Applied Physics Topics 1

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TOPICS 1

- SI System
- Force and Pressure
- Flow
- Tension
- Bernoulli principle
- Venturi effect
- Coanda effect
SI system 1960

Base SI Units

1. Time
2. Distance
3. Amount
4. Current
5. Luminous intensity
6. Mass
7. Temperature
Base SI Units

1. **Second** – *duration (of time)* based on frequency of radiation emitted from Caesium-133

2. **Metre** - *distance* light travels in vacuum in a specified fraction of a second

3. **Mole** - *amount of substance* which contains as many elementary particles as there are atoms in 0.012kg of carbon-12

4. **Ampere** - *current* which produces a force of $2 \times 10^{-7}$ newtons per metre between 2 conductors 1 metre apart in a vacuum
Base SI Units

5. **Candela** (means candle) – *luminous intensity*, in a given direction of a source that emits monochromatic radiation of frequency $540 \times 10^{12}$ Hz

6. **Kilogram** - based on *mass* of a 1kg prototype held at Sevres near Paris

7. **Kelvin** – *unit of thermodynamic T*, is the fraction $1/273.16$ of the thermodynamic T of the triple point of water

• Temperature (K) = Temperature (°C) + 273.16
S M M A C K K
Derived Units

1. **Force** (Newton)  
   • \(1 \text{N} = 1 \text{kg m s}^{-2}\)

2. **Pressure** (Pascal)  
   • \(1 \text{Pa} = 1 \text{N m}^{-2}\)

3. **Energy** (Joule)  
   • \(1 \text{J} = 1 \text{Nm}\)

   J is the energy expended when the point of application of a force of 1N moves 1m in the direction of the force.
Derived Units

4. **Power** (Watt)
   rate of energy expenditure
   
   - $1 \text{W} = 1 \text{J s}^{-1}$

5. **Frequency** (Hertz)

   - $1 \text{Hz} = 1 \text{ cycle per s}$

6. **Volume**
   (Cubic metre and litre)
   
   - $1 \text{L} = 10^{-3} \text{ m}^3$ or $1 \text{m}^3 = 1000 \text{L}$
Force

that which changes or tends to change the state of rest or motion of an object
Or $F = M \times A$ ($2^{nd}$ Newton’s law)

Newton   $N = \text{kg m s}^{-2}$

a force of 1 N will give a mass of 1 kg an acceleration of 1 m per s per s
Weight and mass

- The Weight (W) of a body is a measurement of the gravitational force exerted upon it.
- Measured in Newtons (N).
- In everyday life we use units of Mass (M) in Kg to quote Weight.
- The actual Weight depends on the size of a planet and the distance you are from it.
- \( W = M \times G \) (G- acceleration in ms\(^{-2}\)).
HOW HEAVY IS ONE NEWTON?

- Force of gravity $9.81 \text{ m s}^{-2} = 1 \text{N}$
- Therefore force of gravity on mass of 1 kg = 9.81N
- Known as 1kg weight so $1 \text{N}=1/9.81$
- So $1 \text{N} = 102 \text{ g weight}$
Pressure

- Pressure is the force applied expressed as force per unit area.
- 1 Pascal is a pressure of 1 N acting over an area of 1m$^2$.
- 102g/1m$^2$ - tiny!
- That is why we use kPa.
Pressure equivalents

- 101.325kPa = 1Bar = 750mmHg=1 Atm
- 14.5 lb per inch$^{-2}$ =1 Bar
- 7.3mmHg = 10cm H2O
- 1torr=1mmHg
Gauge and Absolute pressures

- Absolute pressure = Gauge pressure + Atmospheric pressure
- In full oxygen cylinder
  - gauge pressure = 137 bar
  - absolute pressure = 138 bar
- Examples of Gauge P: ventilator, arterial and venous pressure
Flow

- Quantity of a fluid (gas or liquid) passing a point per unit time

- $F = \frac{Q}{t}$

- L/min
Laminar Flow (LF)

- Fluid moves in steady manner
- Flow greatest in centre (x2 of average flow)
- Virtually no flow near edges
- Flow $\propto$ pressure
- Low velocity
Hagen-Poiseuille equation

\[ Q = \frac{\pi Pr^4}{8\eta l} \]

- \( Q \) - flow through a tube
- \( P \) - pressure across tube
- \( r \) - radius of tube
- \( l \) - length of tube
- \( \eta \) - viscosity of fluid
Turbulent flow (TF)

