2023 Academic Challenge

STATE PHYSICS EXAM

Physics Test Production Team

Steven Daniels, Eastern Illinois University – Author/Team Leader
Jie Zou, Eastern Illinois University – Author
Don Pakey, Eastern Illinois University – Reviewer

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. 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·m^2)
Electrostatic Constant	$k = (4\pi\epsilon_0)^{-1}$	8.988×10^9 N·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·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

2023 Academic Challenge
State Physics Exam

1. Consider the quantity that is found by multiplying these fundamental constants:

$$4\pi\epsilon_o m_e m_p G\mu_o^2$$

What are the units of the result of this multiplication?

a. $T^2\ m^2\ s^2$
b. $T\ m^2$
c. $C^2\ T^2\ m^{-2}$
d. $C\ T\ m^{-1}\ A^{-1}$
e. $Kg\ N^2\ T\ m\ C\ A^{-1}$

2. What is the closest to the weight of President Biden in Newtons?

a. 70 N b. 700 N c. 7000 N d. 70000 N e. 700000 N

3. A tanker is travelling at 25.0 knots on a heading 40.0° east of north. A destroyer is travelling at 35.0 knots on a heading 20.0° south of west toward the tanker. What is the relative velocity of the destroyer with respect to the tanker?

a. 58.0 knots 32.4° south of west
b. 49.1 knots 46.2° south of west
c. 40.5 knots 35.6° north of east
d. 36.2 knots 23.7° north of east
e. 20.3 knots 10.9° north of west

4. The drag force on a 3.00 kg parachute with a drag coefficient C_d of 0.700 and an area A of 35.0 m^2 is given by $F_{parachute} = C_d \rho A v^2/2$, where ρ is the density of air (1.29 kg/m^3) and v is the speed of the parachute. Ignoring all drag forces except that on the parachute, what is the magnitude of the acceleration of an 83.0 kg person wearing the parachute while falling vertically at a speed of 5.00 m/s?

a. 9.80 m/s^2
b. 8.90 m/s^2
c. 5.21 m/s^2
d. 5.00 m/s^2
e. 4.20 m/s^2

5. In the situation described in problem 4, what is the terminal velocity of the person wearing the parachute?

   a. 7.12 m/s
   b. 7.30 m/s
   c. 7.56 m/s
   d. 8.00 m/s
   e. 8.19 m/s

6. Which set of units is correct for a Young's modulus?

   a. $\frac{\text{kg}\cdot\text{m}}{\text{s}^2}$
   b. $\frac{\text{kg}\cdot\text{m}^2}{\text{s}^2}$
   c. $\frac{\text{kg}\cdot\text{m}^2}{\text{s}}$
   d. $\frac{\text{kg}}{\text{s}^2\cdot\text{m}}$
   e. $\frac{\text{kg}}{\text{s}^2}$

7. When an object is launched from the ground at an angle 60.0° above horizontal, it reaches a maximum height 45.0 m above the ground. How far does the object travel horizontally from its launch point before returning to the ground?

   a. 90.0 m
   b. 96.0 m
   c. 104 m
   d. 115 m
   e. 126 m

8. In optics, the following criterion is used for determining whether two point objects can be resolved: two point objects can just be resolved if the center of the diffraction pattern of one object coincides with the first diffraction minimum of the other object. What is this criterion called?

   a. Fresnel diffraction criterion
   b. Fraunhofer diffraction principle
   c. Huygens's principle
   d. Rayleigh's criterion
   e. Young's double-slit principle

9. A small block of mass *m* is attached to an ideal spring of force constant *k* on a frictionless horizontal surface. The block is released at *t* = 0 from rest at *x* = 0.200 m (*x* = 0 is the position at which the spring is at its natural length). If *m* = 0.100 kg, *k* = 10.0 N/m, how much work does the spring force do from *t* = 0 to *t* = 2.00 s?

a. 0.167 J
b. 0.120 J
c. 0 J
d. −1.65 J
e. −2.33 J

10. In the situation described in problem 9, what is the speed of the block at *t* = 2.00 s?

a. 0 m/s
b. 1.16 m/s
c. 1.59 m/s
d. 1.70 m/s
e. 1.83 m/s

11. A small object moves in a circle. At an instant of time, it is moving at 2.50 m/s and its speed is increasing at a rate of 4.00 m/s/s. If the radius of the circle is 1.50 m, what is the magnitude of its acceleration at the instant?

