ACADEMIC CHALLENGE FOR ACES ENGINEERING AND SCIENCE

EASTERN ILLINOIS UNIVERSITY

2022 Academic Challenge

REGIONAL 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 K

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1. Consider the following two points measured from the same origin with the *x* direction in the 0˚ direction:

   Point 1: $x = 3.00$ m and $y = 2.00$ m
   Point 2: $r = 5.10$ m and $\theta = 11.3^\circ$

   What is the distance between these two points?

   a. 0.10m b. 1.5m c. 2.24m d. 3.00m e. 9.53m

2. The height of an adult giraffe is most closely given by:

   a. 5 cm b. 5 in c. 5 m d. 5 km e. 5 mi

3. The mass of Neptune is 1.024×10^{26} kg. The density of Neptune is 1640 kg/m^3. Based on this data, what is the radius of Neptune?

   a. 6.38×10^6 m b. 2.46×10^7 m c. 3.97×10^7 m d. 1.66×10^8 m e. 1.41×10^{11} m

4. A plane can fly 60.0 m/s in still air. It travels 500 km directly into a wind of 15.0 m/s. Then it turns around and travels back to its starting point with a 15.0 m/s tailwind. What is the total time it takes to make the trip?

   a. 16.7 min b. 278 min c. 296 min d. 500 min e. 1000 min

5. Vector **A** is given by $r_A = 3.71$ m at an angle of 151˚ and vector **B** is given by $r_B = 4.27$ m at an angle of 247˚. What is **B** – **A**?

   a. 0.57 m at an angle of 96˚
   b. 2.65 m at an angle of 53.1˚
   c. 2.65 m at an angle of 105˚
   d. 5.94 m at an angle of 74.6˚
   e. 5.94 m at an angle of 285˚

6. A punter kicks a football and in so doing accelerates it with a constant acceleration of 65.0 m/s^2 for 0.125 s. Making the approximation that the 0.460 kg ball started from rest, what is the average net force that was applied during the kick?

   8.13 N b. 29.9 N c. 141 N d. 239 N e. 520 N

7. The football in the previous problem leaves the punter's foot at an angle of 57.1° relative to the horizontal. What is the hang time (total time in the air) for this punt? (assume that the ball left the foot at ground level and returns to ground level)

   a. 0.901 s b. 1.39 s c. 1.66 s d. 3.05 s e. 6.10 s

8. A good physics demonstration of uniform circular motion is to swing a pail of water in a vertical circle. What minimum speed must be achieved at the top of the 1.81 m diameter circle so that the 1.37 kg of water in the pail stays at the bottom of the pail?

   a. 2.98 m/s b. 4.21 m/s c. 8.87 m/s d. 13.4 m/s e. 17.7 m/s

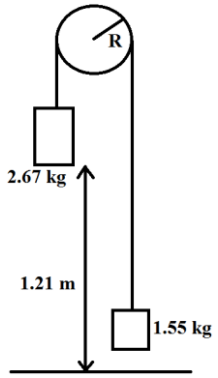
9. At a renaissance fair there is a large dragon themed ride that consists of a large swing. The length of the swing is 8.50 m and the mass of the seats with riders is 575 kg. The swing is powered by the operator giving it a push and is friction free by design. Immediately after the push the swing has a speed of 3.15 m/s and makes an angle of 67.0° with the vertical. What is the speed that the riders experience at the bottom of the swing?

   a. 8.66 m/s b. 10.6 m/s c. 12.4 m/s d. 13.0 m/s e. 13.3 m/s

10. A family is taking their vacation in the Rocky Mountains. Their car, of total mass 1850 kg, is driving up a mountain that is a constant incline of 12.2°. They are traveling at a constant speed of 32.2 m/s. What is the rate of change of gravitational potential energy of the car?

    a. $1.23 \times 10^5 \frac{\text{kg m}^2}{\text{s}^3}$ b. $5.71 \times 10^5 \frac{\text{kg m}^2}{\text{s}^3}$ c. $5.84 \times 10^5 \frac{\text{kg m}^2}{\text{s}^3}$
    d. $9.16 \times 10^5 \frac{\text{kg m}^2}{\text{s}^3}$ e. $9.59 \times 10^5 \frac{\text{kg m}^2}{\text{s}^3}$

11. Consider the Atwood's Machine in the figure. The masses and heights are as shown. The string does not slip on the pulley and the pulley has a mass of 1.85 kg. The pulley can be considered to be a uniform solid disk with a radius R = 15.0 cm. The masses are released from rest. What is the speed of the 2.67 kg mass just before it reaches the floor?

