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GAS LAWS & ANESTHETIC IMPLICATIONS

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INTRODUCTION

What is gas?

A gas is a substance that is in its gaseous phase, but is above its critical temperature

What is pressure?

It is defined as the force per unit area acting at right angles to the surface under consideration

Pressure = force / area

What is temperature?

This is a measure of the average kinetic energy in a system and translates to the degree of hotness or coldness of that system

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



BOYLE'S LAW :

At a **constant temperature**, the volume of a given mass of gas is inversely proportional to the absolute pressure.

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 **2000psig**

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)?



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.

CHARLE'S LAW:

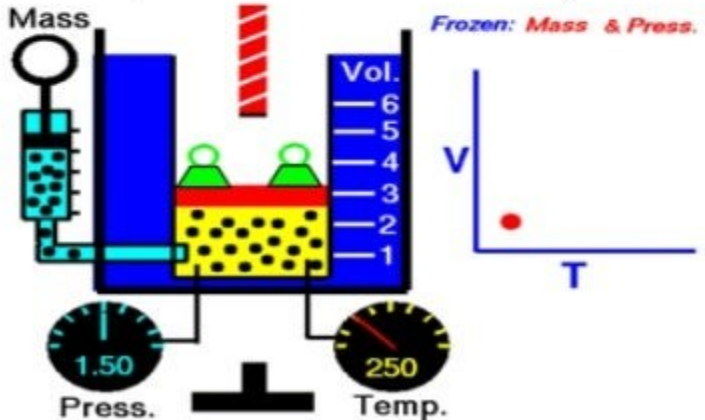
At **constant pressure**, volume of a gas is directly proportional to the temperature.

APPLICATION:

i.Respiratory gas measurements of tidal volume & vital capacity etc are done at ambient temperature while these exchanges actually take place in the body at 37 ^{o}C.

ii.One way of heat loss from the body is that air next to the body surface gets warmer and moves up and thus our patient loses heat this way (esp. important in paediatric anaesthesia)

.



GAY LUSSAC'S LAW:



At **constant volume**, the absolute pressure of the given mass of gas is directly proportional to the temperature.

APPLICATION:

i.Medical gases are stored in cylinders having a constant volume and high pressures (138 Barr in a full oxygen / air cylinder). If these are stored at high temperatures, pressures will rise causing explosions.

ii.Molybdenum steel can withstand pressures till 210 bars. Weakening of metal in damaged cylinders are at a greater risk of explosion due to rise in temperature.

AVOGADRO'S HYPOTHESIS AND IDEAL GAS EQUATION:

Equal volume of gases contain equal number of molecules at standard temperature and pressure (273K and 760mm Hg).

The law can also be defined as one gram molecular weight (one mole) of a gas contains ***6.023×10^{23} (avogadro's number) molecules = occupies 22.4L at STP.***

PV = n RT – is the ideal gas equation.

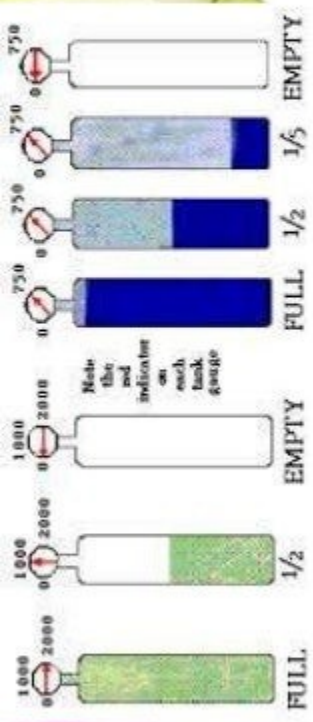


R is the universal gas constant = 1.987 J/degree/mole in SI units.

APPLICATION:

Since the 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.

We cannot use a nitrous oxide cylinder pressure gauge in the same way , that these cylinders contain both vapour and liquid and so the gas laws do not apply.



Then how to find out the quantity of Nitrous oxide.

