2024 Academic Challenge

PHYSICS TEST – REGIONAL

Physics Test Production Team
Steven Daniels, Eastern Illinois University – Author/Team Leader
Eric 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. 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 °C = 273.15 K

Academic Challenge
Physics Test (Regional) – 2024

1. Units of torque are force times distance. Which of the quantities below have the same units as torque? Note: m is mass, v is velocity, t is time, g is acceleration of gravity, and h is height above some origin.

a. mgt b. mgh c. mt^2h d. ght e. mvt

2. Given 3 vectors $\vec{A} = 6.20\hat{x} + 1.57\hat{y}$ and $\vec{B} = 4.87\ at\ 35°\ above\ the + x\ axis$
and $\vec{C} = 2.65\ at\ 40°\ counterclockwise\ from\ the + y\ axis$
What is the vector $\vec{T} = \vec{A} - \vec{B} + \vec{C}$?

a. $0.507\hat{x} + 0.807\hat{y}$ b. $1.33\hat{x} + 4.22\hat{y}$ c. $3.91\hat{x} + 0.807\hat{y}$
d. $4.24\hat{x} - 2.93\hat{y}$ e. $8.49\hat{x} + 6.39\hat{y}$

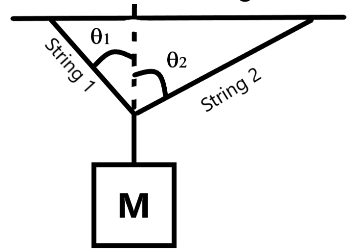
3. A rocket of Elon Musk takes off from the launch pad at time t = 0.00 s. Exactly 6.00 minutes after takeoff the rocket reaches an altitude of 177 km. What constant acceleration could achieve this result?

a. 1.37 m/s^2 b. 2.03 m/s^2 c. 2.73 m/s^2 d. 9.83 m/s^2 e. 983 m/s^2

4. Luca the cat is on the balcony of a 12^{th} floor apartment. The balcony is 36.6 m above the ground. Luca bats a 327 g ball off the balcony with a purely horizontal velocity of 1.47 m/s. How long after leaving the balcony does the ball land on the ground?

a. 2.73 s b. 3.73 s c. 7.47 s d. 8.93 s e. 24.9 s

5. A 6.21 kg mass hangs from a string that is attached to two other strings that are attached to the ceiling. The two strings make angles θ_1 = 40° and θ_2 = 75° relative to the vertical as shown in the diagram. What is the tension T_2 of string 2?



a. 4.40 N   b. 28.4 N   c. 30.4 N   d. 43.2 N   e. 64.9 N

6. A particle is moving along the x-axis according to the equation:

$$x(t) = (25 + 16t - 2.5t^3)m$$

What is the acceleration of the particle the instant when the velocity is zero?

a. 0.00 m/s^2 b. -3.10 m/s^2 c. -21.9 m/s^2 d. 25.0 m/s^2 e. -31.6 m/s^2

7. How many neutrons are in a sample of pure Carbon 14 ($^{14}_{6}C$) with a mass of 8.50 g?

a. 0.0759 moles   b. 0.607 moles   c. 3.64 moles
d. 4.25 moles   e. 4.86 moles

8. A mass m is sliding on frictionless ice with an initial velocity of v_o toward the north. A wind comes up that is directed to the south and applies a force F_W in that direction. The wind continues pushing on the mass until its velocity is v_o towards the south. The total distance that the mass travels in that time is:

a. $\frac{mv_o^2}{F_w}$ b. $\frac{F_w}{mv_o^2}$ c. $\frac{mv_o^2}{2F_w}$ d. $\frac{2F_w}{mv_o^2}$ e. 0.00

9. Middle schooler, Katie, can run 7.18 m/s for her whole leg of a 400 m relay race. She receives the baton while running her speed and runs her leg. The total time that she holds the baton is 14.5 s. How far did she run holding the baton?

