Name: ______________________ student ID: | S | | | | | | | |

Mechanics Exam M2

December 19, 2022
18:30-20:00
Aletta Jacobs Hall 1 (A1-P20)

About the Exam

1. There are 3 questions on the exam (60 points).
2. Write your answers *clearly* and *legibly*. Use standard notation and units when appropriate.
3. **Show all your work** (e.g., free-body diagrams, intermediate steps used in calculations, presumptions about problem) for full credit.
4. You may bring a *scientific* calculator to use on the exam – one will not be provided for you.
5. If you tear the pages apart, *write your name and student ID at the top of each page*.
6. If you use extra papers for your responses, place them ***inside*** the exam behind the cover page when you are done with the exam. *Make sure your name and student ID are on those papers.*

Possibly Useful Information

$\vec{v}(t) \equiv \frac{d\vec{r}}{dt}$	$\vec{r}(t) = \frac{1}{2}\vec{a}t^2 + \vec{v}_0 t + \vec{r}_0$	$\lvert\vec{v}\rvert = \sqrt{v_x^2 + v_y^2 + v_z^2}$	$\vec{r}_{CM} = \frac{\sum m_i \vec{r}_i}{\sum m_i}$	$M\frac{\Delta\vec{r}_{CM}}{\Delta t} = \sum m_i \vec{v}_i$
$\vec{a}(t) \equiv \frac{d\vec{v}}{dt}$	$\vec{v}(t) = \vec{a}t + \vec{v}_0$	$\lvert\vec{a}\rvert = \sqrt{a_x^2 + a_y^2 + a_z^2}$	$\vec{p} = m\vec{v}$	$\vec{F} = \frac{d\vec{p}}{dt}$ $\quad F_x = -\frac{dV}{dx}$
$K = \frac{1}{2}m\lvert\vec{v}\rvert^2$	$dK_{\text{CM}} = \lvert\vec{F}_{\text{ext}}\rvert\lvert d\vec{r}_{\text{CM}}\rvert cos\theta$	$V_g(r) = -\frac{Gm_1m_2}{r}$	$V_g(h) = m\lvert\vec{g}\rvert h$	$W = \int \vec{F}\cdot d\vec{r}$
$\sum \vec{F} = m\vec{a}$	$\lvert\vec{F}_{\text{KF}}\rvert \approx \mu_K \lvert\vec{F}_{\text{N}}\rvert$ $\lvert\vec{F}_{\text{SF}}\rvert \leq \lvert\vec{F}_{\text{SF,max}}\rvert \approx \mu_S\lvert\vec{F}_{\text{N}}\rvert$	$\lvert\vec{F}_{\text{D}}\rvert \approx \frac{1}{2}C\rho A\lvert\vec{v}\rvert^2$	$\vec{F}_{\text{T}}^{\text{A(B)}} = -\vec{F}_{\text{T}}^{\text{B(A)}}$	$m\vec{a}' = -m\vec{A} + \vec{F}_1 + \vec{F}_2 + \cdots$
$\lvert\vec{v}\rvert = \frac{2\pi R}{T}$	$\lvert\vec{a}\rvert = \frac{\lvert\vec{v}\rvert^2}{R}$	$\vec{a} = \frac{d\lvert\vec{v}\rvert}{dt}\hat{v} - \frac{\lvert\vec{v}\rvert^2}{R}\hat{r}$	$\vec{F}_{\text{Sp,x}} = -k_s\vec{x}$	$V_{\text{Sp}}(x) = \frac{1}{2}k_s(x - x_0)^2$
$\frac{d^2x}{dt^2} = -\omega^2 x$	$x(t) = A\cos(\omega t + \theta)$	$\omega \equiv \sqrt{k_s/m}$	$\omega \equiv \sqrt{\lvert\vec{g}\rvert/L}$	$T = \frac{2\pi}{\omega} = \frac{1}{f}$