- N_2O is stored in cylinder as liquid.
- Exists partly as liquid and partly as gas.
- So customary to weigh the cylinder along with its contents.
- From known cylinder wt. and measured wt. amount of N_2O and usage is found out using Avogadro's hypothesis

EXAMPLE:

- Weight of the cylinder N_2O -5.6KGS
- Tare weight – 4.5kgs
- So,weight of N_2O is -1.1kgs
- 44gms of N_2O = 22.4 litres
- Therefore **1.1kgs of N_2O = $\frac{22.4 \times 1100}{44}$ = 560liters**
- So if we give 2litres of N_2O/min, this cylinder will come for ***280min or 4.6 hours***

DALTON'S LAW OF PARTIAL PRESSURES:

In a ***mixture of gases***, the total pressure exerted by the mixture is equal to the sum of the partial pressures of the individual gases, provided the gases donot mix with each other.

P = p1+p2+p3….



HEGAN POISSUILLE'S LAW:

$$Q = \pi r^4 (P1 - P2)/8\eta l$$

Q – Flow

R – radius of cross section of the tube

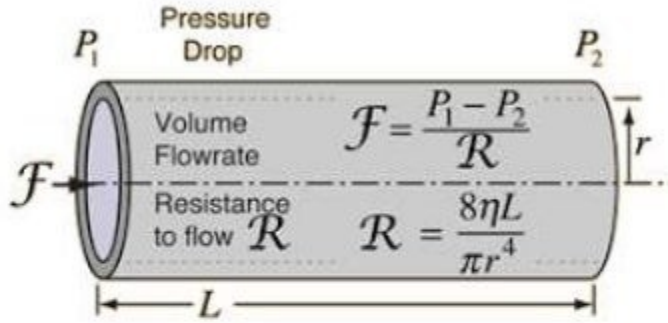
P – pressure

η – viscosity of the gas or liquid

L– length of thetube

If you want to give blood rapidly…

What will you do?



1. **Put a wider gauge cannula**
2. **Increase the drip stand height**
3. **Use a rapid infusion bag**

Hagen-Poiseuille formula

REYNOLD'S NUMBER :

