Physics 2101, Exam #4, Spring 2010

April 28, 2010

Name: KEY

Section: (Circle one)

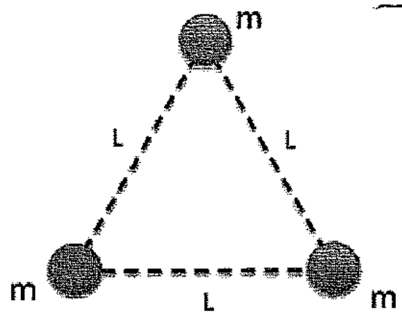
1 (Rupnik, MWF 8:40 AM)	5 (Jin, TTh 12:10 PM)
2 (Rupnik, MWF 10:40 AM)	6 (González, TTh 4:40 PM)
3 (Zhang, MWF 12:40 PM)	7 (Sprunger, TTh 1:40 PM)
4 (Plummer, TTh 9:10AM)	

- Please be sure to write (print) your name and circle your section above.
- Please turn OFF your cell phone and MP3 player!
- Feel free to detach, use, and keep the formula sheet. No other reference material is allowed during the exam.
- You may use either scientific or graphing calculator ...
- **GOOD LUCK!**

SHOW WORK on all problems that are NOT multiple choice

1. (10 pts) Three spherical objects with the same mass m kg are separated by equal distances L by forming a triangular structure. How much work is done by you to set the masses in this configuration, bringing them from an infinite distance?

$\mathcal{U}_i = 0$



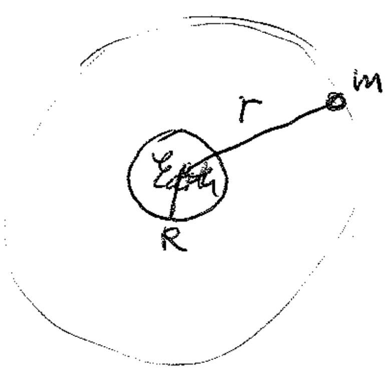
(a) $+Gm^2/L$
(b) $-Gm^2/L$
(c) $+3Gm^2/L$
(d) $-3Gm^2/L$

$$W_{you} = \Delta \mathcal{U} = \mathcal{U}_f - \cancel{\mathcal{U}_i}^{\,0} = -G\frac{m^2}{L}3$$

no important

2. (10 pts) A satellite is launched in a circular **synchronous** orbit around the earth. Neglecting all possible resistance from atmosphere, you conclude based on your knowledge of gravity that...

(a) The height of the orbit depends on the mass of the satellite.
(b) The height of the orbit is independent of the mass of the satellite.
(c) The height of the orbit depends on the mass and size of the satellite.
(d) None of above is correct.



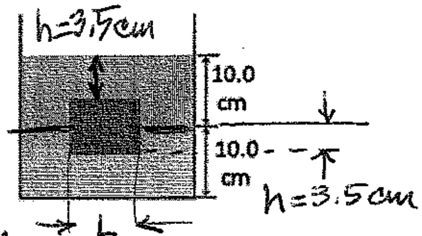
$r = R + h$

on a circular orbit: $|\vec{F}_g| = |\vec{F}_{cp}|$

$$G\frac{\cancel{m}M}{r^{\cancel{2}}} = \frac{\cancel{m}v^2}{\cancel{r}}$$

$$r = \frac{GM}{v^2} = R + h$$ ... not a function of mass of the satellite

3. (15 pts) A cubical block of wood, 10.0 cm on a side, floats at the interface between oil on top and water below, with its lower surface 3.50 cm below the interface (see the cross section view in the figure). The density of the oil is 790 kg/m^3.



$\rho_o = 790\ kg/m^3$ $\qquad h = 3.5\ cm$

$\rho_w = 1000\ kg/m^3$ $\qquad L = 10\ cm = 0.1\ m$

(a) (5 pts) What is the gauge pressure at the upper face of the block?

$$p_{gauge,\,top} = p - p_0 = \rho_o g h = \left(790 \frac{kg}{m^3}\right)\left(9.8 \frac{m}{s^2}\right)\left(3.5\times10^{-2}\, m\right)$$

$$= \underline{270.97\ Pa}$$

(b) (5 pts) What is the gauge pressure of the lower face of the block?

$$p_{gauge,\,bottom} = \rho_o g L + \rho_w g h = \left(790 \frac{kg}{m^3}\right)\left(9.8 \frac{m}{s^2}\right)(0.1\, m) + \left(1000 \frac{kg}{m^3}\right)\left(9.8 \frac{m}{s^2}\right)\left(3.5\times10^{-2}\, m\right) = \underline{1117.2\ Pa}$$

