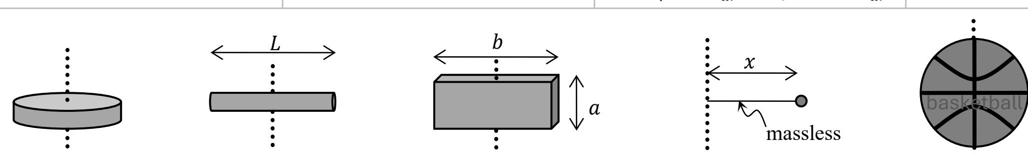
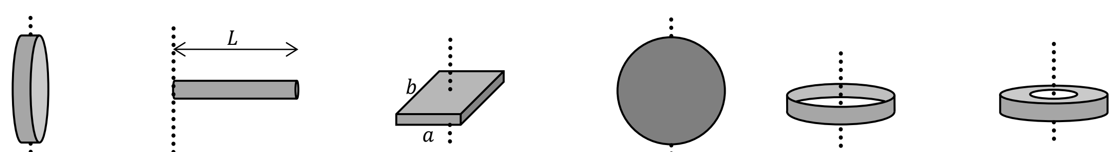
AFTER I GIVE THE SIGNAL TO BEGIN YOU CAN REMOVE THIS SHEET. DO NOT TURN IT IN!

162sp26t2a – Once the exam has officially started, remove the top sheet. The remaining sheets comprise your exam. It is each student's individual responsibility to ensure the instructor has received her or his completed exam. Any exams not received by the instructor earn zero points. Smart watches, phones, or other devices (except scientific calculators) are not permitted during the exam.

$1\ \text{kg}\cdot\frac{\text{m}}{\text{s}^2} = 1\ \text{N}$	$1\ \text{N}\cdot\text{m} = 1\ \text{J}$	$1\ \text{Pa} = 1\frac{\text{N}}{\text{m}^2}$	$1\ \text{W} = 1\ \frac{\text{J}}{\text{s}}$
$\Delta x = \frac{1}{2}a_x t^2 + v_{ix}t$	$v_x = \frac{dx}{dt}$	$a_x = \frac{dv_x}{dt}$	$v_{max} = \omega_0 x_{max}$
$\Sigma\vec{F} = m\vec{a}$	$\Sigma\vec{\tau} = I\vec{\alpha}$	$\mathcal{P} = \frac{dE}{dt}$	$a_{max} = \omega_0^2 x_{max}$
$\omega = 2\pi f = \frac{2\pi}{\mathbb{T}}$	$F_{spring} = k\lvert x\rvert$	$\omega_0 = \sqrt{\frac{k}{m}}$	$x(t) = A\cos(\omega_0 t + \phi)$
$-\omega_0^2 x = \ddot{x}$	$-\frac{\kappa}{I}\theta = \ddot{\theta}$	$-\frac{g}{L}\theta = \ddot{\theta}$	$-\frac{mgr_{CM}}{I_{pivot}}\theta = \ddot{\theta}$
$K = \frac{1}{2}mv^2$	$U = \frac{1}{2}kx^2$	$\sin\theta \approx \tan\theta \approx \theta$	$I_{\parallel axis} = I_{CM} + md^2$
$\vec{F}_{drag} = -b\vec{v}$	$x(t) = Ae^{-bt/2m}\cos(\omega_d t + \phi)$	$\omega_d = \sqrt{\omega_0^2 - \left(\frac{b}{2m}\right)^2}$	$\vec{\tau} = \vec{r}\times\vec{F} \rightarrow rF\sin\theta$ + R.H.R.
$\vec{F}_{driver} = F_0\sin(\omega_{dr}t)\,\hat{\imath}$	$x(t) = A\cos(\omega_{dr}t + \phi)$	$A = \frac{F_0}{\sqrt{m^2(\omega_{dr}^2 - \omega_0^2)^2 + b^2\omega_{dr}^2}}$	$x_{CM} = \frac{x_1 m_1 + x_2 m_2}{m_1 + m_2}$



