ACES – Academic Challenge
Physics Test (State) – 2022

1. Consider the coefficient of viscosity, η, that is shown in the following equation:

$$F = \eta \frac{Av}{l}$$

where *F* is the force between two layers of the fluid, *A* is the cross sectional area of the layers, v is the relative velocity of the layers, and l is the distance between the layers. What dimensions does η have? Note that [m] is mass, [L] is length, and [T] is time.

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

2. The density of Platinum is 2.14×10^4 kg/m^3. What is the radius of a solid sphere of Platinum that has a mass of 1.47 kg?

   a. 2.54 cm b. 3.81 cm c. 4.09 cm d. 5.83 cm e. 24.4 cm

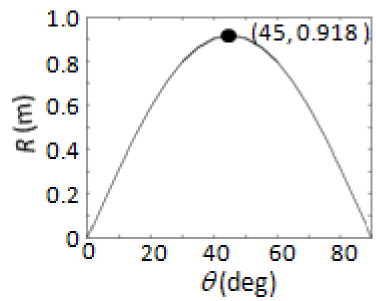
3. A pet hamster, Mollie, who has a mass of 43.7 g, runs at a constant speed of 1.87 m/s. She gets on her hamster wheel and goes that speed. The wheel can be considered to be a 28.9 g cylindrical shell with a radius of 8.23 cm. As Mollie runs on the wheel she appears to be staying in one place according to her owner. What is the magnitude of the angular momentum of the wheel while Mollie runs on it?

   a. $4.45 \times 10^{-3}\ kg\frac{m^2}{s}$ b. 0.0817 $kg\frac{m^2}{s}$ c. 0.657 $kg\frac{m^2}{s}$
   d. 81.7 $kg\frac{m^2}{s}$ e. 445 $kg\frac{m^2}{s}$

4. A sound wave with a frequency higher than 20,000 Hz is known as

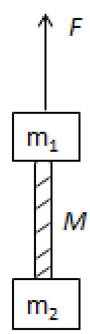
   a. supersonic.
   b. ultrasonic.
   c. infrasonic.
   d. hypersonic.
   e. seismic.

5. Quinn performs an experiment on projectile motion in her middle school science class. She launches a projectile from the ground at a given initial speed and measures the horizontal range R as a function of the initial launch angle θ, as shown in the diagram. Based on the information in the diagram, what is the initial speed of the projectile? Ignore air resistance.



a. 5.18 m/s
b. 4.20 m/s
c. 3.60 m/s
d. 3.00 m/s
e. 2.62 m/s

6. Two blocks of mass m_1 = 0.200 kg and m_2 = 0.300 kg are connected by a non-stretching rope of mass M = 0.100 kg. The two blocks are pulled by a constant, upward force of magnitude F = 7.00 N, as shown in the diagram. Under the force, the blocks accelerate upward. What is the magnitude of the acceleration?



a. 1.87 m/s^2
b. 2.20 m/s^2
c. 3.50 m/s^2
d. 4.16 m/s^2
e. 4.62 m/s^2

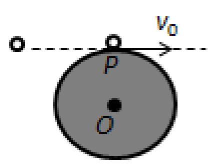
7. In the situation described in problem 6, what is the tension at the lower and upper end of the rope, respectively?

a. 6.85 N each
b. 5.60 N and 7.20 N
c. 4.28 N and 6.67 N
d. 5.00 N and 6.30 N
e. 3.50 N and 4.67 N

8. In recreating the experiment of Galileo, intrepid student Amy set an incline of length 1.65 m at an angle of 28.9˚ above the horizontal. She rolled a solid bronze sphere with a radius of 3.50 cm and a mass of 1.57 kg down the length of the incline. Amy found that rolling the sphere down the incline, starting from rest and without slipping, took 0.988 s. What linear acceleration did she find for the center of mass of the sphere? Note that $I_{sphere} = \frac{2}{5}mR^2$ and $I_{cylinder} = \frac{1}{2}mR^2$.

