ENGINEERING PHYSICS

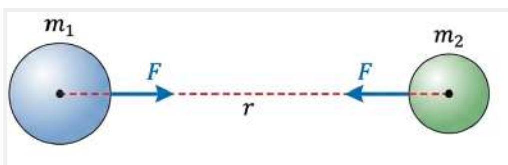
Newton's Second Law of Motion

The foundation of dynamic engineering systems relies heavily on Newton’s Second Law of Motion. This law states that the net external force acting upon a body is directly proportional to, and in the same direction as, the time rate of change of its linear momentum. For a rigid body with a constant mass, this relationship simplifies to the product of the body's mass and its linear acceleration. Mathematically, it is expressed as: F = ma

In this governing equation, F represents the net force vector measured in Newtons (N) or pounds-force (lb_f), m represents the invariant mass of the body in kilograms (kg) or slugs, and a represents the resulting acceleration vector in meters per second squared (m/s^2) or feet per second squared (ft/s^2). This formula serves as a core tool in board examinations for solving problems involving accelerating structures, kinetics of particles, and dynamic equilibrium using D'Alembert's principle.

Newton's Law of Universal Gravitation

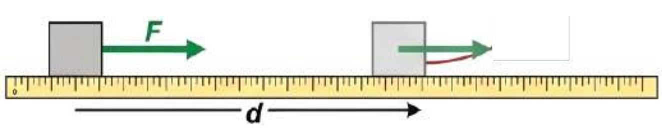
Extending classical mechanics to planetary scales, Newton’s Law of Universal Gravitation establishes that every discrete particle of matter in the universe exerts an attractive gravitational force on every other particle. This mutual gravitational attraction is directly proportional to the product of the individual masses of the interacting bodies and inversely proportional to the square of the linear distance separating their respective geometric centers. The mechanical behavior is represented by the formula: $F = G\frac{m_1 m_2}{r^2}$



Within this gravitational model, F represents the mutual gravitational force of attraction between the two point masses (m_1 and m_2), which acts along the line joining their centers. The parameter r defines the absolute distance between the centers of the two point masses. The term Grepresents the Universal Gravitational Constant, an empirical physical constant whose standard value used in engineering analysis is: $G = 6.670 \, x \, 10^{-11} \frac{m^2}{kg^2}$

Work

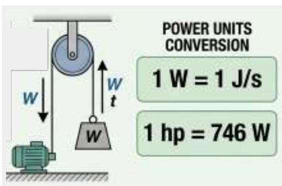
In classical engineering mechanics, work is defined as the energy transferred to or from an object via the application of a force along a displacement. Specifically, when a constant force acts on a particle resulting in a linear translation, the mechanical work performed is the product of the force component acting parallel to the direction of motion and the magnitude of the displacement path. It is expressed mathematically as: $W = Fd$



Here, W represents the scalar mechanical work quantified in Joules (J) or foot-pounds (ft-lb), where 1J = 1N-m. The variable F denotes the constant linear force applied, and d represents the linear displacement distance over which the force operates.

Power

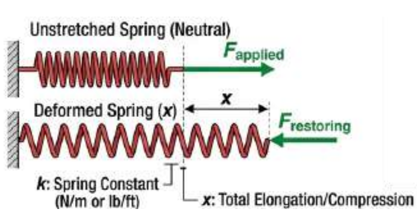
Power serves as a critical parameter in the design of mechanical machinery and electrical motors, tracking the time efficiency of energy expenditure. It is defined fundamentally as the time rate at which mechanical work is performed or energy is transformed. The average power output over a discrete time interval is calculated using the formula: $P = \frac{W}{t}$



In this expression, P represents the mechanical or electrical power expressed in Watts (W) or horsepower (hp), where 1W = 1J/s. The variable W represents the total work performed during the elapsed time duration t.

Work Done on a Spring (Elastic Systems)

When an external force is applied to an ideal elastic spring, the deformation behavior follows Hooke's Law, which dictates that the restoring force is directly proportional to the linear displacement or stretch of the spring. The spring constant k, which represents the structural stiffness of the elastic element, is defined as the ratio of the applied force to the resulting linear deformation: $k = \frac{F}{x}$



Because the force required to deform a spring changes linearly with respect to displacement ($F = kx$), computing the total mechanical work requires integrating the variable force over the total distance stretched or compressed. Evaluating this calculus integral from an unstretched state to a final deformation x yields the standard parabolic equation for the work done on a spring: $W = \frac{1}{2}kx^2$

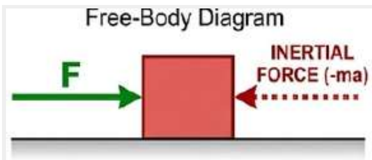
Within this equation, W represents the accumulated elastic potential energy stored within the deformed spring mesh, k represents the spring stiffness constant expressed in Newtons per meter (N/m) or pounds per foot (lb/ft), and x represents the total linear elongation or compression distance measured from the neutral, undeformed equilibrium position.

