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PHYSICS

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1. Measurement/Unit

Derived Units and their Expression

- Frequency: Hertz (Hz) = s^{-1}.
- Power (Electric/Mechanical): Watt (W) = Joule/second (J/s) = Newton-meter/second (N·m/s).
- Pressure: Pascal (Pa) = Newton/meter² (N/m²) = kg/(m·s²). Other units include Bar, Atmosphere, and kg/cm². Note: N/m and J/m² are not units of pressure.
- Force: Newton (N) = kg·m/s². In CGS, 1 dyne = 1 g·cm/s² = 10^{-5} N.
- Spring Constant (k): Newton/meter (N/m).
- Resistivity (ρ): Ohm-meter (Ω·m). Ohm-cm (Ω·cm) is a commonly used non-SI unit. Resistivity is an intrinsic property of a material, independent of its length or cross-section.
- Energy: Joule (J) = Newton-meter (N·m) = kg·m²/s². Other units: Watt-hour (W·h). Note: kg·m/s² is a unit of force (Newton), not energy.
- Gravitational Constant (G): N·m²/kg².
- Impulse: Newton-second (N·s) = kg·m/s.
- Electric Charge: Coulomb (C) = Ampere-second (A·s).
- Electric Potential Difference (Voltage): Volt (V) = Joule/Coulomb (J/C).
- Power of a Lens: Diopter (D) = 1/meter (m^{-1}).
- Magnetic Field Strength (B): Tesla (T), Gauss (G).
- Magnetic Field Intensity (H): Ampere/meter (A/m).
- Magnetic Flux: Weber (Wb).
- Inductance: Henry (H).
- Acceleration: meter/second² (m/s² or $m \cdot s^{-2}$).
- Weight: Newton (N).
- Volume: Cubic meter (m^3). 1 hectare-cm = 100 m^3.
- Stress: Pascal (Pa) = N/m² (same unit as pressure).
- Thermal Conductivity: Watt per meter Kelvin (W/(m·K) or $W \cdot m^{-1} \cdot K^{-1}$).
- Linear Momentum: kg·m/s = Newton-second (N·s).
- Frequency (Sound): Hertz (Hz), s^{-1}, min^{-1}. Decibel (dB) is a unit for sound intensity level, not frequency.
- Wavelength: Angstrom (Å), where 1 Å = 10^{-10} m.
- High Speed: Mach (dimensionless quantity, defined as the ratio of an object's speed to the speed of sound).
- 1 kilowatt-hour (kWh) = 3.6 × 10^6 Joule (J).

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Dimensional Analysis (Dimensions, Homogeneity, Applications)

- Dimensions: Powers to which fundamental units (Mass M, Length L, Time T, Electric Current A, Temperature K, etc.) are raised to represent a physical quantity.
- Principle of Homogeneity of Dimensions: An equation is dimensionally correct if the dimensions of all the terms on both sides of the equation are the same. Quantities with different dimensions cannot be added or subtracted.
- Dimensionless Quantities:
  - Are expressed as $M^0L^0T^0$.
  - Examples: Specific gravity, relative density, relative permittivity (dielectric constant), strain, angle, refractive index, Reynolds number, trigonometric ratios, Euler's number (e), other mathematical constants (π).
  - Any quantity that is a ratio of two similar physical quantities is dimensionless.
- Common Dimensional Formulas:
  - Force (Thrust): $[MLT^{-2}]$
  - Pressure (Stress, Young's Modulus): $[ML^{-1}T^{-2}]$ (Also same as Energy per unit Volume: $[ML^2T^{-2}]/[L^3] = [ML^{-1}T^{-2}]$)
  - Energy (Work, Heat, Torque): $[ML^2T^{-2}]$
    - Equivalent to Power × Time (e.g., I^2Rt, V^2t/R, VIt).
  - Linear Momentum (Impulse): $[MLT^{-1}]$ (Impulse = Force × Time)
  - Angular Momentum (Planck's Constant 'h', Angular Impulse): $[ML^2T^{-1}]$
    - Planck's constant h = Energy/Frequency.
    - Angular Impulse = Torque × Time.
  - Frequency: $[T^{-1}]$
  - Surface Tension: $[MT^{-2}]$ (Force/Length)
  - Mass Density: $[ML^{-3}]$
  - Specific Weight: $[ML^{-2}T^{-2}]$ (Force/Volume)
  - Specific Heat: $[L^2T^{-2}K^{-1}]$ (Energy/(Mass × Temperature))
  - Electric Field: $[MLT^{-3}A^{-1}]$ (Force/Charge)
  - Electric Potential (Emf, Potential Difference): $[ML^2T^{-3}A^{-1}]$ (Work/Charge)
  - Electric Dipole Moment: [LTA] (Charge × Distance)
  - Electric Flux: $[ML^3T^{-3}A^{-1}]$ (Electric Field × Area)
- Dimensional Equivalence:
  - The ratio of Inductance (L) to Resistance (R), i.e., L/R, has the dimension of Time [T] (time constant of an RL circuit).
  - Time is dimensionally equivalent to Distance/Velocity.
  - The unit of the ratio between Thrust (Force) and Impulse (Force × Time) is the same as that of Frequency ($[T^{-1}]$).
- Distinguishing Dimensions:
  - Moment of Inertia ($[ML^2]$) and Moment of a Force (Torque $[ML^2T^{-2}]$) have different dimensions.
  - Dipole moment, Electric flux, and Electric field have different dimensions.

