BASIC PHYSICS APPLIED TO ANAESTHESIOLOGY

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The current practice of Anaesthesiology demands knowledge of physical laws governing the behavior of liquids and gases and also the fundamental principles of the equipments, used for administering anaesthesia. Knowledge of basic physics makes him confident not only in giving safe anaesthesia, but also in trouble shooting when some problem arises. The behavior of the gases has to be understood, so that he can use them effectively and safely.

MOLECULAR WEIGHT:

The molecular weight is the sum of the atomic weights, of all atoms forming a molecule of the compound.

For e.g.: The molecular weight of N₂O is 2 x 14 + 16 (14 is the atomic weight of nitrogen & 16 for oxygen)

O₂ = 2 x 16 = 32

GRAM MOLECULAR WEIGHT:

The molecular weight expressed in grams is called gram molecular weight.

For eg: Gram molecular weight of N₂O = 44gm

ANAESTHETIC IMPORTANCE:

Avogadro found out that at STP, one gram molecular weight of all gases contain the same number of molecule and occupy the same volume. (22.4 litres). The number of molecules in one gram molecule weight of any substance is called Avogadro’s number – 6.023 x 10⁻²³.

Thus 32gms of O₂, 44gms of N₂O and 28gm of N₂ will occupy the same volume (22.4 l) and have the same number of molecules.

HOW TO FIND OUT THE QUANTITY OF N₂O INSIDE THE CYLINDER?

N₂O is stored in the cylinder as liquid. So it is difficult to find out the quantity of N₂O gas and the duration of its usage. Since it partly exists as liquid and gas, it is customary to weigh the cylinder to know its weight along with its contents. Once the total weight and the tare weight of
the cylinder is known, the amount of N\textsubscript{2}O gas and its duration of usage can be calculated using Avogadro’s hypothesis.

Eg: Tare weight of the cylinder: 4.5kg

Weight of the cylinder with N\textsubscript{2}O: 5.6kg

So, weight of the N\textsubscript{2}O: 1.1kg = 1100gm.

44gm (one gram molecular weight of N\textsubscript{2}O) gives rise to 22.4 litres

Therefore, 1100gm will give rise to 22.4/44 x 1100gm: 560 litres.

So, if the anaesthesiologist draws 2 lit/min of N\textsubscript{2}O, then that cylinder will last for 4.6 hours (280 min).

PARTIAL PRESSURE:

If a gas with 6 molecules is filled in a container, the molecules of that gas bombard the walls of its container, to exert a pressure (say x). And in another container, if there are 4 molecules of another gas, they exert a pressure of y. If both the gases are put in a single container, the total pressure exerted will be x + y. It follows that in a mixture of gases, the pressure exerted by each gas is the partial pressure and the pressure of a mixture of gases is the sum of the partial pressures of its constituents – **Dalton’s law of partial pressure**.

![Diagram: Container A, Container B, Container C](image)

The proportion of the pressure exerted by a gas in the total pressure is important and is equated with the volume it occupies. If a pressure exerted by a gas is 50% of the total pressure exerted by all gases in that container, then it will occupy exactly 50% of its volume.

The partial pressure of a gas is important in the medical science, since it is the one which decides the movement of the gas across the membranes. Gas moves from the higher partial pressure to the lower pressure zone. In alveoli, the process of oxygenation and carbon dioxide elimination
occurs on the basis of partial pressure gradient. Likewise, the movement of the inhalational agents is also governed by the law of partial pressure.

**DISSOLUTION OF GAS IN A LIQUID: SOLUBILITY COEFFICIENT**

When a gas is kept in a closed container containing water, or any liquid, the molecules of that gas tend to get dissolved in that liquid. The dissolved molecules in that liquid also exert a pressure. Instead of calling it as partial pressure, we call that as “tension”. So, plasma oxygen tension is nothing but the pressure exerted by the dissolved O₂ molecules in the plasma.

The amount of gas which goes into the solution into a liquid depends upon various factors.

1. The partial pressure of the gas above the liquid: The more the pressure, the more the amount of gas goes into solution. This is called “Henry’s law”.

2. Temperature: the amount of gas dissolved in a hot liquid is far more lesser than in cold liquid.

3. Nature of gas

4. The type of liquid.

**PARTITION CO-EFFICIENT:**

If 1 litre of N₂O is kept above 1 litre of blood in a closed container, N₂O tends to get dissolved in blood. At equilibrium, if we measure the amount of N₂O dissolved in blood, then it will be 0.47 litre. Then, the ratio of 0.47 to 1 is the blood – gas partition co-efficient for N₂O.