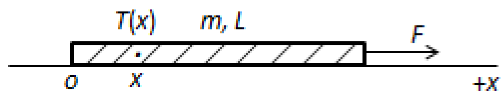
   a. 3.38 $\frac{m}{s^2}$ b. 4.00 $\frac{m}{s^2}$ c. 5.87 $\frac{m}{s^2}$ d. 8.58 $\frac{m}{s^2}$ e. 9.80 $\frac{m}{s^2}$

9. A small 0.100-kg object moves toward a uniform, cylindrical disk. The disk is initially at rest and can rotate without friction about a fixed horizontal axis passing through center *O*. Immediately before the collision, the object moves to the right with initial speed v_0 = 5.00 m/s in a direction tangential to the disk's surface at point *P*. The collision occurs very quickly and after the collision, the object sticks to the surface at point *P*. If the radius of the disk is 0.200 m and its moment of inertia about *O* is 0.0500 kg·m^2, what is the angular speed of the disk immediately after the collision?



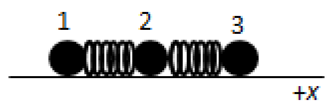
a. 1.76 rad/s
b. 1.85 rad/s
c. 2.00 rad/s
d. 2.35 rad/s
e. 3.00 rad/s

10. A uniform, non-stretching rope of mass *m* = 0.300 kg and length *L* = 1.50 m is pulled by a constant, horizontal force of magnitude *F* = 5.00 N. The rope accelerates on a frictionless, horizontal surface. At the instant shown, the *x*-axis is set along the length of the rope with the origin coincident with the left end of the rope and the positive direction to the right. The dependence of tension *T* on position *x* is found to be linear, *T* = *Ax*. What is the coefficient *A*?



a. 2.00 N/m
b. 3.20 N/m
c. 3.33 N/m
d. 4.06 N/m
e. 4.50 N/m

11. Three point masses are connected by identical, ideal springs of force constant k and are placed along the horizontal x-axis. In the configuration shown, the point masses are at their respective equilibrium positions. When the x-displacements of the point masses 1, 2, and 3 are s_1, s_2, and s_3, respectively, what is the general expression for the net spring force on point mass 2?



a. $k(s_1 - 2s_2 + s_3)$
b. $k(- s_1 + 2s_2 + s_3)$
c. $k(s_1 + 2s_2 + s_3)$
d. $k(- s_1 + s_2 - 2s_3)$
e. $k(2s_1 - s_2 - s_3)$

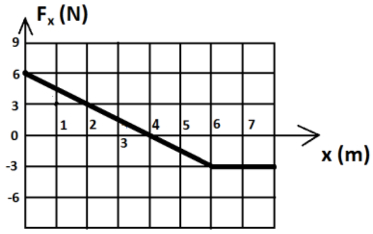
12. In uniform circular motion,

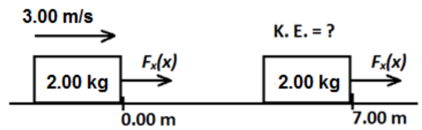
a. velocity is constant.
b. speed is constant.
c. acceleration is zero.
d. centripetal force is constant.
e. centripetal acceleration is constant.

13. Given M = mass, L= length, and T = time, a quantity with dimensions $\frac{M}{T^3}$ could be

a. acceleration per length per time.
b. momentum per time per time.
c. energy per length per time.
d. energy per length.
e. power per area.

14. As a 2.00 kg object moves along the x-axis, it is acted upon by a single force that acts along the x-axis and varies with the object's position as indicated in the graph below. If the velocity of the object is 3.00 m/s in the positive x-direction when the object is at 0.00 m, what will its kinetic energy be when it is at x = 7.00 m?



