Name= **Studio Days/Time=**

Eng. Phys. I **Exam 5 - Chs. 12,13,14 - Static Equilibrium, Gravity, Fluids** **Apr. 22, 2022**

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 $g = 9.80\ \text{m/s}^2$. Ignore air resistance unless it is mentioned in a question. You are allowed to use only a calculator and the attached equation sheet.

1. (4) For an object O to be in static equilibrium, check all of the following that are necessary conditions:

a. The net force on O must be zero.
b. The net force on O must pass through its center of mass.
c. The net torque on O must be zero.
d. The net torque around O's center of mass must be zero.

2. (14) A sign of unknown mass M hangs from a uniform strut of mass $m = 24.0$ kg supported by a hinge at the wall and a cable as shown. The tension in the aluminum cable connected between the end of the strut and the wall is $T = 955$ N.

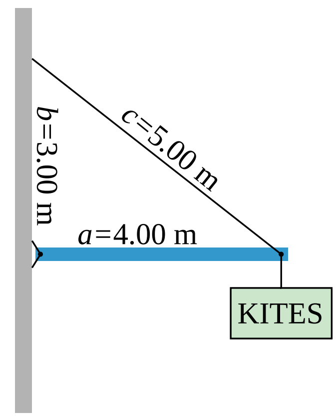

Figure 1.

a) (7) Using the symbols given in the question and the figure, write an expression for the torque on the strut due to the tension, using the hinge as the axis. Then find the numerical value in N·m.

b) (7) Determine the mass M of the sign, in kg.

3. (15) The 5.00 m long aluminum cable in Question 2 is 4.00 mm thick and under a tension of 955 N. The elastic modulus of aluminum is 7.0×10^{10} Pa.

a) (5) How large is the tensile stress σ in the cable, in units of MPa (megapascal)?

b) (5) How large is the tensile strain γ in the cable?

c) (5) Estimate how much the cable has stretched, in millimeters.

2. ______ / 15

4. (3) At an altitude above Earth's surface equal to twice its radius R_{E}, the acceleration due to gravity compared to that at Earth's surface is

a. the same. b. 1/4 as strong. c. 1/9 as strong. d. 3 × as strong. e. 4 × as strong.

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5. (2) **T F** An object in orbit around the Earth has an acceleration that points towards Earth's center.

6. (2) **T F** All geostationary satellites have an orbital period of 48 hours.

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7. (14) A satellite of mass $m = 125$ kg is placed into a circular orbit of radius r around Earth, with a period of $T = 48.0$ hours. Earth's mass is $M_{\mathrm{E}} = 5.97 \times 10^{24}$ kg and its radius is $R_E = 6380$ km.

a) (6) In terms of $G, M_{\mathrm{E}}, m, r, T$, apply Newton's 2nd Law to the mass in orbit (you can have factors like 2 and π but eliminate all other symbols).

b) (4) Solve the equation you wrote down to obtain a formula for the orbital radius in terms of G, M_{E}, T.

c) (4) Obtain the numerical value of the orbital radius, in km.

8. (8) Suppose a package could be released with zero speed from a satellite at an altitude equal to $2R_{\mathrm{E}}$ above Earth's surface, where $R_E = 6380$ km is Earth's radius. How fast will it be moving when its strikes Earth's surface? Ignore air resistance. Earth's mass is $M_{\mathrm{E}} = 5.97 \times 10^{24}$ kg.

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9. (3) Consider 1.00 kg samples of aluminum, iron, lead, and wood (you studied these materials in the lab). Which sample would have the least volume?

a. aluminum. b. iron. c. lead. d. wood. e. all tie.

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10. (3) If 1.00 kg samples of aluminum, iron, lead, and wood are placed in a container of water and reach equilibrium, which would have the largest buoyant force?

a. aluminum. b. iron. c. lead. d. wood. e. all tie.

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11. (2) **T F** The absolute pressure at a point in a fluid is greater than the gauge pressure there.

12. (2) **T F** In a hydraulic system, the piston in the larger cylinder has the greater pressure on it.

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13. (8) Sea water has a density of 1025 kg/m^3. A device is to be sent down to a depth where the gauge pressure is 20.0 atm. What is that depth, in meters?

14. (2) **T F** For an object floating on water, the buoyant force equals the usual weight, mg.