(c) (5 pts) What is the mass of the block? *Hint: use parts (a) and (b) to find your answer.*

at rest $\Rightarrow F_{net} = 0$

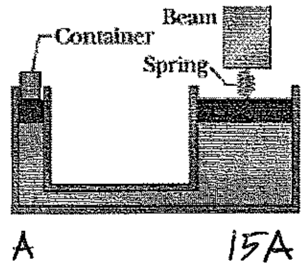
$p = \frac{F}{A} = \frac{F}{L^2}$

$$F_{net} = 0 \Rightarrow mg = F_b = F_{bottom} - F_{top} = L^2 (p_{bottom} - p_{top})$$

$$\Rightarrow m = \frac{L^2 (p_{bott} - p_{top})}{g} = \frac{(0.01\, m^2)(1117.2 - 270.97)\, Pa}{9.8 \frac{m}{s^2}}$$

$$\underline{m = 0.8635\ kg}$$

4. (10 pts) In the figure, a spring with 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 and the output piston has area $15A$. Initially the spring is at its rest length. Then, a mass M of sand is slowly poured into the container.



(a) (5 pt) What is the change of pressure on the output piston, due to the sand poured into the container?

i. $15Mg/A$
ii. Mg/A
iii. $Mg/(15A)$
iv. $Mg/(7.5A)$

$\Delta p_i = \frac{Mg}{A}$

Pascal principle:

$\Delta p_i = \Delta p_o$

$\frac{Mg}{\cancel{A}} = \frac{kx}{15\cancel{A}} \Rightarrow x = \frac{15\,Mg}{k}$

(b) (5 pt) The spring is compressed by a distance

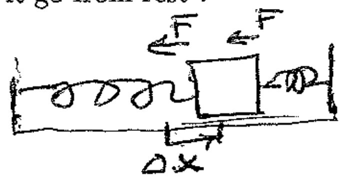
i. Mg/k
ii. $15Mg/k$
iii. $Mg/(15k)$
iv. $Mg/(7.5k)$

5. (15 pts) In the figure below, two identical springs of spring constant $k = 2.5$ N/cm are attached to a block of mass $m = 0.20$ kg. The block is set into motion by displacing the block 3.0 cm to the right of equilibrium, and letting it go from rest .

$k = 2.5 \frac{N}{cm} \frac{100 cm}{1 m} = 250 \frac{N}{m}$

$x_m = 3 cm = 0.03 m$

$m = 0.20 kg$



$2F = -k_{eff}\Delta x$

$-k_1\Delta x - k_2\Delta x = -k_{eff}\Delta x$

$\Rightarrow k_{eff} = k_1 + k_2 = 2k$

(a) (5 pts) What is the period T of the oscillatory motion?

$\omega = \sqrt{\frac{2k}{m}}$

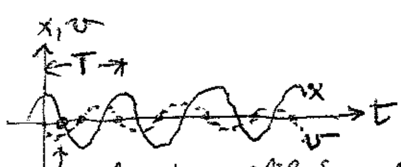
$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{m}{2k}} = 2\pi\sqrt{\frac{0.2 kg}{2(250 \frac{N}{m})}} = (0.02)(2\pi) = 0.04\pi\ s$

$T = 0.126 s$

(b) (5 pts) What is the block's maximum velocity?

$v_m = x_m\omega = x_m\frac{2\pi}{T} = (3\times10^{-2} m)\frac{2\pi}{0.126 s} = 1.5\ m/s$

$v_m = 1.5\ m/s$



first equilibrium position and v is negative, $t = \frac{T}{4}$

(c) (5 pts) At what time will the block go for the first time through the equilibrium position with negative velocity?

$t = 0$ $\qquad$ $t = T/4$ $\qquad$ $t = T/2$ $\qquad$ $t = 3T/4$

6. (15 pts) A sinusoidal wave moving along a string with mass $m = 1.25$ kg and length 100.0m is shown twice below, as crest A travels in the positive direction of an x axis by distance $d = 1.0$ cm in 50.0 ms. The tick marks along the axis are separated by 2.0 cm. The snapshot shown with a solid line is taken at $t = 0$, the one with a dashed line is taken at a later time. The wave equation is of the form $y(x,t) = y_m \sin(kx - \omega t)$.

