

Name: _____ Date: _____

Answer Key: Cosmic Navigators: Senior Year Precision & Dimensional Analysis Quiz

Synthesize complex SI conversions and evaluate measurement uncertainty to calculate trajectories across astronomical and microscopic scales.

1. A research team is measuring the hyperfine transition frequency of a Caesium-133 atom to redefine a local timescale. Which SI base unit are they fundamentally refining, and what physical constant is now fixed to define it?

Answer: A) The Second; based on the fixed numerical value of the Caesium frequency $\Delta\nu_{Cs}$.

Since 2019, the SI second is defined by taking the fixed numerical value of the caesium frequency $\Delta\nu_{Cs}$, the unperturbed ground-state hyperfine transition frequency of the caesium-133 atom, to be 9,192,631,770 when expressed in the unit Hz.

2. An astrophysicist calculates the Schwarzschild radius of a black hole to be 4.25×10^4 meters with an instrumental uncertainty of ± 300 meters. The relative uncertainty of this measurement is approximately _____.

Answer: B) 0.71%

Relative uncertainty is calculated by dividing the absolute uncertainty by the measured value ($300 / 42,500 = 0.007058$), then multiplying by 100 to get 0.71%.

3. True or False: In a complex multi-step physics derivation, the Planck constant (h) can be expressed in the derived SI units of $\text{kg}\cdot\text{m}^2/\text{s}$.

Answer: A) True

The Planck constant is measured in Joule-seconds (J·s). Since a Joule is $1 \text{ kg}\cdot\text{m}^2/\text{s}^2$, multiplying by seconds results in $\text{kg}\cdot\text{m}^2/\text{s}$.

4. A mass spectrometer measures the ratio of m/z (mass-to-charge). If the mass is recorded in unified atomic mass units (u) and charge in elementary charge (e), which conversion factor is necessary to translate the result into the SI derived unit of kg/C ?

Answer: B) Multiply by $1.66 \times 10^{-27} \text{ kg}/\text{u}$ and divide by $1.60 \times 10^{-19} \text{ C}/\text{e}$.

To convert to SI, the mass in 'u' must be multiplied by the atomic mass constant (approx. $1.66 \times 10^{-27} \text{ kg}$) and the charge 'e' must be divided by the elementary charge in Coulombs (approx. $1.60 \times 10^{-19} \text{ C}$).

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5. In the analysis of thermal conductivity, the unit $W/(m \cdot K)$ is used. When decomposed into SI base units (kg, m, s, K), the power aspect (Watt) results in the numerator being _____.

Answer: C) $kg \cdot m^2/s^3$

A Watt is a Joule per second (J/s). A Joule is $kg \cdot m^2/s^2$. Therefore, $J/s = kg \cdot m^2/s^3$.

6. True or False: According to the International Bureau of Weights and Measures (BIPM), the kilogram is currently defined by a physical prototype made of platinum-iridium kept in a vault in Sèvres, France.

Answer: B) False

Since May 2019, the kilogram has been redefined in terms of the Planck constant (h) rather than a physical artifact.

7. When performing Taylor series expansions in physical modeling, why must the argument of a transcendental function (like $\ln(x)$ or e^x) be dimensionless?

Answer: B) To ensure the sum of the power series has consistent dimensions across all terms.

In an expansion like $1 + x + x^2/2!$, adding terms requires each term to have the same dimensions. If 'x' had units (like meters), you would be adding meters to meters squared, which is physically impossible; thus, x must be dimensionless.

8. A volumetric flask is calibrated to 500.00 mL. If a student records a series of measurements as 498.12 mL, 498.11 mL, and 498.13 mL, the data set is _____.

Answer: D) Precise but not accurate.

The measurements are very close to each other (high precision/low standard deviation) but far from the true value of 500.00 mL (low accuracy/high systematic error).

9. True or False: The mole is defined as the amount of substance containing exactly $6.02214076 \times 10^{23}$ elementary entities, a definition that no longer depends on the mass of Carbon-12.

Answer: A) True

The 2019 redefinition fixed Avogadro's number as an exact constant, decoupling the definition of the mole from the mass of Carbon-12.

10. In fluid dynamics, the Reynolds number (Re) is used to predict flow patterns. If $Re = (\rho v d)/\mu$ where ρ is density, v is velocity, d is diameter, and μ is dynamic viscosity, what must be the SI base units of dynamic viscosity for the Reynolds number to remain dimensionless?

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Answer: A) $\text{kg}/(\text{m}\cdot\text{s})$

Dimensional analysis: $[\rho]=\text{M}/\text{L}^3$, $[\nu]=\text{L}/\text{T}$, $[d]=\text{L}$. The numerator is $(\text{M}/\text{L}^3)(\text{L}/\text{T})(\text{L}) = \text{M}/(\text{L}\cdot\text{T})$. For the ratio to be dimensionless, μ must also have units of $\text{M}/(\text{L}\cdot\text{T})$, which is $\text{kg}/(\text{m}\cdot\text{s})$.