Physical Quantities and Concepts

Kinematic-related Concepts

1. **Displacement**: Defined by the change in the position vector, it represents the change in the position of an object and is a vector. For example, if an object moves from the initial position $\overrightarrow{S_0}$ to $\overrightarrow{S_1}$, its displacement is$\Delta\vec{S} = \overrightarrow{S_1} - \overrightarrow{S_0}$.
2. **Average Speed**: Equal to the ratio of the distance traveled by the object to the time taken, it is a scalar. The formula is $averange\ speed = \frac{distance\ traveled}{time\ spent\ travelling}$.
3. **Average Velocity**: It is the ratio of the displacement to the time taken for this displacement to occur. It is a vector, and its direction is the same as that of the displacement. The formula is$\vec{v}_{avg} = \frac{\Delta\vec{s}}{\Delta t}$.
4. **Instantaneous Velocity**: The velocity of a moving object at a certain moment or position. Its magnitude is equal to the derivative of the displacement with respect to time, and its direction is the tangent direction of the trajectory. The formula is $v_s = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$.
5. **Acceleration**: A physical quantity that describes the rate of change of velocity. It is equal to the ratio of the change in velocity to the time taken for this change to occur. It is a vector, and the formula is $a_{avg} = \frac{\Delta\vec{v}}{\Delta t}$. In free fall motion, the acceleration is the gravitational acceleration g , and its direction is vertically downward.

Dynamics-related Concepts

1. **Force**: The interaction between objects that causes an object to accelerate or deform. Force is a vector, such as gravity, elastic force, and friction.
2. **Gravitational Force**: The attractive force of the Earth on an object. Its direction is vertically downward, and its magnitude is $F_G = mg$, where m is the mass of the object and g is the gravitational acceleration.
3. **Spring Force**: Follows Hooke's Law, $F_{sp} = -k\Delta s$, where k is the spring constant and Δs is the displacement of the spring. The direction of the spring force is opposite to the direction of the spring deformation.
4. **Tension**: The pulling force exerted by a rope or rod on an object. Its direction is along the rope or rod. In a string connecting objects, the tension is equal everywhere (when the mass of the string is ignored).
5. **Normal Force**: The force exerted by a supporting surface on an object. Its direction is perpendicular to the supporting surface. For example, when an

object is placed on a table, the normal force exerted by the table on the object is perpendicular to the table surface.

6. **Friction**: Includes static friction and kinetic friction. The static friction force f_s balances the external force when the object is at rest, and its magnitude can vary. The maximum static friction force is $f_{s,max} = \mu_s N$, where μ_s is the coefficient of static friction and N is the normal force. The kinetic friction force is $f_k = \mu_k N$, where μ_k is the coefficient of kinetic friction, and the direction of the kinetic friction force is opposite to the direction of the relative motion of the object.
7. **Buoyancy**: The upward force exerted on an object in a fluid, which is equal to the weight of the fluid displaced by the object. According to Archimedes' principle, $F_B = \rho_{fluid} V_{displaced} g$, where ρ_{fluid} is the density of the fluid and $V_{displaced}$ is the volume of the fluid displaced.

Electricity-related Concepts

1. **Charge**: Divided into positive and negative charges. Charge is quantized, and the elementary charge is $e = 1.602176 \times 10^{-19} C$. The charge of an object is an integer multiple of the elementary charge.
2. **Current**: The amount of charge passing through the cross-section of a conductor per unit time. The formula is $I = \frac{dQ}{dt}$. The direction of the current is defined as the direction of the positive charge movement. The unit is the ampere (A).
3. **Voltage**: The work done by the electric field force in moving a unit positive charge from one point to another. It is also called the potential difference. The formula is $V_{BA} = \frac{U_B - U_A}{q} = -\frac{W_{BA}}{q}$. The unit is the volt (V).
4. **Resistance**: Represents the degree of hindrance of a conductor to the current. The formula is $R = \frac{V}{I}$. The unit of resistance is the ohm (Ω). The resistance is related to the material, length, cross-sectional area, and temperature of the conductor. The formula is $R = \rho \frac{l}{A}$, where ρ is the resistivity, l is the length, and A is the cross-sectional area.
5. **Capacitance**: A physical quantity that describes the ability of a capacitor to store charge. The formula is $Q = CV$. The unit of capacitance is the farad (F). The capacitance formula of a parallel plate capacitor is $C = \epsilon_0 \frac{A}{d}$, where ϵ_0 is the vacuum permittivity, A is the area of the plates, and d is the distance between the plates.