a. 55.7 m   b. 96.0 m   c. 100 m   d. 102 m   e. 104 m

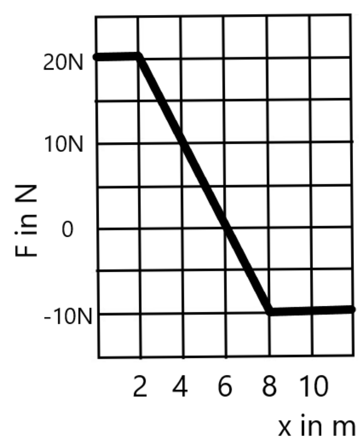
10. Consider a force $\vec{F}$ acting on a mass, m. The mass is moving with a velocity $\vec{v}$. If the force is doing negative work on the mass it could mean that

   a. It is impossible for work to be negative under these circumstances.
   b. The angle between the force and the velocity is greater than zero and less than 90°.
   c. The angle between the force and the velocity is 90°.
   d. The velocity is in the negative direction.
   e. The angle between the force and the velocity is greater than 90° and less than 180°.

11. A platform diver launches herself from the 10.0 m high diving platform. Her arms and legs are extended when she starts making her moment of inertia 31.4 kg m^2. As she leaves the platform she is rotating at a rate of 0.830 rev/s. She then pulls her legs up to her chest reducing her moment of inertia to 3.25 kg m^2. What is her new rate of rotation?

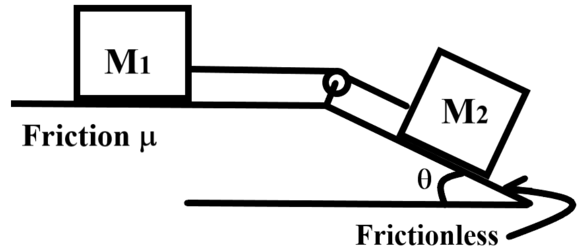
   a. $0.540\ \frac{rad}{s}$ b. $1.28\ \frac{rad}{s}$ c. $8.02\ \frac{rad}{s}$ d. $16.2\ \frac{rad}{s}$ e. $50.4\ \frac{rad}{s}$

12. Malcolm the cat has a mass of 1.48 kg and he is moving along the x axis under a force as shown in the graph. How much work is done by this force as Malcolm moves from x = 2m to x = 10m?



   a. -10 J b. 10 J c. 15 J d. 20 J e. 30 J

13. Consider the figure. M_1 is on a horizontal surface that has a coefficient of static friction $\square_s$, M_2 is on a frictionless incline, and the angle of the incline is given by $\square$. The string is light and passes over a frictionless pulley that is also light. What is the minimum $\square_s$ for which these masses will not move if released from rest?

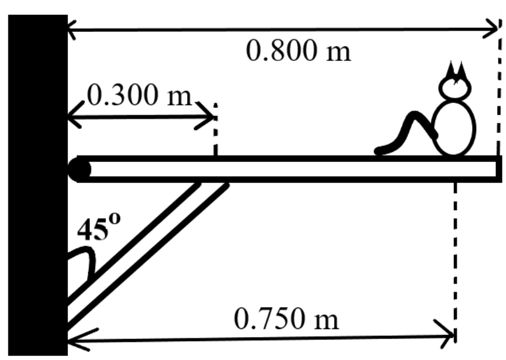


a. $\frac{M_2}{M_1}\cos\theta$ b. $\frac{M_2}{M_1}\sin\theta$ c. $\frac{M_1}{M_2}\operatorname{cosec}\theta$ d. $M_2\sin\theta$ e. $M_1\sec\theta$

14. Consider the arrangement in problem 13. If mass M_1 = 3.00 kg, mass M_2 = 6.5 kg, the coefficient of kinetic friction between M_1 and the surface is .317 (and block M_1 starts to move), and the angle of the incline is 21.7°, what is the acceleration of block M_1?

