

MECHANICS

DIMENSIONS AND PHYSICAL QUANTITIES

ITEM 1

You are working as a design engineer at a manufacturing company. Your team is developing a new high-precision weighing scale that will be used in laboratories to measure small masses accurately. The device must be calibrated correctly to ensure precision in its measurements. Before proceeding with the design, you need to verify the consistency of the formulas used in the calculations.

Task:

1. Identify the fundamental and derived physical quantities required in the calibration of the weighing scale.
2. Use dimensional analysis to check whether the following equations used in the scale design are dimensionally consistent:
 - The force acting on the mass: $F=mg$
 - The oscillation period of the scale's pan: $T=2\pi\sqrt{\frac{l}{g}}$
3. Explain why dimensional analysis is crucial in verifying these equations before building the prototype.
4. Discuss any potential design challenges that could arise due to errors in dimensions and how they can be corrected.

ITEM 2

You are an engineer working on the construction of a bridge. The bridge's support beams must be designed to withstand the forces acting on them without bending excessively. You need to determine whether the stress equation used in the design is dimensionally consistent.

Task:

1. Identify the fundamental and derived quantities involved in stress calculation.
2. Use dimensional analysis to verify the equation for stress: $\sigma = \frac{F}{A}$ where F is the applied force and A is the cross-sectional area.
3. Explain why ensuring dimensional consistency is important in structural engineering.
4. Discuss potential problems if an incorrect formula is used and how to resolve them.

4. Discuss the risks of using incorrect dimensions in medical applications and how to avoid them.

ITEM 7

You are an electrical engineer designing power transmission cables. The equation used to calculate electrical resistance must be verified before selecting materials.

Task:

1. Identify the fundamental and derived quantities related to electrical resistance.
2. Use dimensional analysis to check the equation: $R = \rho \frac{L}{A}$ where R is resistance, ρ is resistivity, L is length, and A is cross-sectional area.
3. Explain why using correct dimensions is essential in electrical circuit design.
4. Discuss the risks of incorrect resistance calculations in electrical grids.

ITEM 8

You are a sports scientist analysing the motion of sprinters to optimize their performance. The equations used to calculate acceleration and force must be verified for accuracy.

Task:

1. Identify the fundamental and derived quantities involved in an athlete's motion.
2. Use dimensional analysis to check the validity of the equation: $v = u + at$ where v is final velocity, u is initial velocity, a is acceleration, and t is time.
3. Explain why verifying dimensions is necessary in sports biomechanics.
4. Discuss how incorrect calculations could affect an athlete's performance analysis.

ITEM 9

You are a marine engineer designing cargo ships. The ship's buoyancy force must be accurately calculated to ensure it remains afloat with different loads.

Task:

1. Identify the fundamental and derived quantities related to buoyancy.
2. Use dimensional analysis to verify Archimedes' principle: $F_B = \rho gV$ where F_B is buoyant force, ρ is fluid density, g is gravitational acceleration, and V is displaced volume.
3. Explain why correct dimensional analysis is essential in ship design.
4. Discuss how incorrect calculations could lead to ship instability.

ITEM 3

You are an astrophysicist designing a communication satellite that will orbit Earth. The satellite's velocity must be calculated correctly to ensure it remains in a stable orbit.

Task:

1. Identify the fundamental and derived quantities needed to describe the motion of a satellite.
2. Use dimensional analysis to verify the equation for orbital velocity: $v = \sqrt{\frac{GM}{r}}$ where G is the gravitational constant, M is the Earth's mass, and r is the orbital radius.
3. Explain the importance of using correct dimensions in space mission planning.
4. Discuss potential challenges if incorrect values are used in calculations and how they could be corrected.

ITEM 4

You are a mechanical engineer working on the braking system of an electric car. You need to verify whether the equation for braking force is dimensionally consistent to ensure passenger safety.

Task:

1. Identify the fundamental and derived quantities involved in stopping a moving car.
2. Verify the dimensional consistency of the equation: $F=ma$ where F is the braking force, m is the car's mass, and a is acceleration.
3. Explain the significance of checking dimensions in car safety systems.
4. Discuss how errors in dimensional analysis could lead to mechanical failure.

ITEM 6

You are a biomedical engineer designing a device to measure blood pressure. The velocity of blood flow in arteries must be calculated accurately for diagnosing heart conditions.

Task:

1. Identify the fundamental and derived quantities related to blood flow.
2. Use dimensional analysis to verify the Bernoulli equation applied to blood flow: $P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$ where P is pressure, ρ is blood density, v is velocity, g is gravitational acceleration, and h is height.
3. Explain why checking dimensional consistency is critical in medical device development.