Name= **Studio Day/Time=**

Eng. Phys. I Exam 4 - Chs. 12,13,15,16,17 - Equilibrium, Gravity, Oscillations, Waves Nov. 12, 2021

Write **neat** & **clear** work. Show **formulas** used, essential steps, results with correct **units** and **significant figures**. Points shown in parenthesis. For TF and MC, choose the *best* answer. Use $g = 9.80$ m/s^2.

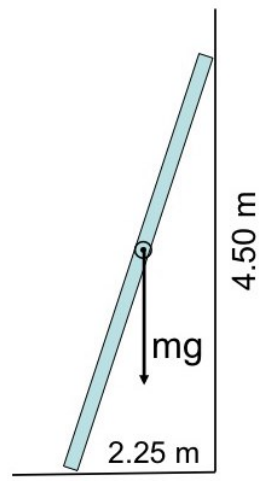
1. (3) Usually 4×4 wooden posts hold up some residential decks. Predominantly what kind of stress are they under?

a. tensile. b. shear. c. compressive. d. no stress if properly installed.

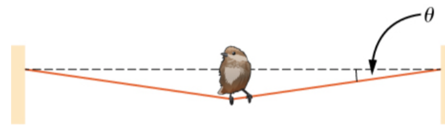
2. (2) **T** **F** The SI unit of elastic modulus is pascals (N/m^2).

3. (2) **T** **F** An even number of forces must act on an object for it to be in static equilibrium.

4. (10) A ladder of mass m is set against and wall as shown. It's center of mass is at its center. There is friction between the ladder and the ground, but not between the ladder and the wall.



What minimum coefficient of static friction between ladder and ground is needed so that the ladder does not slip?



5. (18) A 2.00-mm thick nylon cable (elastic modulus $Y = 5.0 \times 10^9$ Pa) is mounted taut between two supports as shown. Then a bird lands on the center of the cable, pushing it downward by $\theta = 5.0°$ at each support, and stretching its length by 0.38% (that is, the strain in either half is 0.0038).

a) (6) How large is the tensile stress in either half of the cable?

b) (6) How large is the tension in the cable?

c) (6) What does the bird weigh?

6. (2) **T F** If Earth's radius were doubled, the acceleration due to gravity at its surface would be cut in half.

7. (2) **T F** The gravitational force due to a spherical shell of mass acting on a point mass placed inside it is zero.

8. (2) **T F** For a mass in a circular orbit at radius r, the centripetal acceleration v^2/r equals the acceleration due to gravity $g(r)$.

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9. (15) 951 Gaspra is an asteroid just outside the orbit of Mars, with a mass of 2.67×10^{20} kg and an average radius of $R = 265$ km. It has an oblong shape but for this question assume it is roughly spherical.

a) (5) About how large is the average acceleration due to gravity g at its surface?

b) (5) Suppose you can run as fast as 10 m/s on 951 Gaspra. Show a calculation to demonstrate whether you might actually run right off of the asteroid and end up lost in space (or not).

b) (5) If you were visiting 951 Gaspra, and you jumped upward from the surface at 2.0 m/s, how high above its surface would you go before falling back down?

10. (18) A 1.25-kg mass hanging on a spring of spring constant $k = 85$ N/m is undergoing vertical simple harmonic motion around its equilibrium position, $y = 0$. At time $t = 0$ it is passing $y = 0$ with a velocity of 12.0 m/s downward.

a) (5) Find the frequency f of the oscillations.

b) (5) Find the total energy in the oscillations.

c) (5) Determine the amplitude of the oscillations.

d) (3) Write an expression for the position as a function of time, $y(t)$.

11. (16) A guitar string 0.62 m long has a mass of 2.5 grams. The tension is adjusted to 75 N.

a) (6) Find the wave speed in the string.

b) (6) Sketch how the string vibrates in its fundamental mode (or first harmonic). Then, calculate the wavelength.

c) (4) Find the frequency of the fundamental mode.

12. (2) **T** **F** Neighboring nodes in a standing wave pattern are separated by one wavelength.

