2024 Academic Challenge
PHYSICS TEST - STATE

Physics Test Production Team
Steven Daniels, Eastern Illinois University – Author/Team Leader
Eric Dongheon Ha, Eastern Illinois University – Author
Don Pakey, Eastern Illinois University – Reviewer
Aaron White, Illinois Academic Challenge – Coordinator of Test Production

GENERAL DIRECTIONS

Please read the following instructions carefully. This is a timed test; any instructions from the test supervisor should be followed promptly.

The test supervisor will give instructions for filling in any necessary information on the answer sheet. Most Academic Challenge sites will ask you to indicate your answer to each question by marking an oval that corresponds to the correct answer for that question. Only one oval should be marked to answer each question. Multiple ovals will automatically be graded as an incorrect answer.

Be sure ovals are marked as ⬤ , not ⊙ , ⦶ , ◐ , etc.

If you wish to change an answer, erase your first mark completely before marking your new choice.

You are advised to use your time effectively and to work as rapidly as you can without losing accuracy. Do not waste your time on questions that seem too difficult for you. Go on to the other questions, and then come back to the difficult ones later if time remains.

TIME: 40 MINUTES NUMBER OF QUESTIONS: 35

DO NOT OPEN TEST BOOKLET UNTIL YOU ARE TOLD TO DO SO!

Fundamental Constants

Quantity	Symbol	Value
Avogadro's number	N_A	**6.022×10^{23}/mol**
Boltzmann's constant	k	**1.381×10^{-23} J/K**
Electron charge magnitude	e	**1.602×10^{-19} C**
Permeability of free space	μ_0	**$4\pi \times 10^{-7}$ T·m/A**
Permittivity of free space	ε_0	**8.854×10^{-12} $C^2/(N \cdot m^2)$**
Electrostatic Constant	$k = (4\pi\varepsilon_0)^{-1}$	**8.988×10^{9} $N \cdot m^2/C^2$**
Planck's constant	h	**6.626×10^{-34} J·s**
Electron mass	m_e	**9.1094×10^{-31} kg**
Neutron mass	m_n	**1.6749×10^{-27} kg**
Proton mass	m_p	**1.6726×10^{-27} kg**
Speed of light in vacuum	c	**2.9979×10^{8} m/s**
Universal gravitational constant	G	**6.673×10^{-11} $N \cdot m^2/kg^2$**
Universal gas constant	R	**8.3145 J/(mol·K)**

Other information:

Acceleration due to gravity at Earth's surface: $g = 9.80$ m/s^2

0.00 ^{o}C = 273.15 K

Academic Challenge
Physics Test (State) – 2024

1. Platinum has a density of 21.45 grams per cubic centimeter. What is the equivalent value in kilograms per cubic meter?
a. 2.145×10^2 kg/m^3 b. 2.145×10^3 kg/m^3 c. 2.145×10^4 kg/m^3
d. 2.145×10^5 kg/m^3 e. 2.145×10^6 kg/m^3

2. If $\vec{r} = at^3\hat{x} + bt^4\hat{y}$, where a and b are positive constants, when does the velocity vector make an angle of 45° with the *x*- and *y*-axes?
a. $t = \frac{a}{b}$ b. $t = \frac{b}{a}$ c. $t = \frac{a^3}{b^4}$ d. $t = \frac{3a}{4b}$ e. $t = \frac{4a}{3b}$

3. The location of a small airplane weighing 5×10^5 N is given by the equation

$$\vec{r} = (0.03\ \mathrm{m/s^4})t^4\hat{x} + (2\ \mathrm{m/s^3})t^3\hat{y} - (0.5\ \mathrm{m/s^2})t^2\hat{z}$$

Calculate the net force acting on the plane when $t = 10$ s. [Newton's second law]
a. $(0.36 \times 10^5\ \mathrm{N})\ \hat{x} + (1.2 \times 10^5\ \mathrm{N})\ \hat{y} - (1 \times 10^4\ \mathrm{N})\hat{z}$
b. $(0.15 \times 10^5\ \mathrm{N})\ \hat{x} + (1 \times 10^6\ \mathrm{N})\ \hat{y} - (2.5 \times 10^5\ \mathrm{N})\hat{z}$
c. $(1.84 \times 10^6\ \mathrm{N})\ \hat{x} + (6.12 \times 10^6\ \mathrm{N})\ \hat{y} - (5.1 \times 10^4\ \mathrm{N})\hat{z}$
d. $(1.96 \times 10^6\ \mathrm{N})\ \hat{x} + (8.36 \times 10^6\ \mathrm{N})\ \hat{y} - (9.3 \times 10^6\ \mathrm{N})\hat{z}$
e. $(3.6 \times 10^7\ \mathrm{N})\ \hat{x} + (1.2 \times 10^8\ \mathrm{N})\ \hat{y} - (1 \times 10^4\ \mathrm{N})\hat{z}$