$I_{disk} = \frac{1}{2}mR^2$ $\quad I_{\substack{thin\\rod}} = \frac{1}{12}mL^2$ $\quad I_{\substack{thin\\plate}} = \frac{1}{12}mb^2$ $\quad I_{\substack{pnt\\mass}} = mx^2$ $\quad I_{\substack{spherical\\shell}} = \frac{2}{3}mR^2$



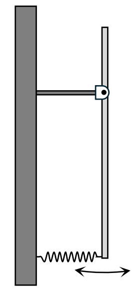
$I_{disk} = \frac{1}{4}mR^2$ $\quad I_{\substack{thin\\rod}} = \frac{1}{3}mL^2$ $\quad I_{\substack{thin\\plate}} = \frac{1}{12}m(b^2 + a^2)$ $\quad I_{\substack{solid\\sphere}} = \frac{2}{5}mR^2$ $\quad I_{\substack{thin\\ring}} = mR^2$ $\quad I_{\substack{thick\\ring}} = \frac{1}{2}m(R_i^2 + R_o^2)$

$y(x,t) = y(x \pm vt)$	$y(x,t) = A\sin(kx - \omega t + \phi)$	$k = \frac{2\pi}{\lambda}$	$v = f\lambda = \frac{\lambda}{\mathbb{T}} = \frac{\omega}{k}$
$\mu = \frac{m}{L}$	$v = \sqrt{\frac{F_{Tension}}{\mu}}$	$\mathcal{P}_{avg} = \frac{1}{2}\mu v\omega^2 A^2$	$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\cdot\frac{\partial^2 y}{\partial t^2}$
$y_{total}(x,t) = y_1(x,t) + y_2(x,t) + \cdots$	$s(x,t) = s_{max}\,\mathbf{cos}(kx - \omega t)$	$\Delta P(x,t) = \Delta P_{max}\,\mathbf{sin}(kx - \omega t)$	$\Delta P_{max} = v_{sound}\rho\omega s_{max}$
$v_{sound} = \sqrt{\frac{Bulk\ Modulus}{density}}$	$v_{\substack{sound\\air}} \approx 331.4\frac{\text{m}}{\text{s}} + \left(0.61\frac{\text{m}}{\text{s}\cdot{}^\circ\text{C}}\right)T_C$	$I = \frac{\mathcal{P}ower}{Area}$	$I = \frac{1}{2}\rho v\omega^2 s_{max}^2$
$\beta = 10\ \text{dB}\ \log_{10}\frac{I}{I_0}$	$I_0 = 10^{-12}\frac{\text{W}}{\text{m}^2}$	$\Delta r \approx d\sin\theta$ if $d \ll L$	$f_{beat} = \lvert f_1 - f_2\rvert$
$\Delta r = \lvert r_1 - r_2\rvert$	$\phi = \frac{\Delta r}{\lambda}180°$	$\Delta r_{des} = (odd\ integer)\frac{\lambda}{2}$	$\Delta r_{con} = (even\ integer)\frac{\lambda}{2}$
$f' = f_{source}\left(\frac{c \pm v_o}{c \mp v_s}\right)$	Use $+v_o$ if obs. towards source. Use $-v_s$ if source towards obs.	Mach # $= \frac{v_{source}}{v_{sound}} = \frac{1}{\sin\theta_{Mach}}$	$\sin(90° - \theta) = \cos\theta$

$\text{T} = 10^{12}$	$\text{G} = 10^9$	$\text{M} = 10^6$	$\text{k} = 10^3$	$\text{c} = 10^{-2}$	$\text{m} = 10^{-3}$	$\mu = 10^{-6}$	$\text{n} = 10^{-9}$	$\text{p} = 10^{-12}$	$\text{f} = 10^{-15}$	$\text{a} = 10^{-18}$

Name:____

A uniform rod of length L & mass m is supported by a pivot located distance $\frac{L}{4}$ from the top of the rod.



A spring of constant k connects the bottom the rod to the wall.
When the rod is parallel to the wall, the spring is unstretched.
The bottom of the rod is displaced slightly and released from rest.
Assume the small angle approximation holds for this problem.

