2023 Academic Challenge

SECTIONAL PHYSICS EXAM

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. 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

Academic Challenge
2023 Sectional Physics Exam

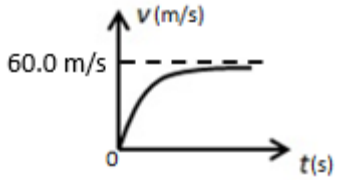
1. An object has density x when measured in g/cm^3. What is the density of the object when measured in kg/m^3?

   a. $10x$ kg/m^3
   b. 10^2x kg/m^3
   c. 10^3x kg/m^3
   d. $10^{-3}x$ kg/m^3
   e. $10^{-9}x$ kg/m^3

2. A small object moves in a circle on a horizontal surface. It encounters kinetic friction with a constant magnitude of 0.500 N. An external force is applied to the object so that it maintains a constant speed. The radius of the circle is 2.50 m. If the object moves in the circle five times, how much work is done on the object by the external force?

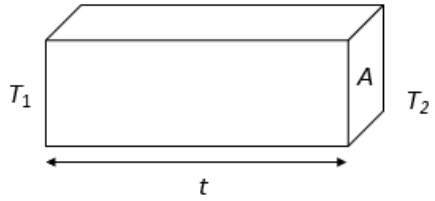
   a. 35.7 J
   b. 39.3 J
   c. 40.8 J
   d. 42.0 J
   e. 0 J

3. The speed versus time of a 50.0-kg bungee jumper during his fall (before the bungee cord becomes taut) is shown in the diagram below. If we model the air drag using the equation, $f_{air} = bv$, where f_{air} is the magnitude of the air drag, b is a coefficient, and v is the speed, what is the value for b?



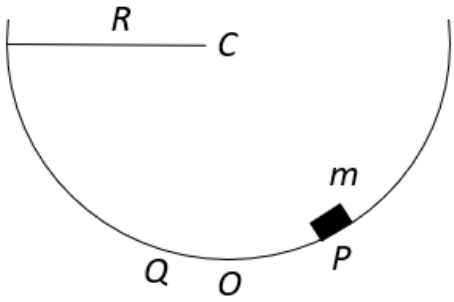
   a. 8.17 kg/s
   b. 8.56 kg/s
   c. 9.26 kg/s
   d. 12.0 kg/s
   e. 13.7 kg/s

4. A slab of building material, as shown in the diagram, has cross-sectional area A and thickness t, and is made of a material of thermal conductivity k. The R-value is defined by the equation $P/A = \Delta T/R$, where P/A is the heat flux and ΔT is the temperature difference between the two sides. In terms of the constants defined in this problem, what is R?



a. $R = A/kt$
b. $R = k + At$
c. $R = t/k$
d. $R = k/At$
e. $R = kAt$

5. A small object of mass m = 0.100 kg is released from rest at point P and slides along a frictionless, circular surface of radius R = 0.500 m, as shown in the diagram. Assuming that point P is of only a small displacement from point O, which is directly below the center C of the circle, what is the period of the object's motion? Ignore air resistance.



a. 1.05 s
b. 1.21 s
c. 1.30 s
d. 1.42 s
e. 1.58 s

6. In the situation described in problem 5, the arc length between point *O* and *P* is 1/36 of the circumference. If the object reaches point *Q* after 0.450 s, what is the angle between the normal at point *Q* and the vertical?

   a. 3.00°
   b. 3.95°
   c. 4.08°
   d. 4.26°
   e. 5.15°

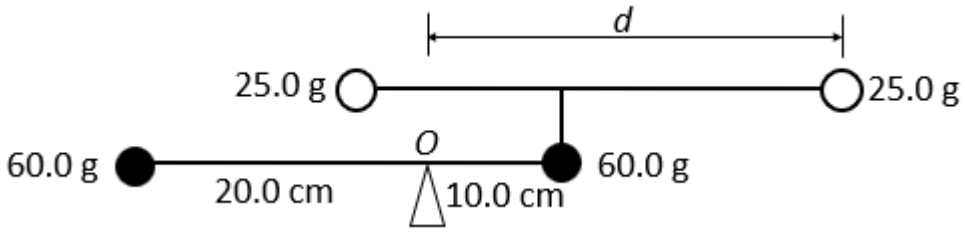
7. A free-fall experiment is done at a point on Earth where $g \neq 9.80$ m/s^2. In the experiment, the *y*-position of an object in meters is measured as a function of time *t* in seconds. The plot of *y* versus *t* is an upward parabolic curve that passes (0, 0) and reaches a minimum value of $y = -0.0128$ m at $t = 0.0512$ s. What is the initial velocity of the object?