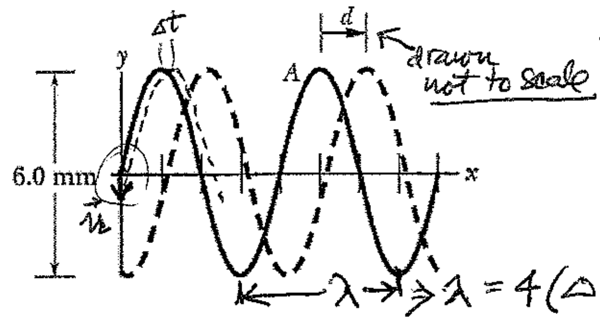
$m = 1.25\,kg$, $L = 100\,m$ $\Big\}$ $\mu = \frac{m}{L} = \frac{1.25}{100}$

$\mu = 0.0125\,kg/m$

$d = 1\,cm = 0.01\,m$

$t = 50\,ms = 0.05\,s$

$v = \frac{d}{t} = \frac{0.01\,m}{0.05\,s} = 0.2\,m/s$



$\Delta x = 2\,cm$ for tick marks

$\lambda = 4(\Delta x) = 4(2\,cm) = 8\,cm = 0.08\,m$

$k = \frac{2\pi}{\lambda}$

(a) (5 pt) What is the wave's angular frequency ω?

$v = \frac{\omega}{k} = \frac{\omega}{2\pi}\lambda \Rightarrow \omega = \frac{v\,2\pi}{\lambda} = \frac{(0.2\,m/s)\,2\pi}{0.08\,m} = 5\pi \frac{rad}{s} = 15.7 \frac{rad}{s}$

$\omega = 15.7 \frac{rad}{s}$

(b) (5 pt) At $t = 0$, which of the following is the velocity vector of the particle in the string at $x = 0$?

Drawing the wave a short time later reveals that particle at $x=0$ moves downward:

$\uparrow$ $\quad\quad$ $\downarrow$ $\quad\quad$ $\rightarrow$ $\quad\quad$ $\leftarrow$

(c) (5 pt) What is tension in the string?

$v = \sqrt{\frac{\tau}{\mu}} \Rightarrow \tau = v^2\mu = \left(0.2\frac{m}{s}\right)^2\left(0.0125\frac{kg}{m}\right) = 5\times10^{-4}\,N$

$\tau = 5\times10^{-4}\,N$

7. (10 pts) You want to design an engine with a brass piston to slide inside a steel cylinder. This engine should operate between 20°C and 150°C. The linear expansion coefficients for brass and steel are $\alpha_{BR} = 2.0 \times 10^{-5}/°C$ and $\alpha_{ST} = 1.2 \times 10^{-5}/°C$. Assume that the coefficients of expansion are constant over this temperature range.

(a) (5 pt) If the piston just fit inside the chamber of the cylinder at 20°C, will the engine be able to run at higher temperature?

i. Yes.
ii. No.
iii. It depends on the size of the piston.

piston expands faster than cylinder
$\Rightarrow$ it would stuck and would not be able to move

(b) (5 pt) If the cylindrical piston is 25.0 cm in diameter at 20°C, what should be the minimum inner diameter of the steel cylinder at that temperature so that the engine will operate at 150°C?

i. > 25.0 cm
ii. 25.0 cm
iii. < 25.0 cm

steel expands slower, so it has to be larger at lower temperature, so that at higher temperatures piston does not get stuck!

8. (15 pts) A block of ice with a mass of 2 kg at initial temperature of $-20°C$ is mixed with with 3kg of water at room temperature, 20°C. The latent heat of fusion of ice is $L_f = 333$ kJ/kg. The specific heat is $c_{ice} = 2220$ J/(kg°C) for ice and $c_w = 4187$ J/(kg°C) for water.

(a) (3 pts) How much heat is needed to warm up this piece of ice to 0°C?

$$Q_1 = m_i c_i \Delta T_i = (2\,kg)(2220\,J/kg°C)(0° + 20°C) = 88800\,J$$

(b) (3 pts) How much heat is needed to melt all the ice?

$$Q_2 = m_i L_f = (2\,kg)(333000\,J/kg) = 666000\,J$$

$$\Rightarrow Q_{ice} = Q_1 + Q_2 = 754800\,J$$

(c) (3 pts) How much heat does it need to be extracted from the water if it were to cool to 0°C?

$$Q_{w,\,most} = m_w c_w \Delta T_w = (3\,kg)(4187\,J/kg°C)(0° - 20°C)$$
$$= -251220\,J$$

Because $|Q_{w,\,most}| < Q_{ice} \Rightarrow T_f = 0°C$

(d) (3 pts) What is the composition of the final mixture?

All frozen ice   A mixture of ice and water   All liquid water

(e) (3 pt) What is the final temperature T_f of the mixture?

$T_f < 0°C$ $T_f = 0°C$ $0°C < T_f < 20°C$ $T_f > 20°C$