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PHYSICS DEPARTMENT

PHY 2048, Fall 2019 — Exam 3 (Final) — December 10th, 2019

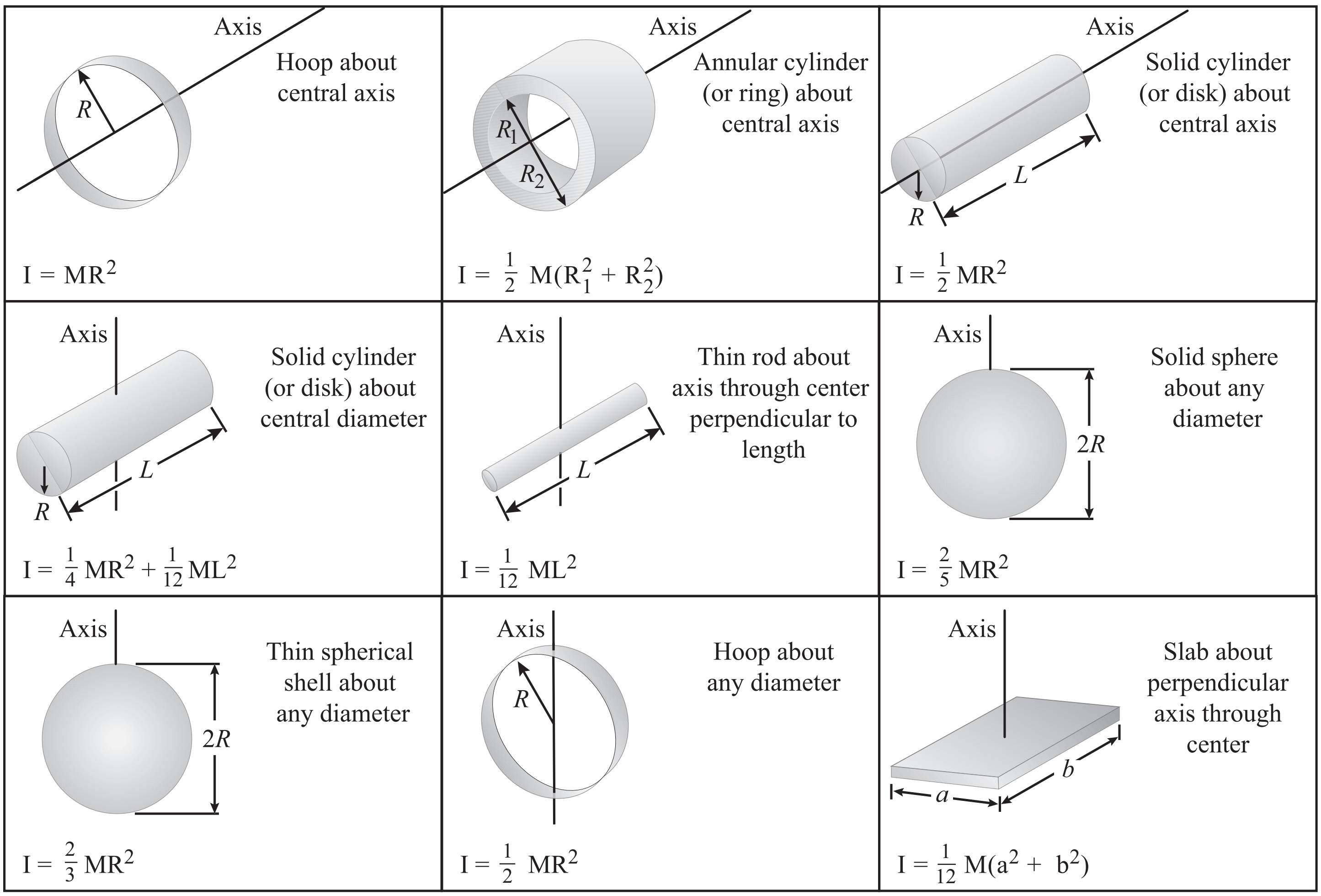
Name (print, last first): ______________________ Signature: ______________________

On my honor, I have neither given nor received unauthorized aid on this examination.