Question	Your Score	Total Points
1		22
2		18
3		20
		60

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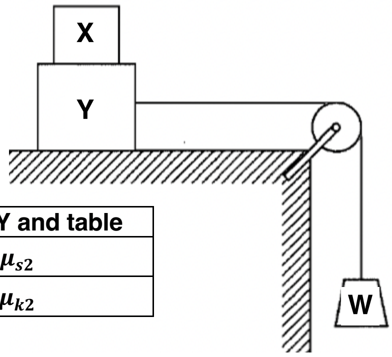
1. Weight over Pulley (22 points)



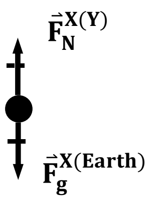
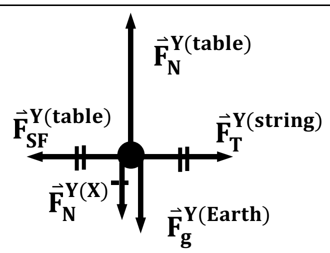
In the figure, block X (**mass m_1**) is resting on top of block Y (**mass m_2**) resting on a *rough table*; a massless string connects the large block to a weight W (**mass M**) that passes over a *frictionless and massless pulley*, set at the end of the table. Presume $m_1 < m_2$.

The (non-zero) coefficients of friction between blocks X and Y, and between block Y and the table, are shown here:

	blocks X and Y	block Y and table
static	μ_{s1}	μ_{s2}
kinetic	μ_{k1}	μ_{k2}

For part a, presume mass M is small enough that it does not descend when released.

a. (10 points) Sketch a free-body diagram (FBD) for each block and include its magnitude.
- Clearly label each force using the convention from the textbook and lectures (e.g., $\vec{F}_T^{\,A(B)}$ means tension force acting on object A by its interaction with object B).
- *Make sure that the magnitudes of the drawn forces are consistent **across the entire system**.*
- Use different hash marks (e.g., ,) to indicate vectors with the same magnitude.

Block X	Block Y
	

	criterion	points
Both blocks	Correct block names are indicated by the first letter in the superscripts.	0.5
	Correct interacting objects are indicated in parenthetical part of superscripts.	1
	Correct types of force are indicated in subscripts.	1
	Indicates $\vec{F}_N^{X(Y)}$ and $\vec{F}_N^{Y(X)}$ have the same magnitude.	0.5
Block X	Marks normal and gravitational forces as equal in magnitude and opposite in direction vertically.	1
Block Y	Marks static friction force and tension as equal in magnitude and opposite in direction horizontally.	1
	Indicates normal force with table is opposite in direction to $\vec{F}_N^{Y(X)}$ and $\vec{F}_g^{Y(Earth)}$ and that its magnitude is the sum of the magnitudes of $\vec{F}_N^{Y(X)}$ and $\vec{F}_g^{Y(Earth)}$.	1

For each force listed above, indicate its magnitude (e.g., $|\vec{F}_g^{\,A(B)}| \to m|\vec{g}|$).

	criterion	points
Block X	$\lvert\vec{F}_N^{X(Y)}\rvert = m_1\lvert\vec{g}\rvert$	0.5
	$\lvert\vec{F}_g^{X(Earth)}\rvert = m_1\lvert\vec{g}\rvert$	0.5
Block Y	$\lvert\vec{F}_N^{Y(table)}\rvert = \lvert\vec{F}_N^{Y(X)}\rvert + \lvert\vec{F}_g^{Y(Earth)}\rvert = m_1\lvert\vec{g}\rvert + m_2\lvert\vec{g}\rvert = (m_1 + m_2)\lvert\vec{g}\rvert$	1
	$\lvert\vec{F}_N^{Y(X)}\rvert = \lvert\vec{F}_N^{X(Y)}\rvert = m_1\lvert\vec{g}\rvert$	0.5
	$\lvert\vec{F}_g^{Y(Earth)}\rvert = m_2\lvert\vec{g}\rvert$	0.5
	$\lvert\vec{F}_{SF}^{Y(table)}\rvert = \mu_{s2}\lvert\vec{F}_N^{Y(table)}\rvert = \mu_{s2}(m_1 + m_2)\lvert\vec{g}\rvert$	0.5
	$\lvert\vec{F}_T^{Y(string)}\rvert = M\lvert\vec{g}\rvert$	0.5

