Physics 110
Exam #3
Spring 2006
May 24, 2006

Multiple Choice	/20
Problem #1	/24
Problem #2	/28
Problem #3	/28
Total	/100

Part I: Free Response Problems

Please show all work in order to receive partial credit. If your solutions are illegible no credit will be given. Please use the back of the page if necessary, but number the problem you are working on. The numbers in parentheses following the question correspond to the point values for each part.

1. The human heart is a mechanical pump. The aorta is a large artery that carries oxygenated blood away from the heat to various organs in the body. For an individual at rest, the blood in the aorta (of radius 1.25cm) flows at a rate of $5\text{x}10^{-3}$ m^3/min.
   a. What is the velocity, in meters per second, of the blood in the aorta? (4)

   $$\text{Volume rate of flow} = 5\times10^{-3}\,\tfrac{m^3}{\text{min}} = Av \rightarrow v = \frac{8.33\times10^{-5}\,\frac{m^3}{\text{sec}}}{\pi(0.0125m)^2} = 0.17\,\tfrac{m}{s}$$

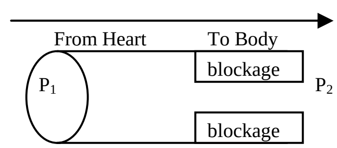
   b. Suppose that the blood flows continuously throughout the body (and not in spurts as it really does), what is the kinetic energy of the blood, per unit volume of blood, in the aorta? (Hint: The density of blood is 1050 kg/m^3.) (6)

   $$\frac{KE}{Vol} = \frac{\frac{1}{2}mv^2}{V} = \frac{1}{2}\rho v^2 = \frac{1}{2}\left(1050\,\tfrac{kg}{m^3}\right)\left(0.17\,\tfrac{m}{s}\right)^2 = 15.1\,\tfrac{J}{m^3}$$

   c. Every time that the heart beats, it does work moving the blood into the aorta and then into the body. Suppose that the heart does 0.5W of work, what is the change in pressure across the aorta? (Hint: The power is the work done moving the blood per unit time.) (8)

   $$P = \frac{Energy}{time} = \frac{work}{time} = \frac{\Delta F\Delta x}{\Delta t} = \Delta PAv \rightarrow \Delta P = \frac{0.5W}{\left(\pi\times(0.0125m)^2\right)\left(0.17\,\tfrac{m}{s}\right)} = 5.99\times10^3\,\tfrac{N}{m^2} = 5.99kPa$$

   d. Suppose that the difference in pressure in *part c* were due to an aortic blockage as shown below. What is the velocity of the blood through the blockage if the person were lying horizontal? This is a medical condition known as atherosclerosis. (Hint: If you cannot calculate a numerical answer to *part c*, you may use 1000 N/m^2.) (6)

   $$P_a + \tfrac{1}{2}\rho v_a^2 + \rho g h_a = P_b + \tfrac{1}{2}\rho v_b^2 + \rho g h_b \rightarrow v_b = \sqrt{v_a^2 + \frac{2(P_a - P_b)}{\rho}}$$

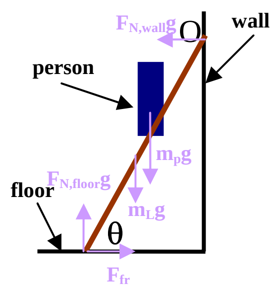
   $$= \sqrt{\left(0.17\,\tfrac{m}{s}\right)^2 + \frac{2\left(5.99\times10^3\,\frac{N}{m^2}\right)}{1050\,\frac{kg}{m^3}}} = 3.38\,\tfrac{m}{s}$$

2. A 5.0m long ladder with mass 100kg is laid against a frictionless wall at an angle θ with respect to the floor as shown below. Suppose that the coefficient of static friction between the floor and ladder is 0.09 and that a painter of mass 60kg has climbed up the ladder and has made it to a point 70% of the length of the ladder when the ladder begins to slip. At what angle θ was the ladder placed? To answer this, perform the following steps.

   a. In your own words, write a brief description of the problem stating the main physical principle(s) behind the problem. (To receive credit, ***do not*** merely restate the problem above!) (4)

      Answers will vary.