Kinetics of Particles: Rectilinear Translation

Kinetics is the branch of engineering mechanics that studies the relationship between the unbalanced forces acting on a body and the resulting changes in its motion. When a rigid body undergoes rectilinear translation—moving along a straight linear path—its dynamic behavior can be analyzed using three fundamental approaches derived from Newton's laws of motion. Each method serves as a specialized analytical tool depending on the known variables given in engineering board problems (such as force, distance, velocity, or time).

D'Alembert's Principle

D'Alembert's Principle provides an alternative formulation of Newton's Second Law of Motion ($F = ma$) by introducing the concept of an imaginary inertial force. The principle states that the resultant of the external forces acting on a body and the dynamic kinetic reaction (the inertial force, -ma) equal zero when considered as a system in dynamic equilibrium. This method allows engineers to treat dynamic kinetics problems using the familiar static equations of equilibrium (Σ F = 0). It is highly useful when a problem requires relating forces directly to the linear acceleration of a system. Mathematically, it is expressed as: $F - ma = 0$



Where F represents the algebraic sum of all real external forces acting along the line of motion, m is the mass of the body, and a is the linear acceleration. By treating the term -ma as a resisting force acting in a direction opposite to the acceleration, dynamic problems are effectively reduced to a static equivalent layout.

Work-Energy Principle

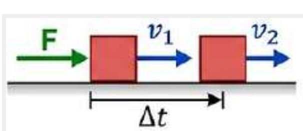
The Work-Energy Principle provides a powerful scalar method for solving kinetics problems without needing to calculate acceleration directly. This principle states that the net mechanical work (W) performed by all external forces acting on a body over a given displacement is precisely equal to the corresponding net change in the kinetic energy (ΔKE) of that body. It is primarily used in board examinations when an analysis requires relating forces directly to a corresponding change in linear velocity over a specified distance. The fundamental relationship is expressed as: $W = \Delta KE$

$$W = \frac{1}{2}m\left(v_2^{\,2} - v_1^{\,2}\right)$$

Where W is the net work ($F \cdot d$), m is the mass of the particle, v_1 is the initial linear velocity, and v_2 is the final linear velocity. This scalar formulation simplifies calculations involving complex forces where tracking time is unnecessary.

Linear Impulse-Momentum Principle

The Linear Impulse-Momentum Principle is a vector-based framework derived by integrating Newton's second law with respect to time. It states that the total linear impulse applied to a body over a discrete time interval matches the resulting change in the body's linear momentum. This approach is highly effective for solving engineering problems that relate a constant or time-varying force directly to a corresponding change in velocity when the elapsed time duration (Δt) is known. $F\Delta t = m\left(v_2 - v_1\right)$

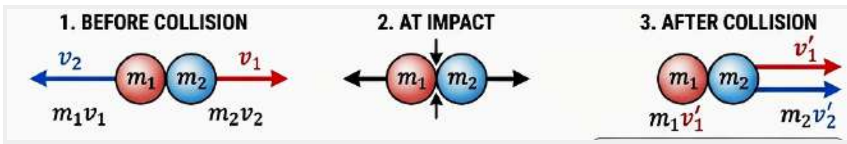


In this proper equation, $F\Delta t$ represents the linear impulse (force multiplied by the time interval over which it acts), m is the mass of the body, v_1 is its initial velocity, and v_2 is its final velocity.

The Law of Conservation of Momentum

When two or more bodies interact or collide within an isolated system where external forces (such as friction or gravity) are absent or negligible, the total linear momentum of the system remains constant. The Law of Conservation of Momentum dictates that the total linear momentum before a collision must exactly equal the total linear momentum after the collision. For a two-body system consisting of masses m_1 and m_2, the equation is modeled as:

$$m_1 v_1 + m_2 v_2 = m_1 v'_1 + m_2 v'_2$$



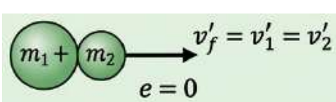
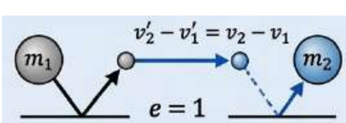
Where m_1 and m_2 represent the structural masses of the two interacting bodies. The parameters v_1 and v_2 denote their respective initial velocities prior to impact, while v'_1 and v'_2 denote their final velocities immediately following the collision. Because momentum is a directional vector quantity, proper sign conventions must be rigorously maintained for velocities moving left or right along the rectilinear axis.