YOUR TEST NUMBER IS THE 5-DIGIT NUMBER AT THE TOP OF EACH PAGE.

(1) **Code your test number on your answer sheet (use lines 76–80 on the answer sheet for the 5-digit number).** Code your name on your answer sheet. **DARKEN CIRCLES COMPLETELY**. Code your UFID number on your answer sheet.
(2) Print your name on this sheet and sign it also.
(3) Do all scratch work anywhere on this exam that you like. **Circle your answers on the test form.** At the end of the test, this exam printout is to be turned in. No credit will be given without both answer sheet and printout.
(4) **Blacken the circle of your intended answer completely, using a #2 pencil or blue or black ink**. Do not make any stray marks or some answers may be counted as incorrect.
(5) **The answers are rounded off. Choose the closest to exact. There is no penalty for guessing.**
(6) Hand in the answer sheet (scantron) separately. Only the scantron is graded.

Use $g = 9.80\ \text{m/s}^2$



PHY2048 Exam 1 Formula Sheet

Vectors

$\vec{a} = a_x\hat{i} + a_y\hat{j} + a_z\hat{k}$ $\quad \vec{b} = b_x\hat{i} + b_y\hat{j} + b_z\hat{k}$ $\qquad$ Magnitudes: $|\vec{a}| = \sqrt{a_x^2 + a_y^2 + a_z^2}$ $\quad |\vec{b}| = \sqrt{b_x^2 + b_y^2 + b_z^2}$

Scalar Product: $\vec{a} \cdot \vec{b} = a_x b_x + a_y b_y + a_z b_z$ $\qquad$ Magnitude: $\vec{a} \cdot \vec{b} = |\vec{a}||\vec{b}|\cos\theta$ (θ = angle between $\vec{a}$ and $\vec{b}$)

Vector Product: $\vec{a} \times \vec{b} = (a_y b_z - a_z b_y)\hat{i} + (a_z b_x - a_x b_z)\hat{j} + (a_x b_y - a_y b_x)\hat{k}$

Magnitude: $|\vec{a} \times \vec{b}| = |\vec{a}||\vec{b}|\sin\theta$ (θ = angle between $\vec{a}$ and $\vec{b}$)

Motion

Displacement: $\Delta\vec{r} = \vec{r}(t_2) - \vec{r}(t_1)$

Average Velocity: $\vec{v}_{ave} = \dfrac{\Delta\vec{r}}{\Delta t} = \dfrac{\vec{r}(t_2) - \vec{r}(t_1)}{t_2 - t_1}$ $\qquad$ Average Speed: s_{ave} = (total distance)/Δt

Instantaneous Velocity: $\vec{v} = \dfrac{d\vec{r}(t)}{dt}$ $\qquad$ Relative Velocity: $\vec{v}_{AC} = \vec{v}_{AB} + \vec{v}_{BC}$

Average Acceleration: $\vec{a}_{ave} = \dfrac{\Delta\vec{v}}{\Delta t} = \dfrac{\vec{v}(t_2) - \vec{v}(t_1)}{t_2 - t_1}$ $\qquad$ Instantaneous Acceleration: $\vec{a} = \dfrac{d\vec{v}}{dt} = \dfrac{d^2\vec{r}}{dt^2}$

Equations of Motion for Constant Acceleration

$\vec{v} = \vec{v}_0 + \vec{a}t$

$\vec{r} - \vec{r}_0 = \vec{v}_0 t + \frac{1}{2}\vec{a}t^2$

$v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$ (in each of 3 dim)

Newton's Laws

$\vec{F}_{net} = 0 \Leftrightarrow \vec{v}$ is a constant (Newton's First Law)

$\vec{F}_{net} = m\vec{a}$ (Newton's Second Law)

"Action = Reaction" (Newton's Third Law)

Force due to Gravity

Weight (near the surface of the Earth) = mg (**use g=9.8** m/s^2)

Magnitude of the Frictional Force

Static: $f_s \leq \mu_s F_N$ $\qquad$ Kinetic: $f_k = \mu_k F_N$

Uniform Circular Motion (Radius R, Tangential Speed $v = R\omega$, Angular Velocity ω)