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For parts b-d, use the given variables (m_1, m_2, M, $\mu_{s1}, \mu_{k1}, \mu_{s2}, \mu_{k2}$,) and fundamental constants as needed.

b. (3 points) Derive an expression for the largest value of mass M such that blocks X and Y remain at rest.

criterion		points
Writes expression for maximum frictional force.	$\left\lvert\vec{F}_{SF}^{Y(table)}\right\rvert = \mu_{s2}\left\lvert\vec{F}_{N}^{Y(table)}\right\rvert = \mu_{s2}(m_1+m_2)\lvert\vec{g}\rvert$	1
Equates frictional force to tension.	$\mu_{s2}(m_1+m_2)\lvert\vec{g}\rvert = \left\lvert\vec{F}_{T}^{Y(string)}\right\rvert = M\lvert\vec{g}\rvert$	1
Correctly solves for M.	$M = \mu_{s2}(m_1+m_2)$	1

For parts c and d, mass M is large enough so that it descends when released.

c. (5 points) Presume blocks X and Y ***move together as one unit*** (they do not slip). Derive an expression for the tension in the string.

criterion		points
Correctly applies Newton's second law to hanging weight.	$\sum \vec{F} = m\vec{a} \qquad M\lvert\vec{g}\rvert - \lvert\vec{F}_T\rvert = M\lvert\vec{a}\rvert$	1
Correctly applies Newton's second law to two-block system.	$\sum \vec{F} = (m_1+m_2)\vec{a} \qquad \lvert\vec{F}_T\rvert - \left\lvert\vec{F}_f^{Y(table)}\right\rvert = (m_1+m_2)\lvert\vec{a}\rvert$	1
Use previous equations to solve for acceleration.	$\lvert\vec{F}_T\rvert = M\lvert\vec{g}\rvert - M\lvert\vec{a}\rvert \qquad \lvert\vec{F}_T\rvert = \left\lvert\vec{F}_f^{Y(table)}\right\rvert + (m_1+m_2)\lvert\vec{a}\rvert$ $\left\lvert\vec{F}_f^{Y(table)}\right\rvert = \mu_{k2}(m_1+m_2)\lvert\vec{g}\rvert$ $\mu_{k2}(m_1+m_2)\lvert\vec{g}\rvert + (m_1+m_2)\lvert\vec{a}\rvert = M\lvert\vec{g}\rvert - M\lvert\vec{a}\rvert$ $M\lvert\vec{a}\rvert + (m_1+m_2)\lvert\vec{a}\rvert = M\lvert\vec{g}\rvert - \mu_{k2}(m_1+m_2)\lvert\vec{g}\rvert$ $\lvert\vec{a}\rvert(M+m_1+m_2) = \lvert\vec{g}\rvert[M - \mu_{k2}(m_1+m_2)]$ $\lvert\vec{a}\rvert = \frac{\lvert\vec{g}\rvert[M-\mu_{k2}(m_1+m_2)]}{(M+m_1+m_2)}$	2.5
Correctly solves for tension.	$\lvert\vec{F}_T\rvert = M(\lvert\vec{g}\rvert - \lvert\vec{a}\rvert) = M\left(\lvert\vec{g}\rvert - \frac{\lvert\vec{g}\rvert[M-\mu_{k2}(m_1+m_2)]}{(M+m_1+m_2)}\right)$ $= M\lvert\vec{g}\rvert\left(1 - \frac{[M-\mu_{k2}(m_1+m_2)]}{(M+m_1+m_2)}\right)$	0.5

d. (4 points) Presume blocks X and Y ***do not*** move together as one unit (they slip). Derive an expression for the magnitude of the acceleration *for block Y*.