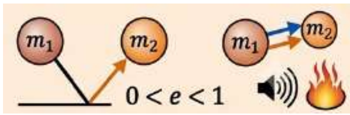
Coefficient of Restitution (e)

The nature of the impact and the energy lost during a collision depends heavily on the materials of the colliding bodies. This relationship is quantified by the **coefficient of restitution** (e), which is a dimensionless ratio comparing the relative velocity of separation after a collision to the relative velocity of approach before the collision. $e = \frac{v'_2 - v'_1}{v_2 - v_1}$

Where v_1 and v_2 are the velocities before impact, and v'_1 and v'_2 are the velocities after impact.

Depending on the physical properties of the materials, collisions are classified into three distinct operating regimes based on the value of e:

	**Perfectly Inelastic Collision (e = 0):** In this regime, the colliding bodies possess no elastic rebound capacity. Upon impact, they stick together completely and move forward as a single unified mass with a shared final velocity ($v'_1 = v'_2$). Energy loss due to deformation and heat is maximized.
	**Perfectly Elastic Collision (e = 1):** This represents an ideal scenario where no mechanical kinetic energy is lost to heat or permanent material deformation. The total kinetic energy and total momentum are both perfectly preserved, allowing the bodies to rebound with maximum possible separation speed.



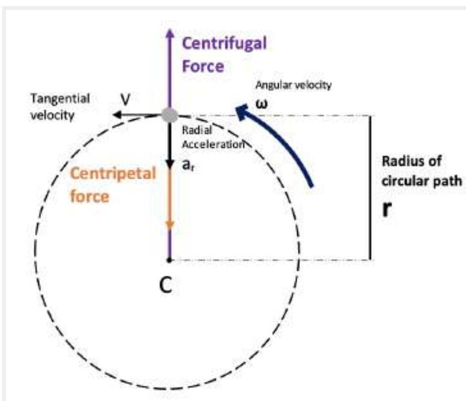
Inelastic Collision (0 < e < 1): This represents real-world engineering scenarios. The bodies rebound away from each other, but a portion of the system's kinetic energy is lost to internal friction, sound, and minor material deformations.

Kinetics of Particles: Curvilinear Translation

Curvilinear translation describes a kinematic state where a particle moves along a curved path rather than a straight line. When analyzing a body navigating a curvature, such as a vehicle traversing a banked turn, the system is best modeled using normal and tangential coordinates. Unlike rectilinear translation where acceleration only shifts the magnitude of velocity, curvilinear kinematics requires tracking components that alter both the speed and the spatial direction of the velocity vector.

Centripetal Force

Centripetal force (F_n) is defined fundamentally as the net normal force acting on a body moving along a curved trajectory that continuously alters the direction of its velocity vector by pulling the body inward toward the instantaneous center of curvature. Because velocity is always tangential to the path, any change in its spatial direction demands an acceleration oriented perpendicular to the motion, directed straight toward the pivot center. Applying Newton's Second Law along the normal coordinate axis yields the standard expression for centripetal force: $F_n = ma_n$



The parameter a_n represents the normal or centripetal acceleration, which acts as a direct geometric function of how fast the object is traveling relative to the tightness of the curve. It can be quantified using either linear tangential velocity (v) or angular rotational velocity (ω): $a_n = \frac{v^2}{r} = \omega^2 r$Substituting these acceleration terms into the force relationship establishes the primary calculation models utilized in board examinations to evaluate tracking mechanics, highway banking, and structural curves: $F_n = m\frac{v^2}{r}$

Within this governing framework, m represents the mass of the translating body, v denotes its instantaneous linear velocity, ω represents its angular velocity, and r serves as the absolute radius of curvature of the path.

Tangential Force

Tangential force (F_t) is the force component that acts directly parallel to the path of curvature at any given instant, operating tangent to the continuous trajectory. While the normal centripetal force changes the *direction* of the velocity vector, the tangential force is responsible for changing the *magnitude* of the velocity (i.e., whether the body is speeding up or slowing down along its path). By applying Newton's Second Law along the tangential coordinate line, the relationship is stated as: $F_t = ma_t$

Here, a_t represents the tangential acceleration component. The fundamental definition of tangential linear acceleration is the time rate of change of speed $\left(a_t = \frac{dv}{dt}\right)$, which relates to angular acceleration (α) through the radius multiplier: $a_t = \alpha r$

Consequently, the formula for tangential force must be modeled as: $F_t = m\alpha r$

This distinction is vital for board exam kinetics problems where a rotating or revolving mass experiences an applied torque that directly drives a linear speed increase along the boundary arc.