13. (2) **T** **F** The waves on a guitar string are transverse waves.

14. (2) **T** **F** Sound waves in air are longitudinal waves.

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15. (10) While talking, a person speaking emits sound waves with a power of 1.66 mW isotropically.

a) (5) How strong is the sound intensity heard by a person 5.0 m from the speaker?

b) (5) How high is the sound level in decibels heard by a person 5.0 m from the speaker?

Score = ______________/106.

Prefixes

$z=10^{-21}$,	$a=10^{-18}$,	$f=10^{-15}$,	$p=10^{-12}$,	$n=10^{-9}$,	$\mu=10^{-6}$,	$m=10^{-3}$,	$c=10^{-2}$,	$k=10^{3}$,	$M=10^{6}$,	$G=10^{9}$,	$T=10^{12}$,	$P=10^{15}$,	$E=10^{18}$,	$Z=10^{21}$
zepto,	atto,	femto,	pico,	nano,	micro,	milli,	centi,	kilo,	mega,	giga,	tera,	peta,	exa,	zeta.

Physical Constants

$g = 9.80$ m/s^2 (gravitational acceleration)
$G = 6.67 \times 10^{-11}$ N·m^2/kg^2 (gravitational constant)
$M_E = 5.98 \times 10^{24}$ kg (mass of Earth)
$R_E = 6380$ km (mean radius of Earth)
$m_e = 9.11 \times 10^{-31}$ kg (electron mass)
$m_p = 1.67 \times 10^{-27}$ kg (proton mass)
$c = 299\ 792\ 458$ m/s (speed of light)
1 amu = 1 u = $1.6605402 \times 10^{-27}$ kg (atomic mass unit)

Units & Conversions

1 inch = 1 in = 2.54 cm
1 foot = 1 ft = 12 in = 0.3048 m
1 mile = 5280 ft =1760 yards
1 mile = 1609.344 m = 1.609344 km
1 m/s = 3.6 km/hour
88 ft/s = 60 mile/hour
1 acre = (1 mile)^2/640 = 43 560 ft^2
1 hectare = (100 m)^2 = 10^4 m^2
1 lb = 4.45 N
1 N = 0.225 lb
1 J = 1 joule = 1 N·m

Geometry

Triangles: $A = \frac{1}{2}bh$, Circles; $C = 2\pi r$, $A = \pi r^2$, arc $= s = r\theta$. Spheres: $A = 4\pi r^2$, $V = \frac{4\pi}{3}r^3$

Trigonometry

$\sin\theta = \frac{\text{(opp)}}{\text{(hyp)}}$, $\cos\theta = \frac{\text{(adj)}}{\text{(hyp)}}$, $\tan\theta = \frac{\text{(opp)}}{\text{(adj)}}$.

$\text{(opp)}^2 + \text{(adj)}^2 = \text{(hyp)}^2$, $a^2 + b^2 - 2ab\cos\gamma = c^2$, $\frac{\sin\alpha}{a} = \frac{\sin\beta}{b} = \frac{\sin\gamma}{c}$.

Chapter 2 - Vectors - Magnitude & Direction

2D Vectors:	$\vec{\mathbf{a}} = a_x\hat{\mathbf{i}} + a_y\hat{\mathbf{j}}$,	magnitude = $a = \sqrt{a_x^2 + a_y^2}$,	direction $\to \tan\theta = a_y/a_x$.
Components:	$a_x = a\cos\theta$,	$a_y = a\sin\theta$,	θ=angle to $+x$-axis.
Addition:	$\vec{\mathbf{a}} + \vec{\mathbf{b}}$, head to tail.	Subtraction: $\vec{\mathbf{a}} - \vec{\mathbf{b}}$ is $\vec{\mathbf{a}} + (-\vec{\mathbf{b}})$,	$-\vec{\mathbf{b}}$ is $\vec{\mathbf{b}}$ reversed.
Scalar product:	$\vec{\mathbf{a}} \cdot \vec{\mathbf{b}} = ab\cos\phi$,	$\vec{\mathbf{a}} \cdot \vec{\mathbf{b}} = a_xb_x + a_yb_y + a_zb_z$,	$\hat{\mathbf{i}} \cdot \hat{\mathbf{i}} = 1$, $\hat{\mathbf{i}} \cdot \hat{\mathbf{j}} = 0$, etc.
Cross product:	$\lvert\vec{\mathbf{a}} \times \vec{\mathbf{b}}\rvert = ab\sin\phi$,	$\hat{\mathbf{i}} \times \hat{\mathbf{j}} = \hat{\mathbf{k}}$, etc.	$\hat{\mathbf{i}} \times \hat{\mathbf{i}} = \hat{\mathbf{j}} \times \hat{\mathbf{j}} = \hat{\mathbf{k}} \times \hat{\mathbf{k}} = 0$.