Errors in Measurement (Types, Absolute, Relative, Percentage, Propagation)

- Error in Measurement: Difference between the true value and the measured value of a quantity.
- Types of Errors:
  - Systematic Errors: Errors that tend to be in one direction (either positive or negative). They arise due to identifiable causes and can be minimized or eliminated.
    - Instrumental Errors: Due to imperfect design or faulty calibration of the instrument (e.g., zero error, wear and tear, using a chain calibrated at one temperature in a different temperature – leads to a cumulative error).
    - Environmental Errors: Due to changes in external conditions like temperature, pressure, humidity (e.g., expansion/contraction of measuring tape with tem-

perature – causes systematic cumulative error).
- Observational/Personal Errors: Due to individual's bias, lack of proper setting of the apparatus, or carelessness in taking observations (e.g., parallax error).
- Errors due to Imperfection in Experimental Technique/Procedure: (e.g., heat loss in calorimetry).
- Cumulative Error: A systematic error that adds up over successive measurements, consistently affecting the result in the same direction (e.g., a short tape will consistently overestimate length, a long chain due to high temperature will consistently under-measure length).
- Negative Error: Occurs when the measured value is less than the true value. (e.g., using an expanded chain at higher temperature; the chain is effectively longer, so it will cover a given distance in fewer applications, leading to an underestimation of the actual length – a negative error that is cumulative).

◦ Random Errors: Errors that occur irregularly and are random in magnitude and direction. They arise due to unpredictable fluctuations in experimental conditions or personal judgment. They cannot be eliminated completely but can be minimized by taking multiple readings and averaging.
- Compensating Error: Random errors often tend to cancel each other out over many observations, meaning the positive and negative errors balance out to some extent.

◦ Gross Errors: Errors due to carelessness of the observer, like reading an instrument incorrectly, recording observations wrongly, or using wrong values in calculations. Can be avoided by being alert and careful.

- Absolute Error (Δa): The magnitude of the difference between the true value (or mean value) and the individual measured value. Δa = |a*mean - ai*|. *Its unit is the same as the measured quantity.*
- *Mean Absolute Error (Δamean): The arithmetic mean of all absolute errors. If amean is the true value, Δamean = (Σ |Δai|) / n.*
- *Relative Error (δa): The ratio of the mean absolute error to the mean value of the quantity being measured. δa = Δamean / amean. It is a dimensionless quantity.*
- *Percentage Error (% Error): The relative error expressed as a percentage. % Error = (Δamean / amean) × 100%. It is a dimensionless quantity.*
- *Propagation of Errors: How errors combine in mathematical operations:*
  - *Error in a Sum or Difference (Z = A ± B): The maximum absolute error is the sum of the absolute errors: ΔZ = ΔA + ΔB.*
  - *Error in a Product or Quotient (Z = A × B or Z = A / B): The maximum relative error is the sum of the relative errors: ΔZ/Z = ΔA/A + ΔB/B.*
  - *Error in a Quantity Raised to a Power (Z = A^n): The maximum relative error is 'n' times the relative error of A: ΔZ/Z = n(ΔA/A).*
  - *Error in a General Combination (Z = A^p B^q / C^r): The maximum relative error is given by: ΔZ/Z = p(ΔA/A) + q(ΔB/B) + r(ΔC/C).*