Centrifugal Force

Centrifugal force (F_C) is defined as an outward force that tends to move a body directly away from the center of rotation. In classical Newtonian mechanics, true forces must arise from direct interactions between physical bodies. When a dynamic system is analyzed from a stationary, inertial reference frame, centrifugal force does not exist; the inward centripetal force is the sole real input keeping the object tracking along the curve.

However, when an engineer analyzes the system from a non-inertial, rotating reference frame (such as sitting inside the turning vehicle), centrifugal force manifests as an apparent or "pseudo-force." It acts as an inertial reaction to the constant change in direction, matching the magnitude of the centripetal force exactly but pointing in the directly opposite direction:

$$F_C = m\frac{v^2}{r}$$

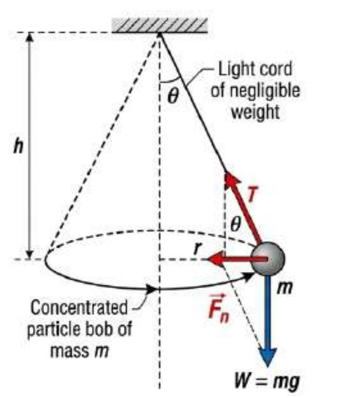
In practical structural design—such as calculating the optimal banking angle of a highway curve or evaluating the overturning vulnerability of a locomotive—treating centrifugal force as a real outward vector balancing the static forces allows engineers to apply D'Alembert's principle to curvilinear systems effortlessly.

Applications of Curvilinear Translation

The mechanical principles governing curvilinear translation extend to classic engineering applications where centripetal acceleration balances gravimetric and structural forces. Two primary systems regularly encountered in board examinations are the conical pendulum and the banking angles designed for highway curves.

Conical Pendulum

A conical pendulum consists of a concentrated particle or bob of mass m suspended from a rigid, fixed point by a light cord of negligible weight. Instead of bobbing back and forth along a single linear arc like a simple pendulum, the mass sweeps out a perfectly uniform horizontal circle at a constant speed, causing the suspension string to trace the surface of an inverted right circular cone.



When analyzing the dynamic equilibrium of the suspended bob via D'Alembert's principle, three distinct forces interact: the downward gravitational weight of the bob (W = mg), the internal axial tension force vector tracking along the cord (T), and the inward centripetal force vector (F_n) pulling the mass toward the center of the horizontal path loop. Resolving these forces along the vertical and horizontal coordinate axes yields the standard system of equations:

- **Cord Tension Calculation:** Because there is zero vertical acceleration, the vertical component of the tension vector must balance the downward gravitational weight exactly ($T cos\theta = W$). Solving directly for the absolute magnitude of the internal tension yields: $T = \frac{W}{cos\theta}$

- **Geometric Angle Relationship:** The horizontal component of the tension vector provides the net inward force required to maintain curvilinear motion ($T sin\theta = F_n$). Dividing the horizontal force expression by the vertical equilibrium equation cancels the tension variable, isolating the angular geometry as a direct ratio of the normal centripetal force to the structural dead weight: $tan\theta = \frac{F_n}{W} = \frac{m(v^2/r)}{mg}$

$$tan\theta = \frac{v^2}{gr}$$

- **Period of Revolution (t):** The total time period t required for the suspended bob to complete one full horizontal revolution ($2\pi\ radians$) depends entirely on the vertical drop height h measured from the pivot anchor down to the plane of the circular loop path. By substituting the geometric relationships into the constant angular velocity model, the operational period simplifies to:

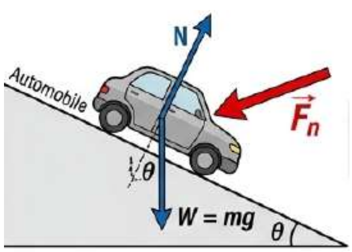
$$t = 2\pi\sqrt{\frac{h}{g}}$$

Within this framework, T represents the absolute tension sustained by the structural cord, W denotes the weight of the mass particle, θ is the angle of inclination between the cord and the vertical axis,h is the vertical height profile, v is the linear tangential speed, r is the radius of the horizontal circle, and g is the acceleration due to gravity.

Banking Angle of a Highway Curve

When an automobile navigates a curved roadway path, it undergoes curvilinear translation and experiences an outward inertial reaction known as centrifugal force. If the roadway surface is perfectly flat, the vehicle relies entirely on the lateral tire friction force to prevent skidding outward. To improve safety, highway designers tilt the road surface inward at a specific inclination angle θ. This engineering technique is called banking. Banking allows the normal reaction force of the road surface to assist in pushing the vehicle toward the center of the curve.