Centripetal Acceleration: $a = \dfrac{v^2}{R} = R\omega^2$ $\qquad$ Period: $T = \dfrac{2\pi R}{v} = \dfrac{2\pi}{\omega}$

Projectile Motion

Range: $R = \dfrac{v_0^2 \sin(2\theta_0)}{g}$

Quadratic Formula

If: $ax^2 + bx + c = 0$ $\qquad$ Then: $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Work (W), Mechanical Energy (E, Kinetic Energy (K)), Potential Energy (U)

Kinetic Energy: $K = \frac{1}{2}mv^2$ $\qquad$ Work: $W = \displaystyle\int_{\vec{r}_1}^{\vec{r}_2} \vec{F} \cdot d\vec{r}$ $\qquad$ When force is constant $W = \vec{F} \cdot \vec{d}$

Power: $P = \frac{dW}{dt} = \vec{F} \cdot \vec{v}$ $\qquad$ Work-Energy Theorem: $K_f = K_i + W$

PHY2048 Exam 2 Formula Sheet

$\Delta U = -W = -\int_{\vec{r}_1}^{\vec{r}_2} \vec{F} \cdot d\vec{r}$ $\quad F_x = -\frac{dU}{dx}$ $\quad$ Mechanical Energy: $E_{\rm mec} = K + U$

Work-Energy: $W(\text{external}) = \Delta K + \Delta U + \Delta E(\text{thermal})$

Springs

Hooke's Law: $F_x = -kx$ $\quad$ Elastic Potential energy (x from spring equilibrium): $U(x) = \frac{1}{2}kx^2$

Center of Mass and Momentum

Center of Mass: $\vec{r}_{\rm com} = \frac{1}{M_{\rm tot}} \sum_{i=1}^{N} m_i \vec{r}_i$

Linear Momentum: $\vec{p} = m\vec{v}$ $\quad$ Impulse: $\vec{J} = \Delta\vec{p} = \int_{t_i}^{t_f} \vec{F}(t)dt$ $\quad \vec{F} = \frac{d\vec{p}}{dt}$

$\vec{P}_{\rm tot} = M_{\rm tot}\,\vec{v}_{\rm com}$ $\quad \vec{F}_{\rm net} = \frac{d\vec{P}_{\rm tot}}{dt} = M_{\rm tot}\,\vec{a}_{\rm com}$

Rockets: Thrust $= Ma = v_{\rm rel}\frac{dM}{dt}$ $\quad \Delta v = v_{\rm rel}\ln(\frac{M_i}{M_f})$

Elastic Collisions of Two Bodies, 1D

$v_{1f} = \frac{m_1-m_2}{m_1+m_2}v_{1i} + \frac{2m_2}{m_1+m_2}v_{2i}$ $\quad v_{2f} = \frac{2m_1}{m_1+m_2}v_{1i} + \frac{m_2-m_1}{m_1+m_2}v_{2i}$

Rotational Variables

angular position: $\theta(t)$ $\quad$ angular velocity: $\omega(t) = \frac{d\theta(t)}{dt}$ $\quad$ angular acceleration: $\alpha(t) = \frac{d\omega(t)}{dt} = \frac{d^2\theta(t)}{dt^2}$

arc length: $s = r\theta$ $\quad$ velocity: $v = r\omega$ tangential acceleration: $a_{\rm T} = r\alpha$ $\quad$ centripetal acceleration: $a_{\rm c} = r\omega^2$

For constant angular acceleration α:

$$\omega = \omega_0 + \alpha t \qquad \omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0) \qquad \theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

Rotational (Moment of) Inertia and Rolling

$I = \sum_{i=1}^{N} m_i r_i^2$ (discrete) $\quad I = \int r^2\,dm$ (continuous)

Parallel Axis: $I = I_{\rm com} + M_{\rm tot}d^2$ (d is displacement from c.o.m.)

Kinetic Energy: $K_{\rm rot} = \frac{1}{2}I\omega^2$ $\quad K_{\rm roll} = \frac{1}{2}Mv_{\rm com}^2 + \frac{1}{2}I_{\rm com}\omega^2$

Torque etc.