4. A launcher propels an object with mass *M* from level ground. The object is launched at an angle *θ* above the horizontal and stays airborne for a duration *T* before returning to the ground. Considering that the launcher imparts the initial velocity, what is the amount of work performed on the object by the launching device? Ignore the air resistance.
a. $2M\left(\frac{gT}{\sin\theta}\right)^2$ b. $\frac{M}{2}\left(\frac{gT}{\sin\theta}\right)^2$ c. $\frac{M}{4}\left(\frac{gT}{\sin\theta}\right)^2$ d. $\frac{M}{8}\left(\frac{gT}{\sin\theta}\right)^2$ e. $\frac{M}{64}\left(\frac{gT}{\sin\theta}\right)^2$

5. In the scenario described in the previous problem, what amount of work is done on the object if it is launched at the same angle *θ* but remains airborne for four times the duration?
a. $2M\left(\frac{gT}{\sin\theta}\right)^2$ b. $\frac{M}{2}\left(\frac{gT}{\sin\theta}\right)^2$ c. $\frac{M}{4}\left(\frac{gT}{\sin\theta}\right)^2$ d. $\frac{M}{8}\left(\frac{gT}{\sin\theta}\right)^2$ e. $\frac{M}{64}\left(\frac{gT}{\sin\theta}\right)^2$

6. A lightweight container is suspended from a vertical spring scale possessing a force constant of 2000 N/m. If a 5 kg object is placed in the container and released from rest, what will be the maximum distance the spring stretches as it oscillates?
a. 2.45 cm b. 4.9 cm c. 9.8 cm d. 24.5 cm e. 48 cm

7. While moving at a speed of 5 m/s, a 50 kg shark unexpectedly consumes a 10 kg octopus that was initially at rest. What is the total amount of mechanical energy dissipated during this feeding event? Disregard any drag effects from the water.

a. 104 J b. 250 J c. 500 J d. 521 J e. 625 J

8. An electric motor, starting from rest, accelerates at a constant rate of 8 rad/s^2. How long does it take for the motor to reach an angular velocity of 50 rad/s?

a. 0.99 s b. 1.99 s c. 6.25 s d. 19.63 s e. 39.27 s

9. A person stands in the center of a turntable. The turntable itself possesses a moment of inertia of 2 kg·m^2. With a consistent torque of 4 N·m, the system of the turntable and person requires 5 s to accelerate from rest to an angular speed of 1.5 rad/s. What is the moment of inertia of the person? All torques and moments of inertia are measured relative to the center of the turntable, and we are disregarding friction in the turntable axle.

a. 0.67 kg·m^2 b. 8 kg·m^2 c. 11.33 kg·m^2
d. 18.67 kg·m^2 e. 20 kg·m^2

10. A rocket is moving at a non-relativistic speed in a gravity-free region of space and experiences no atmospheric drag. At a specific moment, the rocket (including fuel) has a mass of *M* (unit: kg), expels fuel mass at a rate of *R* (unit: kg/s), and the expelled fuel has an exhaust velocity relative to the rocket of *u* (unit: m/s). Relative to an inertial frame, what is the magnitude of the acceleration of the rocket at this instant? Utilize dimensional analysis to derive the solution to this problem.

a. $\frac{R \cdot u}{M}$ b. $\frac{R \cdot M}{u}$ c. $\frac{M \cdot u}{R}$ d. $\frac{R}{M \cdot u}$ e. $\frac{M}{R \cdot u}$

11. A 35 kg object is suspended from the lower end of a 2-meter-long wire fastened to the ceiling. The time it takes for a transverse pulse to travel from the bottom to the top of the wire is 0.04 seconds. Calculate the mass of the wire.

