane vapor.

15. How do you estimate the cost of volatile anaesthetics?

If 2% of sevoflurane is used with a fresh gas flow of 6 litres, then every minute 120 ml of vapour will be used and per hour it will be 7200ml of vapour. Since 1ml of liquid sevoflurane will give 180 ml of vapour, then 7200/180=40 ml of the liquid sevoflurane will be used per hour. Since cost of 250 ml of sevoflurane is Rs. 7500, 1 ml will cost Rs 30. Then 40 ml would cost

40x30=1200 Rs.

So the cost of sevoflurane anaesthesia if it is used at 2% per hour is Rs. 1200 per 1 hr.

16. Why would you not use connectors with sharp curves?

At the sharp bends the flow converts into a turbulent flow as the **REYNOLD NUMBER** will be more than 2000. This will increase the resistance to the flow. Every piece of anaesthetic equipment, because of diameters & shape of connectors, number & arrangement will effect FGF. Wide bore & curved rather than sharp angles should be preferred.

17. What happens if you administer ENTONOX in very cold climate?

Entonox is a 50:50 mixture of O_2 & N_2O. The critical temperature of oxygen is -118^{o} C and of N_2O is 37^{o} C. when these gases are mixed in a same cylinder, then the critical temperature of the mixture will be -6^{o} C due to **POYNTING EFFECT** and the mixture will remain as gas at room temperature. In cold climates if the temperature is less than -6^{o} C, then N_2O will separate into its liquid form and will remain in the bottom of the cylinder and the patient will get only O_2 initially and hence will not produce any analgesia. Later patient gets only N_2O which can result in hypoxia. Hence in such situation cylinder should be thoroughly shaken before use.

18. How VENTURI'S EFFECT is used in checking the integrity of the inner tube of the Bain's Circuit?

The integrity of the inner tube is very essential as any leak in that can result in large apparatus dead space. One of the tests used for the same is PETHIK'S TEST. In this test after closing the expiratory valve and the inner tube, keeping 3 litres of flow of O_2 one should see that the reservoir bag is full. Then simultaneously, O_2 flush is activated and also the thumb occluding the outer tube is released. If the inner tube does not have any leak, then the reservoir bag will collapse. This is due to **VENTURI'S EFFECT,** because at the opening of the inner tube into the outer tube due to the flow of 30-70 litres of O_2 which produces a sudden fall in the pressure, sucking the O_2 from the bag & collapsing it. If there is any leak in the inner tube, then the reservoir bag will not collapse.

19. What is the importance of selecting a right sized endotracheal tube?

The size of the endotracheal tube(ETT)selected for a particular patient should not increase resistance for breathing. So for an adult male patient one can select 8.5 or 9 mm internal diameter ETT & for female patient 7 or 7.5 mm internal diameter ETT should be selected. As we know that for laminar flow, according to Hegan- Poissuilles law, the resistance increases by 4^{th} power whenever radius of the tube is decreased. Any increase in there resistance will increase the work of breathing and produces an early fatigue of the respiratory muscles of the patient. Normal resistance offered by the adult airway is < 2 cms of H_2O/ litre/sec. With the right sized ETT the resistance increases to 5 cms of H_2O/ liter/sec. Whenever secretion gets collected inside of the tube &decreases the lumen, then the resistance can increase to 10 cms of H_2O/ liter/sec

20. **Why one should monitor the ETT cuff pressure during prolonged surgeries when N2O is used as a carrier gas and air is used to inflate the cuff?**

N2O is 37 times more diffusible than N2. Hence N2O will enter the cuff of the ETT before N2 can diffuse out the cuff, which increases the pressure as the volume cannot increase **(BOYLE'S LAW).** This can produce damage to the tracheal mucosa & can produce post-operative sore throat. So cuff pressure is essential. The same problem can occur in closed pneumothorax patient if N2O is used as the pressure in the pleural cavity may increase producing tension pneumothorax. Hence whenever the patient develops pneumothorax N2O should be cut off. And also for patients posted for middle ear surgeries use of N2O should be restricted. If a patient develops an air embolism per operatively, N2O should be cut off.

21. **How using mixture of oxygen and helium improves flow in a patient with tracheal narrowing, instead of oxygen and N2O or air?**