6. **Electric Field**: The ratio of the electric force F exerted on a charge placed at a certain point in the electric field to its charge q. The formula is $\vec{E} = \frac{\vec{F}}{q}$. The electric field strength is a vector, and its direction is the same as the direction of the electric force exerted on a positive charge at that point. The unit is newton per coulomb (N/C) or volt per meter (V/m).
7. **Electric Flux**: The product of the electric field strength and the area through which it passes. The formula is $\int \vec{E} \cdot d\vec{A}$. The unit of electric flux is newton meter squared per coulomb (N · m²/C).
8. **Electric Potential**: The electric potential energy per unit positive charge at a certain point in the electric field. The formula is $V = \frac{U}{q}$. Electric potential is a scalar, and the unit is the volt (V).
9. **Electric Potential Energy**: The potential energy of a charge in an electric field, which is equal to the product of the charge and the electric potential. The formula is $U = qV$.

Magnetism-related Concepts

1. **Magnetic Field**: It exerts a force on magnets, currents, or moving charges placed in it. The magnetic field strength is represented by the magnetic induction intensity $\vec{B}$. The unit is the tesla (T).
2. **Magnetic Flux**: The number of magnetic field lines passing through a certain area. The formula is $\Phi_B = \int \vec{B} \cdot d\vec{A}]$. The unit of magnetic flux is the weber (Wb).
3. **Electromotive Force (EMF)**: The work done by the non-electrostatic force in moving a unit positive charge from the negative electrode to the positive electrode of a power source. The unit is the volt (V). For example, the electromotive force of a battery is equal to the voltage across the battery terminals when no load is connected.
4. **Inductance**: Includes self-inductance and mutual inductance. Self-inductance is the electromotive force generated in a coil due to the change in its own current. The formula is $\varepsilon = -L\frac{dI}{dt}$. Mutual inductance is the electromotive force generated in one coil due to the change in the current of another coil. The formula is $\varepsilon_2 = -M\frac{dI_1}{dt}$. The unit of inductance is the henry (H).

Other Concepts

1. **Time**: Used to describe the sequence of events and the duration of a process. It is a scalar, and the unit is the second (s).
2. **Mass**: The amount of matter contained in an object. It is a measure of inertia and also a factor in the magnitude of gravitational force. The unit is the kilogram (kg).
3. **Energy**: The ability to do work, including kinetic energy, potential energy, electrical energy, magnetic energy, and other forms. The unit is the joule (J).
4. **Power**: The work done per unit time. The formula is $P = \frac{dW}{dt}$. The unit is the watt (W).
5. **Work**: The product of the force and the distance moved in the direction of the force. The formula is $W = \vec{F} \cdot \vec{d}$. The unit is the joule (J).
6. **Angular Displacement**: The change in the angle of an object in circular motion. The unit is the radian (rad).
7. **Angular Velocity**: The rate of change of angular displacement with respect to time. The formula is $\omega = \lim_{\Delta t \to 0} \frac{\Delta \theta}{\Delta t} = \frac{d\theta}{dt}$. The unit is the radian per second (rad/s).
8. **Angular Acceleration**: The rate of change of angular velocity with respect to time. The unit is the radian per second squared (rad/s²).
9. **Period**: The time required for an object to complete one full cycle of periodic motion. The unit is the second (s).
10. **Frequency**: The number of complete cycles of periodic motion per unit time. The formula is $f = \frac{1}{T}$. The unit is the hertz (Hz).
11. **Wavelength**: The distance traveled by a wave in one vibration cycle. The unit is the meter (m).

Laws, Theorems, and Formulas

1. **Uniform Linear Motion**
   - **Velocity Formula**: $v = \frac{s}{t}$ (v represents velocity, s represents displacement, and t represents time).
   - **Displacement Formula**: $s = vt$
2. **Uniformly Accelerated Linear Motion**
   - **Velocity Formula**: $v = v_0 + at$ (v_0 is the initial velocity, and a is the acceleration).
   - **Displacement Formula**: $s = v_0 t + \frac{1}{2} a t^2$.

- **Velocity-Displacement Formula**: $v^2 - v_0^2 = 2as$.
- **Average Velocity Formula**: $\vec{v} = \frac{v_0+v}{2}$ (only applicable to uniformly accelerated linear motion).