a. 0.137 kg b. 0.274 kg c. 3.43 kg d. 6.86 kg e. 13.72 kg

12. By what factor should the sound intensity be increased to achieve a 15 dB rise in the sound intensity level?

a. 1.5 b. 4.64 c.9.28 d.15 e. 31.62

13. An infinitely long, straight wire has a line charge density of 2.5×10^{-10} C/m. At what distance from the wire does the electric field magnitude reach 4 N/C?

a. 1.124 m b. 2.247 m c. 4.494 m d. 7.059 m e. 8.988 m

14. If a wire of resistance R is stretched to four times its original length, what will be its resistance in terms of *R*? Assume that the density and resistivity of the material remain constant during the stretching process, and that the amount of material does not change.
a. $0.25R$ b. $2R$ c. $4R$ d. $8R$ e.$16R$

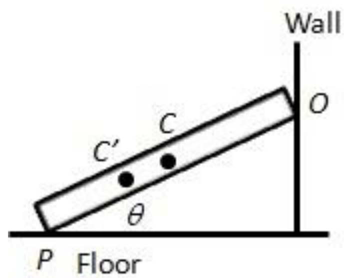
15. The critical angle for total internal reflection at a liquid-vacuum interface is 48°. If a light ray traveling through the liquid approaches the interface with an angle of incidence of 30°, what is the angle at which the refracted ray in the vacuum deviates from the surface normal?
a. 30.6° b. 33.1° c. 36.7° d. 41.7° e. 42.3°

16. A laser beam with a wavelength of 535 nm travels through a vacuum and strikes the perfectly flat end of a transparent rod at normal incidence. The rod, which has an index of 1.45 and is considerably longer than the wavelength (535 nm) of the incoming light, is coated with a thin layer of transparent dielectric material on its end. The dielectric material has an index of refraction of 1.55. What is the minimum nonzero thickness of this thin dielectric coating required to maximize the transmission of light into the rod?
a. 86.3 nm b. 172.6 nm c. 184.5 nm d. 345.2 nm e. 369.0 nm

17. The surface of a blackbody radiator emits a total power of 1 W when the surface temperature is 0 ºC. What is the total power emitted by the surface when the temperature increases to 300 ºC?
a. 3.14 W b. 19.39 W c. 21.74 W d. 136.58 W e. 273.15 W

18. Which of the following particles is a lepton?
a. graviton b. axion c. magnetic photon
d. electron e. proton

19. A long, thin object of length L and mass m is in static equilibrium with one end leaning against a frictionless wall at point O and the other end of being in contact with the floor at point P, as shown in the diagram. The coefficient of static friction between the object and the floor is μ_s, and the object makes an angle θ with respect to the horizontal. If the weight is redistributed so the center of mass moves from the geometrical center C to C', which statement below is correct?



a. The normal force exerted by the floor on the object increases.
b. The normal force exerted by the floor on the object decreases.
c. The minimum value of θ for static equilibrium increases.
d. The minimum value of θ for static equilibrium decreases.
e. The minimum value for θ stays the same.

20. During a certain 6.00 s time interval, the potential energy of a system changes from 10.0 J to 90.0 J and the kinetic energy of the system changes from 65.0 J to 40.0 J. What is the average power applied to the system by external forces during the specified time interval?

a. 4.17 W b. 4.17 hp c. 9.17 W d. 13.3 W e. 17.5 W

21. A satellite is in a geosynchronous orbit. That means that it is an orbit with a period of 24 hours so that the satellite is always directly above the same point on the equator. Which statement is true about this satellite?

a. The satellite is not accelerating.
b. The satellite is in a state of free fall toward the Earth.
c. There is a tangential force that helps the satellite to keep up with the Earth's rotation.
d. The force of gravity toward the center of the Earth is balanced by a force away from the center of the Earth.
e. The force of gravity is neutralized by the distance.

22. At what temperature is the Kelvin scale reading equal to 3 times the Fahrenheit scale reading?

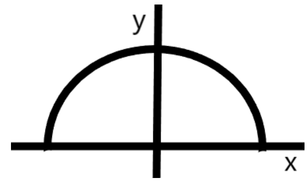
a. 85.1°F b. 91.0°F c. 104°F d. 574°F e. 1150°F

23. An electron has a total energy of 3.33 times its rest energy of 0.511 MeV. What is the momentum of this electron?

a. $0.487\frac{MeV}{c}$ b. $0.954\frac{MeV}{c}$ c. $1.19\frac{MeV}{c}$

d. $1.62\frac{MeV}{c}$ e. $3.18\frac{MeV}{c}$

24. Where is the center of mass of this semicircular hoop of uniform linear density λ, total mass M, and radius R? The coordinate system is as shown and the ordered pairs are (x, y).