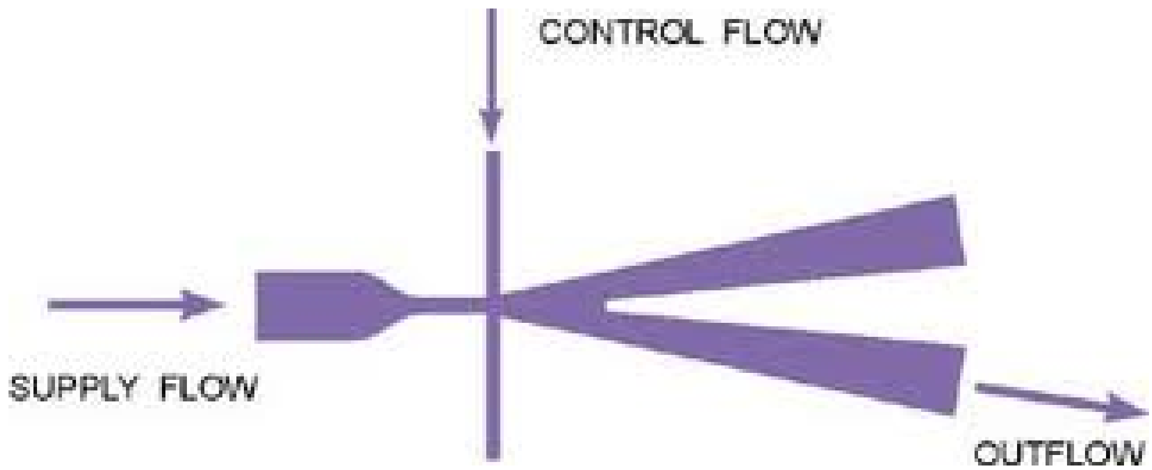
Whenever there is tracheal stenosis the flow of gases will be turbulent and hence there will be increase in the resistance and decreases flow across the stenosis. Flow and resistance will depend on the density of the gas as per **GRAHAM'S LAW.** Mixture of oxygen and helium will have a decreased density compared to O2 or air. And hence using HELIOX will decrease the resistance and increase the flow.

22. **Why can there be unequal gas flow to the alveoli where there has been a slight narrowing of the bronchiole before it divides?**

This due to **COANDA EFFECT** as there is narrowing before the branching, the pressure drops, the velocity of the air increases, but the flow tends to cling to one side & doesn't divide evenly between the branches. Mucus plug at the branching of tracheo-bronchial tree may cause maldistribution of respiratory gases. It may also explain some cases of Myocardial Infraction, where there may be some narrowing, before the branching of the coronaries. Unequal flow may result because of atherosclerotic plaques in the vascular tree.

23. **How COANDA EFFECT is used in ventilators?**

If a tube is made to narrow and branch, the flow of the gases can be made to flow preferentially through one of the branch & then alternately through the other branch by connecting two tubes inserted at each side at the exit of the narrow tube.



24. What is entrainment ratio and how it is calculated?

Entrainment ratio is defined as the ratio of entrained flow to the driving flow.

The total entrained flow is due to the Bernoulli effect and jet entrainment.

Entrainment ratio = entrained flow/driving flow.

Thus a 9 to 1 entrainment ratio indicates that there are 9 litres/min being entrained by a driving gas of 1 litre/min .

25. What is the application of Henry's law in knowing the amount of gas carried in solution?

Henry's law states that the amount of a gas dissolved in a unit volume of a solvent is directly proportional to its partial pressure at STP. The law also predicts how much of a gas dissolves in a liquid. According to this law, the volume of gas that dissolves in a liquid is equal to its solubility coefficient times its partial pressure.

$V = \alpha \times P_{GAS}$

Where V = volume of the gas dissolved, α is the solubility coefficient of the gas in the liquid and P_{gas} is the partial pressure above the liquid.

The amount of gas carried in solution in blood is governed by Henry's law.

The solubility coefficient of oxygen is 0.003 ml/dl. Thus at 100mmHg of oxygen tension , the amount of oxygen in the dissolved form will be 0.3 ml.

Deep sea diving – when divers breathe gases under pressure, nitrogen and other gases pass into solution in the tissues. If they return to atmospheric pressure, the nitrogen comes out of solution as small bubbles in the joints and elsewhere giving rise to **decompression sickness**.

26. What is an Azeotrope and how Raoult's law is applied for azeotropes?

Raoult's law states that the reduction of vapour pressure of a solvent is proportional to the molar concentration of the solute. Raoult's law applies to all solutions and the substance dissolved in solution need not be a solid or a gas but may be another liquid.

Azeotrope is a mixture which vaporizes in the same proportion as the volume concentrations of the components in solution. Ether and halothane form an azeotrope, provided that they are in the ratio of one part of ether to two parts of halothane. The molar concentration of ether is 3.19mol/litre and halothane is 6.30 mols/litre. According to Raoult's law the vapour pressure will also be in the same proportions. This means that the components of azeotrope evaporate in the ratio of one part of ether to two parts of halothane, so the relative volume concentration of the liquid mixture do not change.

27. what is circuit compressible volume and how it is calculated?

Circuit compressible volume is "the expansion of the ventilator circuits during inspiration due to positive pressure, leading to a small lost volume of gas that does not reach the patient , but is recorded as part of the expired tidal volume".

Calculation of circuit compressible volume -

(a)Set the respiratory rate to 10/min and tidal volume to 150 ml, and maximum high pressure alarm limit.

(b) completely occlude the patient Y-connection of the ventilator circuit .

(c) record the expired tidal volume and the peak inspiratory pressure(PIP) during Y-occlusion.

(d) divide the expired tidal volume by the peak inspiratory pressure. This will be the **circuit compression factor.**

(e) multiply the circuit compression factor (ml/cmH2O)by the PIP during mechanical ventilation or PIP-PEEP if PEEP is used, to get the circuit compressible volume.

Example – if the exp. Tidal volume is 150ml and PIP is 50cmH20, then

circuit compression factor is 150/50=3ml/cmH2O

If during mechanical ventilation PIP-PEEP is 15cmH2O, then the circuit compressible volume will be 15x3=45ml. This has to be deducted from the expired tidal volume to get the corrected tidal volume or actual tidal volume delivered to the patient.

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