Thus partition co-efficient is defined as the ratio of the amount of substance present in one phase compared with another, the two phases being of equal volume and in equilibrium.

**SOLUBILITY AND UPTAKE OF ANAESTHETICS;**

Consider an example of 3 jars containing 1 litre of blood each at body temperature and exposed to an atmosphere of nitrous oxide, halothane and ether respectively. The amount of ether goes into solution will be the highest, as it has the highest solubility coefficient.
That’s what happens in the alveoli also. As ether gets dissolved in the blood quickly and in large amount, the partial pressure in the alveoli will be kept lower. Blood will keep on taking the ether (as ink in a sponge) till the partial pressure in the alveoli and blood becomes equal. When it happens, 12 times more ether will be there in the blood, compared to the alveoli. Since it takes time to equilibrate the blood and then brain, it takes lots of time to induce a patient with ether.

OIL SOLUBILITY AND ANAESTHETIC POTENCY;

Fat is an important constituent of many body tissues, being present in cell membranes and neurons in particular. Fat and oil are very similar and because it is easier to measure the solubilities in oil, oil is normally used for measurements.

Agents that have the highest oil solubility are found to have the greatest potency as anaesthetics and this was the basis of the Meyer – Overton theory of anaesthesia. Oil gas solubility coefficient for N₂O is 1.4, ether is 65, and halothane is 224. So, halothane is a very potent anaesthetic compared to other drugs and needs a lesser concentration in alveoli and brain.

PRESSURE REDUCING VALVES:

Consider a cylinder C containing half full of water. The water exerts a force on the bottom of the container. The force acting on the bottom area of the container is called as “pressure” of that water column (force exerted on a unit area is called pressure).

Suppose another small, wide container has got half full water, the same principle can be applied. Here also, a pressure head is developed because of the stored water. But the force is less, as the height of the water column is less, compared to the previous container.

If both these containers are connected by a tube, then water will flow from higher pressure to the lower pressure initially. Once pressure equilibrium is established, water flow will cease.
The pressure in the tall container \( C = P \times a \)

The pressure in the short and wide container \( c = p \times A \)

(Pressure in the tall container will be high because of deep water column. So it is named as capital ‘P’ and in the next container the opposite is true. So small ‘p’ is given. Likewise, the area in the tall, narrow container is small, so small letter ‘a’ is given and the reverse for the short, wide container).

As in equilibrium, pressure in both the containers are same, it can be represented as

\[ P \times a = p \times A \]

So, it can be stated that large force acting on a small area can be balanced by small force acting on a large area. This is the basic principle governing the pressure regulators.

PRESSURE REGULATORS:

The purpose of the pressure regulator is not only to reduce the cylinder pressure (2000psi of \( O_2 \) and 750psi of \( N_2O \) cylinders) and also to give a constant reduced pressure irrespective of the cylinder pressure. Any design of the pressure regulator model should fulfill the above two purposes.

SIMPLE MODEL:

The high pressure (\( P \)) gas from the cylinder is made to flow through a small nozzle which is guarded by a small valve with a small surface area “\( a \)” which in turn connected to a large diaphragm with large surface area (\( A \)) by a J shaped connector.

Gas from the cylinder tries to open the small valve and enters into the low pressure chamber of the regulator. If the flow meter tap (\( T \)) is closed, then the gas in the low pressure chamber tries to
lift the large diaphragm. If sufficient gas is collected in the low pressure chamber of the regulator with a particular pressure, it lifts the large diaphragm. Because of the J shaped connector, it tends to close the small valve which prevents the further escape of gas from the cylinder through the nozzle. So, at equilibrium the force on either side is balanced.

Pressure acting small valve, which tries to open the small valve = P x a

Pressure acting on the large diaphragm which tries to close the valve = p x A

At equilibrium P x a = p x A, which is the same formula, as in the previously described water model.