criterion		points
Correctly applies Newton's second law to hanging weight.	$\sum \vec{F} = m\vec{a} \qquad M\lvert\vec{g}\rvert - \lvert\vec{F}_T\rvert = M\lvert\vec{a}\rvert$	0.5
Correctly applies Newton's second law to block Y.	$\sum \vec{F} = m_2\vec{a} \qquad \lvert\vec{F}_T\rvert - \left\lvert\vec{F}_f^{Y(table)}\right\rvert - \left\lvert\vec{F}_f^{Y(X)}\right\rvert = m_2\lvert\vec{a}\rvert$	1.5
Correctly solves for magnitude of acceleration for block Y.	$\lvert\vec{F}_T\rvert = M\lvert\vec{g}\rvert - M\lvert\vec{a}\rvert \qquad \lvert\vec{F}_T\rvert = m_2\lvert\vec{a}\rvert + \left\lvert\vec{F}_f^{Y(table)}\right\rvert + \left\lvert\vec{F}_f^{Y(X)}\right\rvert$ $M\lvert\vec{g}\rvert - M\lvert\vec{a}\rvert = m_2\vec{a} + \left\lvert\vec{F}_f^{Y(table)}\right\rvert + \left\lvert\vec{F}_f^{Y(X)}\right\rvert$ $\lvert\vec{a}\rvert(m_2 + M) = M\lvert\vec{g}\rvert - \left\lvert\vec{F}_f^{Y(table)}\right\rvert - \left\lvert\vec{F}_f^{Y(X)}\right\rvert$ $\left\lvert\vec{F}_f^{Y(X)}\right\rvert = \mu_{k1}m_1\lvert\vec{g}\rvert \qquad \left\lvert\vec{F}_f^{Y(table)}\right\rvert = \mu_{k2}(m_1+m_2)\lvert\vec{g}\rvert$ $\lvert\vec{a}\rvert(m_2 + M) = M\lvert\vec{g}\rvert - \mu_{k2}(m_1+m_2)\lvert\vec{g}\rvert - \mu_{k1}m_1\lvert\vec{g}\rvert$ $\lvert\vec{a}\rvert = \frac{M - \mu_{k2}(m_1+m_2) - \mu_{k1}m_1}{(m_2 + M)}\lvert\vec{g}\rvert$	2

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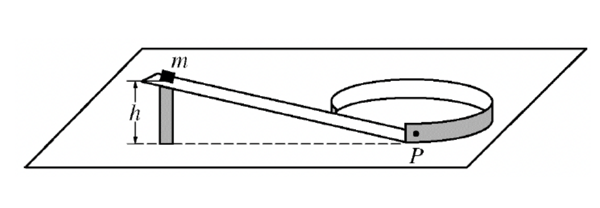
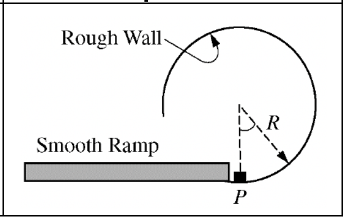
2. Block Sliding on Ramp (18 points)

side view	top view
	

A block (**mass m**) starts from rest at the top of a frictionless ramp (**height h**) above a horizontal table (see side view). This block slides down the smooth ramp until it reaches point P, at the bottom of the ramp, with **speed v_0**.
At point P, the block moves along the rough circular vertical wall (**radius R**, **coefficient of kinetic friction μ_k**) and slides on the frictionless table (see top view).

In your responses, use the given variables (m, h, v_o, R, μ_k) and fundamental constants as needed.

a. (3 points) Derive an expression for the height of the ramp (h).

criterion		points
Indicates energy is conserved.	$V_i + K_i = V_f + K_f$	1
Correct substitutions for potential and kinetic energies	$m\lvert\vec{g}\rvert h_i = \frac{1}{2}m\lvert\vec{v}_f\rvert^2$	1
Correctly solves for height.	$h_i = \frac{{v_0}^2}{2\lvert\vec{g}\rvert}$	1

Alternate solutions possible with kinematics and dynamics equations.