   a. 0 m/s
   b. 0.255 m/s
   c. 0.376 m/s
   d. − 0.420 m/s
   e. − 0.500 m/s

8. In the situation described in problem 7, if the instantaneous *y*-velocity is plotted as a function of time *t*, what is the expected slope of the best-fit line? All data are measured in SI units.

   a. 9.81 m/s^2
   b. 9.77 m/s^2
   c. − 9.50 m/s^2
   d. 8.00 m/s
   e. − 7.66 m/s

9. A rigid structure consists of four point masses and light connecting rods, as shown in the diagram. The two horizontal rods have equal length. The structure is in static equilibrium about pivot point *O*. What is the horizontal distance *d* from the 25.0-g mass on the right to point *O*? Ignore friction.



a. 25.5 cm
b. 27.0 cm
c. 27.5 cm
d. 28.6 cm
e. 29.5 cm

10. To determine the gas constant, pressure *p* of 1 mole of an ideal gas at a constant volume of 0.0200 m^3 is measured as a function of the absolute temperature *T*. When *p* is plotted as a function of *T*, the equation for the best fit line is found to be $y = 420x + 100$. What is the measured gas constant? All data are in SI units.

a. 8.40 J/mol·K
b. 8.40 N/mol·K
c. 8.31 J/mol·K
d. 8.31 N/m^3·K
e. 8.15 J/K

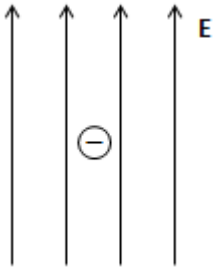
11. In a nuclear reaction, if the reaction energy is positive, what is the reaction called?

a. A hydraulic reaction
b. An inert reaction
c. An isothermal reaction
d. An endoergic reaction
e. An exoergic reaction

12. In an optics lab, students measure the index of refraction of a glass prism for various emission lines of a mercury source and plot a graph of index of refraction as a function of wavelength. What is the graph called?

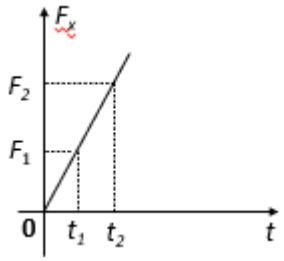
    a. Huygens' curve
    b. Blackbody radiation curve
    c. Reflection curve
    d. Refraction curve
    e. Dispersion curve

13. A negatively-charged particle of mass m = 40.0 g and charge $q = -4.00\ \mu C$ is released from rest in a uniform electric field **E** that is directed upward, as shown in the diagram. If $E = 2.00 \times 10^4$ N/C, which statement is correct about the motion of the particle?



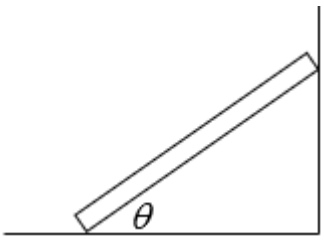
    a. It moves upward at a constant speed.
    b. It moves with an acceleration of 8.00 m/s^2, directed upward.
    c. It moves with an acceleration of 11.8 m/s^2, directed downward.
    d. It moves with an acceleration of 14.6 m/s^2, directed downward.
    e. It remains stationary.

14. The diagram shows a horizontal force F_x as a function of time t. What is the impulse delivered by the force from t_1 to t_2?



    a. $F_2t_2 - F_1t_1$
    b. $F_2t_2 + F_1t_1$
    c. $2(F_2 - F_1)(t_2 - t_1)$
    d. $(F_1 + F_2)(t_2 - t_1)$
    e. $(F_1 + F_2)(t_2 - t_1)/2$

15. A ladder of 2.00 m length and 5.00 kg mass has its top leaning against a frictionless wall and its bottom resting on a horizontal surface, as shown in the diagram. The coefficient of static friction between the ladder and the horizontal surface is 0.400. The minimum angle θ for which the ladder can remain at rest without slipping is 45.0°. How far is the center of mass of the ladder measured from its top? Assume that the mass of the ladder is distributed non-uniformly along its length.