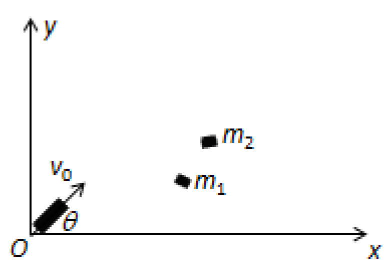


a. 6.00 J   b. 9.00 J   c. 15.0 J   d. 18.0 J   e. 24.0 J

15. A 0.500-kg object accelerates in the *x*-direction. At a given instant, the kinetic energy of the object increases at a rate of 10.0 J/s. If the *x*-velocity of the object at the instant is 5.00 m/s, what is the *x*-acceleration of the object?

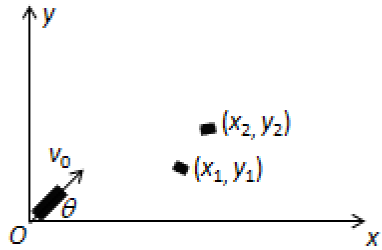
a. 4.00 m/s^2
b. 4.55 m/s^2
c. 5.00 m/s^2
d. 5.68 m/s^2
e. 6.50 m/s^2

16. A firecracker is thrown into the air at $t = 0$ from the origin with initial speed $v_0 = 3.00$ m/s at an angle $\theta = 60.0°$ counterclockwise from the +*x*-axis. The firecracker breaks up into two fragments of mass m_1 and m_2 somewhere in midair, as shown in the diagram. What are the *xy*-coordinates (x_{cm}, y_{cm}) of the center-of-mass of the two-fragment system at time *t*? Assume $m_1 = 2m_2$. Ignore air resistance.



a. $x_{cm} = (2.50 \text{ m/s})t$ and $y_{cm} = (0.50 \text{ m/s})t + (4.50 \text{ m/s}^2)t^2$
b. $x_{cm} = (3.00 \text{ m/s})t$ and $y_{cm} = (1.50 \text{ m/s})t - (9.80 \text{ m/s}^2)t^2$
c. $x_{cm} = (1.50 \text{ m/s})t$ and $y_{cm} = (2.60 \text{ m/s})t - (4.90 \text{ m/s}^2)t^2$
d. $x_{cm} = (1.00 \text{ m/s})t + (9.80 \text{ m/s}^2)t^2$ and $y_{cm} = (2.00 \text{ m/s})t - (4.90 \text{ m/s}^2)t^2$
e. $x_{cm} = (1.50 \text{ m/s})t$ and $y_{cm} = -(4.90 \text{ m/s}^2)t^2$

17. In the situation described in problem 16, if the xy-coordinates of the fragment with mass m_1 are (x_1, y_1) at time t, what are the coordinates (x_2, y_2) of the other fragment with mass m_2 at the time?



a. $x_2 = (3.00 \text{ m/s})t - x_1$ and $y_2 = (3.00 \text{ m/s})t - (19.6 \text{ m/s}^2)t^2 - y_1$
b. $x_2 = (4.50 \text{ m/s})t - 2x_1$ and $y_2 = (7.79 \text{ m/s})t - (14.7 \text{ m/s}^2)t^2 - 2y_1$
c. $x_2 = (1.50 \text{ m/s})t + 3x_1$ and $y_2 = (3.00 \text{ m/s})t - (9.80 \text{ m/s}^2)t^2 + 2y_1$
d. $x_2 = (4.50 \text{ m/s})t - x_1$ and $y_2 = (7.79 \text{ m/s})t - (14.7 \text{ m/s}^2)t^2 - y_1$
e. $x_2 = (1.50 \text{ m/s})t + 2x_1$ and $y_2 = (3.00 \text{ m/s})t - (9.80 \text{ m/s}^2)t^2 - y_1$

18. Consider a uniform meter stick balanced on a fulcrum at the 36.3 cm mark on the stick. A mass of 175 g is suspended from the meter stick at the 23.4 cm mark on the stick. The meter stick is balanced so that it is horizontal. What is the mass of the meter stick?

a. 113 g b. 165 g c. 186 g d. 271 g e. 299 g

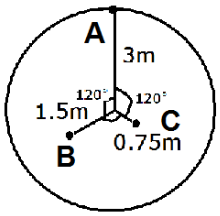
19. Both starting from the same point, student A walks 500 m directly east and student B walks 700 m directly north. What is the displacement of student B from student A after they complete their walks?