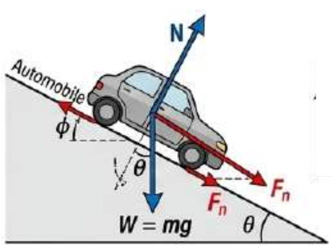
1. Ideal Case: Friction Angle Not Considered



In an ideal scenario where the tire-road friction is completely neglected or when ice eliminates surface traction, the vehicle must navigate the curve safely based solely on the banking geometry. In this condition, the normal force vector N exerted by the road on the vehicle tilts inward. The vertical component of this normal force balances the vehicle's weight ($N\,cos\theta = W$), while the horizontal component supplies the exact centripetal force required to round the bend ($N\,sin\theta = F_n$). Dividing these two vector equations yields the standard ideal banking formula: $tan\,\theta = \frac{v^2}{gr}$

The angle calculated using this equation is known as the **ideal banking angle**. At this specific angle and design velocity (v), a vehicle will navigate the curve smoothly without requiring any lateral friction force between the tires and the pavement.

2. Practical Case: Friction Angle (ϕ) Considered



In real-world engineering design, the stabilizing effects of road friction must be included. The total resistance of a banked curve against skidding is modeled by combining the mechanical banking angle θ with the structural friction angle ϕ. The friction angle is directly related to the coefficient of static friction (f) by the standard trigonometric function: $tan\phi = f$

When lateral tire friction acts to keep the car tracking safely on its path, the combined angular limits alter the force equilibrium equations. The maximum safe speed limits before side-slipping occurs are evaluated using the compound tangent identity: $tan(\theta + \phi) = \frac{v^2}{gr}$

Within this comprehensive design model, θ represents the physical banking angle of the highway structure, ϕ represents the internal friction angle of the tire-pavement interface, v denotes the linear velocity of the vehicle, r defines the absolute radius of curvature of the highway bend, and g is the standard gravitational constant ($9.81 m/s^2$ for metric calculations or $32.2\ ft/s^2$ for US customary units).

Dynamics of Rotating Rigid Bodies

When a rigid body undergoes rotational motion rather than translation, its kinetic behavior depends not only on its total mass but also on how that mass is spatially distributed relative to the axis of rotation. In classical engineering mechanics, analyzing systems with rotating masses requires adapting the standard concepts of linear kinetic energy and mass to their rotational counterparts.

Rotational Kinetic Energy

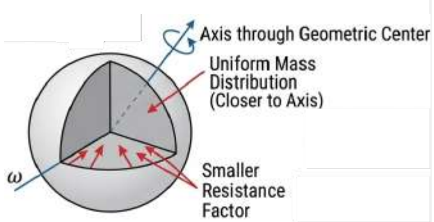
Rotational kinetic energy (KE) is the energy possessed by a rigid body due to its rotational motion around a fixed axis. Just as linear kinetic energy acts as a function of mass and linear velocity $\left(\frac{1}{2}mv^2\right)$, rotational kinetic energy is modeled as a function of the mass distribution factor and the angular speed. The mathematical expression is written as: $KE = \frac{1}{2}I\omega^2$

Within this foundational equation, ω represents the instantaneous angular velocity of the rotating body, expressed in radians per second (rad/sec). The parameter I represents the **mass moment of inertia**, which serves as the rotational analog to linear mass. It quantifies the structural resistance of a body to changes in its rotational speed.

Mass Moment of Inertia (I) for Standard Geometric Shapes

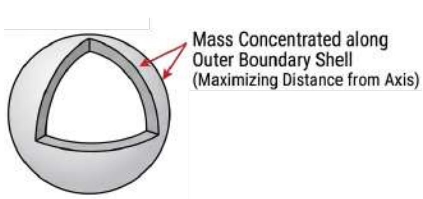
The mass moment of inertia (I) measures a body's resistance to angular acceleration around a specific axis. For homogeneous rigid bodies with uniform density, calculus integration yields precise algebraic formulas for common geometric shapes. Board examinations frequently feature four primary rotational profiles:

1. Solid Sphere



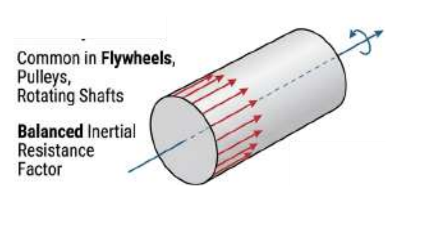
A solid, uniform sphere of mass m and outer radius R distributes its mass relatively close to its central axis of rotation. Integrating its volume elements across three dimensions yields a smaller resistance factor compared to hollow structures. Its mass moment of inertia about any axis passing through its geometric center is defined by the formula: $I = \frac{2}{5}mR^2$