a. 1.50 m/s^2 b. 2.19 m/s^2 c. 3.46 m/s^2 d. 4.75 m/s^2 e. 5.25 m/s^2

15. Malcolm the cat is sitting on the end of a shelf that is constructed as shown in the figure. The shelf is attached to the wall by a pin connection that allows the shelf to rotate. The shelf is supported underneath by a metal bar that is connected to the shelf and the wall by pins such that the bar applies its support force in the direction parallel to the metal bar. The shelf is uniform and has a total mass of 0.882 kg. Malcolm weighs 31.2 N. What is the magnitude of the force the metal bar applies to the shelf in order to keep it stationary and horizontal?



a. 0.00 N b. 39.9 N c. 56.4 N d. 127 N e. 1100 N

16. A spring of spring constant k = 195 N/m is compressed 45.7 cm from equilibrium by a mass m = 16.2 kg as shown in the diagram. The mass is not attached to the spring. The area near the uncompressed position of the spring is frictionless. There is a rough surface beyond the spring with coefficient of kinetic friction 0.024.

What is the potential energy stored in the spring?

a. 2.85 J b. 6.24 J c. 20.4 J d. 69.1 J e. 89.1 J

17. In the situation described in problem 16, what distance will the mass move across the rough surface before coming to rest?

a. 0.128 m b. 0.248 m c. 4.01 m d. 5.34 m e. 17.5 m

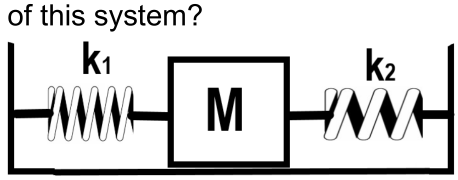
18. For many years muscle cars were built and an important measure of their worth was their acceleration. A certain muscle car, with a mass of 1650 kg, is able to go from zero miles per hour to 60.0 miles per hour (26.8 m/s) in 4.79 s with constant acceleration. If the wheels of that car were 42.5 cm in diameter, what is the number of revolutions those tires will make in going from zero to 26.8 m/s? (assume that the tires roll without slipping)

a. 24.0 rev b. 30.2 rev c. 48.1 rev d. 151 rev e. 302 rev

19. For the muscle car in the previous problem, what power output would be necessary to create this level of constant acceleration over the given time period? You can neglect the moment of inertia of the wheels for this problem. Note that 1 hp is equal to 746 W.

a. 83.0 hp b. 142 hp c. 166 hp d. 284 hp e. 332 hp

20. Consider the mass in the figure sliding on a frictionless surface. Two springs are attached to the mass and to fixed walls of the system. The mass is moved a bit to one side and released. If M = 7.00 kg and k_1 = 6200 N/m and k_2 = 3750 N/m what is the frequency of oscillations (in Hz) of this system?



a. 2.98 Hz b. 6.00 Hz c. 18.7 Hz d. 37.7 Hz e. 55.7 Hz

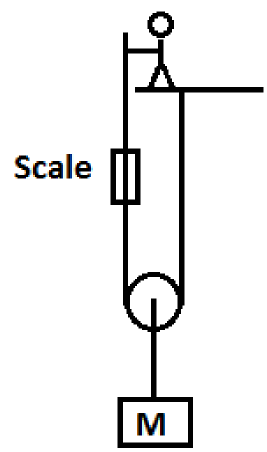
21. The internal energy of N molecules of an ideal monatomic gas depends on

a. the four variables R, T, P, and V.
b. the three variables T, P, and V.
c. The two state variables T, and P.
d. The two state variables T, and V.
e. The one state variable T.