$\vec{\tau} = \vec{r} \times \vec{F}$ $\quad \tau = rF\ \sin\theta$ $\quad$ Angular Momentum: $\vec{L} = \vec{r} \times \vec{p}$ $\quad L = I\omega$ $\quad \vec{\tau} = \frac{d\vec{L}}{dt}$

Work done by a constant torque: $W = \tau\Delta\theta = \Delta K_{\rm rot}$

Power done by a constant torque: $P = \tau\omega$ $\quad$ For torque acting on a body with rotational inertia I: $\vec{\tau} = I\vec{\alpha}$

Precession frequency: $\Omega = \frac{mgr}{I\omega}$ (r is moment arm)

Stress and Strain(Y = Young's modulus, B = bulk modulus)

Linear: $\frac{F}{A} = Y\frac{\Delta L}{L}$ $\quad$ Volume: $P = \frac{F}{A} = -B\frac{\Delta V}{V}$

Law of Gravitation

Magnitude of Force: $F_{grav} = G\frac{m_1 m_2}{r^2}$ $\quad G = 6.67 \times 10^{-11}\mathrm{Nm^2/kg^2}$

Potential Energy: $U_{grav} = -G\frac{m_1 m_2}{r}$ $\quad$ Total Mechanical Energy for circular orbit: $E = -\frac{GMm}{2r}$

Law of Periods: $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ $\quad$ Escape Speed: $v_{escape} = \sqrt{\frac{2GM}{R}}$

PHY2048 Exam 3 Formula Sheet

Ideal Fluids

Pressure: $P = \frac{F}{A}$ Units: 1 Pa = 1 N/m^2; 10^5 Pa = 1 bar $\simeq$ 1 atm

Equation of Continuity: $R_V = Av =$ constant (volume flow rate)

Bernoulli's Equation (y-axis up): $P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$

Fluids at rest (y-axis up): $P_2 = P_1 + \rho g(y_1 - y_2)$ Buoyancy Force: $F_{Buoy} = M_{fluid}\, g$

Simple Harmonic Motion (SHM) (angular frequency $\omega = 2\pi f = 2\pi/T$)

$x(t) = x_{\max}\cos(\omega t + \phi)$

Linear Harmonic Oscillator: $T = 2\pi\sqrt{\frac{m}{k}}$ Simple Pendulum: $T = 2\pi\sqrt{\frac{L}{g}}$ Physical Pendulum: $T = 2\pi\sqrt{\frac{I}{Mgh}}$

Torsion Oscillator: $T = 2\pi\sqrt{\frac{I}{\kappa}}$ Damped harmonic oscillator: $x(t) = e^{-bt/2m}x_{\max}\cos(\omega t + \phi)$

Sinusoidal Traveling Waves (frequency $f = 1/T = \omega/2\pi$, wave number $k = 2\pi/\lambda$)

$$y(x,t) = y_{\max}\sin(\Phi) = y_{\max}\sin(kx \pm \omega t + \phi) \quad (- = \text{right moving}, + = \text{left moving})$$

Wave Speed: $v_{wave} = \frac{\omega}{k} = \frac{\lambda}{T} = \lambda f$ Wave Speed (taught string): $v_{wave} = \sqrt{\frac{\tau}{\mu}}$

Kinetic Energy Transmitted: $\frac{dK}{dt} = \frac{1}{2}\mu v_{\text{wave}}\omega^2 y_{\max}^2\cos^2(kx \pm \omega t + \phi)$

Standing Waves on a String (L = length, n = harmonic number)

$$y'(x,t) = 2y_{\max}\sin(kx)\cos(\omega t)$$

Allowed Wavelengths & Frequencies: $\lambda_n = 2L/n$ $f_n = \frac{v_{wave}}{\lambda_n} = \frac{n v_{wave}}{2L}$ $n = 1, 2, 3\cdots$

Sound Waves (P = Power)

Sound wave displacement: $s(x,t) = s_m\cos(kx \pm \omega t)$ Sound wave pressure: $\Delta p(x,t) = \Delta p_m\cos(kx \pm \omega t)$

Intensity (W/m^2): $I = \frac{P}{A}$ Isotropic Point Source: $I(r) = \frac{P_{source}}{4\pi r^2}$ Speed of sound: $v_{sound} = \sqrt{\frac{B}{\rho}}$

Doppler Shift: $f_{obs} = f_s\frac{v_{sound} - v_D}{v_{sound} - v_s}$ (f_s = frequency of source, v_s, v_D = speed of source, detector)

Change $-v_D$ to $+v_D$ if the detector is moving opposite the direction of the propagation of the sound wave.