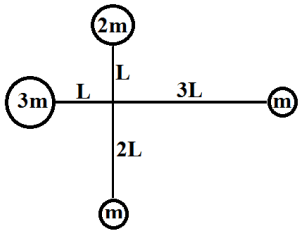


    a. 2.17 m/s b. 2.27 m/s c. 2.51 m/s d. 3.64 m/s e. 4.87 m/s

12. For the situation in problem 11, what is the magnitude of the angular velocity of the pulley 0.250 s after the masses are released?

a. 0.532 rad/s b. 3.24 rad/s c. 3.56 rad/s d. 8.12 rad/s e. 9.13 rad/s

13. Consider the object in the figure. The masses can be considered point masses and the bars connecting them can be considered massless. The object rotates about an axis that is perpendicular to the paper and through the intersection of the two bars. Find the rotation rate if the rotational kinetic energy of the object is $\frac{43\ \mathrm{mL}^2}{\mathrm{T}^2}$ where T is the period of revolution of the system.

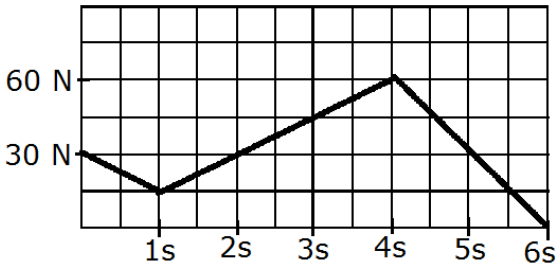


a. 1.54 $\frac{\mathrm{rad}}{\mathrm{T}}$ b. 2.19 $\frac{\mathrm{rad}}{\mathrm{T}}$ c. 3.09 $\frac{\mathrm{rad}}{\mathrm{T}}$ d. 6.28 $\frac{\mathrm{rad}}{\mathrm{T}}$ e. 6.56 $\frac{\mathrm{rad}}{\mathrm{T}}$

14. A uniform meter stick balances at its geometric center. When a small chain is hung from one end of this meter stick, the balance point of the chain-stick system moves 11.0 cm toward that end. The mass of the chain divided by the mass of the stick is

a. 0.220 b. 0.282 c. 0.780 d. 1.12 e. 3.55

15. A graph of force acting in a constant direction on a 12.0 kg object as a function of time is shown. If the object starts from rest, what is its velocity at 6.00 seconds?

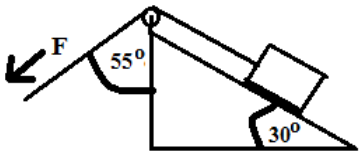


a. −30.0 m/s b. −5.00 m/s c. −2.5 m/s d. 7.50 m/s e. 16.3 m/s

16. Continuing problem 15, what is the equation for the acceleration between 4 seconds and 6 seconds? (all constants have the appropriate units)

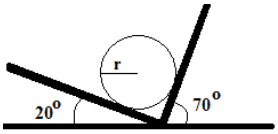
a. $a = 9.8$ b. $a = 12 - t$ c. $a = 15 - 2.5t$ d. $a = 180 - 30t$ e. $a = 180 - 15t - 2.5t^2$

17. A block of weight *w* remains at rest on a frictionless surface that is inclined 30.0° from horizontal, while force **F** is applied to the rope that passes over the frictionless pulley at the angle of 55.0° from the vertical as shown. The rope has negligible mass. What is the magnitude of force **F**?



a. *w* cos 30.0° b. *w* sin 30.0° c. *w* cos 30.0°/cos 55.0°
d. *w* cos 30.0°/sin 55.0° e. *w* sin 30.0°/cos 55.0°

18. A 2.50 kg sphere of radius *r* = 36.5 cm rests in a frictionless, V-shaped groove, as shown in the diagram. What is the magnitude of the contact force of the sphere on the left side surface of the groove?



a. 6.96 N b. 8.38 N c. 14.6 N d. 23.0 N e. 24.5 N

19. In an inelastic collision between two particles with no external forces acting

a. the total momentum of the system is constant and the total kinetic energy of the system is also constant.
b. the total momentum of the system is constant but the total kinetic energy of the system is not constant.
c. the total mechanical energy of the system is conserved.
d. the total potential energy of the system is constant.
e. the total moment of inertia of the system is constant and the angular velocity of the system is not constant.