22. Luca is a 1.23 kg cat who is playing with a 0.103 kg toy that is hanging at the end of a 2.76 m light string that is attached to the ceiling which is 3.14 m above the floor. Luca jumps up and grabs the toy causing them both to begin swinging like a pendulum. They swing up so that the string makes a maximum angle of 28.9° with the vertical. What is the magnitude of Luca's speed the next time the string makes an angle of 6.43° with the vertical?

a. 1.21 m/s b. 1.78 m/s c. 2.53 m/s d. 2.70 m/s e. 5.71 m/s

23.
A 35.0 kg mass is attached to a massless, frictionless pulley. The pulley is suspended from a platform as shown. The person pulls upward on the massless rope so that the mass moves upward at a constant speed. There is a scale attached to the rope in such a way that it measures the force of tension in the rope. What is the reading on the scale?



a. 0.00 N b. 35.0 N c. 172 N d. 343 N e. 687 N

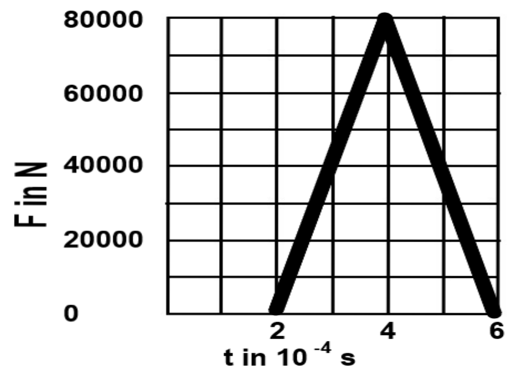
24. Katie is sitting 1.18 m from her TV speaker. The intensity of sound at Katie's ears is 2.24×10^{-5} W/m^2. Her Mom tells her to turn the TV volume down and move farther away from the TV. Katie turns the volume down 4.20 dB and moves to 2.89 m from the speaker. Assuming that the speaker acts as a point source of sound, what intensity of sound does Katie experience now?

a. $8.89\times10^{-7}\ \frac{W}{m^2}$ b. $1.42\times10^{-6}\ \frac{W}{m^2}$ c. $3.73\times10^{-6}\ \frac{W}{m^2}$
d. $8.52\times10^{-6}\ \frac{W}{m^2}$ e. $2.24\times10^{-5}\ \frac{W}{m^2}$

25. A spaceship of total mass m is in circular orbit around the Earth at an altitude of r above the surface of the Earth. Given that M_E is the mass of the Earth, R_E is the radius of the Earth, and G is the gravitational constant what is the speed of the spaceship relative to the Earth?

a. $\sqrt{\frac{GM_E}{R_E}}$ b. $\sqrt{\frac{Gm}{r}}$ c. $\sqrt{\frac{GmM_E}{R_E+r}}$ d. $\sqrt{\frac{GM_E}{R_E+r}}$ e. $\sqrt{\frac{GM_E}{r}}$

26. A major league baseball pitcher throws a baseball of mass 0.145 kg with a speed of 41.0 m/s. The batter strikes the ball applying a force from the 0.940 kg bat as shown in the graph. Assuming that the bat and ball interact entirely in one plane, what speed will the ball have as it leaves the bat? Note: as indicated the time axis is in units of 10^{-4} seconds.



a. 41.0 m/s b. 58.0 m/s c. 69.3 m/s d. 82.0 m/s e. 151. m/s

27. A block of wood with a thickness, h, and density of 0.806 g/cm^3, is floating in a container of glycerin, with a density of 1.26 g/cm^3. Slowly and carefully, ethyl alcohol with a density of 0.806 g/cm^3 is added to the container until the alcohol has a depth of 2h above the surface of the glycerin. Which statement is correct?

a. The wood floats on top of the alcohol with a fraction sticking up out of the alcohol.
b. The wood does not change its position (partially submerged in the glycerin).
c. The wood sinks below the surface of the glycerin.
d. The wood balances half in the glycerin and half in the alcohol.
e. The wood floats in the alcohol just above the surface of the glycerin.