If the real values are replaced, then

P = cylinder pressure = 2000psi

A = surface area of small valve = 10mm (say for example)

P = the pressure what we have to know (The reduced pressure of the regulator)

A = 100mm (example)

P x a = p x A

2000 x 10 = p x 100

P = 2000/10 x 100 = 200psi

So, the pressure in the regulator chamber will be 200psi. If you analyse this formula, then the importance of the ratio of the diaphragm and the small valve will be realized. Here in this example, the ratio is 10:1. So the reduced pressure from the cylinder will be in the same ratio. We can summarize like this – the ratio of the diaphragm to the small valve decides the ratio of the pressure reduction.

But the problem is the inconsistency of the output pressure. When the cylinder pressure is 2000psi, the output pressure will be 200psi. If cylinder pressure gets reduced to 1000psi, then the output pressure will also get reduced to 100psi. (10: 1 ratio)

In order to avoid this, in the modern regulators springs have been added, so that in the end, the output pressure remains constant.

Modern regulators are called as ‘preset regulators’, meaning that the output pressure has been set at the factory. In fact, the output pressure can be altered be altering the spring tension.
In this example, a coiled collapsible hollow paper tube (P) is attached to hollow wooden pipe (W). Normally the paper tube is made as to remain as a coiled tube and in a collapsed state. When somebody blows air into the hollow wooden tube, the air flows inside the coiled paper tube and the pressure inside rises. This rise of pressure causes the coiled paper tube to straighten out. Once the pressure is released, the paper tube regains its original shape.

The principle governing this experiment: If a compressed gas is kept in a container, the pressure exerted by the gas is distributed equally on all sides of the container. If the container is made in such a way that it can expand or straighten out in only one direction, it will do so in that direction and remain in that shape as long as the pressure is maintained inside.

The above principle is used in the construction of Bourdon pressure gauge. Instead of a paper tube, a soft metal tube is used. The coiled tube is connected to the cylinder gas line. Once the cylinder is open, the gas from the cylinder and yolk enters into the hollow tube and the coiled, hollow tube straightens out. This movement is magnified with the aid of levers and a needle is attached to it. The needle moves over a calibrated scale to show the pressure of the cylinder.
VENTURI PRINCIPLE:

In the following example, fluid flows from the left to right in a particular velocity and pressure. If the flow is laminar, the velocity of all the layers of the fluid will be the same. If the pressure exerted by the running fluid is measured, the pressure will be the maximum at the centre and least near the side walls. You would have experienced this in a running river. The pressure loss near the side walls is due to its friction because of its velocity.

If this tube is narrowed at the right end, then the velocity of the fluid increases. Remember – with a garden hose, we partially close the end of the tube to increase the velocity of the water jet so as that it reaches a long distance.

As the velocity of the fluid increases, the pressure loss near the side walls also becomes more. So it records a lesser pressure than before. If the tube is further narrowed on the right end, the velocity of the fluid further gets augmented. If the tube is further narrowed down, at one point, the pressure near the side walls becomes negative.

This development of negative pressure near the side walls because of the speeding fluid is made use in developing many medical instruments and has the application in anaesthesia also.

The reason for the fall of pressure:

Flowing fluid contains energy in two forms; potential energy associated with its pressure and kinetic energy associated with its flow. When the fluid gets speeded up, there is great gain of kinetic energy. Such an increase of kinetic energy can only occur if there is a fall in potential energy, because the total energy present must remain constant. In consequence, a marked fall in pressure occurs at a point, where the fluid flows very fast to that extent that it becomes subatmospheric. This forms the basis of venturi principle.

APPLICATION OF VENTURI PRINCIPLE:

Diffuser or injector:

A jet of gas, say oxygen, is delivered from the cylinder through a high pressure tube and its nozzle. Since the velocity of the jet is high, a negative pressure develops on the two sides of jet.
The ambient air is sucked in through the side openings (A&B), so that a mixture of oxygen and air is delivered to the patient. The air sucked in is called ‘entrained air’. This device gives a fixed concentration of mixture of two gases.

The size of the side openings can be varied so that the amount of entrained air can be altered, so that the final concentration of mixture can be decided by the size of the side openings.

Instead of air getting sucked in, fluid can also made to run into the side openings, so that the fluid gets mixed with the fast jet and made to hit upon an object. This hit will break up the fluid into fine droplets which will be carried in the oxygen jet. This is the basic principle behind nebulizers.

This same venturi principle can also be used in designing suction apparatus, ventilators, & gas mixers.

CONCLUSION:

It is necessary to understand the basic physics behind every anaesthetic instrument, so that it becomes easy to operate and if necessary to trouble shoot the problem associated with them.

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