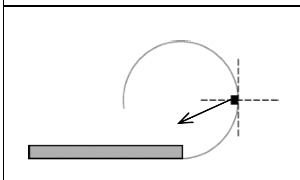
b. (2 points) After passing point P, the block remains in contact with the wall and moves with a **speed v**. The vertical component of the net force on the moving block is ______. Choose one:

______ upward ______ zero ______ downward

Justify the response you chose.

criterion	points
Selected "zero."	1
Provides correct explanation that vertical component of net force is not accelerating. **If incorrect choice was selected, then no point was awarded for the explanation.**	1

c. (3 points) *Sketch an arrow starting on block shown in the figure below* to indicate the **horizontal component of the net force** on the moving block in the position shown. Justify the direction of the arrow you sketched.

criterion		points
	Sketched single arrow pointing downward and to the left.	1
	Indicates left direction is due to centripetal force.	1
	Indicates downward direction is due to friction (slows forward motion).	1

d. (2 points) Determine an expression for the magnitude of the normal force ($\vec{F}_N$) exerted on the block by the circular wall as a function of v.

criterion		points
Indicates Newton's second law applies to scenario.	$\sum \vec{F} = m\vec{a}$	1
Correctly substitutes normal force for net force and linear acceleration with centripetal acceleration.	$\lvert\vec{F}_N\rvert = \frac{m\lvert\vec{v}\rvert^2}{R}$	1

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e. (3 points) Derive an expression for the magnitude of the tangential acceleration of the block at the instant the block attains a speed of v.

criterion		points
Applies Newton's second law to correctly substitute relevant forces.	$-\lvert\vec{F}_f\rvert = -\mu_k \lvert\vec{F}_N\rvert = m\lvert\vec{a}_t\rvert$	1
Equates tangential acceleration with part d.	$-\mu_k \lvert\vec{F}_N\rvert = -\mu_k \frac{m\lvert\vec{v}\rvert^2}{R} = m\lvert\vec{a}_t\rvert$	1
Correctly solves for tangential acceleration of the block.	$\lvert\vec{a}_t\rvert = -\mu_k \frac{\lvert\vec{v}\rvert^2}{R}$	1

f. (5 points) Derive an expression for $v(t)$, the speed of the block as a function of time t after passing point P.

criterion		points
May substitute $\frac{d\lvert\vec{v}\rvert}{dt}$ for $\vec{a}_t$ or use $m\frac{d\lvert v\rvert}{dt} = -\lvert\vec{F}_f\rvert$.	$\frac{d\lvert\vec{v}\rvert}{dt} = -\mu_k \frac{\lvert\vec{v}\rvert^2}{R}$ $\quad OR \quad$ $m\frac{d\lvert\vec{v}\rvert}{dt} = -\lvert\vec{F}\rvert_f$	1
Correctly completes separation of variables.	$\frac{1}{\lvert\vec{v}\rvert^2} dv = -\frac{\mu_k}{R} dt$	1
Uses correct limits.	$\int_{v_0}^{v} \frac{1}{\lvert\vec{v}\rvert^2} dv = \int_0^t -\frac{\mu_k}{R} dt$	1
Correctly integrates to solve for speed.	$\left[-\frac{1}{\lvert\vec{v}\rvert}\right]_{v_0}^{v} = \left[-\frac{\mu_k t}{R}\right]_0^t$ $\quad$ $\frac{1}{\lvert\vec{v}\rvert} - \frac{1}{v_0} = \frac{\mu_k t}{R}$ $\lvert\vec{v}\rvert = \frac{R v_0}{R + \mu_k v_0 t}$ $\quad OR \quad$ $\lvert\vec{v}\rvert = \frac{v_0}{1 + \left(\frac{\mu_k v_0 t}{R}\right)}$	2

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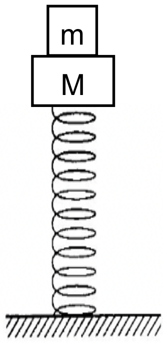
3. Oscillations and Frames (20 points)



The figure on the right shows a system that consists of a small block ($\boldsymbol{m} = \mathbf{2.0}$ **kg**) *resting* on top of a large block ($\boldsymbol{M} = \mathbf{4.5}$ **kg**); this large block is *connected* to the top of a *massless spring* ($\boldsymbol{k} = \mathbf{820}$ **N/m**).