a. 4.17 m/s^2
b. 5.78 m/s^2
c. 6.00 m/s^2
d. 6.25 m/s^2
e. 7.00 m/s^2

12. Consider a particle of mass 528 g that is moving in 1 dimension according to the equation:

$$s = 1.71\,t^4 - 3.01\,t^2 + 15$$

where s is in meters. What is the position of the particle at time 1.20 s?

a. 4.60 m b. 9.80 m c. 13.7 m
d. 14.2 m e. 23.5 m

13. In the previous problem what is the acceleration of the particle at the time 1.20 s?

a. 2.43 m/s^2
b. 4.60 m/s^2
c. 12.4 m/s^2
d. 23.5 m/s^2
e. 29.5 m/s^2

14. A train is travelling on straight level tracks. There is a pendulum of length 1.65 m that is hanging from the center of the train's ceiling. The train brakes with a constant force from 42.9 m/s to 23.7 m/s in a time of 16.1 s. What is the angle that the pendulum makes with the vertical during the deceleration?

a. 0.121°
b. 6.94°
c. 8.54°
d. 15.2°
e. 50.0°

15. A blue 4 door car of mass 1820 kg is travelling with a velocity of 38.6 m/s. It stops under a constant braking force. It takes 149 m to come to a stop. If the same braking force is applied another time when the initial speed is 29.0 m/s how long will it take to stop?

a. 3.86 s
b. 5.00 s
c. 5.13 s
d. 5.80 s
e. 7.72 s

16. Consider a spherical shell of radius R and thickness d (where d is much smaller than R) with a total mass of M. What is the force of gravity felt by a small mass, m, placed at a point 2R and that felt by the same small mass placed at a point R/2?

a. $G\frac{Mm}{(2R)^2}$ $and\ 0$
b. $G\frac{Mm}{(R)^2}$ $and\ 0$
c. $G\frac{Mm}{(2R)^2}$ $and\ G\frac{Mm}{(R)^2}$
d. $G\frac{Mm}{(2R)^2}$ $and\ G\frac{Mm}{\left(\frac{R}{2}\right)^2}$
e. $G\frac{Mm}{(R)^2}$ $and\ G\frac{Mm}{(R/2)^2}$

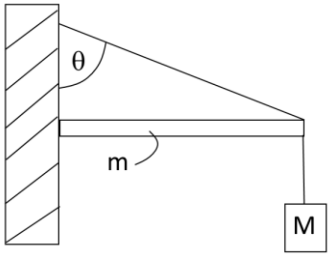
17. A 8.00 kg wooden box rests on a large flat steel plate of total mass 65.5 kg. One end of the steel plate is raised up so that it makes an angle with the horizontal. The angle at which the box starts to slide down the incline is 27.2°. What is the coefficient of static friction between the box and the plate?

a. 0.122 b. 0.294 c. 0.347 d. 0.475 e. 0.514

18. A certain Uranium isotope decays by alpha decay into a Thorium isotope of mass 3.7520×10^{-25} kg and an alpha particle of mass 6.6443×10^{-27} kg. In the process the final decay products have a total kinetic energy of 9.61×10^{-13} J. If the original Uranium isotope started at rest, what is the speed of the Thorium isotope after the decay?

a. 2.11×10^{5} m/s
b. 2.99×10^{5} m/s
c. 1.19×10^{6} m/s
d. 1.60×10^{6} m/s
e. 1.69×10^{6} m/s

19. The uniform bar in the figure has a mass, m, and the bar projects out from the wall perpendicular to the wall. The bar is held in place on the wall by the normal force and the force of friction. A light wire is attached to the wall above the bar and makes an angle θ with the wall with the other end attached to the bar to hold it up. A mass M, is also attached to the bar at the end as shown. What is the tension in the top wire?

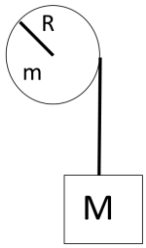


a. $(M+m)g$
b. $\frac{M}{\sin\theta}g$
c. $\left(m+\frac{M}{2}\right)\frac{g}{\sin\theta}$
d. $\left(\frac{m}{2}+M\right)\frac{g}{\cos\theta}$
e. $(m+M)\frac{g}{\sin\theta}$

20. In special relativity, a set of equations is used to transform the spacetime coordinates of an event from one inertial frame to another. What is the set of equations called?

a. Galilean coordinate transformation
b. Lorentz coordinate transformation
c. Fourier transform
d. Einstein's mass-energy equivalence
e. Newtonian transformation

21. A thin uniform solid disk is mounted so that it is free to rotate on an axis through the center. The disk has a radius R and a mass m. A thin light string is wound around the edge of the disk and extends to another mass M as shown in the diagram. What is the acceleration of the mass M? The moment of inertia of a disk on an axis through its center and perpendicular to the disk is $\frac{1}{2}mR^2$.

