2024 Academic Challenge
PHYSICS TEST - SECTIONAL

Physics Test Production Team
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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)

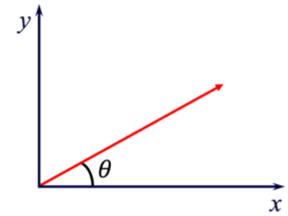
Other information:

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

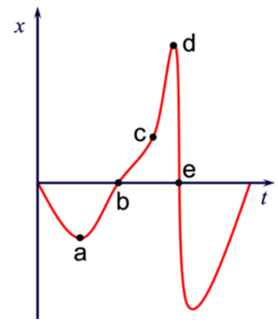
0.00 ^oC = 273.15 K

Academic Challenge
Physics Test (Sectional) – 2024

1. In a vacuum, with the speed of light *c* and 1 ft equivalent to 0.3048 m, what is the time, in nanoseconds, it takes for light to traverse a distance of 2 ft? [Unit conversion]
a. 1.0167 ns b. 1.0334 ns c. 1.0567 ns d.2.0167 ns e. 2.0334 ns



2. Consider the angle θ, measured counterclockwise from the positive *x*-axis as illustrated. Among these vectors, which one has the greatest θ? [Components of vectors]
a. $48\,\hat{x} + 36\,\hat{y}$ b. $-48\,\hat{x} - 36\,\hat{y}$ c. $-36\,\hat{x} + 48\,\hat{y}$
d. $-36\,\hat{x} - 48\,\hat{y}$ e. $36\,\hat{x} - 48\,\hat{y}$



3. The *x*-*t* graph illustrating the motion of an object along the *x*-axis is displayed. At which of the five points (a–e) is the velocity v_x greatest? [Instantaneous velocity]
a. Point a b. Point b c. Point c d. Point d e. Point e

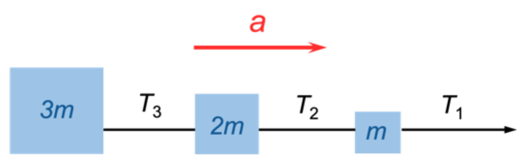
4. A ball is launched at an angle of 50° above the horizontal and hits a building 20 m away, positioned 10 m above its launch point. Determine the magnitude of the ball's initial velocity (*i.e.*, the velocity at which the ball is thrown), assuming no influence from air resistance. [Two-dimensional projectile motion]
a. 17.52 m/s b. 18.52 m/s c. 19.52 m/s d. 20.52 m/s e. 21.52 m/s

5. An object is in motion along a horizontal circle at a consistent speed, *v*. The time required for the object to complete one full revolution is denoted as *T* seconds. If the speed doubles, what adjustment factor is needed for the period *T* to ensure that the centripetal (radial) acceleration, a_c, remains constant? To arrive at the solution, begin by formulating an expression for the centripetal (radial) acceleration, a_c, of the object in terms of *v* and *T*, without explicitly incorporating the radius of the horizontal circle, *r*. [Motion in a circle]
a. *T* must be halved to keep a_c the same
b. *T* must be the same to keep a_c the same
c. *T* must be doubled to keep a_c the same
d. *T* must be tripled to keep a_c the same
e. *T* must be quadrupled to keep a_c the same

6. In the preceding question, how should the period T change to ensure the centripetal (radial) acceleration, a_c, remains constant when the radius of the horizontal circle, r, doubles? [Motion in a circle]

a. T must be increased by $\sqrt{2}$ to keep a_c the same
b. T must be decreased by $\sqrt{2}$ to keep a_c the same
c. T must be increased by 2 to keep a_c the same
d. T must be decreased by 2 to keep a_c the same
e. T must be increased by 4 to keep a_c the same

7. Three blocks of mass 3m, 2m, and m are connected by strings and pulled with constant acceleration a. What is the relationship between the tension in each of the strings? [Newton's second law]



a. $T_1 > T_2 > T_3$ b. $T_1 < T_2 < T_3$ c. $T_1 = T_2 = T_3$
d. All tensions are zero e. Tensions are random