2. Hollow Sphere



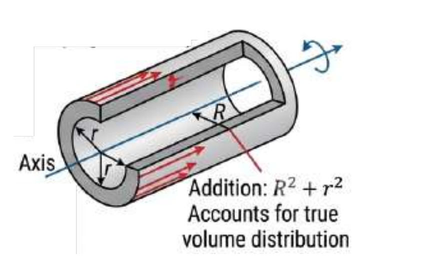
Conversely, a hollow, thin-walled sphere of mass m and radius R concentrates its entire mass along its outer boundary shell, maximizing its distance from the central rotational axis. Because the mass is located at the furthest possible radius, it offers greater resistance to angular acceleration than a solid sphere of equal mass. Its moment of inertia is modeled as: $I = \frac{2}{3}mR^2$

3. Solid Cylinder



A solid cylinder (often analyzed as a flywheel, pulley, or rotating shaft) has a mass m and an outer radius R. When rotating about its longitudinal geometric center axis, its mass distribution yields a balanced inertial resistance factor. The equation used to calculate its rotational resistance is: $I = \frac{1}{2}mR^2$

4. Hollow Cylinder



A hollow cylinder (or thick-walled pipe) features an internal void defined by an inner radius r and an outer radius R. The mass moment of inertia for a hollow cylinder is derived by summing the squares of the inner and outer boundary radii, multiplied by a half-fractional mass coefficient. The true, corrected engineering standard formula is: $I = \frac{1}{2}m\left(R^2 + r^2\right)$

This addition of the squared radii accounts for the true volume distribution of a hollow cylinder and is essential for avoiding systemic errors when solving rotational kinetics problems on the board exam.

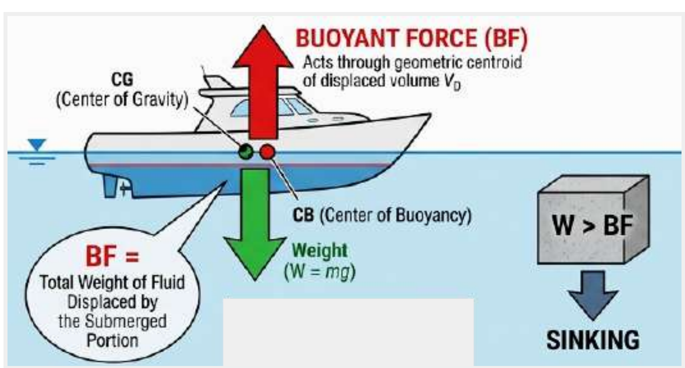
Fluid Dynamics

Hydrostatic Principles

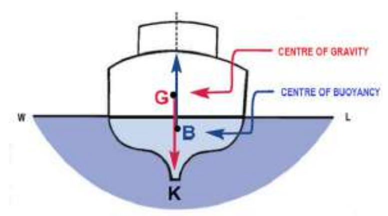
Fluid mechanics plays a significant role in engineering board examinations, particularly regarding hydrostatics, which focuses on fluids at rest. One of the most critical principles within this domain is the behavior of bodies submerged or floating within a fluid system. This behavior is governed by the net vertical pressure distributions acting on the boundaries of the body, creating a lifting phenomenon known as buoyancy.

Buoyancy and Archimedes' Principle

Buoyancy describes the net upward force exerted by a fluid on any object completely or partially immersed within it. This physical phenomenon is governed by Archimedes' Principle, which states that when a body is surrounded by a fluid at rest, it experiences an upward vertical force equal in magnitude to the total weight of the fluid that the body physically displaces. The fundamental mathematical expression used to calculate this force is written as: $BF = \gamma_w V_D$



Within this standard governing equation, BF represents the absolute buoyant force acting on the body. The parameter γ_w denotes the specific weight (or unit weight) of the surrounding fluid medium. The term V_D represents the volumetric displacement, which is the physical volume of the portion of the body that is submerged beneath the fluid's surface line.

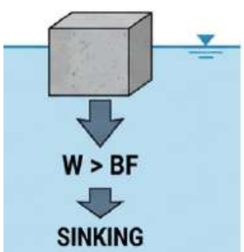


The upward buoyant force acts specifically through the **center of buoyancy** (CB). The center of buoyancy is defined as the geometric centroid of the *displaced fluid volume* (V_D), not the body itself. The relative spatial positioning between the CG and the CB is crucial for evaluating the rotational stability and righting moments of ships and submarines.

Equilibrium of Floating Bodies

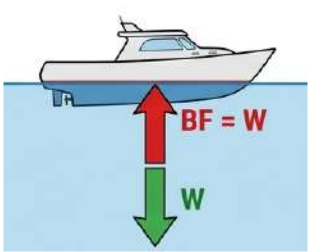
When an object is placed in a fluid, its static equilibrium depends entirely on the relationship between its total dead weight (W) and the maximum potential buoyant force (BF) it can generate.