Least Count of Measuring Instruments

- *Least Count (LC): Smallest measurement an instrument can make accurately.*
- *LC determines the precision of an instrument; a smaller LC means higher precision.*
- *Measurements must be reported with their last significant digit corresponding to the instrument's LC.*
- *Reporting a measurement with precision finer than the instrument's LC is incorrect (implies false precision).*

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- *Example: For a meter scale with LC = 1 mm (or 0.001 m):*
  - *A reading like 25.3 cm (or 253 mm) is appropriate (precision to 1 mm).*
  - *A reading like 25.34 cm (or 253.4 mm) is over-precise (implies 0.1 mm LC).*
  - *A reading like 0.50 mm is over-precise (implies 0.01 mm LC).*
- *Precision vs. Accuracy:*
  - *Precision: Consistency/reproducibility of measurements; fineness of measurement. Directly related to LC.*
  - *Accuracy: Closeness of a measurement to the true value.*

Non-SI Units (e.g., Astronomical Unit, Light-Year, Electron-Volt)

- *Angstrom (Å): Unit of wavelength. 1 Å = 10^{-10} m. Typical atomic sizes are ~1 Å.*
- *Nanometre (nm): Unit of length. 1 nm = 10^{-9} m. Nanotechnology deals with 1-100 nm sized particles.*
- *Micron (µm): Unit of length (micrometre). 1 µm = 10^{-6} m = 10^{-4} cm.*
- *Femtometre (fm) / Fermi: Unit for nuclear sizes. 1 fm = 10^{-15} m. Smallest unit of length among common options.*
- *X-unit (XU): Unit for X-ray wavelengths. 1 XU ≈ 1.002 × 10^{-13} m.*
- *Light-year (ly): Unit of very large distance, especially astronomical distances. It is the distance light travels in vacuum in one Julian year.*
  - *Reason for use: Constant speed of light in vacuum.*
  - *1 ly ≈ 9.461 × 10^{12} km ≈ 9.461 × 10^{15} m.*
- *Astronomical Unit (AU): Unit of distance. Average distance between Earth and the Sun. 1 AU ≈ 1.496 × 10^{11} m.*
- *Parsec (pc): Unit of very large distance. 1 pc ≈ 3.26 light-years ≈ 3.086 × 10^{16} m.*
- *Furlong: Unit of distance. 1 furlong ≈ 201.168 m.*
- *Atmosphere (atm): Non-SI unit of pressure. 1 atm is the pressure exerted by a 760 mm column of mercury at 0 °C. 1 atm ≈ 1.01325 × 10^{5} Pa.*
- *Bar: Non-SI unit of pressure. 1 bar = 10^{5} Pa. 1 atm ≈ 1.01325 bar.*
- *Torr: Non-SI unit of pressure. 1 torr ≈ 133.322 Pa. (1 atm = 760 torr).*
- *Curie (Ci): Non-SI unit of radioactivity. The SI unit is Becquerel (Bq). 1 Ci = 3.7 × 10^{10} Bq.*
- *Carat: Unit of mass for gemstones (e.g., diamonds). 1 carat = 200 mg = 0.2 g.*
- *Horsepower (HP): Non-SI unit of power. 1 HP ≈ 746 W.*
- *Kilowatt-hour (kWh): Commercial unit of electrical energy. 1 kWh = 3.6 × 10^{6} J.*
- *Jiffy: Unit of time (very short interval). Not a unit of distance.*

Physical Quantities (Fundamental and Derived)