   b. Draw a *carefully labeled free body* diagram showing all of the forces that act on the ladder. (9)



   c. From your free body diagram, determine expressions for the normal forces due to the wall and the floor. (You will have two separate expressions and also do not evaluate them at this point.) (6)

$$\sum F_x : \quad -F_{N,wall} + F_{fr} = ma_x = 0$$
$$\sum F_y : \quad F_{N,floor} - m_L g - m_p g = ma_y = 0$$
$$\therefore F_{N,wall} = F_{fr} = \mu_s F_{N,floor} \quad and \quad F_{N,floor} = m_L g + m_p g$$

   d. Write an expression for the sum of the torques about the origin O (shown above) in terms of the angle θ and then evaluate your expression using the information given. (Hints: You will need the fact that $\sin(90-\theta) = \cos\theta$ and for counter-clockwise rotations choose + for the direction of the torque.) (9)

$$\sum \tau = 0 \rightarrow \; -F_{N,floor} l \sin(90-\theta) + F_{fr} l \sin\theta + m_l g \frac{l}{2} \sin(90-\theta) + m_p g(0.3l)\sin(90-\theta) = 0$$

$$\therefore -F_{N,floor} l \cos\theta + F_{fr} l \sin\theta + m_L g \frac{l}{2} \cos\theta + 0.3 l m_p g \cos\theta = 0$$

$$-(m_L + m_p) gl \cos\theta + \mu_s (m_L + m_p) gl \sin\theta + m_L g \frac{l}{2} \cos\theta + 0.3 l m_p g \cos\theta = 0$$

$$\tan\theta = \frac{0.5 m_L + 0.7 m_p}{\mu_s (m_L + m_p)} = \frac{0.5(100kg) + 0.7(60kg)}{0.09(160kg)} = 6.39 \rightarrow \theta = 81.1^0$$

3. During most of its lifetime a star maintains an equilibrium size in which the inward force of gravity on each atom is balanced by an outward pressure force due to the heat of nuclear reactions in its core. After all of the hydrogen "fuel" is consumed by nuclear fusion, the pressure force drops and the star undergoes a ***gravitational collapse*** until it becomes a neutron star. In a neutron star, the electrons and protons are squeezed together by gravity until they fuse into neutrons. Neutron stars spin very rapidly and emit intense radio pulses, one pulse per rotation. These pulsating stars were discovered in the 1960's and are called ***pulsars***.

   a. A star with the mass (M = 2x10^{30} kg) and size (R = 3.5x10^{8} m) of our Sun rotates once every 30 days. What is the initial magnitude of the angular velocity of this ordinary star? (4)

$$\omega_i = \frac{2\pi}{T_i} = \frac{2\pi}{30 days \times \frac{24hr}{1day} \times \frac{3600s}{1hr}} = 2.42\times10^{-6}\ \tfrac{rad}{s}$$

   b. If after undergoing gravitational collapse, the star forms a pulsar that is observed to emit radio pulses every 0.1 s. What is the final magnitude of the angular velocity of the pulsar? (6)

$$\omega_f = \frac{2\pi}{T_f} = \frac{2\pi}{0.1s} = 62.8\ \tfrac{rad}{s}$$

   c. If the star does not lose any mass in the collapse, what is the radius of the neutron star after the collapse? (Hint: Consider the star before and after the collapse to be a solid sphere with moment of inertia $I_{star} = \frac{2}{5}MR^2$.) (9)

   By conservation of angular momentum:

$$I_i\omega_i = I_f\omega_f \rightarrow \tfrac{2}{5}M_{star}R^2_{s,before}\omega_i = \tfrac{2}{5}M_{star}R^2_{s,after}\omega_f$$

$$\therefore R_{s,after} = \sqrt{R^2_{s,before}\frac{\omega_i}{\omega_f}} = \sqrt{\left(3.5\times^8 m\right)^2\left(\frac{2.42\times10^{-6}}{62.8}\right)} = 68.7km$$

   d. Is there a change in kinetic energy of the collapsing star? ***If your answer is yes***, how much work did gravity do in collapsing the star and why is work done collapsing the star? ***If your answer is no*** then explain why gravity does no work in collapsing the star. (9)