Change $-v_s$ to $+v_s$ if the source is moving opposite the direction of the propagation of the sound wave.

Angle of the Mach cone: $\sin(\theta) = \frac{c_{\text{sound}}}{v_{\text{source}}}$

Beat frequency: $f_{beat} = f_1 - f_2$ Resonance for pipe open on both ends: $f = \frac{nv}{2L}$ n = 1,2,3,...

Resonance for pipe closed at one end: $f = \frac{nv}{4L}$ n = 1,3,5,... Sound level: $\beta = (10\text{ dB})\log_{10}\frac{I}{I_0}$

1. A propeller blade has a radius (i.e. distance from the central shaft of the propeller to the end) of 0.5 meters. It starts from rest with an angle with respect to the horizontal given by $\theta = 0.1t^2$ where t is the time in seconds. At a time of $t = 3$ s, what is the magnitude of the total linear acceleration (in m/s^2) of a point at the end of a blade?

   (1) 0.21 (2) 0.18 (3) 0.10 (4) 0.28 (5) 0.38

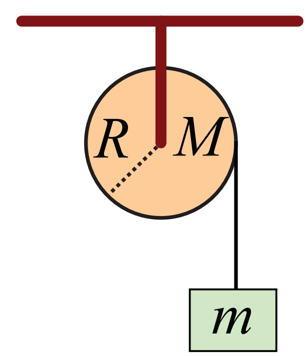
2. A stationary hand grenade of mass 4 kg explodes into 3 pieces. Two pieces, each of 1 kg, fly off with the angle between them of 74°, each with 10 m/s. How fast does the third (2 kg) piece travel in m/s?

   (1) 8 (2) 10 (3) 12 (4) 16 (5) 20

3. A merry-go-round is a uniform disk of mass M and radius R. A man (who can be considered to be point-like) has a mass of double that of the merry-go-round, so $m_{man} = 2M$. This man is on the merry-go-round near its outside edge and the merry-go-round is turning with an angular velocity of ω_1 The man then moves to a position half-way between the center and the rim. What is the merry-go-round's final angular velocity? Assume that there is no friction or other external torques.

   (1) 2.5 ω_1 (2) 2.0 ω_1 (3) 3.0 ω_1 (4) 1.5 ω_1 (5) 1.0 ω_1

4. A mass m hangs from a (mass-less) rope which is wound around a frictionless pulley which is a uniform disk of mass M and radius R, and released. What is the tension in the rope?



   (1) $mg\,(1 - \frac{m}{m + M/2})$

   (2) mg

   (3) $\frac{mMg}{m + M}$

   (4) $mg\,(1 + \frac{m}{m + M/2})$

   (5) $\frac{mg}{m + M/2}$

5. You stand on a bathroom scale and it reads 50 kg. You take it into an elevator and during a certain time period the elevator is going up with a speed that changes smoothly from 5 m/s to 3 m/s. During this time, what will the scale read if you are standing on it?

   (1) Less than 50 kg (2) More than 50 kg (3) 50 kg (4) There is not enough information (5) 0

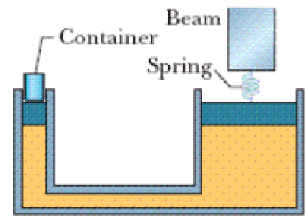
6. A heavy ball hangs from a mass-less rope which is attached to the ceiling by a hook. The rope is pulling the ball upwards to stop it from falling, and we can call this force the 'action' force. Which of the following forces is the 'reaction' force paired with this action force by Newton's Third Law.

   (1) The force of the ball pulling down on the rope
   (2) The gravitational force ('weight') pulling down on the ball
   (3) The tension of the rope pulling down the hook.
   (4) The force of the hook pulling up on the rope.
   (5) The force of the hook pulling the ceiling down.