******1) Determine the *period* of small oscillations.

- I may give partial credit if multiple correct steps of the process are shown.
- If you incorrectly plug into a memorized formula, no partial credit is available.
- **Simplify your work such that no fractions appear in the denominator of your final result.**

1	

A horizontal mass spring system uses mass m and spring constant k. The system experiences a *small* amount of damping. The system is driven by an oscillator operating at angular frequency ω.

2) Which best describes the motion of the mass? Circle the best answer.

Position decays *exponentially* to equilibrium without oscillation	Oscillation at rate $\omega_0 = \sqrt{k/m}$ with *decaying* amplitude	Oscillation at rate ω with *decaying* amplitude	Oscillation at rate $\omega_0 = \sqrt{k/m}$ with *constant* amplitude	Oscillation at rate ω with *constant* amplitude	Impossible to determine without more information	None of the other answers is correct

A horizontal mass spring system uses mass m and spring constant k. The system experiences damping. A student pulls the mass to the right and releases it from rest.

3) Which damping condition causes the mass to reach final equilibrium most rapidly? Circle the best answer.

Underdamped	Critically damped	Overdamped	Underdamped & critically damped both work equally well	Overdamped & critically damped both work equally well	Overdamped & underdamped both work equally well	All three cases work equally well	Impossible to determine without more information	None of the other answers is correct

Two vehicles travel directly towards each other. Vehicle A travels to the right, honking the horn. Vehicle B travels to the left moving 22.5% slower. The driver of vehicle B observes the horn frequency is shifted by 5.00%. Assume the speed of sound is c.

4a) Which way is the frequency of the horn shifted? Circle the best answer.

Up	Down	Impossible to determine without more info

***4b) Determine the speed of vehicle A. Answer as a decimal number with three sig figs times c.

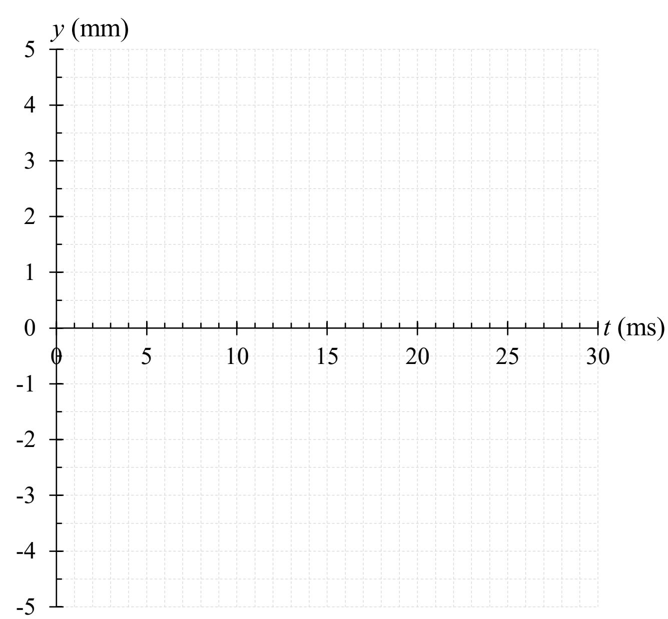
4b	

A sinusoidal string wave has amplitude 4.00 mm and wavelength 30.0 cm when string tension is 5.55 N. The wave moves *to the left* at $15.00\,\frac{\text{m}}{\text{s}}$ with phase angle 90.0°.

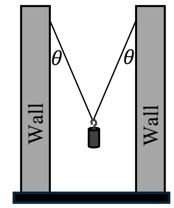
5a) Determine wavenumber (physics definition, not chemistry's).
5b) Determine period of the wave.
5c) Determine angular frequency of the wave.
5d) Determine initial vertical *velocity* of the string segment at the origin.
5e) Determine linear mass density of the string.
5f) Write an equation for the vertical position of string segments as a function of both horizontal position and time. Include #'s with units instead of variables for known parameters.
**5g) Sketch a plot of the vertical position of the string segment *at the origin* versus time for the first 30.0 ms. Use the plot at the bottom of the page.