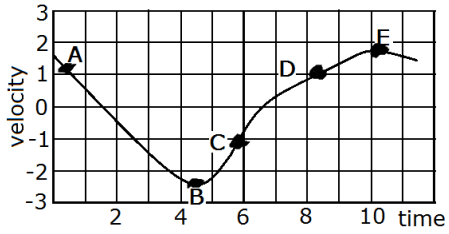
20. Information about G, e, ε_0, and h is given in the fundamental constants section at the beginning of this exam. What are the units of the quantity $\frac{e^2 h}{\varepsilon_o G}$?

a. $\frac{\mathrm{kg^3 m^2}}{\mathrm{s}}$ b. $\frac{\mathrm{m^2}}{\mathrm{kg\ s}}$ c. $\frac{\mathrm{C^4\ kg\ s^3}}{\mathrm{m^4}}$ d. $\frac{\mathrm{C^2\ kg\ m^2}}{\mathrm{s^2}}$ e. $\frac{\mathrm{kg\ m^2}}{\mathrm{C^2 s}}$

21. In a car sound system people often want the bass to be much louder than the treble. If one wants the ratio of the bass sound intensity to the treble sound intensity to be 1.33 for the frequencies of 125 Hz (bass) and 1190 Hz (treble), what is the bass to treble amplitude ratio?

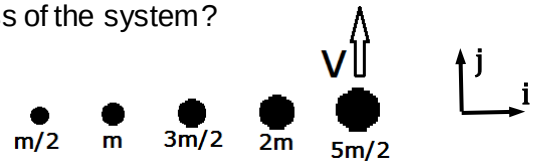
a. 1.00 b. 2.68 c. 7.16 d. 8.25 e. 11.0

22. Given the graph of velocity verses time shown below, which of the labeled points is the largest magnitude acceleration?



a. Point A b. Point B c. Point C d. Point D e. Point E

23. Consider the 5 masses shown in the diagram below. If the particle on the right moves in the vertical direction with a speed of *v* with the other 4 masses remaining stationary what is the velocity of the center of mass of the system?



a. $\frac{1}{3}v\mathbf{j}$ b. $\frac{5}{2}v\mathbf{j}$ c. 0 d. $\frac{1}{5}v\mathbf{i}+\frac{1}{2}v\mathbf{j}$ e. $\frac{1}{3}v\mathbf{i}+\frac{1}{3}v\mathbf{j}$

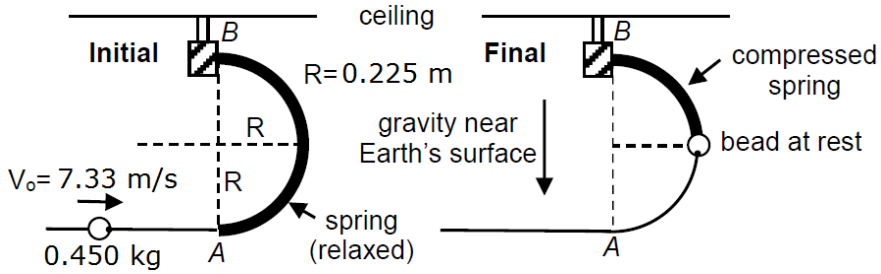
24. A reasonable statement of Pascal's Principle (sometimes stated as Pascal's Law) is:

a. Any body completely or partially submerged in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the body.
b. In a diffusion process, molecules move from a region where their concentration is high to a region where their concentration is lower.
c. Equal volumes of a gas at the same temperature and pressure contain the same number of molecules.
d. The condition Av = constant is equivalent to the fact that the amount of fluid that enters one end of a given tube in a given time interval equals the amount of fluid leaving the tube in the same time interval, assuming no leaks.
e. Pressure applied to an enclosed fluid is transmitted undiminished to every point of the fluid and to the walls of the containing vessel.

25. If two objects are in the same circular orbit about the Sun at a radius of 1.25 AU (so that all other bodies can be neglected) but close enough that there is a measurable gravitational force between them, then the gravitational attraction between the objects will cause

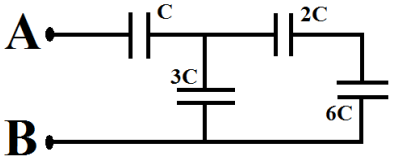
a. the two objects to fall closer to each other thus reducing their mutual potential energy and that energy will be transferred to their orbit making both objects increase their orbit radius.
b. the two objects to remain exactly the same distance apart and in the same orbit.
c. the two objects to move in the same radius orbit but perpendicular to their direction of orbit. They will move in opposite directions relative to the original orbit so that they conserve momentum.
d. the lead object to fall to a lower orbit and speed up relative to the following object which will rise to a higher orbit and slow down relative to the lead object.
e. the lead object to rise to a higher orbit and speed up relative to the following object which will fall to a lower orbit and slow down relative to the lead object.