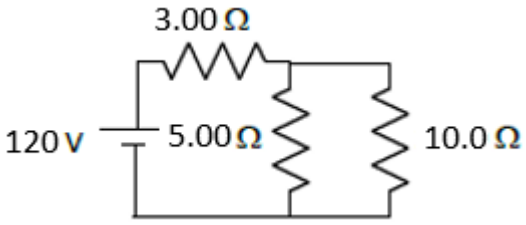


a. 1.00 m
b. 1.20 m
c. 1.32 m
d. 1.51 m
e. 1.66 m

16. A sample of radioactive isotope *A* with a mean lifetime 40.0 s contains 9.00×10^{16} isotope *A* atoms. A sample of radioactive isotope *B* with a mean lifetime 50.0 s contains 3.00×10^{16} isotope *B* atoms. How much time will pass before the number of isotope *A* atoms is the same as the number of isotope *B* atoms? Note: neither isotope is a decay product of the other.

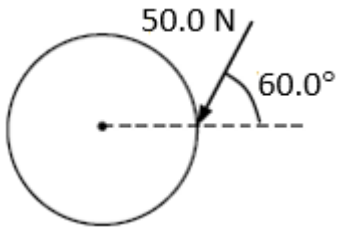
a. 220 s
b. 200 s
c. 155 s
d. 150 s
e. 148 s

17. What is the magnitude of the voltage drop across the 3.00 Ω resistor in the circuit shown in the diagram?



a. 60.0 V
b. 56.9 V
c. 45.2 V
d. 40.0 V
e. 36.6 V

18. The 0.300 m diameter wheel shown in the diagram has a moment of inertia 4.00 kg·m^2 about the axis through the center of the wheel and is acted on by the 50.0 N force, as shown. If the wheel is initially spinning counterclockwise about the axis through the center of the wheel with an angular velocity 6.00 revolutions per second, what will be the angular velocity 20.0 s later?

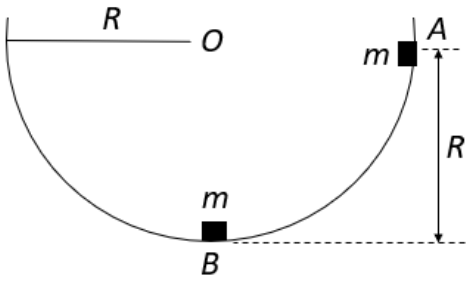


a. 0.830 revolutions per second counterclockwise
b. 0.830 revolutions per second clockwise
c. 5.26 revolutions per second counterclockwise
d. 5.26 revolutions per second clockwise
e. 10.5 revolutions per second counterclockwise

19. Which experiment demonstrates the wave nature of light?

a. Compton's X-ray scattering from an electron
b. The photoelectric effect
c. Davisson-Germer's experiment on electron diffraction by crystals
d. Röntgen's experiment on the production of X-rays
e. Young's double-slit experiment

20. Object *A* slides down from rest along a frictionless circular path with center *O* and radius *R*. It then collides with object *B* of the same mass *m*, as shown in the diagram. After the collision, the two objects stick together. What is the speed of the two objects right after the collision?



a. $\sqrt{2gR}$
b. $\sqrt{gR/2}$
c. $\sqrt{gR}/2$
d. $\sqrt{mgR/2}$
e. 0

21. Two point masses are separated by a certain distance. If each mass is increased by a factor of three and the distance is increased by a factor of 2, how will the gravitational force between the two masses change?

a. It will stay the same.
b. It will increase by a factor of 9/2.
c. It will be halved.
d. It will be tripled.
e. It will increase by a factor of 9/4.

22. Which scientist below gave an interpretation to the absolute square of the wave function in terms of a probability distribution function?

a. Erwin Schrödinger
b. Max Born
c. Albert Einstein
d. Niels Bohr
e. Enrico Fermi

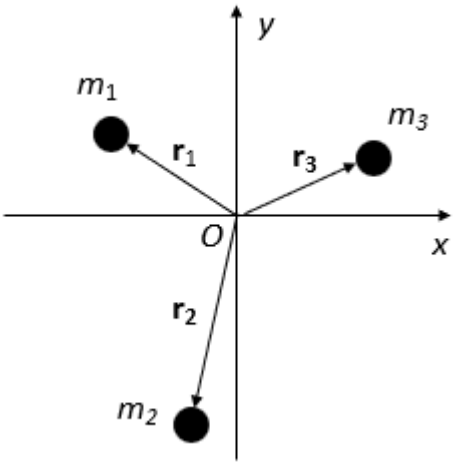
23. When the tensile stress is sufficiently small, it is proportional to the tensile strain. What is the proportionality constant called?

    a. Spring constant
    b. Hooke's constant
    c. Bulk modulus
    d. Young's modulus
    e. Shear modulus

24. Consider a simple pendulum of mass 1.65 kg and length 1.80 m. An astronaut has this pendulum set up on the Moon. She measures the period of this pendulum to be 7.00 s. From the results of her experiment what does she predict the acceleration of gravity on the Moon to be?