Chapter 3 - 1D Kinematics - Straight-line motion

Velocity:	$v_{\text{ave}} = \frac{\Delta x}{\Delta t}$,	$\Delta x = x - x_0$,	$v(t) = \frac{dx}{dt}$= slope of $x(t)$.
Acceleration:	$a_{\text{ave}} = \frac{\Delta v}{\Delta t}$,	$\Delta v = v - v_0$,	$a(t) = \frac{dv}{dt}$= slope of $v(t)$.
Constant acceleration:	$v = v_0 + at$,	$v_{\text{ave}} = \frac{1}{2}(v_0 + v)$.	
	$x = x_0 + v_0t + \frac{1}{2}at^2$.	$x = x_0 + v_{\text{ave}}t$,	$v^2 = v_0^2 + 2a\Delta x$.
Free fall ($+y$-axis is up):	$y = y_0 + v_{0y}t - \frac{1}{2}gt^2$,	$v_y = v_{0y} - gt$,	$v_y^2 = v_{0y}^2 - 2g\Delta y$.

Chapter 5 - Newton's laws and forces

Newton's 1st Law:	$\vec{a} = \frac{d\vec{v}}{dt} = 0$ unless $\vec{F}_{\text{net}} \neq 0$,	$\vec{F}_{\text{net}} = \sum \vec{F}_i$ = sum of all forces on a mass.
Newton's 2nd Law:	$\vec{F}_{\text{net}} = m\vec{a}$,	$F_{\text{net},x} = ma_x$, $F_{\text{net},y} = ma_y$, $F_{\text{net},z} = ma_z$.
Newton's 3rd Law:	$\vec{F}_{AB} = -\vec{F}_{BA}$,	Forces exist in action-reaction pairs.
Gravitational force near Earth:	$F_G = mg$, downward.	Apparent weight is force measured by a scales.
Gravity components on inclines:	$F_\parallel = mg\sin\theta$, $F_\perp = mg\cos\theta$,	← for incline at angle θ to horizontal.
Spring force:	$F_s = -kx$,	x is the displacement from equilibrium.

Chapter 6 - Friction, circular motion

Static friction (object is stuck):	$f_s \leq \mu_s N$,	Can balance other forces in any direction.
Kinetic friction (object sliding):	$f_k = \mu_k N$,	Acts **against** the relative motion of surfaces.
Centripetal acceleration:	$a_c = \frac{v^2}{r}$,	Points towards the center of the circle.

Chapter 7 - Work and kinetic energy

Work done by a force:	$dW = \vec{\mathbf{F}} \cdot d\vec{\mathbf{r}} = F\ dr\ \cos\theta$,	$W_{AB} = \int_A^B \vec{\mathbf{F}} \cdot d\vec{\mathbf{r}}$ (along the path $A \to B$).
Work of a constant force:	$W = \vec{\mathbf{F}} \cdot \Delta\vec{\mathbf{r}}$,	$\Delta\mathbf{r} = \vec{\mathbf{r}}_B - \vec{\mathbf{r}}_A$ = displacement.
Work done by a spring:	$W_s = -\frac{1}{2}k(x_B^2 - x_A^2)$,	B=final stretch, A =initial stretch.
Work-KE theorem, power:	$\Delta\text{KE} = W_{\text{net}}$ = all works on m.	$\text{KE} = \frac{1}{2}mv^2$, $P = \frac{dW}{dt}$, $P_{\text{ave}} = \frac{\Delta W}{\Delta t}$.