28. A certain sample of Neptunium, $^{239}_{93}Np$, that started out with a radioactivity of 14.7 Ci is measured again at 0.952 days later when the radioactivity is found to be 11.1 Ci from the Neptunium. What is the half-life of Neptunium?

a. 0.719 days b. 0.775 days c. 1.26 days
d. 2.35 days e. 3.39 days

29. Consider the equation $a = \frac{b^2 c}{d f^3}$ where the dimensions of the variables are $b = \frac{[M]}{[L]}$ and $c = \frac{1}{[L]}$ and $d = \frac{[L]}{[T]}$ and $f = \frac{[T][M]}{[L]^2}$. What dimensions does a have?

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

30. Luca, a 1.23 kg cat, launches himself at an initial horizontal speed of 2.55 m/s and slides across a frictionless floor. He collides with Malcolm, a 1.48 kg cat who had been at rest. Immediately after the collision both cats are separately moving across the frictionless floor. Luca has a velocity of 1.18 m/s at an angle of 25.0° from his initial direction of motion. What is the magnitude of the velocity of Malcolm after the collision?

a. 0.437 m/s b. 1.14 m/s c. 1.30 m/s d. 2.06 m/s e. 3.86 m/s

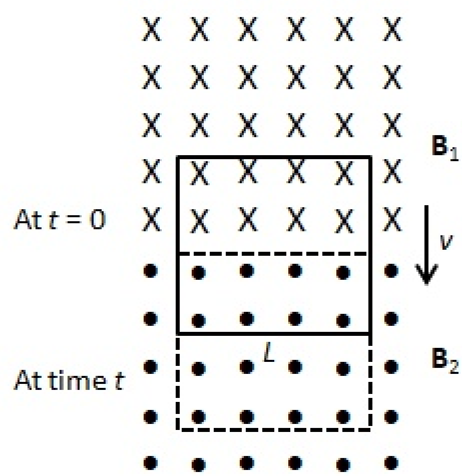
31. In a certain movie theater the projector is created with a single convex lens. The object to be magnified on the screen is exactly 9.16 m from the screen. The magnification of this lens system is -86.9. What is the focal length of the lens such that the object is focused on the screen?

a. 0.101 m b. 0.103 m c. 0.105 m d. 0.109 m e. 0.115 m

32. At FermiLab 2 particles, a proton and an electron, are moving in opposite directions in the collider. At a certain point the two particles are brought together to make a collision. According to the experimenter the electron is moving at a speed of 0.805c and the proton is moving at a speed of 0.190c. With what speed would the electron be moving toward the proton in the proton's frame of reference?

a. 0.590c b. 0.615c c. 0.726c d. 0.863c e. 0.995c

33. A loop of coil in the shape of a square with side length L moves downward at a constant speed v between two uniform magnetic fields, $\mathbf{B}_1$ and $\mathbf{B}_2$, as shown in the diagram. The two magnetic fields are equal in magnitude but opposite in direction. The top and bottom sides of the coil are parallel to the boundary between the two magnetic fields. The coil has resistance R. At t = 0, half of the coil is in $\mathbf{B}_1$ and half is in $\mathbf{B}_2$; at time t, the coil has just entered $\mathbf{B}_2$ completely. What is the direction of the induced current produced in the coil in the process from t = 0 to t?



a. Out of the page
b. Into the page
c. Counterclockwise
d. Clockwise
e. There is no induced current.

34. In the situation described in problem 30, if $B_1 = B_2$ = 2.00 T, v = 5.00 m/s, L = 0.300 m, and R = 5.00 Ω, what is the induced current produced in the process from t = 0 to t?

a. 0 A b. 0.600 A c. 1.20 A d. 2.40 A e. 3.60 A

35. Which of the following statements about a collection of gas molecules at a certain temperature in a container is true?
   a. The molecules have a range of kinetic energies.
   b. All the molecules move with the same velocity.
   c. The kinetic energy of the molecules is zero.
   d. All of the molecules have the same momentum.
   e. The lower the temperature, the greater are the molecular speeds.