15. (2) **T F** Bernoulli's equation represents conservation of energy in a moving fluid.

16. (2) **T F** For viscous fluid flowing through a horizontal pipe of uniform cross-section, the pressure difference needed to produce a given flow rate increases linearly with the length of the pipe.

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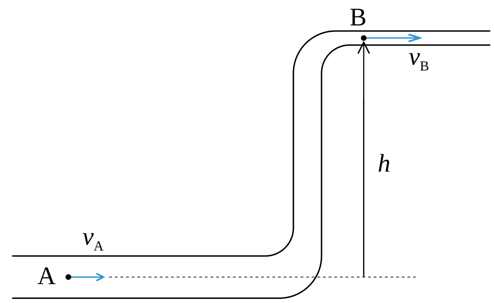
17. (12) The diagram with $h = 4.00$ m shows water flowing through a section of a pipe system at a flow rate $Q = 2.50$ L/s (liters per second). The absolute pressure at point A is $p_A = 162$ kPa, and the pipe's cross-sectional area there is $A_\mathrm{A} = 25.0\ \mathrm{cm}^2$. Assume the water is incompressible and nonviscous.



a) (6) How fast is the water flowing at point A?

b) (6) The pipe's cross-sectional area at point B is $A_\mathrm{B} = 5.00\ \mathrm{cm}^2$. Find the water pressure there, in kPa.

18. (8) Aluminum has a density that is 2.70 times that of water. Assuming a 100-kg sample of aluminum, calculate the buoyant force on it when fully submerged in water.

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19. (6) Whole blood has a viscosity $\eta = 2.08 \times 10^{-3}$ Pa$\cdot$ s at human body temperature. Consider the flow through an artery 12.0 cm long with an internal radius of 2.00 mm. What pressure difference is required between the ends of the artery to get a blood flow rate $Q = 4.00$ cm^3/s?

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

Algebra

Quadratic equations: $ax^2 + bx + c = 0$, solved by $x = \left(-b \pm \sqrt{b^2 - 4ac}\right)/(2a)$.

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 = $ (opp)/(hyp), $\cos\theta = $ (adj)/(hyp), $\tan\theta = $ (opp)/(adj), (opp)^2 + (adj)^2 = (hyp)^2.

$\sin^2\theta + \cos^2\theta = 1$, $a^2 + b^2 - 2ab\cos\gamma = c^2$, $\frac{\sin\alpha}{a} = \frac{\sin\beta}{b} = \frac{\sin\gamma}{c}$, $\alpha + \beta + \gamma = 180^\circ = \pi$ rad.

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 $\rightarrow \tan\theta = a_y/a_x$
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:	$v_{\text{avg}} = \Delta x/\Delta t$	$\Delta x = x - x_0$	$v(t) = \frac{dx}{dt}$= slope of $x(t)$
Acceleration:	$a_{\text{avg}} = \Delta v/\Delta t$	$\Delta v = v - v_0$	$a(t) = \frac{dv}{dt}$= slope of $v(t)$
Integrals = areas:	$x(t) = x_0 + \int_0^t v(t')dt'$,	$v(t) = v_0 + \int_0^t a(t')dt'$.	
Constant acceleration:	$v = v_0 + at$,	$v_{\text{avg}} = \frac{1}{2}(v_0 + v)$,	$\Delta x = v_{\text{avg}}\Delta t$.
	$x = x_0 + v_0t + \frac{1}{2}at^2$,	$x = x_0 + v_{\text{avg}}t$,	$v^2 = v_0^2 + 2a\Delta x$.
	(position from acceleration)	(using average velocity)	(timeless equation)
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:	$\vec{a} = d\vec{v}/dt = 0$ 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:	$F_{g,\parallel} = mg\sin\theta$, $F_{g,\perp} = mg\cos\theta$	$\leftarrow$ 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:	$a_c = v^2/r$	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 gravity:	$W_g = -mg\Delta y$	$\Delta y = y_B - y_A$ (final minus initial height)
Work done by a spring:	$W_s = -\frac{1}{2}k(x_B^2 - x_A^2)$	B=final stretch, A =initial stretch.
Work done by friction:	Use formula for constant force.	Friction's work can be positive or negative!!
Work-KE theorem:	$\Delta\text{KE} = W_{\text{net}} =$ all works on m.	$\text{KE} = \frac{1}{2}mv^2, \quad P = \frac{dW}{dt}, \quad P_{\text{ave}} = \frac{\Delta W}{\Delta t}$.
Instantaneous power:	$P = dW/dt$	$\leftarrow$ the rate of doing work by some force.
When $\vec{\mathbf{F}}$ acts on m:	$P = \vec{\mathbf{F}} \cdot \vec{\mathbf{v}}$	$\leftarrow$ instantaneous power only due to $\vec{\mathbf{F}}$
Average power:	$P_{\text{ave}} = \Delta W/\Delta t$	$\leftarrow$ average over time interval Δt.