1. Fully Submerged or Sinking Bodies



If the average density of the body exceeds the density of the surrounding fluid, the downward gravitational force will be greater than the upward buoyant force even when the object is completely underwater (W > BF). Consequently, the body will sink to the bottom unless supported by an external structural reaction.

2. Freely Floating Bodies



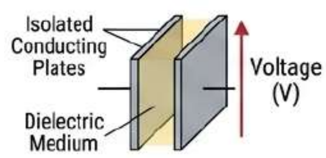
For a body that stabilizes and rests freely at the fluid interface without any external mechanical support, a state of perfect vertical static equilibrium ($\Sigma F_y = 0$) is achieved. In this configuration, the upward buoyant force generated by the submerged portion of the object exactly balances the total gravitational weight of the entire body: BF = W

By expanding this equilibrium relationship ($\gamma_{fluid} V_D = \gamma_{body} V_{total}$), engineers can calculate exactly how low a structure (such as a concrete barge, floating dock, or hydrometer) will ride in the water. This relationship allows for the precise determination of the draft height and freeboard margins required to satisfy safety codes under varying loading conditions.

Basic Electricity

The study of basic electrical circuits forms an essential foundation for multidisciplinary engineering board examinations. Circuit analysis involves understanding how electrical charge is stored, how it flows through conducting mediums, and how energy is distributed across combinations of passive network elements such as capacitors and resistors. These networks are governed by fundamental empirical laws and conservation principles.

Capacitance and Charge Storage

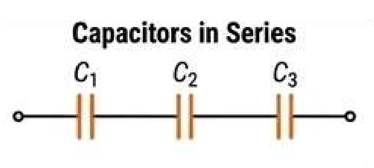


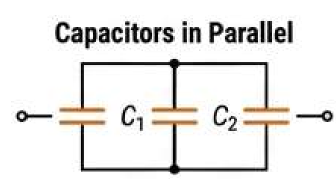
Capacitance (C) represents the quantitative measure of a body's or electrical component's ability to hold, collect, and store electrical charge per unit of potential difference. An ideal capacitor typically consists of two isolated conducting plates separated by a dielectric medium. When a voltage is applied across these plates, equal and opposite charges accumulate on their respective surfaces, establishing an internal electrostatic field. The governing relationship is defined as: $C = \frac{Q}{V}$

In this expression, Q represents the magnitude of the net electrical charge accumulated on either conductor, measured in coulombs (C), and V denotes the potential difference (voltage) established between the conductors, measured in volts (V). The standard SI unit of capacitance is the farad (F), where a single farad is equivalent to one coulomb per volt (1 F = 1 C/V).

Capacitors in Combination

Depending on the circuit architecture, capacitors can be arranged in network configurations to alter the overall storage capability:

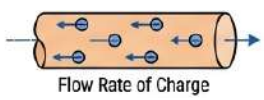




- **Capacitors in Series:** When capacitors are daisy-chained sequentially in a single line, the same net electrical charge must pass through each component ($Q = Q_1 = Q_2 = Q_3 = \ldots$). Consequently, the total voltage drop across the network is the sum of the individual voltage drops ($V = V_1 + V_2 + V_3 + \ldots$). The equivalent total capacitance (C) decreases and is calculated using the reciprocal relationship: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$

- **Capacitors in Parallel:** When capacitors are connected across the same common electrical nodes, they experience identical potential differences ($V = V_1 = V_2 = V_3 = \ldots$). The total stored charge is the sum of the charges on each capacitor ($Q = Q_1 + Q_2 + Q_3 + \ldots$). As a result, the equivalent total capacitance (C) increases linearly and is determined by direct addition: $C = C_1 + C_2 + C_3 + \ldots$

Electric Current

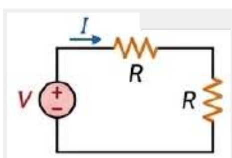


Electric current (I) is defined as the time rate of flow of net electrical charge through a defined cross-sectional area of a conducting medium. It represents the active migration of free electrons under the influence of an electromotive force. The relationship is modeled as: $I = \frac{Q}{t}$

Where I is the electric current measured in amperes (A), Q is the net electrical charge in coulombs (C), and t is the discrete time interval in seconds (s). One ampere corresponds to a flow rate of one coulomb per second (1 A = 1 C/s).

Ohm's Law

Ohm's Law establishes the fundamental empirical relationship governing direct-current (DC) resistive elements. It states that the electric current flowing through a homogeneous conductor is directly proportional to the potential difference applied across its terminals and inversely proportional to its internal electrical resistance. Mathematically, it is expressed as: $V = IR$



Here, V represents the voltage or potential difference measured in volts (V), I is the electric current in amperes (A), and R represents the electrical resistance of the component, measured in ohms (Ω).