3. **Free Fall Motion**
   - **Velocity Formula**: $v = gt$ (g is the gravitational acceleration, usually taken as $9.8m/s$).
   - **Displacement Formula**: $h = \frac{1}{2}gt^2$.
   - **Velocity-Displacement Formula**: $v^2 = 2gh$.
4. **Vertical Upward Throwing Motion**
   - **Velocity Formula**: $v = v_0 - gt$.
   - **Displacement Formula**: $h = v_0 t - \frac{1}{2}gt^2$.
   - **Velocity-Displacement Formula**: $v^2 - {v_0}^2 = -2gh$ (during the upward process, v_0 is positive, and during the downward process, v is negative).
5. **Horizontal Projectile Motion**
   - **Horizontal Direction**: $x = v_0 t$ ($v_0$is the horizontal initial velocity).
   - **Vertical Direction**: $y = \frac{1}{2}gt^2$, $v_y = gt$.
   - **Resultant Velocity**: $v = \sqrt{{v_0}^2 + v_y^2} = \sqrt{{v_0}^2 + (gt)^2}$.
   - **Resultant Displacement**: $s = \sqrt{x^2 + y^2}$.
6. **Uniform Circular Motion**
   - **Linear Velocity**: $v = \frac{2\pi r}{T}$ (r is the radius, and T is the period).
   - **Angular Velocity**: $\omega = \frac{2\pi}{T}$.
   - **Relationship between Linear and Angular Velocity**: $v = \omega r$.
   - **Centripetal Acceleration**: $a = \frac{v^2}{r} = \omega^2 r$.
   - **Centripetal Force**: $F = ma = m\frac{v^2}{r} = m\omega^2$.

Dynamics-related Laws and Theorems

1. **Newton's First Law (Law of Inertia)**: Any object will remain in a state of uniform linear motion or rest until an external force forces it to change its state of motion.
2. **Newton's Second Law**: $F_{net} = ma$ (F_{net} is the net external force, m is the mass of the object, and a is the acceleration).

3. **Newton's Third Law**: The forces of action and reaction between two interacting objects are always equal in magnitude, opposite in direction, and act on the same straight line.
4. **Hooke's Law**: $F = -kx$ (F is the spring force, k is the spring constant, x is the deformation of the spring, and the negative sign indicates that the direction of the spring force is opposite to the direction of the deformation).
5. **Law of Universal Gravitation**: The magnitude of the gravitational force between two objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers of mass. The formula is $F = G\frac{Mm}{r^2}$, where G is the gravitational constant, M and m are the masses of the two objects, and r is the distance between their centers of mass.

Electricity-related Laws and Theorems

1. **Coulomb's Law**: $F_{12} = F_{21} = k\frac{|q_1 q_2|}{r^2}$ (k is the electrostatic constant, q_1 and q_2 are the charges of the two-point charges, and r is the distance between the two-point charges. The force between the charges acts along the line connecting them).
2. **Gauss's Law**: In a vacuum, the electric flux through any closed surface is equal to the algebraic sum of all the charges enclosed by the surface divided by ϵ_0. The formula is $\oint \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\epsilon_0}$.
3. **Definition of Electric Field Strength**: $E = \frac{F}{q}$ (E is the electric field strength, F is the electric force exerted on the test charge, and q is the charge of the test charge).
    - **Electric Field Strength Formula for a Point Charge**: $E = k\frac{Q}{r^2}$ (Q is the charge of the source charge).
4. **Electric Force Formula**: $F = qE$ (q is the charge of the object, and E is the electric field strength).
5. **Electric Potential Energy Formula**: $E_P = q\varphi$ (E_P is the electric potential energy, q is the charge, and φ is the electric potential).
6. **Potential Difference Formula**: $U_{AB} = \varphi_A - \varphi_B = \frac{W_{AB}}{q}$ (U_{AB} is the potential difference between two points, and W_{AB} is the work done by the electric field force in moving the charge from point to point).
7. **Definition of Capacitance**: $C = \frac{Q}{U}$ (C is the capacitance, Q is the charge stored in the capacitor, and U is the voltage across the capacitor plates).

- **Capacitance Formula for a Parallel Plate Capacitor**: $C = \frac{\epsilon_0 S}{d}$ (ϵ_0 is the vacuum permittivity, S is the area of the plates facing each other, and d is the distance between the plates).