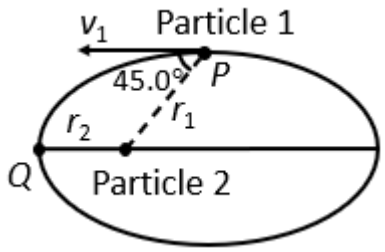


a. $\frac{m}{M+m}g$
b. $\frac{M}{M+m}g$
c. $\frac{M+\frac{1}{2}m}{M}g$
d. $\frac{m}{M+\frac{1}{2}m}g$
e. $\frac{M}{M+\frac{1}{2}m}g$

22. As a continuation of the previous problem consider the disk alone. What is the moment of inertia of the disk along an axis parallel to the radius drawn in the figure and through the center of the disk?

a. $\frac{1}{2}mR^2$
b. $\frac{1}{4}mR^2$
c. $\frac{1}{6}mR^2$
d. $\frac{1}{8}mR^2$
e. $\frac{1}{12}mR^2$

23. Particle 1 moves in an elliptical orbit about particle 2, as shown in the diagram (not drawn to scale). Assume particle 2 is stationary and consider only the gravitational attraction between the two particles. Suppose the speed of particle 1 at point *P* is v_1 = 2.00 m/s and $r_1 = 3.41r_2$, what is the speed of particle 1 at point *Q*, the closet point to particle 2?

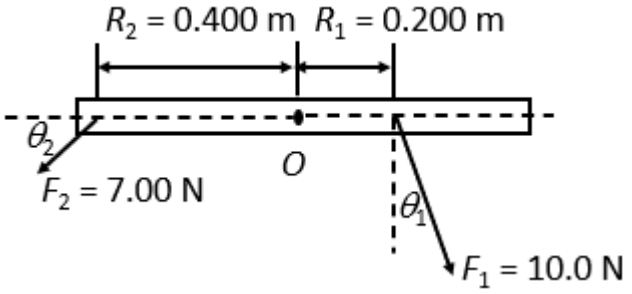


a. 4.82 m/s
b. 5.03 m/s
c. 5.50 m/s
d. 5.69 m/s
e. 6.00 m/s

24. In the reference textbooks Fermat's Principle is related as

a. The path of a ray of light between two points is the path that minimizes the travel time.
b. There is a 180° phase shift in light reflected at a surface of higher index of refraction but no phase shift if the index of refraction is lower than that of the incident medium.
c. All points of a wave front of light may be regarded as new sources of wavelets that expand in every direction.
d. No two electrons in the same atom can have identical values for all four of their quantum numbers.
e. Any periodic wave can be approximated by a superposition of purely sinusoidal waves of different amplitudes and frequencies in the form of a sum.

25. Two forces act on a rigid body, as shown in the diagram. If $\theta_1 = 30.0°$, what is θ_2 so that the net torque acting on the rigid body about point *O* is zero?



a. 32.3°
b. 35.0°
c. 38.2°
d. 42.6°
e. 45.0°

26. A small object of mass 0.300 kg is in projectile motion. At an instant of time, its *x*- and *y*-components of velocity are 5.00 m/s and 2.00 m/s, respectively. What is the instantaneous power of gravity at this instant? The +*x*-direction is to the right and the +*y*-direction is upward.

a. 5.20 W
b. 2.86 W
c. −14.7 W
d. −15.8 W
e. −5.88 W

27. For the hydrogen atom, what are the distinct (n, l, m_l) states with $n = 2$? Here, n is the principal quantum number, l is the orbital quantum number, and m_l is the magnetic quantum number.

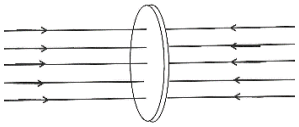
a. (2, 1, 1), and (2, 1, -1)
b. (2, 0, 0), (2, 1, 0), and (2, 1, 1)
c. (2, 0, 0), (2, 1, 0), (2, 1, 1), (2, 1, -1), and (2, 2, 2)
d. (2, 0, 0), (2, 1, 0), (2, 1, 1), and (2, 1, -1)
e. (2, 0, 0), (2, 0, 1), (2, 0, 3), and (2, 0, 4)

28. A scientist used alpha particles to determine that atoms have a positively charged nucleus that was relatively high in mass and small in size. For their discoveries this scientist received the Nobel Prize in Chemistry in 1908. Who was the scientist?