a. 200 m 35.5° south of east
b. 200 m 35.5° north of west
c. 860 m 54.5° south of east
d. 860 m 54.5° north of west
e. 860 m 60.5° south of west

20. A planet has a spherically distributed mass that is 5.00 times the mass of the earth, but has a gravitational acceleration at its surface that is twice the gravitational acceleration at the surface of the earth. If the radius of the earth is R_e, what is the radius of the planet?

a. $(5/2)R_e$
b. $\sqrt{2/5}\,R_e$
c. $\sqrt{5/2}\,R_e$
d. $(2/5)R_e$
e. $2R_e$

21. Three masses are attached to a solid massless disk in the arrangement shown in the figure. The masses A, B, and C are 3.60 kg, 7.20 kg, and 14.4 kg respectively. Their radial positions are shown in the figure (note that the angles between the line positions are all 120˚). The disk is rotated about an axis through its center and perpendicular to the page. The rotation is caused by a constant torque of 80.0 Nm. The disk starts from rest. What is the rotational kinetic energy of the system after 26.6 seconds? Note that the moment of inertia of a solid disk rotating through its center is $I = \frac{1}{2}MR^2$.



a. 20,000 J
b. 39,900 J
c. 59,900 J
d. 67,400 J
e. 79,800 J

22. A rocket fires exhaust material with a velocity of v_{ex} to move forward. What can be said about the velocity of the rocket?

a. The maximum velocity is v_{ex}.
b. The speed can approach v_{ex} asymptotically but can never achieve v_{ex} exactly.
c. For a rocket with mass it is impossible to even approach v_{ex} in any practical sense.
d. The velocity of the rocket depends on the object that the exhaust is pushing against (for example the Earth).
e. The maximum velocity can greatly exceed v_{ex}.

23. For transverse waves traveling down a string of given linear mass density, which relationship gives the dependence of the average power transmitted on the tension T of the string, and the frequency f and amplitude A of the wave?

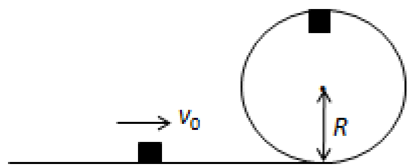
a. $P_{ave} \propto \sqrt{T} f^2 A$
b. $P_{ave} \propto \sqrt{T} f A^2$
c. $P_{ave} \propto T f^2 A^2$
d. $P_{ave} \propto \sqrt{T} f^2 A^2$
e. $P_{ave} \propto T^2 f^2 A$

24. Red light and green light of wavelength 650 nm and 550 nm, respectively, pass through a double slit with a slit separation of 1.75 mm. A screen is placed 3.50 m from the double slit. What is the separation distance between the red and green bright fringes of the same order, *m* = 1? Assume normal incidence.

a. 0.50 mm
b. 0.40 mm

c. 0.30 mm
d. 0.20 mm
e. 0.10 mm

25. A small object moves with speed v_0 on a horizontal surface before entering a vertical, circular track. The object then moves along the inner surface of the track of radius *R*. What is the minimum v_0 required for the object to reach the top of the track? Ignore friction and air resistance.



a. $\sqrt{gR}$
b. $\sqrt{2gR}$
c. $\sqrt{3gR}$
d. $\sqrt{4gR}$
e. $\sqrt{5gR}$

26. In the situation described in problem 25, include friction between the object and the circular track. If the mass of the object is 0.200 kg, v_0 = 6.00 m/s, *R* = 0.500 m, and the speed of the object at the top of the track is 2.25 m/s, how much work is done by friction?

a. – 1.00 J
b. – 1.13 J
c. – 1.28 J
d. 1.40 J
e. 1.56 J

27. How many 4 watt Christmas lights can you connect in parallel on a 120V – 15A household circuit and have them all fully lit?