8. If you have a standard weight of 600 N and stand on a scale inside an elevator undergoing upward acceleration at a rate of 3 m/s², what will be the reading on the scale? [Newton's second law]

a. 416 N b. 784 N c. 1800 N d. 4080 N e. 5880 N

9. A car of mass 500 kg is pushing a truck of mass 1000 kg on a level road. The car exerts a horizontal force of 2000 N on the truck. What is the magnitude of the force that the truck exerts on the car? [Newton's third law]

a. 0 N b. 1000 N c. 1500 N d. 2000 N e. 4000 N

10. To keep a 20 kg box moving at a constant speed of 4 m/s on a horizontal surface with a coefficient of kinetic friction of 0.3, what horizontal force is required? [Newton's first law, Newton's second law, Friction forces]

a. 6 N b. 24 N c. 59 N d. 80 N e. 653 N

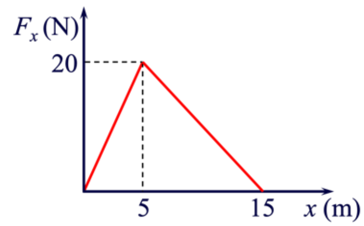
11. How much distance does the box slide before it comes to a stop when the force calculated in the previous problem is no longer applied? [Newton's second law, Motion with constant acceleration]

a. 0.3675 m b. 2.72 m c. 3.44 m d. 4.72 m e. 5.44 m

12. What are the physical dimensions of mechanical work, when [L] = length, [M] = mass, and [T] = time? [Work, Dimensional analysis, Previous exam: 2014 State Problem 2]
a. $[M]^2[L]/[T]$ b. $[M][L]^2/[T]$ c. $[M]^2[L]/[T]^2$
d. $[M][L]^2/[T]^2$ e. $[M]^2[L]^2/[T]^2$

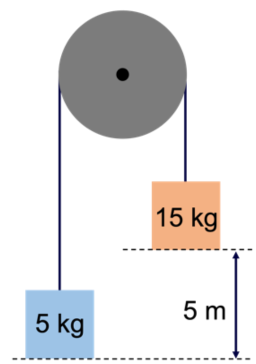
13. Two SUVs pull a disabled trailer. Each SUV exerts a constant force of 5×10^5 N, one 10° west of north and the other 10° east of north, as they pull the trailer 1 km toward the north. What is the total work they do on the trailer? [Work]
a. 8.68×10^7 J b. 1.74×10^8 J c. 4.92×10^8 J d. 9.85×10^8 J
e. 4.92×10^9 J

14. A person applies a force $\vec{F}$ parallel to the x-axis to a 20 kg sled moving on a surface. As the person controls the speed of the sled, the x-component of the force he/she applies varies with the x-coordinate of the sled, as shown in the figure. Determine the work done by $\vec{F}$ when the sled moves from x = 0 to 15 m. [Work and energy with varying forces]



a. 100 J b. 150 J c. 200 J d. 250 J e. 300 J

15. Two boxes connected by a lightweight rope are released from rest, with the 15 kg box positioned 5 m above the floor. Utilize the principle of conservation of energy to determine the speed at which the box strikes the floor. Disregard friction and the mass of the pulley. [Conservation of energy]



a. 7 m/s b. 49 m/s c. 75 m/s d. 98 m/s e. 196 m/s

16. On a frictionless, horizontal air table, puck A, with a mass of 0.4 kg, is in motion towards puck B, which initially rests with a mass of 0.55 kg. Following the collision, puck A moves to the left with a velocity of 0.15 m/s, and puck B moves to the right with a velocity of 0.75 m/s. What was the initial speed of puck A before the collision? [Conservation of momentum]
a. 0.481 m/s b. 0.581 m/s c. 0.681 m/s
d. 0.781 m/s e. 0.881 m/s

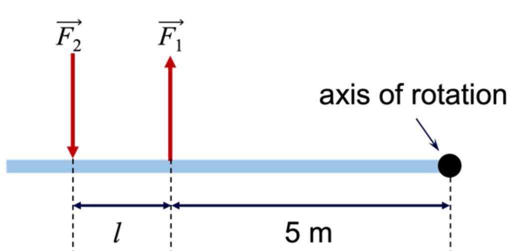
17. A 0.2 kg glider (Glider A) is moving to the right with a speed of 0.9 m/s on a frictionless, perfectly horizontal air track. The glider has a head-on collision with a 0.3 kg glider (Glider B) that is moving to the left with a speed of 2 m/s. Find the final velocity of each glider if the collision is elastic. [Conservation of momentum, Elastic collision]
a. Glider A will move to the left at 2.58 m/s, and Glider B will move to the right at 0.32 m/s.
b. Glider A will move to the right at 2.58 m/s, and Glider B will move to the left at 0.32 m/s.
c. Glider A will move to the left at 0.32 m/s, and Glider B will move to the right at 2.58 m/s.
d. Glider A will move to the right at 0.32 m/s, and Glider B will move to the left at 2.58 m/s.
e. Glider A will move to the left at 0.32 m/s, and Glider B will move to the left at 2.58 m/s.

