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Kinematics

- *Distance* is defined as the total length of *path* travelled.
- *Velocity* is defined as the rate of change of displacement.
- *Acceleration* is defined as the rate of change of velocity.

Dynamics

- *Newton's First Law of Motion* states that an object at rest will remain at rest and an object in motion will remain in motion at constant velocity in a straight line in the absence of an *external* resultant force.
- The *linear momentum* of a body is the product of its mass and velocity. The linear momentum is in the *same direction* as it velocity.
- *Newton's Second Law of Motion* states that the rate of change of momentum of a body is directly proportional to the resultant force acting on the body and occurs *in the direction* of the resultant force.
- *Newton's Third Law of Motion* states that if body A exerts a force on body B, then body B exerts a force of the *same type* that is equal in magnitude and opposite in direction on body A.
- *Impulse* is defined as the product of *average* force acting on an object and the time for which the force acts.
- The *Principle of Conservation of Linear Momentum* states that the total momentum of a system remains constant provided no *external* resultant force acts on the system.

Forces

- *Hooke's Law* states that the force is directly proportional to the extension in a material if its *limit of proportionality* is not exceeded.
- The *centre of gravity* of an object is the point at which the entire weight of a body may be considered to act.
- The *moment* of a force is equal to the product of the force and the *perpendicular* distance of the *line of action* of the force from the pivot. It is also the turning effect of a force.
- *Torque of a couple* is defined as the product of one of the forces and the *perpendicular* distance between the *lines of action* of the forces.
- The *Principle of Moments* states that if a body is in equilibrium, the sum of all the clockwise moments about *any axis* must be equal to the sum of anticlockwise moments about the *same axis*.
- *Density* is defined as the mass per unit volume of a substance.
- *Pressure* is defined as force per unit area, where the force is *acting perpendicularly* to the area.
- Deriving $p = \rho g h$:
  1. Consider a point at a depth h below the surface of a liquid of density ρ.
  2. The force F acting perpendicularly on a surface area A at depth h is due to the weight of the liquid column above A to give pressure p. Thus, $p = \frac{F}{A} = \frac{mg}{A} = \frac{\rho A h}{g} = \rho g h$.
- *Upthrust* is the upward force exerted by a fluid on a body immersed in the fluid (due to pressure difference in the fluid).
- *The origin of upthrust:* Upthrust is a result of the pressure difference between top and bottom surfaces of the body, resulting in a net upwards force being exerted on the body by the third medium in which the body is located.
- *Archimedes' Principle* states that when a body is totally or partially immersed in a fluid, it experiences an upward force (upthrust) equal to the weight of fluid displaced.
- *The Principle of Floatation* states that, for any object floating in *equilibrium*, the upthrust is equal to the weight of the object.

Work, Energy, and Power

- *Work done* is defined as the product of a force and the displacement in the direction of the force.
- *One joule of work* is defined as the work done by a force of 1 Newton when its *point of application* moves through a distance of 1 metre in the direction of the force.
- *Energy* is defined as the ability to do work.
- *The Principle of Conservation of Energy* states that energy can neither be created or destroyed in *any process*. It can be transformed from one form to another, and transferred from one body to another.
- Deriving $E_k = \frac{1}{2}mv^2$:
  1. Consider a constant horizontal applied force F acting on an object of mass m travelling with initial velocity u to reach a final velocity v over a displacement s.
  2. For uniform acceleration, $v^2 = u^2 + 2as$ so $as = \frac{1}{2}(v^2 - u^2)$. Combined with Newton's Second Law, $W = Fs = mas = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$. When the object starts from rest, $u = 0$.
  3. By conservation of energy, *the work done by force* F *must be converted into the kinetic energy* E_k *of the object*. Hence, $E_k = W = \frac{1}{2}mv^2 - \frac{1}{2}m(0)^2 = \frac{1}{2}mv^2$.
- The *Work-Energy Theorem* states that the net work done by *external* forces acting on a particle is equal to the change in kinetic energy of the particle.
- Deriving $E_p = mgh$:
  1. Consider an object from the Earth's surface — which is taken as the reference for zero gravitational potential energy — raised up by a *constant force* F *equal to and opposite to the weight* mg of the object such that the object moves up at *constant velocity* to a height h_2.
  2. Thus, the object moves at constant speed so $\Delta E_k = 0$. Therefore,

     $$\begin{aligned} \Delta E_p &= W \\ E_p - 0 &= Fs \\ E_p &= mgh. \end{aligned}$$

     Where E_p is the gravitational potential energy at height h above the Earth's surface.
- Know how to $\Delta E_p = \frac{1}{2}kx^2$ from area under graph.
- *Power* is defined as the rate of doing work.
- Derive $P = Fv$: $P = \frac{dW}{dt} = \frac{Fds}{dt} = Fv$.