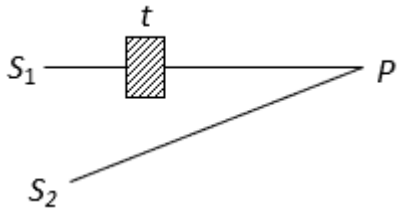
    a. 1.45 m/s^2
    b. 1.60 m/s^2
    c. 1.63 m/s^2
    d. 1.70 m/s^2
    e. 2.03 m/s^2

25. Three point masses, m_1, m_2, and m_3, are in the *xy*-plane, as shown in the diagram. The position vectors of m_1, m_2, and m_3 are $\mathbf{r}_1$, $\mathbf{r}_2$, and $\mathbf{r}_3$, respectively. Which is the correct expression for the net gravitational force on m_1?



    a. $\frac{Gm_1m_2}{|\mathbf{r}_1-\mathbf{r}_2|^3}(\mathbf{r}_1-\mathbf{r}_2)+\frac{Gm_1m_3}{|\mathbf{r}_1-\mathbf{r}_3|^3}(\mathbf{r}_1-\mathbf{r}_3)$
    b. $-\frac{Gm_1m_2}{|\mathbf{r}_1-\mathbf{r}_2|^3}(\mathbf{r}_1-\mathbf{r}_2)+\frac{Gm_1m_3}{|\mathbf{r}_1-\mathbf{r}_3|^3}(\mathbf{r}_1-\mathbf{r}_3)$
    c. $-\frac{Gm_1m_2}{|\mathbf{r}_1-\mathbf{r}_2|^3}(\mathbf{r}_1-\mathbf{r}_2)-\frac{Gm_1m_3}{|\mathbf{r}_1-\mathbf{r}_3|^3}(\mathbf{r}_1-\mathbf{r}_3)$
    d. $-\frac{Gm_1m_2}{|\mathbf{r}_1-\mathbf{r}_2|^2}(\mathbf{r}_1-\mathbf{r}_2)-\frac{Gm_1m_3}{|\mathbf{r}_1-\mathbf{r}_3|^2}(\mathbf{r}_1-\mathbf{r}_3)$
    e. $\frac{Gm_1m_2}{|\mathbf{r}_1-\mathbf{r}_2|^3}(\mathbf{r}_1-\mathbf{r}_2)-\frac{Gm_1m_3}{|\mathbf{r}_1-\mathbf{r}_3|^3}(\mathbf{r}_1-\mathbf{r}_3)$

26. Two light sources, S_1 and S_2, have equal distance d from point P. The sources are in phase and have the same frequency of 5.00×10^{14} Hz. A piece of glass is inserted perpendicularly in the path from S_1 to P, as shown in the diagram. The glass has thickness t = 1.20 cm and index of refraction n = 1.50. Which statement is correct about the interference of the two light waves at point P?



a. The two light waves have intermediate interference at point P.
b. The two light waves have destructive interference at point P.
c. The two light waves have constructive interference at point P.
d. The two light waves do not interfere at point P.
e. The type of interference of the two light waves at P depends on the value for d.

27. An incompressible fluid flows through a tube with a wide section and a narrow section. The diameter of the wide section is 50.0 cm and that of the narrow section is 25.0 cm. If the flow speed in the wide section is 10.0 m/s, what is the volume flow rate in the narrow section?

a. 5.66 m^3/s
b. 4.00 m^3/s
c. 3.93 m^3/s
d. 2.57 m^3/s
e. 1.96 m^3/s

28. A standing wave is formed on a string tied at both ends. The length of the string is 1.50 m. When vibrating in its third normal mode, the string produces a sound of 260 Hz. What is the wave speed traveling on the string?

a. 344 m/s
b. 270 m/s
c. 260 m/s
d. 252 m/s
e. 221 m/s

29. Three points, *A*, *B*, and *C*, have *xy*-coordinates given by *A* (−1, 1), *B* (2, 3), and *C* (1, −2). Vector 1 points from *A* to *B* and vector 2 points from *B* to *C*. What is the sum of these two vectors?

    a. $2\hat{x} - 3\hat{y}$
    b. $-2\hat{x} + 3\hat{y}$
    c. $4\hat{x} - 3\hat{y}$
    d. $-4\hat{x} - 3\hat{y}$
    e. $3\hat{x} - 5\hat{y}$