Chapter 8 - Potential energy and Conservation of energy

PE for gravity:	$\Delta U = mg\Delta y,$	$U(y) = mgy+$ constant.
PE for springs:	$\Delta U = \frac{1}{2}k(x_B^2 - x_A^2),$	$U(x) = \frac{1}{2}kx^2$ + constant.
Arbitrary system:	$\Delta E_{\text{total}} = 0,$	$E_{\text{total}} = E_{\text{mec}} + E_{\text{thermal}} + E_{\text{other}}$. (nothing is left out of energy accounting).

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.

Center of mass:	$\vec{\mathbf{r}}_{\text{com}} = \frac{m_1\vec{\mathbf{r}}_1 + m_2\vec{\mathbf{r}}_2 + \ldots}{m_1 + m_2 + \ldots},$	$\vec{\mathbf{v}}_{\text{com}} = \frac{m_1\vec{\mathbf{v}}_1 + m_2\vec{\mathbf{v}}_2 + \ldots}{m_1 + m_2 + \ldots}$	
1D elastic collisions:	$v_{1\text{f}} = 2v_{\text{com}} - v_{1\text{i}}$	$v_{2\text{f}} = 2v_{\text{com}} - v_{2\text{i}},$	Equal masses swap velocities.
Other collisions:	$\vec{P}_{\text{total}} = M\vec{\mathbf{v}}_{\text{com}} =$ const.	$\vec{P}_{\text{total}} = m_1\vec{\mathbf{v}}_1 + m_2\vec{\mathbf{v}}_2 =$ const.	

Extended objects: The point $\vec{\mathbf{r}}_{\text{com}}$ moves as a point mass $M = \sum_i m_i$ subjected to net force $\vec{F}_{\text{net}}$.

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.
Bulk modulus B:	b-stress $= \Delta p,$	b-strain $= \Delta V/V_0,$	b-stress $= B\times$ b-strain.
Units:	stress in Pa=N/m^2,	strain = % or no units,	Y, S, B in Pa=N/m^2.

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:	$U = -Gm_1m_2/r,$	$\Delta U + \Delta K = 0,$	$\Delta K = -\Delta U,$	$\Delta K = \frac{1}{2}m(v_\text{f}^2 - v_\text{i}^2).$
Orbits:	$F = mv^2/r,$	$v = 2\pi r/T,$	$v_{\text{orb}} = \sqrt{GM/r},$	Kepler: $T^2 = \frac{4\pi^2}{GM}\bar{r}^3.$

Chapter 14 - Fluids

1 atmosphere = 1 atm = 101.3 kPa = 1.013 bar = 760 torr = 760 mm Hg = 14.7 lb/in^2.

Units:	1 Pa = 1 N/m^2,	1 bar = 10^5 Pa,	1 mm Hg = 1 torr = 133.3 Pa.
Density:	$\rho = m/V,$	$\rho_{H_2O} = 10^3$ kg/m^3 (4°C),	10^3 kg/m^3 = 1 g/cm^3.
Pressure:	$p = F/A,$	$p_2 = p_1 + \rho gd,$	$p_{\text{abs}} = p_{\text{atm}} + p_{\text{gauge}}.$
Archimedes:	$F_B = \rho_{\text{fluid}}gV_s,$	Bernoulli energy conserv.$\rightarrow$	$p + \rho gy + \frac{1}{2}\rho v^2 =$ const.
Flow rates:	$Q = Av,$	$Q_m = \rho Av,$	$Q = (p_2 - p_1)\pi r^4/(8\eta L).$
Viscosity:	$F = \eta vA/L,$	$N_R = 2\rho vr/\eta,$	$N_R < 2000$ laminar, $N_R > 3000$ turbulent.