$$Re = \frac{\rho v d}{\eta}$$

Where

Re – Reynold's number

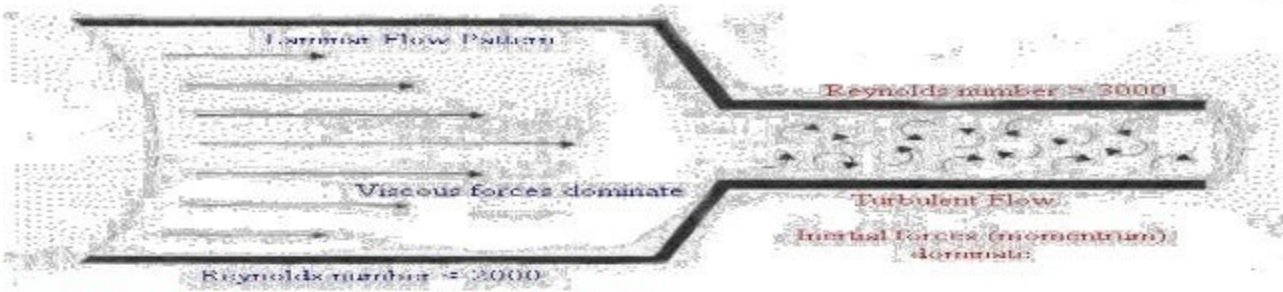
ρ – density of fluid

v – velocity of fluid

d – diameter of tube and

η – viscosity of fluid

Reynold's number



- 2000 – indicates turbulent flow
- <2000 – indicates laminar flow

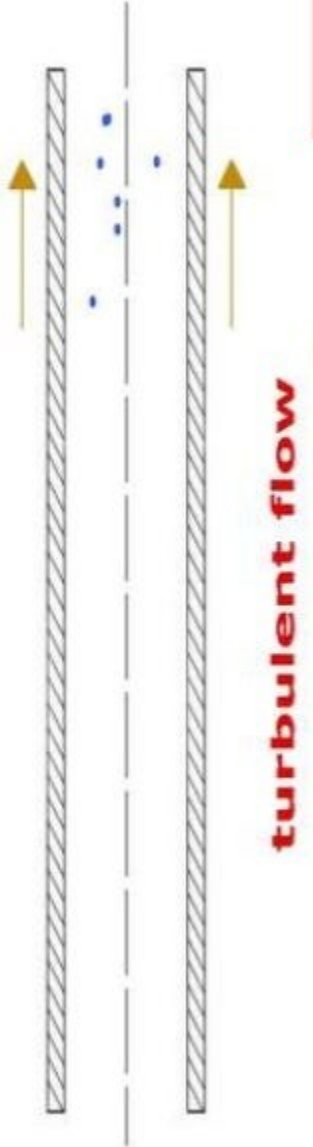
Why would you not use connectors with sharp curves?

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



GRAHAM'S LAW FOR TURBULENT FLOW:

States that flow rate is

1. **Directly proportional to the square root of the pressure gradient on either sides of the tube**
2. **Inversely proportional to the square root of the density of the fluid.**

APPLICATION

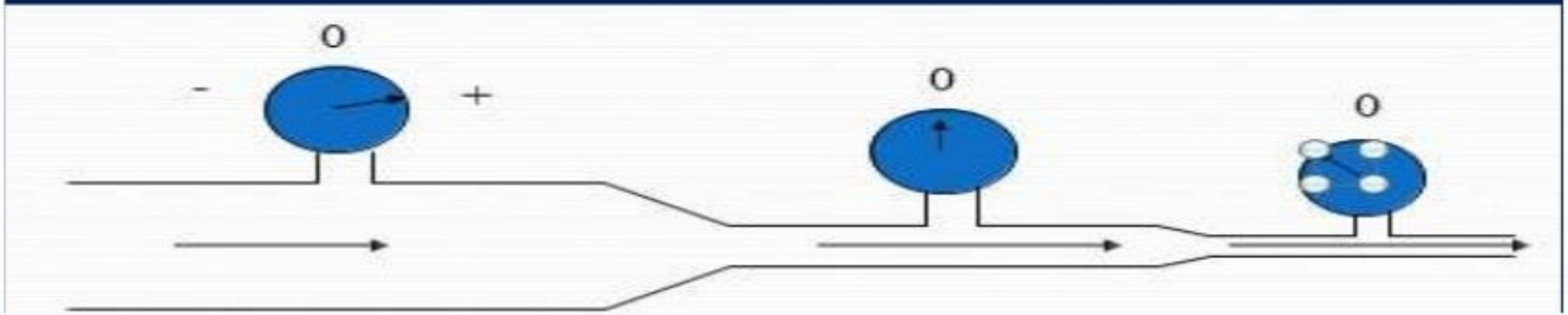
If the anaesthesia machine is used in a high altitude area, where the atmospheric pressure is very low, the density of the gas decreases, but viscosity will not change. As higher flows depend on density and as per **GRAHAM'S LAW FOR TURBULENT FLOW, flow is inversely proportional to square root of density i.e.**

- **FLOW ά 1/√ density**
- **Flow will be higher the actual flows that are set in the flow meters.**
- **The opposite will occur under hyperbaric conditions.**

BERNOULLI'S PRINCIPLE :

States that when a gas flowing through a tube, encounters a constriction, at that point, the pressure drops and velocity increases.

Clinical application of Bernoulli's theorem:



APPLICATION

•In the anasthesia machine, there is a pressure regulation of the gases from the cylinder to the point of delivery to the patient.

• 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 increasedbefore reaching the flow meter assembly.

VENTURI EFFECT :

The entrainment of the air from the surroundings due to fall in the pressure at the point of constriction is called venturi's effect.



APPLICATION:

•Used in checking the integrity of tubings in ***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 O2 one should see that the reservoir bag is full. Then simultaneously, O2 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.