- Occurs if constriction reached which results in fluid velocity increasing
- Fluid swirls in eddies
- Resistance higher than for same laminar flow
- Flow is not directly proportional to pressure
Laminar versus Turbulent

Occurs if constriction reached which results in fluid velocity increasing
Onset of turbulent flow > 2000

Reynold's number (Re) \( = \frac{\rho \cdot v \cdot d}{\eta} \)

- \( d \) = the diameter of the tube
- \( v \) = the velocity of flow (m/s)
- \( \rho \) = rho, the density of the fluid in kg.m\(^{-3}\)
- \( \eta \) = eta, the viscosity of the fluid in pascal seconds or (kg/m.s)
Clinical Applications of TF: Respiratory cycle

- TF usually predominates in peak flow (>50 l/min)
- Otherwise flow laminar
- LF - bronchi/smaller airways due to reduction in velocity
- In general
  - quiet breathing – laminar
  - speaking, coughing, deep breathing - turbulent in larger airways
Clinical Application of TF

- For typical anaesthetic mix:
- critical flow (l/min) ~ airway diameter (mm)
- i.e. in 9mm tube becomes turbulent if flow exceeds 9 l/min
Viscosity

- Flow is inversely proportional to viscosity

- Blood viscosity increases with:
  1. Low temperatures
  2. Increasing age
  3. Cigarette smoking
  4. Increasing hematocrit
  5. Plasma proteins elevation

\[ \dot{Q} = \frac{\pi Pr^4}{8\eta l} \]
Tension (Laplace Law)

- Cylinders: \[ P = \frac{T}{R} \]
- Spheres: \[ P = \frac{2T}{R} \]

- \( P \) = pressure gradient across wall
- \( T \) = tangential force acting along a length of wall (N/m)
Tension. Clinical aspects

- As diameter of a vessel becomes smaller, collapsing force becomes greater.
- => vessel closure at low pressures: critical closing pressure.

- Alveoli - unless surfactant present, small alveoli tend to empty into larger.
- Aortic aneurysm: \[ P = \frac{T}{R}. \quad 80\text{mmHg} = \frac{T}{2\text{cm}} \]
Bernoulli Principle

- The total energy in a steadily flowing fluid system is a constant along the fluid path.
- Fluid pressure is inversely proportional to its velocity.
- 1726
Bernoulli Principle

- based on law of conservation of energy

- the total energy of a fluid flow is given by

\[ E = PV + mgh + \frac{1}{2}mv^2 \]

- \( PV \) = the potential energy of pressure
- \( mgh \) = the potential energy due to gravity
- \( \frac{1}{2}mv^2 \) = the kinetic energy of motion (flow)
Bernoulli Principle

- Velocity of flow $\uparrow$ due constriction
- $\Rightarrow$ gain of kinetic energy
- Pressure $\downarrow$ (↓ potential energy)
- Total energy constant
- LF important for efficiency
Bernoulli Principle

Lower pressure is caused by the increased speed of the air over the wing.

Since the pressure is higher beneath the wing the wing is pushed upwards.
Bernoulli Principle

An increase in the flow velocity of an ideal fluid will be accompanied by a simultaneous reduction in its pressure
Venturi Effect

- Opening of a side tube causes entrainment of another fluid
- Nebulisers, O2 masks, injectors, suction

ER = Entrained Flow / Driving Flow

- 5 to 1 = 5 l/min of air is entrained by 1l/min of O2
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Orthopedic Spine Surgeon
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VENTRAIN
Expiratory Ventilation Assistance
Coanda effect

- The tendency of a fluid jet to be attracted to a nearby surface

Henri Marie Coandă
1885-1972
Coanda effect

- If no opening on the side of a narrowing in a tube a region of low pressure is established
- Stream tends to adhere to the wall
- If tube then diverges stream may adhere to either wall diverting flow to one or other lumen
Coanda effect application

- Mucus plug at the branching of tracheo-bronchial tree may cause maldistribution of respiratory gases
- Unequal flow may result because of atherosclerotic plaques in the vascular tree
- Fluid logic used in ventilators employs this principle to replace valves
- Mitral valve regurgitation assessment
Coanda effect as an explanation for unequal ventilation of the lungs in an intubated patient?

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QUESTIONS?