Both blocks are currently at rest and the system is not oscillating.

a. (2 points) Determine the distance the spring is compressed from its original length.

criterion		points
Uses Hooke's law.	$\vec{F}_{\mathrm{Sp,x}} = -k_{\mathrm{s}}\lvert\vec{x}\rvert$	1
Correctly solves for $\vec{x}$.	$\vec{x} = \frac{(m+M)\lvert\vec{g}\rvert}{k_{\mathrm{s}}} = \frac{(2.0\ \mathrm{kg} + 4.5\ \mathrm{kg})(9.8\ \mathrm{m/s^2})}{820\ \mathrm{N/m}} = 0.078\ \mathrm{m}$	1

For parts b and c, the blocks are pushed down and released so that the system oscillates.

b. (2 points) Determine the frequency of oscillation.

criterion		points
Identifies frequency relationships.	$\frac{2\pi}{\omega} = \frac{1}{f} \qquad \omega \equiv \sqrt{k_{\mathrm{s}}/m}$	1
Correctly solves for frequency. Point also awarded for $\omega = 11\ \mathrm{s^{-1}}$.	$f = \frac{\omega}{2\pi} = \frac{\sqrt{k_{\mathrm{s}}/m}}{2\pi} = \frac{\sqrt{820\frac{\mathrm{N}}{\mathrm{m}}/(2.0\ \mathrm{kg} + 4.5\ \mathrm{kg})}}{2\pi} = 1.8\ \mathrm{s^{-1}}$	1

c. (3 points) Determine the magnitude of the *maximum acceleration* that both blocks can attain ***and*** remain in contact with each other.

criterion	points
Indicates that if large block compresses spring with acceleration greater than $\lvert\vec{g}\rvert$, the small block will lose contact with it… concludes $\lvert\vec{a}_{\max}\rvert$ of large block must be $\lvert\vec{g}\rvert = 9.8\ \mathrm{m/s^2}$. OR Uses Newton's second law to mathematically determine maximum acceleration of small block. $\sum \vec{F} = m\vec{a} \qquad m\lvert\vec{g}\rvert - \lvert\vec{F}_{\mathrm{N}}\rvert = m\lvert\vec{a}\rvert$ When $\lvert\vec{F}_{\mathrm{N}}\rvert = 0$, small block loses contact with large block. Thus, $\lvert\vec{a}_{\max}\rvert = \lvert\vec{g}\rvert = 9.8\ \mathrm{m/s^2}$.	3

d. (4 points) Determine the additional distance the spring can be compressed from its *original compression* in part a without exceeding the *maximum acceleration* calculated in part c.

criterion		points
Indicates maximum acceleration occurs when compression of spring is at the amplitude (A).	$\vec{a}_{\max} = \frac{d^2x}{dt^2} = -\omega^2 x = -\omega^2 A$	2
Correctly substitutes $\lvert\vec{a}_{\max}\rvert$ from part c to solve for amplitude.	$\vec{a}_{\max} = -\lvert\vec{g}\rvert = -\omega^2 A$ $A = \frac{\lvert\vec{g}\rvert}{\omega^2} = \frac{9.8\ \mathrm{m/s^2}}{(11\ \mathrm{s^{-1}})^2} = 0.081\ \mathrm{m}$	2

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The small block is removed. The large block and spring system is suspended from the ceiling of an elevator car. The elevator car moves upward with a constant acceleration of 3.4 m/s². *Choose the upward direction as positive.*

e. (4 points) Determine the amplitude of the resulting oscillation.