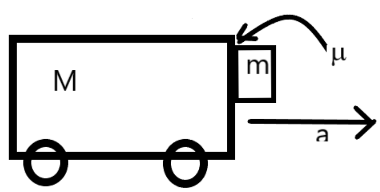
a. (0, 0)   b. (0, R/2)   c. (0, R/π)   d. (0, 2R/π)   e. (R, 0)

25. In an isothermal expansion of an ideal gas from volume V_1 to V_2 what is the work done by the gas?

a. $nRT(V_2 - V_1)$ b. $\frac{3}{2}nRT$ c. $\frac{nRT}{\gamma+1}({V_2}^{\gamma+1} - {V_1}^{\gamma+1})$

d. $nRT({V_2}^2 - {V_1}^2)$ e. $nRT\left\{ln\frac{V_2}{V_1}\right\}$

26. Consider a cart of mass 8.19 kg that is on frictionless wheels. A wooden block of mass 1.23 kg is on the vertical surface at the front of the cart. The coefficient of static friction between the cart and the block is 0.379. What is the minimum acceleration of the cart such that the block stays on the front of the cart without sliding down?



a. 3.71 m/s^2 b. 12.8 m/s^2 c. 25.9 m/s^2 d. 31.8 m/s^2 e. 29.4 m/s^2

27. A block of mass m is released from rest at the top of a rough ($\mu_k > 0$) incline of length L that makes an angle θ above the horizontal. The block reaches the end of the incline in a time t. What is the time t?

a. $\sqrt{\frac{2L}{gsin\theta - \mu_k gcos\theta}}$ b. $\sqrt{\frac{L}{gsin\theta - \mu_k gcos\theta}}$ c. $\sqrt{\frac{2L}{gcos\theta - \mu_k gsin\theta}}$

d. $\sqrt{\frac{L}{gcos\theta - \mu_k gsin\theta}}$ e. $\sqrt{\frac{4L}{gcos\theta - \mu_k gsin\theta}}$

28. Amy is at the top of a 11.7 m tall building. She hits a ball horizontally from the top with an initial speed of 6.32 m/s. There is an open field with a fence that is 9.33 m from the building and 2.00 m tall in the direction that Amy hits the ball. Which of the following statements is true?
    a. The ball first strikes the ground inside the fence.
    b. The ball first strikes the fence on the side nearest the building.
    c. The ball first strikes the fence on the top of the fence.
    d. The ball first strikes the ground outside of the fence.
    e. Cannot be determined from the given information.

29. As a continuation of problem 29, Amy hits the ball from the roof at an angle of 40.0° above the horizontal with a new initial velocity. The ball lands 25.0 m from the building. What is the magnitude of the velocity she hit the ball with this time?

    a. 6.32 m/s b. 12.6 m/s c. 13.4 m/s d. 15.8 m/s e. 16.2 m/s

30. A certain force is given by $\vec{\boldsymbol{F}} = Cx^2y\hat{x} + Cx^2y\hat{\boldsymbol{y}}$ What is the potential energy function associated with this force?

    a. 2Cxy b. 4Cxy c. Cx^2 d. $2Cxy + Cx^2$

    e. This force is not conservative and has no potential energy function.

31. Mimas is a moon of Saturn. It has a radius of 198 km (consider it spherical for this problem). It follows a circular orbit around Saturn of radius 1.86×10^5 km. The orbital period is 22 hours 36 minutes. Mimas also rotates on its axis with a period of 22 hours 36 minutes. The mass of Mimas is 3.75×10^{19} kg. What is the moment of inertia of Mimas about the axis through the center of Saturn and perpendicular to the radius of the orbit vector? The moment of inertia of a sphere on an axis through the center of the sphere is $\frac{2}{5}MR^2$.

    a. $5.88 \times 10^{23}\ kg\ m^2$ b. $5.19 \times 10^{29}\ kg\ m^2$ c. $5.88 \times 10^{29}\ kg\ m^2$

    d. $5.19 \times 10^{35}\ kg\ m^2$ e. $1.30 \times 10^{36}\ kg\ m^2$

32. As a continuation of problem 31, what is the angular momentum of Mimas about the center of Saturn?

    a. $5.37 \times 10^{23}\ kg\ \frac{m^2}{s}$ b. $4.54 \times 10^{25}\ kg\ \frac{m^2}{s}$ c. $1.59 \times 10^{31}\ kg\ \frac{m^2}{s}$

    d. $1.00 \times 10^{32}\ kg\ \frac{m^2}{s}$ e. $6.03 \times 10^{33}\ kg\ \frac{m^2}{s}$