5a	
5b	
5c	
5d	
5e	

5f	



Mass M hangs from a string at the angle θ shown in the figure. Distance between the two walls is d. When the string is plucked, transverse string waves require time Δt to travel from the hanging mass to the wall (one-way travel). Assume the mass of the string is much, much smaller than the hanging mass.



*****6a) Determine the mass of the string. Ensure your result is fully simplified.

Notice part b at the bottom of the page…

6a	

6b) Imagine we used the same set-up with same length string but the walls were farther apart. How would the new wave travel time ($\Delta t'$) compare to the original wave travel time Δt? Circle the best answer.

$\Delta t' > \Delta t$	$\Delta t' = \Delta t$	$\Delta t' < \Delta t$	Impossible to determine without more information

***7) A speaker radiates sound *hemispherically*. A sensor located $0.888\ \text{m}$ from the speaker records 122.5 dB. Assume attenuation is negligible. Determine the power output of the speaker.

7	

On a $40.0\ ℃$ day, two adjacent frequencies of an organ pipe are $20\underline{0}$ Hz and $28\underline{0}$ Hz.

8a) Determine the speed of sound.

8b) Determine the fundamental frequency of this pipe.

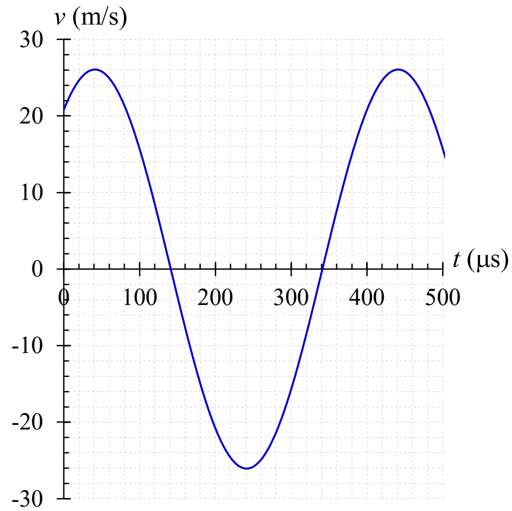
8c) Are boundary condition mixed or matched for this pipe? Write answer in the box.

**8b) Determine the length of the pipe.

8a	
8b	
8c	
8d	

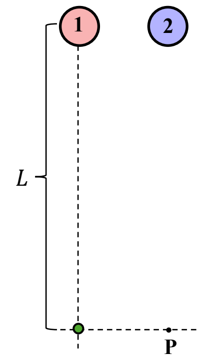
It is possible to use semiconductor fabrication techniques to build extremely small micro-electromechanical systems (MEMS). In one such device a mass-spring oscillator uses mass 3.20×10^{-10} kg. The plot at right shows an observed oscillation.

9a) Determine period of the oscillation.
9b) Determine angular frequency of oscillation.
9c) Determine the spring constant of the oscillator.
9d) Determine amplitude of the oscillation. Amplitude, not *velocity* amplitude.
9e) Determine the maximum force acting on the mass during oscillations.
**9f) Determine phase angle assuming we use $x(t) = A\cos(\omega t + \phi)$.
Your result only needs to be within 5% mine since you have to read off a graph.



9a	
9b	
9c	
9d	
9e	
9f	

This could be time consuming for only 3 points. Focus on regular credit and attempt this once you have tried all the regular credit.



***Extra Credit:** Two sound sources emitting sound waves in phase at frequency f are separated by some unknown distance. A sound sensor is located at the origin shown in the figure, distance L from speaker **1**. Point **P**, located directly below speaker **2**, is labeled in the figure for ease of communication. Assume the speed of sound is c for this problem. As the sensor was moved from the origin to point **P**, the following observations were made:

- The sound level at the origin was a minimum.
- The sound level at point P was a minimum.
- Three sound level maxima were recorded between the origin and point **P**.

Determine a simplified algebraic expression for d. Do not assume the small angle approximation is valid at any point in your derivation.

EC	

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