criterion		points
Uses Newton's second law and Hooke's law to determine distance spring is stretched when at rest.	$\sum \vec{F} = 0 \qquad \vec{F}_{\mathrm{Sp,x}} = -k_{\mathrm{s}}\lvert\vec{x}\rvert \qquad m\lvert\vec{g}\rvert - k_{\mathrm{s}}\lvert\vec{x}\rvert = 0$ $\lvert\vec{x}_{\mathrm{rest}}\rvert = \frac{m\lvert\vec{g}\rvert}{k_{\mathrm{s}}} = \frac{(4.5\ \mathrm{kg})(9.8\ \mathrm{m/s^2})}{820\ \frac{\mathrm{N}}{\mathrm{m}}} = 0.054\ \mathrm{m}$	1.5
Correctly determines effective gravity inside elevator.	$\lvert\vec{g}_{\mathrm{eff}}\rvert = \lvert\vec{g}\rvert + \lvert\vec{a}_{\mathrm{elevator}}\rvert = 9.8\ \frac{\mathrm{m}}{\mathrm{s^2}} + 3.4\ \frac{\mathrm{m}}{\mathrm{s^2}} = 13\ \frac{\mathrm{m}}{\mathrm{s^2}}$	0.5
Uses Newton's second law and Hooke's law to determine distance spring is stretched when elevator is accelerating.	$\sum \vec{F} = 0 \qquad \vec{F}_{\mathrm{Sp,x}} = -k_{\mathrm{s}}\lvert\vec{x}\rvert \qquad m\lvert\vec{g}_{\mathrm{eff}}\rvert - k_{\mathrm{s}}\lvert\vec{x}\rvert = 0$ $\lvert\vec{x}_{\mathrm{acc}}\rvert = \frac{m\lvert\vec{g}_{\mathrm{eff}}\rvert}{k_{\mathrm{s}}} = \frac{(4.5\ \mathrm{kg})(13\ \mathrm{m/s^2})}{820\ \frac{\mathrm{N}}{\mathrm{m}}} = 0.071\ \mathrm{m}$	1.5
Correct subtraction to find amplitude.	$\lvert\vec{x}_{\mathrm{acc}}\rvert - \lvert\vec{x}_{\mathrm{rest}}\rvert = 0.017\ \mathrm{m}$	0.5

f. (2 points) From a person's perspective outside the building, how does the frequency of oscillation appear compared to the actual frequency of oscillation inside the elevator? Choose one:

______ smaller ______ same ______ larger

Justify the response you chose.

criterion	points
Selects same.	1
Indicates frequency is only dependent on spring force constant and mass.	1

g. (3 points) Presume the elevator is now filled with a fluid that causes the system to experience a drag force of $\vec{F}_D = -0.7v$ in the direction of motion. Write the equation of motion for this scenario with respect to position as a function of time. ~~Your answer should have this form: $x(t) = \ldots$~~

criterion		points
Uses Newton's second law and correctly substitutes relevant forces.	$\sum \vec{F} = m\vec{a}$ $\vec{F}_g + \vec{F}_D + \vec{F}_{sp} = m\vec{a}$	1
Substitutes previous relations to set up second order differential equation.	$m\lvert\vec{g}\rvert - k_{\mathrm{s}}\lvert\vec{x}\rvert - 0.7\frac{dx}{dt} = m\frac{d^2x}{dt^2}$ $k_{\mathrm{s}}\lvert\vec{x}_{\mathrm{rest}}\rvert - k_{\mathrm{s}}\lvert\vec{x}\rvert - 0.7\frac{dx}{dt} = m\frac{d^2x}{dt^2}$ $-k_{\mathrm{s}}(\lvert\vec{x}\rvert - \lvert\vec{x}_{\mathrm{rest}}\rvert) - 0.7\frac{dx}{dt} = m\frac{d^2x}{dt^2}$ $(4.5\ \mathrm{kg})\frac{d^2x}{dt^2} + 0.7\frac{dx}{dt} + \left(820\frac{\mathrm{N}}{\mathrm{m}}\right)(\lvert\vec{x}\rvert - 0.054\ \mathrm{m}) = 0$	2