Chapter 8 - Potential energy and Conservation of energy

PE for gravity:	$\Delta U = mg\Delta y$,	$U(y) = mgy+$ constant,	$\leftarrow$(near Earth' surface).
PE for springs:	$\Delta U = \frac{1}{2}k(x_B^2 - x_A^2)$,	$U(x) = \frac{1}{2}kx^2$ + constant.	
Any arbitrary system:	$\Delta E_{\text{total}} = 0$,	$E_{\text{total}} = E_{\text{mec}} + E_{\text{thermal}} + E_{\text{other}}$.	

Chapter 9 - Linear momentum and collisions

Linear Momentum:	$\vec{\mathbf{p}} = m\vec{\mathbf{v}}$,	Impulse Theorem:	$\Delta\vec{\mathbf{p}} = \vec{\mathbf{J}} = \int \vec{\mathbf{F}}(t)\,dt = \vec{\mathbf{F}}_{\text{ave}}\Delta t$.
Instantaneous force:	$\vec{\mathbf{F}} = \frac{d\vec{\mathbf{p}}}{dt}$,	Average force:	$\vec{\mathbf{F}}_{\text{ave}} = \frac{\Delta\vec{\mathbf{p}}}{\Delta t}$.
Conservation (@ $\vec{\mathbf{F}}_{\text{net}} = 0$):	$\Delta\vec{\mathbf{p}}_{\text{total}} = 0$,	$\vec{\mathbf{p}}_{1\text{i}} + \vec{\mathbf{p}}_{2\text{i}} = \vec{\mathbf{p}}_{1\text{f}} + \vec{\mathbf{p}}_{2\text{f}}$,	i=initial, f=final.

Chapters 10 - Rotational motion

Coordinates:	1 rev = 2π rad	1 rev = 360°,	$\omega = 2\pi f$,	$f = \frac{1}{T}$.
Averages:	$\omega_{\text{ave}} = \frac{\Delta\theta}{\Delta t}$,	$\Delta\theta = \omega_{\text{ave}}\Delta t$,	$\alpha_{\text{ave}} = \frac{\Delta\omega}{\Delta t}$,	$\Delta\omega = \alpha_{\text{ave}}\Delta t$.
Radius factors:	$l = \theta r$,	$v = \omega r$,	$a_{\tan} = \alpha r$,	$a_c = \omega^2 r$.
Const. acceleration:	$\omega = \omega_0 + \alpha t$,	$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$,	$\omega_{\text{ave}} = \frac{1}{2}(\omega_0 + \omega)$,	$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$.

Torque:	$\vec{\tau} = \vec{\mathbf{r}} \times \vec{\mathbf{F}}$,	$\tau = rF\sin\theta$,	$\tau = r_\perp F = rF_\perp$,	$\hat{\mathbf{i}} \times \hat{\mathbf{j}} = \hat{\mathbf{k}}$, etc.	
Dynamics, inertia:	$I = \Sigma\, m\, r^2$,	$I = \int dm\, r^2$,	$\tau_{\text{net}} = I\alpha$,	$K_{\text{rot}} = \frac{1}{2}I\omega^2$.	
Rotational inertias:	$I = MR^2$,	$I = \frac{1}{2}MR^2$,	$I = \frac{2}{5}MR^2$,	$I = \frac{1}{12}ML^2$,	$I = I_0 + md^2$.
(about centers)	thin hoop,	solid cylinder,	solid sphere,	thin rod,	parallel axis theorem.
Work, power:	$dW = \tau\, d\theta$,	$W = \int \tau\, d\theta$,	$W = \tau_{\text{ave}}\Delta\theta$,	$P = \tau\omega$.	