Temperature and Ideal Gases

- The *Zeroth Law of Thermodynamics* If bodies A and B are separately in thermal equilibrium with body C, then bodies A and B are in thermal equilibrium with each other.
- *One mole* is defined as the amount of substance that contains as many elementary particles as there are atoms in 0.012kg of carbon-12.
- *Avogadro's Constant* N_A is the number of atoms in 0.012kg of carbon-12.
-

	Assumptions of the Kinetic Theory of Gases
M	The molecules of the gas are in *rapid* and *random* motion.
A	There are *no intermolecular* attractive forces.
N	Any gas consists of a *very large number* of molecules.
T	The duration of collisions is negligible compared to the time interval between collisions.
E	The collisions between gas molecules, and between gas molecules and the container walls are *perfectly elastic*.
V	The volume of the gas molecules themselves is negligible compared to the volume of the container.

- Deriving $p = \frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$:
  1. Consider a cubic container of side l containing N molecules, each of mass m.
  2. Change in momentum due to *elastic* collision between wall and molecule = $2mc_x$
  3. Time interval between collisions, $\Delta t = \frac{2l}{c_x}$.
  4. By Newton's 2nd Law, $F = \frac{2mc_x}{\frac{2l}{c_x}} = \frac{mc_x^2}{l}$.
  5. Since $A = l^2$, Pressure due to 1 particle, $p = \frac{mc_x^2}{l^3} = \frac{mc_x^2}{V}$.
  6. Pressure due to N particles, $p_N = \frac{Nmc_x^2}{V}$.
  7. By Pythagoras'Theorem, $c^2 = c_x^2 + c_y^2 + c_z^2$. The average speed in the x, y, and z directions can be taken to be $c_x = c_y = c_z$ so $c^2 = 3c_x^2$. Now, $p_N = \frac{Nm\langle\frac{1}{3}c^2\rangle}{V} = \frac{1}{3}\frac{Nm\langle c^2\rangle}{V}$.

First Law of Thermodynamics

- The *heat capacity* of a body is defined as the amount of thermal energy required to raise its temperature by one Kelvin / degree Celsius.
- The specific *heat capacity* of a body is defined as the amount of thermal energy required to raise the temperature of one unit mass of the substance by one Kelvin / degree Celsius.
- The *specific latent heat* of a body is defined as the thermal energy required to change *phase* of one unit mass of a substance, *without a change in temperature*.
- *Internal energy* of a system is a sum of *random distribution* of kinetic and potential energy *associated with the molecules* of the system.
- The *First Law of Thermodynamics* states that the *increase* in internal energy of a closed system is the *sum* of heat *supplied* to the system and the work done *on* the system.

Gravitational Fields

- *Newton's Law of Gravitation* states that the force of attraction between any two point masses is directly proportional to the product of their masses and inversely proportional to the square of their separation.
- A *gravitational field* is a region in space where mass experiences a gravitational force acting on it.
- Gravitational field strength at a point is defined as the gravitational force per unit mass acting on a small mass placed at that point
- The *gravitational potential energy* of a mass at a point is defined as the work done by an *external agent* in bringing the mass from infinity to that point (without any change in kinetic energy).
- *Gravitational potential* at a point is defined as the work done per unit mass by an *external agent* in bringing a mass from infinity to that point (without a change in kinetic energy).

□

$$\begin{tikzcd} U_G = -\frac{GMm}{r} \arrow[r, "-\frac{d}{dr}"] \arrow[d, "\frac{1}{m}"'] & F_G = -\frac{GMm}{r^2} \arrow[d, "\frac{1}{m}"'] \\ \phi = -\frac{GM}{r} \arrow[r, "-\frac{d}{dr}"] & g = -\frac{GM}{r^2} \end{tikzcd}$$

□ $U_G = m\phi$ & $\Delta U_G = m\Delta\phi$.

□ Gravitational force provides the centripetal force:

$$\begin{aligned} F_G &= F_c \\ \frac{GMm}{r^2} &= mr\omega^2 = mr\left(\frac{2\pi}{T}\right)^2 \\ T^2 &= \frac{4\pi^2}{GM}r^3 \\ T^2 &\propto r^3 \end{aligned}$$

□ Gravitational force provides the centripetal force:

$$\begin{aligned} & F_G = F_c \\ \text{For A:} \quad & \frac{Gm_A m_B}{(r_A + r_B)^2} = m_A r_A \omega^2 \\ \text{For B:} \quad & \frac{Gm_A m_B}{(r_A + r_B)^2} = m_B r_B \omega^2 \end{aligned}$$

The centre of mass of the system is at point P where

$$m_A r_A = m_B r_B$$

such that both stars have the same angular velocity ω.

□ Escape velocity $v_{min} = \sqrt{\frac{2GM}{r}}$ (where Min E_k needed is the gain in E_p to reach infinity).