7. Two blocks, one on top of the other, are on (frictionless) ice. The lower block has a mass of 20 kg, the upper block has a mass of 5 kg. The lower block is pulled horizontally with a force of 25 N. The coefficients of friction for the surface between the blocks are $\mu_s = 0.51$ and $\mu_k = 0.41$. What is the magnitude of the force of friction (in Newtons) on the upper block?

   (1) 5 (2) 10 (3) 49 (4) 25 (5) 20

8. In the figure, a spring of spring constant k is between a rigid beam and the output piston of a hydraulic lever. An empty container with negligible mass sits on the input piston. The input piston has area A_i, and the output piston has area $13A_i$. Initially the spring is at its rest length. When 10.9 kg of sand is slowly poured into the container the spring compresses by 6.3 cm. What is the spring constant k in units of N/m?

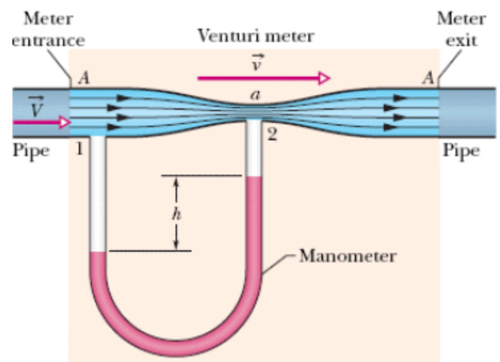


(1) 22000
(2) 11000
(3) 1700
(4) 260
(5) 130

9. Suppose that you release a small ball from rest at a depth of 0.43 m below the surface in a pool of water, and that the ball shoots to a height of 1.72 m above the water surface after it emerges from the water. If the drag force on the ball from water is negligible, what is the ratio of the density of the ball to that of water?

(1) 1/5 (2) 1/7 (3) 1/6 (4) 1/4 (5) 1/3

10. A *venturi meter* is used to measure the flow speed of a fluid in a pipe. The meter is connected between two sections of the pipe (see figure); the cross-sectional area A of the entrance and exit of the meter matches the pipe's cross-sectional area. Between the entrance and exit, the fluid flows from the pipe with speed V and then through a narrow "throat" of cross-sectional area a with speed v. A manometer connects the wider portion of the meter to the narrower portion. The change in the fluid's speed is accompanied by a change $\Delta p = -12$ kPa in the fluid's pressure, which causes a height difference h of the liquid in the two arms of the manometer. (Here Δp means pressure in the throat minus pressure in the pipe.) Suppose that the fluid has density 10^3 kg/m^3, and that the cross-sectional area of the pipe is $A = 78$ cm^2. If the rate of fluid flow is 0.014 m^3/s, what is the cross-sectional area a of the throat?

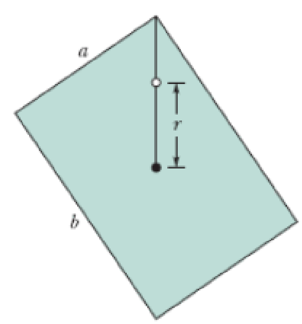


(1) 27 cm^2 (2) 78 cm^2 (3) 61 cm^2 (4) 44 cm^2 (5) 10 cm^2

11. A particle undergoes simple harmonic motion with an amplitude of 1.2 mm and a maximum speed of 3.4 m/s. What is the period of the motion?

(1) 2.2 ms (2) 0.35 ms (3) 0.80 ms (4) 1.2 ms (5) 1.7 ms

12. A rectangular block, with face lengths $a = 29$ cm and $b = 42$ cm, is to be suspended on a thin horizontal rod running through a narrow hole in the block. The block is then to be set swinging about the rod like a pendulum, through small angles so that it is in simple harmonic motion. The figure shows one possible position of the hole, at a distance $r = 20$ cm from the block's center, along a line connecting the center with a corner. What is the block's period of oscillation?



(1) 1.1 s
(2) 2.5 s
(3) 1.8 s
(4) 3.2 s
(5) 3.9 s

13. The suspension system of a 1700 kg automobile "sags" 10 cm when the chassis is placed on it. Assume that each wheel supports 425 kg, and that the damping constant for the spring and shock absorber system of one wheel is $b = 1060$ kg/s. By how much does the oscillation amplitude decrease each cycle?