Electric Power

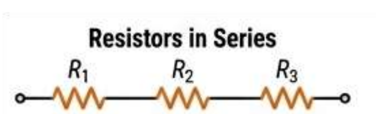
Electric power (P) is the rate at which electrical energy is dissipated or converted into another form of energy (such as thermal energy or heat) within a circuit element.

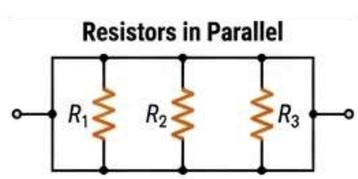
The definitive electrical power equation is: P = IV

Where P represents the electric power in Watts (W). By substituting Ohm's Law (V = IR) into this expression, the power relation can also be adapted to alternative forms regularly used in board exams: $P = I^2R$ and $P = \frac{V^2}{R}$

Resistors in Combination

Resistors can be arranged in networks to divide voltages or currents according to the requirements of the circuit design.





1. Resistors in Series

When resistors are connected end-to-end in a single pathway, the electric current passing through them is uniform ($I = I_1 = I_2 = I_3 = \ldots$). The total voltage drop across the string equals the sum of the individual potential drops ($V = V_1 + V_2 + V_3 + \ldots$). Therefore, the equivalent total resistance (R) accumulates linearly: $R = R_1 + R_2 + R_3 + \ldots$

2. Resistors in Parallel

When resistors are connected side-by-side across the same pair of nodes, the voltage drop across each branch is identical ($V = V_1 = V_2 = V_3 = \ldots$).

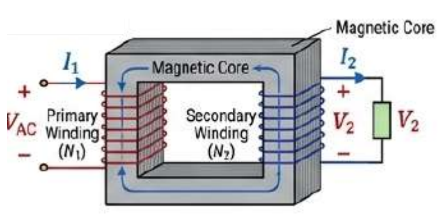
The total current entering the parallel node splits across the parallel paths ($I = I_1 + I_2 + I_3 + \ldots$). Consequently, the equivalent total resistance (R) decreases and is calculated via the reciprocal sum model: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

Kirchhoff's Laws

For complex electrical circuits that cannot be simplified using basic series or parallel reductions, circuit analysis relies on **Kirchhoff's Laws**. These laws are direct expressions of the fundamental conservation laws of physics applied to electrical networks.

1. **Kirchhoff's Current Law (KCL):** Derived from the Principle of Conservation of Electric Charge, KCL states that the algebraic sum of all electric currents entering or leaving any junction (node) in an electrical network is exactly equal to zero. Alternatively, it dictates that the total current entering a junction must equal the total current flowing out of that same junction.
2. **Kirchhoff's Voltage Law (KVL):** Derived from the Principle of Conservation of Energy, KVL states that the algebraic sum of all the potential differences (voltages), including electromotive forces and resistive drops, around any closed loop or mesh pathway within a circuit must equal zero.

Transformers



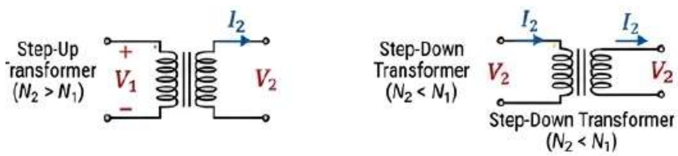
A transformer is a static electrical device that converts alternating current (AC) of a specific voltage level into an alternating current of a different voltage level through the principle of mutual electromagnetic induction, without requiring direct electrical contact between the two circuits. It consists of a magnetic core wrapped with two distinct insulated wire windings: the primary winding (input side) and the secondary winding (output side).

The Ideal Transformer Relationship

In an ideal transformer with zero core losses and complete magnetic flux linkage, the ratio of the primary to secondary electromotive forces is directly proportional to the number of wire turns in the respective coils, and inversely proportional to their respective currents due to the conservation of energy ($P_{in} = P_{out}$): $\frac{I_1}{I_2} = \frac{\xi_2}{\xi_1} = \frac{N_2}{N_1}$

In electrical engineering, ξ (or E) specifically denotes the **electromotive force (emf)** or voltage induced within the windings, measured in volts (V). The parameters N_1 and N_2 represent the number of turns in the primary and secondary coils, while I_1 and I_2 represent the primary and secondary currents, respectively.

Classifications based on Turn Ratio



- **Step-Up Transformer ($N_2 > N_1$):** If the secondary winding contains more turns than the primary winding, the induced output voltage increases $\xi_2 > \xi_1$), while the output current decreases proportionally.
- **Step-Down Transformer ($N_2 < N_1$):** If the secondary winding contains fewer turns than the primary winding, the induced output voltage decreases ($\xi_2 < \xi_1$), while the output current increases proportionally.