33. If tissue from a Columbian Mammoth was found in the Rocky Mountains we could use Carbon dating to determine when it lived. The isotope of Carbon used is ${}^{14}_{6}C$ with an atomic weight of 14.0 AMU and a radioactive half-life of 5730 years. Upon testing the percentage of ${}^{14}_{6}C$ in the mammoth tissue is 22.0% of that found in living tissue today. When did this Columbian Mammoth die? Ignore any variation in time of the atmospheric ${}^{14}_{6}C$ concentration.

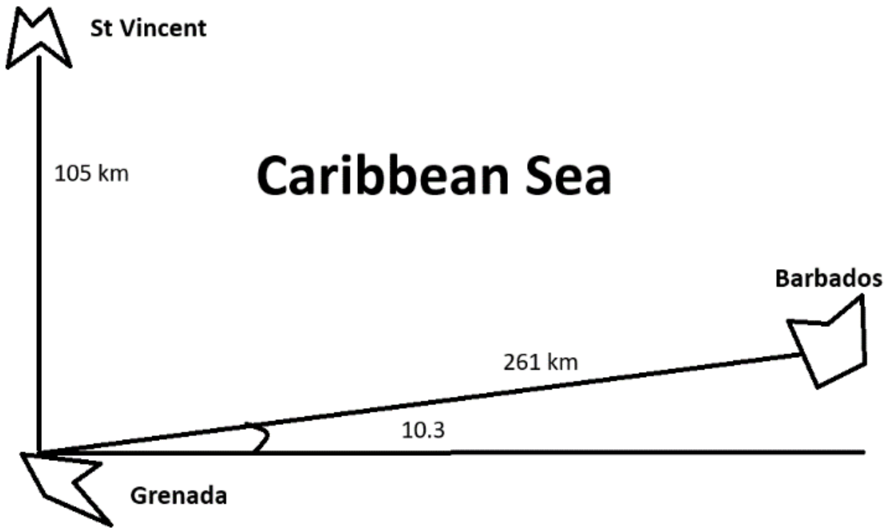
a. 26000 years ago b. 12500 years ago c. 8680 years ago

d. 5440 years ago e. 2050 years ago

34. Consider a tennis pro returning a serve. The tennis ball makes a collision with the racquet. Initially both are moving in opposite directions. Consider the motion of both to be entirely along the x axis. During the collision the ball reverses its direction of motion, while the racquet continues in its original direction. The ball must stop momentarily before reversing direction. Which of these statements is true about the system at the time that the ball stops? Consider F_b and F_R to be the force on the ball and racquet respectively and a_b and a_R to be the magnitude of the acceleration of the ball and racquet respectively. Also, neglect any force that might be applied by the tennis pro.

a. $F_b = F_R$ and $a_b = a_R$
b. $F_b = F_R$ and $a_b > a_R$
c. $F_b > F_R$ and $a_b = a_R$
d. $F_b = F_R$ and $a_b < a_R$
e. $F_b > F_R$ and $a_b > a_R$

35. Consider this map of some islands in the Caribbean Sea. For the purposes of this problem St. Vincent is 105 km due north of Granada and Barbados is 10.3° N of E and a distance of 261 km away from Grenada. Captain Kupitz directs her vessel to start off from Grenada directly towards Barbados with a speed of 5.01 km/hr relative to the water and makes no further corrections to her course. After 15.0 hours, she finds herself at St. Vincent. Assuming that the ocean currents were solely responsible for Captain Kupitz's misdirection, and that those currents are constant, what is the velocity of those currents?



a. $1.94\ \frac{m}{s}\ due\ North$
b. $4.93\ \frac{km}{hr}\ at\ 51.1°\ West\ of\ North$
c. $6.10\ \frac{km}{hr}\ at\ 51.1°\ South\ of\ East$
d. $6.41\ \frac{km}{hr}\ at\ 38.9°\ North\ of\ West$
e. $7.85\ \frac{km}{hr}\ at\ 38.9°\ West\ of\ North$

SCRATCH PAPER