Chapter 11 - Angular momentum

Angular momentum:	$\vec{\mathbf{l}} = \vec{\mathbf{r}} \times \vec{\mathbf{p}}$,	$l = rp\sin\theta$,	$l = r_\perp p = rp_\perp$,	$\vec{\mathbf{L}} = \int \vec{\mathbf{r}} \times \vec{\mathbf{v}}\, dm$,	$L = I\omega$.
Dynamics:	$\frac{d}{dt}\vec{\mathbf{L}} = \vec{\tau}_{\text{net}}$,	$\Delta\vec{\mathbf{L}} = \vec{\tau}_{\text{ave}}\Delta t$,	conservation$\rightarrow$	$\vec{\mathbf{L}}_{\text{total}}$ =const.	$\leftarrow$(@ $\vec{\tau}_{\text{net}} = 0$).

Chapter 12 - Static equilibrium

Statics requirements:	$\sum F_x = \sum F_y = \sum F_z = 0$,	$\sum \tau = 0$,	$\tau = rF\sin\theta$.
Stress & strain:	stress = $F_\perp/A$,	strain = $\Delta L/L_0$,	stress = $Y\times$ strain.
Shear forces:	stress = $F_\parallel/A$,	strain = $\Delta x/L_0$,	stress = $S\times$ strain.

Chapter 13 - Gravitation

Gravitational force:	$F = Gm_1m_2/r^2$,	$F = mg$,	$g = GM/r^2$,	$v_{\text{escape}} = \sqrt{2GM/R}$.
Gravitational PE:	$U = -Gm_1m_2/r$,	$\Delta U + \Delta K = 0$,	Kepler's orbits:	$T^2 = \frac{4\pi^2}{GM}r^3$.

Chapter 15 - Oscillations

Oscillations:	$x = A\cos(\omega t + \phi)$,	$v = -\omega A\sin(\omega t + \phi)$,	$a = -\omega^2 x$,	$\omega = 2\pi f = \frac{2\pi}{T}$.
Mass on a spring:	$F = -kx = ma$,	$\omega = \sqrt{k/m}$.		
Torsion oscillator:	$\tau = -\kappa\theta = I\alpha$,	$\omega = \sqrt{\kappa/I}$.		
Pendula:	$\tau = -mgL\theta = I\alpha$,	$\omega = \sqrt{g/L}$ (simple),	$\omega = \sqrt{mgL/I}$ (physical).	
Energy:	$E = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$,	$E = \frac{1}{2}kA^2$,	$E = \frac{1}{2}mv_{\max}^2$,	$v_{\max} = \omega A$.

Chapter 16 - Waves

Traveling waves:	$\lambda = vT$,	$v = f\lambda$,	$v = \sqrt{\frac{F_T}{\mu}}$,	$\mu = m/L$ (strings).
Wave number, speed:	$k = 2\pi/\lambda$,	$\omega = 2\pi/T$,	$v = \omega/k$,	$y(x,t) = A\sin(kx - \omega t + \phi)$.
Intensity, power:	$I = P/A$,	$I = P/4\pi r^2$,	$P = E_\lambda/T$,	$P = \frac{1}{2}\mu A^2\omega^2 v$.
Standing waves:	node-to-node = $\lambda/2$.			

Chapter 17 - Sound

Speed of sound:	$v = \sqrt{B/\rho}$ (fluids),	$v = \sqrt{Y/\rho}$ (solids),	$v = \sqrt{\gamma RT/M}$ (ideal gas).
Speed in air:	$v = (331\text{m/s})\sqrt{1 + T_C/273°\text{C}}$,	$v(0°\text{C}) = 331$ m/s,	$v(20°\text{C}) = 343$ m/s.
Intensity I:	$I = P/A$,	$I = P/4\pi r^2$.	
Sound level β:	$\beta = (10\text{ dB})\log\frac{I}{I_0}$,	$I = I_0\ 10^{\beta/(10\text{ dB})}$,	$I_0 = 10^{-12}$ W/m^2 (threshold).
Standing waves:	nodes @ ends of strings,	nodes @ ends of closed tubes,	antinodes @ ends of open tubes.
Doppler shift:	$f_O = f_S\frac{v+v_O}{v+v_S}$ (use x-comps.),	v=sound,	v_O=observer, v_S=source.