a. 3.75
b. 30.0
c. 60.0
d. 450
e. 576

28. In a particle collider a proton is accelerated to a speed of 0.805c and moves toward the right in the lab reference frame. An anti-proton is accelerated in the opposite direction and moves at 0.190c in the lab frame. As the two particles speed towards each other, what speed does the anti-proton see the proton approaching with?

a. 0.597c b. 0.726c c. 0.863c d. 0.977c e. 0.995c

29. Consider the time independent normalized wave function for a particle in a one dimensional infinite square well in the second excited state (n=3). The width of the square well given by L and the energy of the ground state of the square well given by E. The wave function for this particle is:

a. $\Psi_3(x) = 3\sqrt{\frac{2}{L}}\sin\frac{\pi x}{L}$

b. $\Psi_3(x) = \sqrt{\frac{2}{E}}\sin\frac{3\pi x}{L}$

c. $\Psi_3(x) = \sqrt{\frac{3}{L}}\sin\frac{3\pi x}{L}$

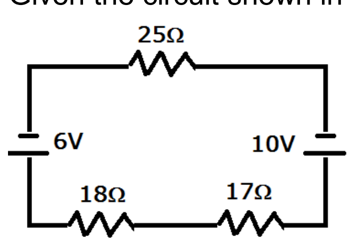
d. $\Psi_3(x) = \sqrt{\frac{2}{L}}\sin\frac{2\pi x}{L}$

e. $\Psi_3(x) = \sqrt{\frac{2}{L}}\sin\frac{3\pi x}{L}$

30. A thin lens is made from leaded glass that has an index of refraction of 1.78. The lens is bi-concave with radii of curvature of $R_1 = -21.4\ cm$ and $R_2 = +33.8\ cm$. What is the focal length of this lens?

a. -5.95 cm b. -13.1 cm c. -16.8 cm d. -58.3 cm e. -74.8 cm

31. Given the circuit shown in the figure, what is the current in the 18.0Ω resistor?



a. 66.6 mA b. 119 mA c. 267 mA d. 274 mA e. 474 mA

32. A sample of neptunium-239 ($^{239}_{93}Np$), starts out with a radioactivity of 14.7 Ci. The radioactivity of the sample (ignoring daughter products) is 11.1 Ci when measured again 0.952 days later. What is the halflife of neptunium?

a. 0.719 days b. 1.26 days c. 1.94 days d. 2.35 days e. 3.39 days

33. A certain compound has the following properties:

Specific Heat in the liquid state	$133\ \frac{kJ}{kg\ K}$
Specific Heat in the solid state	$118\ \frac{kJ}{kg\ K}$
Latent Heat of fusion	$45\ \frac{kJ}{kg}$
Latent heat of vaporization	$24\ \frac{kJ}{kg}$
Freezing point	43˚F
Boiling Point	176˚F

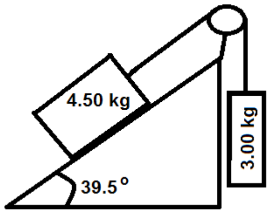
How much heat energy will it take to heat 1.36 kg of this material from 21˚F to 62˚F?

a. $3.57 \times 10^6 J$ b. $3.93 \times 10^6 J$ c. $4.67 \times 10^6 J$ d. $5.22 \times 10^6 J$ e. $7.03 \times 10^6 J$

34. Which of the following statements is correct?

a. An isobaric process is always reversible.
b. The entropy of the Universe increases in all natural processes.
c. An isothermal process is always reversible.
d. An adiabatic process is always reversible.
e. Avogadro's number is the number of hydrogen atoms in 1.00 liter of Hydrogen gas at standard temperature and pressure.

35. Consider the system shown in the figure. This is a frictionless system and the pulley and string have negligible mass. When released from rest what is the acceleration of the 4.50 kg mass?



a. 0.180 m/s^2 up the incline.
b. 0.180 m/s^2 down the incline.

c. 0.300 m/s^2 up the incline.
d. 0.300 m/s^2 down the incline.
e. 1.96 m/s^2 down the incline.