8. **Ohm's Law**: $I = \frac{U}{R}$ （(I is the current, U is the voltage across the resistor, and R is the resistance).
9. **Resistance Law**: $R = \rho \frac{l}{A}$ (ρ is the resistivity, l is the length of the conductor, and A is the cross-sectional area of the conductor).
10. **Joule's Law**: $Q = I^2Rt$ (Q is the heat generated by the current passing through the conductor, I is the current, R is the resistance, and t is the time).
11. **Time Constant**: $\tau = RC$. The time constant τ represents the speed of charging or discharging of a capacitor in an RC circuit. The unit is the second. R is the resistance value in ohms, and C is the capacitance value in farads.
12. **Capacitor Charging Formula**: $q(t) = C\varepsilon\left(1 - e^{-\frac{t}{RC}}\right) = q_{max}(1 - e^{-\frac{t}{\tau}})$, where $q(t)$ is the charge on the capacitor at time t , ε is the electromotive force of the power source, and $q_{max} = C\varepsilon$ is the maximum charge that the capacitor can be charged to.
13. **Voltage across the Capacitor during Charging**: $v_C(t) = \varepsilon\left(1 - e^{-\frac{t}{RC}}\right)$, where $v_C(t)$ is the voltage across the capacitor at time t.
14. **Capacitor Discharging Formula**: $q(t) = q_0 e^{-\frac{t}{RC}} = q_0 e^{-\frac{t}{\tau}}$, where q_0 is the initial charge on the capacitor.
15. **Voltage across the Capacitor during Discharging**: $v_C(t) = v_0 e^{-\frac{t}{RC}}$, where v_0 is the initial voltage across the capacitor.
16. **RC Circuit Current Formula**: $i(t) = \frac{\varepsilon}{R} e^{-\frac{t}{RC}} = i_0 e^{-\frac{t}{RC}}$, where $i_0 = \frac{\varepsilon}{R}$ is the initial current.
17. **Capacitive Reactance of the Capacitor**: $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$, where ω is the angular frequency, f is the frequency, and C is the capacitance value. The capacitive reactance X_C represents the hindrance of the capacitor to alternating current, and the unit is the ohm.
18. **Impedance of the RC Series Circuit**: $Z = \sqrt{R^2 + X_C^2} = \sqrt{R^2 + (\frac{1}{\omega C})^2}$. The impedance Z represents the total hindrance of the RC series circuit to alternating current, and the unit is the ohm.
19. **Inductive Reactance of the Inductor**: $X_L = 2\pi f L$, where f is the frequency, and L is the inductance of the inductor. The inductive reactance X_L represents

the hindering effect of the inductor on the alternating current, and the unit is the ohm.

20. **Ohm's Law for a Closed Circuit：** $I = \frac{E}{R+r}$ (E is the electromotive force of the power source, R is the external circuit resistance, and r is the internal resistance of the power source).
    - **Terminal Voltage：** $U = E - Ir$

Electromagnetism-related Concepts

1. **Ampere's Force Formula**: $F = BIL\sin\theta$ (F is the Ampere force, B is the magnetic induction intensity, I is the current intensity, L is the length of the wire, and θ is the angle between the current direction and the magnetic field direction).
2. **Lorentz Force Formula**: $F = qvB\sin\theta$ (F is the Lorentz force, q is the charge of the charged particle, v is the velocity of the particle, B is the magnetic induction intensity, and θ is the angle between the velocity direction of the particle and the magnetic field direction).
3. **Faraday's Law of Electromagnetic Induction**: $E = n\frac{\Delta\Phi}{\Delta t}$ (E is the induced electromotive force, n is the number of turns of the coil, $\Delta\Phi$ is the change in magnetic flux, and Δt is the change time).
4. **Induced Electromotive Force Generated by a Conductor Rod Cutting Magnetic Field Lines**: $E = BLv\sin\theta$ (v is the velocity of the conductor rod cutting the magnetic field lines, and θ is the angle between the velocity direction and the magnetic field direction).
5. **Lenz's Law**: The induced current has such a direction that the magnetic field of the induced current always opposes the change in the magnetic flux that causes the induced current.
6. **Ampere's Law (Ampere's Circuital Law)**: In a steady magnetic field, the line integral of the magnetic field intensity along any closed path is equal to the algebraic sum of all the currents enclosed by this closed path. The formula is $\oint \vec{H} \cdot d\vec{l} = \sum I$.
7. **Law of Conservation of Energy (Reflected in Circuits and Electromagnetic Induction)**: Energy neither arises out of nothing nor disappears into nothing. It only transforms from one form to another or transfers from one object to other objects, while the total amount of energy remains unchanged.

Wave Optics-related Concepts

1. **Refractive Index Formula**: $n = \frac{c}{v}$ (n is the refractive index, c is the speed of light in vacuum, and v is the speed of light in the medium).

2. **Law of Refraction (Snell's Law)**: $n_1 \sin\theta_1 = n_2 \sin\theta_2$ (n_1 and n_2 are the refractive indices of the two media, θ_1 is the incident angle, and θ_2 is the refracted angle).
3. **Relationship between the Wavelength, Frequency, and Wave Speed of Light**: $v = \lambda f$ (λ is the wavelength, and f is the frequency).