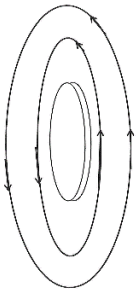
a. Einstein
b. Geiger
c. Maxwell
d. Bohr
e. Rutherford

29. When we draw vector fields we show the strength of the field by the density of the lines and the direction of the field by arrows. Drawing the gravitational field lines from a thin massive disk would result in which diagram for the field lines near the disk?

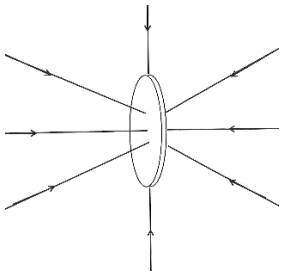
a.



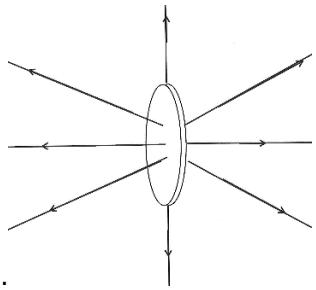
b.



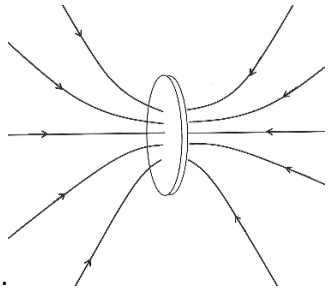
b.



d.



e.



30. A uniform meter stick of mass per unit length 0.547 g/cm has 2 masses added to it. A 35.0 g mass is located at the 20.0 cm mark on the meterstick. A 47.0 g mass is located at the 95.0 cm mark on the meterstick. At what mark on the meter stick is the center of mass of the system is located?

a. 51.1 cm b. 53.0 cm c. 55.0 cm d. 57.8 cm e. 64.9 cm

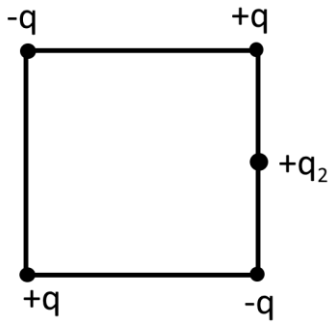
31. Consider a diatomic gas at room temperature, whose molecules can be modeled as rigid dumbbells. In terms of the number of moles of the gas, n, and the universal gas constant, R, what does the equipartition theorem predict the heat capacity, C_v, at constant volume to be?

a. $\frac{1}{2}nR$
b. $\frac{3}{2}nR$
c. $2nR$
d. $\frac{5}{2}nR$
e. $\frac{7}{2}nR$

32. A vehicle is moving directly toward a whistle and a person in the vehicle hears the sound and identifies it as a C note with frequency 512 Hz. After passing the whistle the person hears the whistle as one octave lower or 256 Hz. The speed of sound in the still air of the whistle is 342 m/s. What is the speed of the vehicle?

a. 114 m/s
b. 128 m/s
c. 171 m/s
d. 228 m/s
e. 342 m/s

33. Consider the charge arrangement shown in the figure. Four charges of magnitude q are located at the corners of a square of side *l* with signs as shown. What is the magnitude of the force on a positive charge, q_2, located at the midpoint of a side of the square, as shown?



a. 0
b. $\frac{4kqq_2}{l^2}$
c. $\frac{4kqq_2}{l^2}\left\{2-\frac{\sqrt{3}}{9}\right\}$
d. $\frac{8kqq_2}{l^2}\left\{1-\frac{\sqrt{2}}{4}\right\}$
e. $\frac{8kqq_2}{l^2}\left\{1-\frac{\sqrt{5}}{25}\right\}$

34. A 4.50 V voltage source charges a 25.8 μF capacitor (that has zero charge on it at the beginning) through a circuit with a 81.5 Ω resistor in series with the capacitor. How long does it take to charge the capacitor to 85.0% of the final charge?

a. 1.79 ms b. 2.47 ms c. 3.99 ms d. 8.04 ms e. 1.79 s

35. The activity of a radioactive specimen is its decay rate. What is the SI unit of activity?

a. Gray
b. Farad
c. Coulomb
d. Curie
e. Becquerel