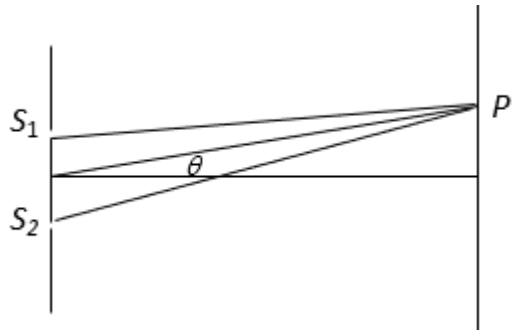
30. Two cars, car 1 and car 2, move in a straight line in the same direction. Car 1 and car 2 start with the same initial position but different initial velocities of v_1 and v_2, respectively. Car 1 maintains a constant velocity, while car 2 increases its velocity at a constant acceleration *a*. If $v_1 > v_2$, how long will it take before car 2 catches up with car 1?

    a. $2a/(v_1 - v_2)$
    b. $(v_1 - v_2)/a$
    c. $2(v_1 - v_2)/a$
    d. $(v_1 - v_2)/a^2$
    e. $2(v_1 - v_2)^2/a$

31. Let [L], [M], and [T] represent the dimensions of length, mass, and time, respectively. What is the dimension of intensity?

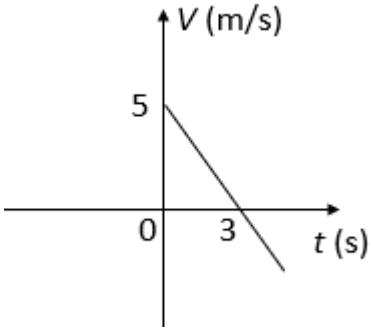
    a. [M][L][T]
    b. $[M][L]^2[T]^{-1}$
    c. $[M]^2[L][T]^3$
    d. $[M][L][T]^{-2}$
    e. $[M][T]^{-3}$

32. In a double slit experiment, monochromatic light waves of wavelength λ travel from S_1 and S_2 to a point *P* above the central axis on a distant screen, as shown in the diagram. If the light wave at slit S_2 differs in phase from that at slit S_1 by $\phi = \phi_2 - \phi_1$, what is the condition for angle θ so that a bright fringe of the 1st order occurs at *P*? Assume the slit separation is *d*.



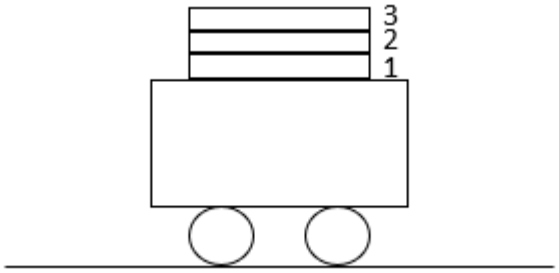
a. $d\tan\theta = \lambda - \phi$
b. $d\sin\theta = \lambda - \frac{\phi}{\pi}$
c. $d\cos\theta = \left(1 - \frac{\phi}{2\pi}\right)\lambda$
d. $d\sin\theta = \left(1 - \frac{\phi}{2\pi}\right)\lambda$
e. $d\sin\theta = \left(1 + \frac{\phi}{2\pi}\right)\lambda$

33. The velocity-vs-time graph of an object moving in the *x*-direction is shown in the diagram. Which statement is true about the motion at *t* = 3.00 s?



a. The object is moving in the +*x*-direction at 0.600 m/s and has no acceleration.
b. The object is momentarily at rest and accelerating in the +*x*-direction at 1.67 m/s^2.
c. The object is at rest and has no acceleration.
d. The object is momentarily at rest and is accelerating in the –*x*-direction at 1.67 m/s^2.
e. The object is moving in the –*x*-direction at 0.600 m/s and has no acceleration.

34. A car moves at a constant acceleration on a horizontal surface carrying three identical mattresses on its roof, as shown in the diagram. The mattresses are not tied to each other nor to the car and remain stationary relative to the car. If each mattress is 20.0 kg and the acceleration of the car is 2.00 m/s^2, what is the force of static friction between mattress 1 and the roof of the car? Assume the roof of the car is horizontal and air resistance is negligible.



a. 80.0 N
b. 90.0 N
c. 100 N
d. 110 N
e. 120 N

35. In the situation described in problem 34, what is the force of static friction between mattresses 2 and 1?

a. 80.0 N
b. 90.0 N
c. 100 N
d. 110 N
e. 120 N