(1) 55% (2) 50% (3) 45% (4) 40% (5) 35%

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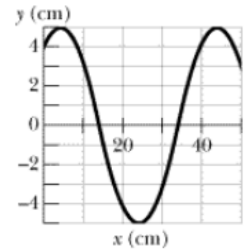
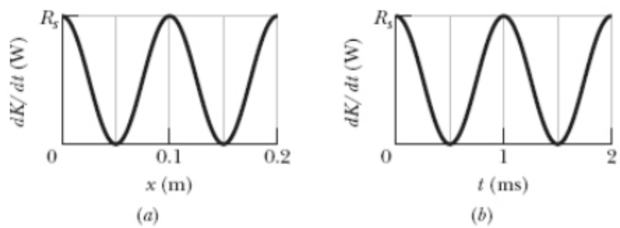
14. The figure shows a plot of the displacement as a function at time $t = 0$; the y intercept is 4.0 cm. If the wave is of the form $y(x,t) = y_m \sin(kx - \omega t + \varphi)$ what is the wave number k?



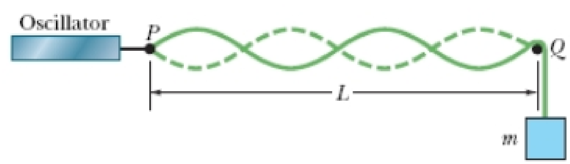
(1) 5π rad/m
(2) 4π rad/m
(3) 3π rad/m
(4) 2π rad/m
(5) Insufficient information

15. A sinusoidal wave is sent along a string with amplitude $s_m = 3$ mm. As it travels, the kinetic energies of the mass elements along the string vary. Figure (a) gives the rate dK/dt at which kinetic energy passes through the string elements at a particular instant, plotted as a function of distance x along the string. Figure (b) is similar except that it gives the rate at which kinetic energy passes through a particular mass element (at a particular location), plotted as a function of the time t. For both figures, the scale on the vertical (rate) axis is set by $R_s = 11$ W. What is the linear mass density μ of the string?



(1) 2.5 g/m (2) 2.2 g/m (3) 1.9 g/m (4) 1.6 g/m (5) 1.3 g/m

16. In the figure, a string, tied to a sinusoidal oscillator at P and running over a support at Q, is stretched by a block of mass $m = 0.58$ kg. What oscillator frequency is associated with the fourth harmonic on the string if the separation is $L = 0.9$ m and the linear density is $\mu = 1.1$ g/m?



(1) 160 Hz (2) 320 Hz (3) 240 Hz (4) 400 Hz (5) 80 Hz

17. Diagnostic ultrasound of frequency 500 kHz is used to examine tumors in soft tissue. What is the wavelength in the tissue if the speed of sound there is 1300 m/s?

(1) 2.6 mm (2) 3.3 mm (3) 4.0 mm (4) 1.9 mm (5) 1.2 mm

18. A sound wave $s(x,t) = s_m \cos(kx - \omega t + \phi)$ travels at 343 m/s through air in a long horizontal tube. At one instant, air molecule A at $x = 2.00$ m is at its maximum positive displacement of 6.0 nm and air molecule B at $x = 2.05$ m is at a positive displacement of 1.5 nm. All the molecules between A and B are at intermediate displacements. What is the frequency of the wave?

(1) 1400 Hz (2) 1300 Hz (3) 1200 Hz (4) 1100 Hz (5) 1000 Hz

19. A well with vertical sides and water at the bottom resonates at 8 Hz and has no lower frequency. The air-filled portion of the well acts as a tube with one closed end (at the bottom) and one open end (at the top). Assuming that the speed of sound of the air in the tube is 343 m/s, how far down in the well is the water surface?

(1) 10.7 m (2) 12.4 m (3) 14.1 m (4) 15.8 m (5) 17.5 m

20. A bat navigates through ultrasonic beeps with a frequency of $f = 40$ kHz. If the bat is moving with a speed 0.040 times the speed of sound towards a flat, stationary, wall, with what frequency does the bat hear the signal reflected from the wall?

(1) 43 kHz (2) 40 kHz (3) 37 kHz (4) 34 kHz (5) 46 kHz