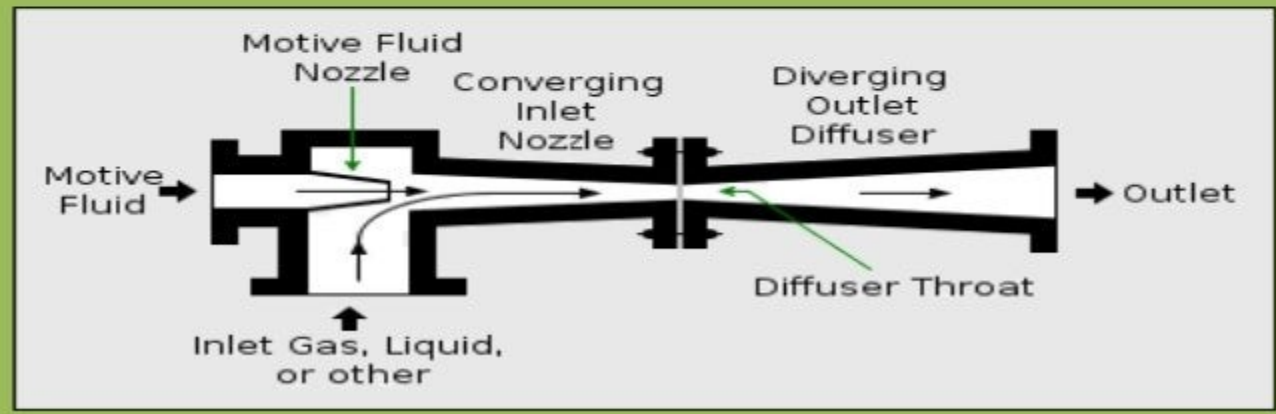
•This is due to **VENTURI'S EFFECT, because at the opening of the inner tube into the outer tube due to the flow of 30-70 litres of O2 which produces a sudden fall in the pressure, sucking the O2 from the bag & collapsing it. If there is any leak in the inner tube, then the reservoir bag will not collapse.**

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.

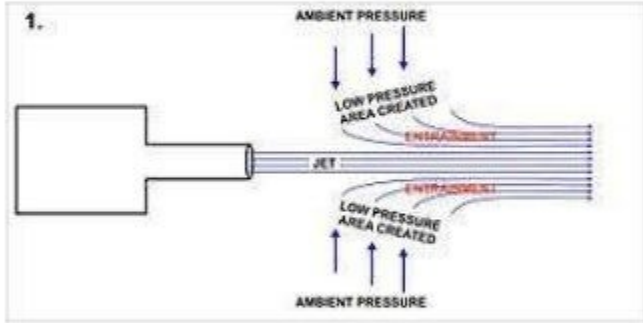
Entrainment ratio = entrained flow/driving flow.

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



COANDA EFFECT :

If a constriction occurs at a bifurcation, due to increase in velocity and reduction of pressure, hence the fluid/air tends to stick to the side of the branch causing maldistribution.



APPLICATION:

1. Mucus plug at the branching of tracheo-bronchial tree may cause maldistribution of respiratory gases.

2. Unequal flow may result because of atherosclerotic plaques in the vascular tree

CRITICAL TEMPERATURE:

Temperature beyond which a gas cannot be compressed to the liquid state.

The pressure of the gas at the critical temperature is called the critical pressure and the volume occupied by the gas is called the critical volume

O_2 – -118 c, 50bar

N_2O – 36.5 c, 72bar

CO_2 –31 c, 73bar

POYNTING EFFECT:

When two gases one of high and the other of low critical temperatures are mixed in a container, the critical temperature of the gas with the higher value is lowered (pseudo critical temp) and the mixture will remain gaseous above the pseudo critical temperature.



•Entonox is a 50:50 mixture of O_2 & N_2O.

• The critical temperature of **oxygen is -118° C** and of **N_2O is 37° C.**

• When these gases are mixed in a same cylinder, then the critical temperature of the mixture will be ***-6° 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 ° 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.

ADIABATIC CHANGES AND JOULE THOMPSON EFFECT:

When a gas is subjected to sudden compression, the heat energy is produced rapidly and the reverse occurs when there is sudden expansion There is no exchange of energy with the surroundings. This is an adiabatic change.

In joule thompson effect, when a gas is allowed to escape through a narrow opening, there is a sudden temperature drop.



APPLICATION

-used in manufacture of oxygen

✓When 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 ^{0} 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.**


Thank
You!