$$KE_{rot,i} = \tfrac{1}{2}I_i\omega_i^2 = \tfrac{1}{2}\left(\tfrac{2}{5}\times2\times10^{30}kg\times\left(3.5\times10^8 m\right)^2\right)\left(2.42\times10^{-6}\ \tfrac{rad}{s}\right)^2 = 2.87\times10^{35}J$$

$$KE_{rot,f} = \tfrac{1}{2}I_f\omega_f^2 = \tfrac{1}{2}\left(\tfrac{2}{5}\times2\times10^{30}kg\times\left(6.87\times10^4 m\right)^2\right)\left(62.8\tfrac{rad}{s}\right)^2 = 7.45\times10^{42}J$$

$$\therefore \Delta KE = 7.44999\times10^{42}J = W_{gravity}$$

Part II: Multiple-Choice

Circle the best answer to each question. Any other marks will not be given credit. Each multiple-choice question is worth 2 points for a total of 20 points.

1. If ocean waves strike the shore every 3.0s and the horizontal distance between adjacent maxima and minima is 1.0m, the wave speed is
   a. 0.33m/s b. 0.67 m/s c. 1.5m/s d. 3.0m/s

2. Which of the following relationships correctly describes the relationship between frequency f and the period T of a sinusoidal wave?
   a. $fT = 1$ b. $f / T = 1$ c. $f + T = 1$ d. $f - T = 1$

3. A solid body can be in rotational equilibrium only when
   a. it has zero angular momentum.
   b. it is in free fall.
   c. its external forces sum to zero.
   d. its external torques sum to zero.

4. In a healthy person standing at rest, a comparison of the arterial blood pressure measured in the arm with that measured in the leg shows that the pressure in the leg
   a. is lower because the blood flow rate is less.
   b. is lower because resistance in the arteries causes pressure loss.
   c. is the same because there is no hydrostatic pressure ($\rho g\Delta h$) difference.
   d. is greater because the column of blood between the arm and the leg has a hydrostatic pressure ($\rho g\Delta h$) difference.

5. Thirty milliliters of an anesthetic solution is drawn into a 5g syringe and is found to have a combined mass of 80g. The density of the anesthetic solution is
   a. $6.3\text{x}10^{-5}$ g/ml b. $6.6\text{x}10^{-2}$ g/ml c. 2.5 g/ml d. 2.7 g/ml

6. A string of length 5m and mass **0.04g** has a mass of 50g hanging from it. What is the speed of a transverse wave along this string?
   a. 0.10 m/s b. 0.31 m/s c. 19.8 m/s d. 248 m/s

   The mass density should be given as above. This gives D for the answer. On the actual exam there was no correct solution so everyone got the question.

7. A cup is filled to the very top with water and a floating ice cube. When the ice cube melts, which of the following occurs?
    a. The water overflows the cup.
    b. The water level in the cup decreases.
    c. The water level remains the same.
    d. There is not enough information given to answer the question.

8. A dumbbell shaped object is composed of two point masses connected by a light rod. The masses are separated by a distance *2R* and the system is rotated about the center of mass. If one decides to rotate the object about one end rather than at the center of mass, the moment of inertia in the latter case
    a. increases.
    b. decreases.
    c. remains the same.
    d. depends on the forces involved on the rod.

9. A solid sphere ($I_{solid} = \frac{2}{5}MR^2$) and a hollow sphere ($I_{solid} = \frac{2}{3}MR^2$) of the same mass and radius roll without slipping at the same speed. Compared to the hollow sphere, the kinetic energy of the solid sphere is
    a. greater.
    b. less.
    c. the same.
    d. unable to be determined.

10. A steel cable (ρ = 7850 kg/m^3) is used to hang traffic lights from poles and as such is stretched from pole to pole across an intersection. If a wave pulse (of frequency f = 60s^{-1} and amplitude of 0.5mm) were to be generated by the person hanging the wire and this wave propagated down the cable at a speed v = 4512 m/s, the intensity of the transverse wave on this steel cable is at the other pole is approximately
    a. 3.34x10^3 W/m^2.
    b. 6.29x10^5 W/m^2.
    c. 3.34x10^8 W/m^2.
    d. 6.29x10^{11} W/m^2.