18. A 1kg uniform cube with a volume of 0.125 m^3 rests on the floor. On top of the cube is a uniform sphere with a diameter of 0.6 m and a mass of 0.9 kg. What is the distance from the floor to the center of mass of the two-object system? [Center of mass]
a. 0.125 m above the floor   b. 0.3 m above the floor   c. 0.392 m above the floor
d. 0.5 m above the floor   e. 0.511 m above the floor

19. Starting from rest, a flywheel with a radius of 0.5 m experiences a constant angular acceleration of 1.2 rad/s^2. What is the resultant acceleration magnitude for a point on the rim after 2 seconds of acceleration? [Relating linear and angular kinematics]
a. 0.6 m/s^2 b. 2.88 m/s^2 c. 2.94 m/s^2 d. 3.48 m/s^2 e. 4.08 m/s^2

20. The total angular momentum of a system is a conserved quantity only if ____________________. [Conservation of angular momentum, Previous exam: 2013 State Problem 17]
a. no net external force acts on the system.
b. no internal forces act within the system.
c. no internal torques act within the system.
d. no net external torque about any axis acts on the system.
e. no internal forces or internal torques act within the system.

21. Two forces, equal in magnitude but acting in opposite directions with a force magnitude of 10 N each, are applied. To produce a net counterclockwise torque of 7 N·m, what should be the distance l between these forces? [Rigid-body equilibrium, Torque]

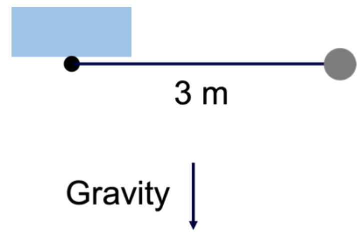


a. 0.35 m   b. 0.5 m   c. 0.7 m   d. 1.25 m   e. 2.5 m

22. At Point 1 along the pipeline, the water is flowing at a speed of 4 m/s, and the gauge pressure measures 7×10^4 Pa. Point 2 is positioned 15 m below Point 1, and the pipe's diameter at Point 2 is three times larger than that at Point 1. Calculate the gauge pressure at Point 2. The density of water is 1000 kg/m^3. [Fluid mechanics, Bernoulli's equation]

a. 0.85×10^5 Pa　　b. 2.09×10^5 Pa　　c. 2.25×10^5 Pa
d. 3.85×10^5 Pa　　e. 5.25×10^5 Pa

23. A small sphere of mass 0.2 kg, at the end of a non-stretchable pendulum, string of length 3 m, has velocity v downward when the string is horizontal. The forces acting on the sphere at this instant are due to the string's tension and gravity. What must be the value of v so that the magnitude of the sphere's total acceleration at this instant be 2 times the acceleration due to gravity at the Earth's surface? [Gravity, Previous exam: 2013 Sectional Problem 21]



a. 5.136 m/s　　b. 6.136 m/s　　c. 7.136 m/s
d. 8.136 m/s　　e. 9.136 m/s

24. Fasten a 0.4 kg air-track glider to the end of a massless ideal spring and initiate its oscillation. Calculate the spring's force constant by measuring the time it takes for the glider to pass through the equilibrium point for the first and second times, with the elapsed time being 3 seconds. [Simple harmonic motion]

a. 0.44 N/m　b. 0.75 N/m　c. 1.25 N/m　d. 1.75 N/m　e. 2.44 N/m

25. The alarm on a truck is producing sound waves with a frequency of 500 Hz. If your car is moving away from the stationary truck, what speed must you be traveling to perceive a frequency of 470 Hz? There is no wind, and we assume that the speed of sound is 344 m/s. [Sound wave, Doppler effect, Unit conversion]