26. A small bead of mass 0.450 kg slides with speed, v_o = 7.33 m/s, along a frictionless, horizontal wire which bends upward (at point A) into a semi-circular curve of radius, R = 0.225 m. A relaxed (uncompressed) spring of negligible mass is anchored at point B and is coiled around the wire, extending down along the semi-circle to point A, as shown. As the bead contacts the spring at point A, it compresses the spring, eventually coming to rest momentarily one-half the way up the semi-circle. Using energy concepts, what is the effective spring constant of the spring, assuming that the spring force is proportional to its arc length compression?



a. 15.9 N/m b. 19.6 N/m c. 178 N/m d. 194 N/m e. 438 N/m

27. Consider the capacitor circuit shown. What is the equivalent capacitance between the points A and B given the capacitances shown for the capacitors.



a. (11/35)C b. (1/2)C c. (9/11)C d. (11/12)C e. 12C

28. How fast would a neutron (m = 1.68x10^{-27} kg) have to travel to have a relativistic mass equivalent to a motionless Σ^o (m = 2.13x10^{-27} kg) particle?

a. 0.382c b. 0.615c c. 0.905c d. 1.27c e. It is physically impossible

29. In a Carnot engine the adiabatic expansion step in the process is done reversibly. The temperature of the gas begins at 785K and ends at 342K. The volume of the gas begins at 1.30×10^{-3} m^3. After the adiabatic process is completed the volume has changed. What is the entropy change of this system during this process?

a. -1.04×10^{-2} J/K b. 0.00 J/K c. 1.81×10^{-3} J/K d. 2.98×10^{-3} J/K e. 1.04×10^{-2} J/K

30. Consider a conducting spherical shell of radius *r*. A charge -2*q* is located a distance *r*/2 from the center of the conductive sphere. A charge of 3*q* is then added to the spherical shell. After static equilibrium is established the charge on the inner and outer surfaces of the shell are respectively:

a. $-2q$ and q b. $-2q$ and $3q$ c. $\frac{1}{2}q$ and $\frac{5}{2}q$ d. $2q$ and q e. $2q$ and $-3q$

31. A quantum harmonic oscillator absorbs a photon of wavelength 532 nm causing it to increase its quantum energy state from 3 to 5. What is the ground state energy of this harmonic oscillator?

a. 0.00 J b. 1.49×10^{-20} J c. 2.97×10^{-20} J d. 5.95×10^{-20} J e. 9.34×10^{-20} J

32. When camping, it is common to see a swarm of mosquitos flying about. If a 0.250 cubic meter volume contains 3250 mosquitos and each one flies in random directions at a speed of 1.05 m/s, then how far would one fly on average before colliding with another mosquito? Assume that the mosquitos are modelled as spheres that are 3.00 mm in diameter.

a. 48.1 cm b. 73.9 cm c. 192 cm d. 232 cm e. 814 cm

33. Which has the fewest atoms: 1.00 kg of Oxygen, 1.00 kg of Carbon, or 1.00 kg of Helium?

a. Oxygen b. Carbon c. Helium d. They all have the same number of atoms
e. Not enough information given to determine which has the fewest atoms

34. Consider a binary star system. This particular system is measured to be 47.5 light years away from Earth. The smallest diameter telescope that could distinguish these two stars is 1.85 m (diameter). Consider the wavelength of the light to be 562 nm. What is the separation of these stars? (1 light year = 9.46×10^{15}m)

a. 3.51×10^{9}m b. 1.36×10^{11}m c. 1.67×10^{11}m d. 2.08×10^{13}m e. 2.08×10^{24}m

35. What is the distance of closest approach of a 0.300 MeV alpha particle ($^{4}_{2}\mathrm{He}$) to the nucleus of a silver atom ($^{107}_{47}\mathrm{Ag}$)? Assume that the silver atom remains at rest during the collision and that this is a head on collision.

a. 1.87×10^{-21} m b. 9.61×10^{-15}m c. 4.51×10^{-13}m d. 1.03×10^{-12}m e. 6.72×10^{-7}m