- *Physical Quantities are measurable properties of objects or systems.*
- *Fundamental Quantities (Base Quantities): Independent quantities whose units are defined independently.*
  1. *Length (meter, m)*
  2. *Mass (kilogram, kg)*
  3. *Time (second, s)*
  4. *Electric Current (ampere, A)*
  5. *Thermodynamic Temperature (kelvin, K)*
  6. *Amount of Substance (mole, mol)*
  7. *Luminous Intensity (candela, cd)*
- *Derived Quantities: Quantities obtained by mathematically combining fundamental quantities.*
  - *Volume: Unit is m^3 (e.g., Liter is a unit of volume, not fundamental).*
  - *Force: Unit is Newton (N) or kg·m/s^2.*
  - *Pressure: Unit is Pascal (Pa) or N/m^2.*
  - *Energy/Work/Heat: Unit is Joule (J) or Calorie (cal). (Joule and Calorie are units for the same physical quantity - Energy).*
  - *Power: Unit is Watt (W) or J/s.*
  - *Stress: Unit is N/m^2 (same as pressure).*

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- *Scalar Quantities: Have magnitude only, no direction.*
    - *Examples: Energy, Power, Pressure, Temperature, Gravitational Potential, Mass, Length, Time, Distance, Speed.*
- *Vector Quantities: Have both magnitude and direction.*
    - *Examples: Impulse, Force, Velocity, Acceleration, Displacement, Momentum.*
- *Dimensionless (Unitless) Quantities: Quantities that are ratios of two similar physical quantities, hence having no units.*
    - *Example: Strain (change in dimension / original dimension).*
- *Amplitude of Sound Waves: Can be measured in units of:*
    - *Distance (referring to particle displacement from equilibrium).*
    - *Pressure (referring to pressure variation from equilibrium pressure, called pressure amplitude).*

Prefixes for SI Units

- *One nanometer (nm) = 10^{-9} metres (m).*
- *One nanometer (nm) = 10^{-7} cm.*
- *One metre (m) = 10^{9} nanometres (nm).*
- *The word "Nano" is derived from the Greek word "nanos," meaning "dwarf."*
- *Nanotechnology deals with particles typically of the size 10^{-9} m.*
- *One Angstrom (Å) = 10^{-10} m.*
- *The relation between Angstrom and nanometer is 1 nm = 10 Å.*
- *One-millionth part of a gram (10^{-6} g) is known as a microgram (µg).*
- *Prefix 'micro' (µ) denotes 10^{-6}.*
- *Prefix 'nano' (n) denotes 10^{-9}.*

SI Base Units and their Definitions

- *Kelvin (K): SI base unit for thermodynamic temperature. Cannot be negative; 0 K (absolute zero) is the lowest possible temperature.*
- *Candela (cd): SI base unit for luminous intensity.*
- *Ampere (A): SI base unit for electric current.*
- *Kilogram (kg): SI base unit for mass.*
- *Metre (m): SI base unit for length.*
- *Second (s): SI base unit for time.*
- *Newton (N): SI derived unit for force.*
- *Pascal (Pa): SI derived unit for pressure.*
- *Henry (H): SI derived unit for inductance.*
- *Weber (Wb): SI derived unit for magnetic flux.*
- *Coulomb (C): SI derived unit for electric charge.*
- *Kilogram-metre per second (kg·m/s): SI derived unit for momentum.*

Significant Figures

1. *Definition: Significant figures (SF) are the digits in a number that carry meaning contributing to its precision.*
2. *Rules for Determining Significant Figures:*
    - *All non-zero digits are significant. (e.g., 123.45 has 5 SF).*
    - *Zeros between two non-zero digits are significant. (e.g., 101.05 has 5 SF).*
    - *Leading zeros (zeros before the first non-zero digit) are NOT significant. They only indicate the position of the decimal point. (e.g., 0.00051 has 2 SF).*
    - *Trailing zeros (zeros at the end of a number) are significant if the number contains a decimal point. (e.g., 12.00 has 4 SF, 120. has 3 SF).*
    - *Trailing zeros are NOT significant if the number does not contain a decimal point, unless specified by scientific notation. (e.g., 1200 has 2 SF, but 1.200 x 10^3 has 4 SF).*
    - *Exact numbers (e.g., counts, defined constants like the '6' in surface area = $6s^2$) have infinite significant figures and do not limit the SF in a calculation.*
3. *Rules for Arithmetic Operations with Significant Figures:*
    - *Multiplication and Division: The result should retain the same number of significant figures as the quantity with the least number of significant figures involved in the calculation.*