a. 20.6 km/h　　b. 30.6 km/h　　c. 40.6 km/h
d. 64.3 km/h　　e. 74.3 km/h

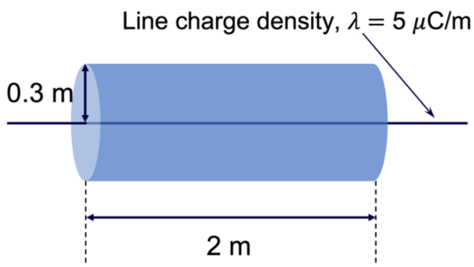
26. A gas within a cylinder undergoes expansion, transitioning from a volume of 0.1 m^3 to 0.25 m^3. Heat is supplied to the gas precisely to sustain a constant pressure of 1.8×10^5 Pa throughout the expansion. The total heat added amounts to 1.3×10^5 J. Calculate the change in the internal energy of the gas. [Internal energy and the first law of thermodynamics]

a. 0.93×10^5 J　　b. 1.03×10^5 J　　c. 1.37×10^5 J
d. 1.47×10^5 J　　e. 1.57×10^5 J

27. An aircraft jet engine takes in 10000 J of heat and discards 7000 J each cycle. What is the thermal efficiency of the engine? [Heat engine]

a. 30 % b. 43 % c. 53 % d. 63 % e. 70 %

28. Consider a cylinder with radius $r = 0.3$ m and length $l = 2$ m, hosting an infinite line of positive charge along its axis. The line charge density is $\lambda = 5$ μC/m. Calculate the electric flux through the cylinder arising from this infinite line of charge. Assume that the cylinder and the line chare is in vacuum. The permittivity of vacuum is $\epsilon_0 = 8.854 \times 10^{-12}$ $C^2/N{\cdot}m^2$. [Electric flux, Gauss's law]



a. 0.169×10^6 $N{\cdot}m^2/C$ b. 0.529×10^6 $N{\cdot}m^2/C$ c. 0.765×10^6 $N{\cdot}m^2/C$
d. 1.129×10^6 $N{\cdot}m^2/C$ e. 3.765×10^6 $N{\cdot}m^2/C$

29. A parallel-plate vacuum capacitor has 10 J of energy stored in it. The separation between the plates is 3 mm. If the separation is decreased to 1.5 mm, what is the energy stored if the capacitor remains connected to the potential source so the potential difference between the plates remains constant? [Energy storage in a capacitor]

a. 2.5 J b. 5 J c. 7.5 J d. 10 J e. 20 J

30. A 2 μF capacitor is charging through a 15 Ω resistor with a 15 V power supply. What will be the current when the capacitor reaches half of its maximum charging capacity? [RC circuit]

a. 0.25 A b. 0.5 A c. 0.75A d. 1A e. 1.25 A

31. A concave mirror has a radius of curvature of 30 cm. What is the focal length of the mirror when it is immersed in liquid with an index of refraction of 1.5? [Reflection at a spherical surface]

a. 10 cm b. 15 cm c. 20 cm d. 22.5 cm e. 30 cm

32. The work function of silver is 4.3 eV. A surface of silver is exposed to light of wavelength 250 nm. What is the maximum speed of the electrons emitted from the surface? The conversion factor between electron volts and joules is 1 eV = 1.602×10^{-19} J. [Photoelectric effect]

a. 4.817×10^5 m/s b. 5.017×10^5 m/s c. 5.217×10^5 m/s
d. 5.417×10^5 m/s e. 5.617×10^5 m/s

33. Find the width L of a one-dimensional box where the ground-state energy of an electron equals the absolute value of the ground state of a hydrogen atom. The magnitude of the ground state energy of an electron in a hydrogen atom is 13.6 eV. In the specified box range $0 \leq x \leq L$, the potential energy is zero, and the entire energy is kinetic. The conversion factor between electron volts and joules is 1 eV = 1.602×10^{-19} J. [Particle in a box]

a. 1.663×10^{-10} m b. 3.226×10^{-10} m c. 3.326×10^{-10} m
d. 4.703×10^{-10} m e. 5.663×10^{-10} m

34. At a velocity of 0.700c, a spaceship zooms past a planet. A physicist on the planet gauges the length of the in-motion spaceship to be 50 m. Subsequently, after the spaceship has landed on the planet, the same physicist measures the length of the now stationary spaceship. What value does the physicist record? [Relativity of length]

a. 25.7 m b. 35.7 m c. 45.7 m d. 60 m e. 70 m

35. The period of time that it takes for the activity of a sample of a radioactive isotope to decrease to 50 % of its initial activity is called the isotope's ___________. [Activities and half-lives, Previous exam: 2012 Sectional Problem 35]

a. decay constant b. atomic mass c. cross-section
d. half-life e. mean lifetime

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