Physics 2010 (Schroeder) Name _____
spring 2004

Problem Set 5

(due Friday, February 13)

1. For each of the following situations, draw a qualitatively accurate force diagram for each object involved, and identify all pairs of forces that are "third-law partners." (a) You jump off the ground. (Draw diagrams for both you and the earth during the time when you are still in contact with the ground, accelerating upward.) (b) A little box sits on top of a bigger box sitting on an incline. Both are at rest. (Draw diagrams for both boxes.) (c) A person hangs from a helicopter by a rope as the helicopter begins to accelerate upward. (Draw diagrams for the person, the helicopter, and the rope.)

2. A bowling ball crashes head-on into a bowling pin at the end of the lane. Obviously the ball exerts a force on the pin. Does the pin also exert a force on the ball? If so, which of these two forces is greater in magnitude? Explain fully.

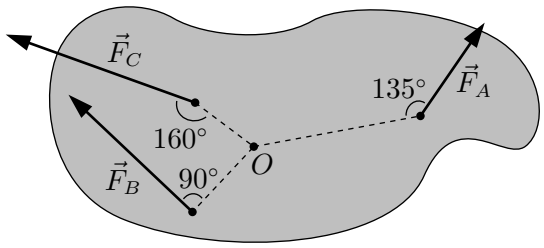
3. A mule is asked to pull a plow. The mule resists, explaining "If I tug on the plow, Newton's third law asserts that the plow will tug on me with an equal and opposite force. Since these forces cancel each other out, it is obvious that we're not going to go anywhere. Therefore, there is no point in even trying." Carefully explain the error in the mule's reasoning, and draw force diagrams for the mule and the plow showing how it is possible for both to accelerate.

4. Paddy the bricklayer (whose mass is 75 kg) has 100 kg of leftover bricks that he needs to bring down from the top of a 14-story building. To avoid hauling them down by hand, he hangs a rope from a pulley and hoists a barrel to the top, tying off the rope at ground level. After loading the bricks into the barrel, he goes back down to untie the rope, clinging tightly to it. Much to his surprise (as he has not studied physics), he begins to accelerate upwards. (a) What is his acceleration? (Please neglect the mass of the empty barrel, the rope, and the pulley, as well as any friction in the pulley.) (b) How fast is Paddy going when he collides into the barrel, 7 floors (25 meters) above the ground?

5. You need to drive your car (mass 1000 kg) and tow a trailer (mass 500 kg) up an icy 10% incline, at constant speed. The coefficient of friction between your tires and the road surface is 0.18. Can you make it? (A 10% incline is one that rises 10 meters for every 100 meters of horizontal distance.)

6. The length of a bicycle pedal crank is 0.152 m. A foot applies a vertical, downward force of 111 N on the pedal. What is the magnitude of the torque about the axle when the crank makes an angle with the vertical of (a) 30°, (b) 90°, (c) 180°?

7. The object shown on the next page is anchored at point O. Three forces act on the object as shown; their magnitudes are $|\vec{F}_A| = 10$ N, $|\vec{F}_B| = 16$ N, and $|\vec{F}_C| = 19$ N, and the points where they act are 8.0 m, 4.0 m, and 3.0 m from O, respectively. What is the net torque about O?



8. Find the location of the center of mass of the earth-sun system. (Look up the needed data, for instance, inside the front cover of your textbook.)

9. Explain why your back muscles get tired when you wash dishes (in the sink—not an automatic dishwasher!).

10. While sitting in a chair, extend your leg straight outward and think about the tension in your upper leg muscle (just above the knee). Try to make a very rough estimate of this tension force. To do this, you'll need to estimate the mass of your lower leg, the position of its center of mass, and the vertical distance between the knee joint and the point where the muscle attaches. To estimate the mass of your lower leg, please don't cut it off and weigh it! Instead, estimate its volume in liters and assume that each liter has a mass of one kilogram. See page 143 of your textbook for some helpful illustrations.

11. Even when your head is held erect, its center of mass is not directly over the principal point of support (the "atlanto-occipital joint"). The muscles in the back of your neck must therefore exert a force to keep it erect. (This is why your head falls forward when you fall asleep in class.) (a) Calculate the force exerted by these muscles, assuming that they pull straight down along a line 5.0 cm behind the a-o joint; Take the mass of your head to be 5.0 kg and its center of gravity to be 2.5 cm in front of, and 7 cm above, the a-o joint. (b) What is the downward force on the a-o joint? (For an illustration of all this, see page 143 of your textbook.)

12. During a wrestling match, a 150-kg wrestler briefly stands on one hand, in a maneuver designed to perplex his already moribund adversary. How much does his upper arm bone shorten in length? (Model the bone as a uniform rod, 38 cm in length and 2.1 cm in radius.)

Study Guide

Newton's third law

You should be able to state Newton's third law correctly, identify "third-law partners," and solve constrained motion problems that involve more than one object.

Torque

You should be able to calculate torques, and express them in terms of distance, force, and angle using the equation

$$\tau = |\vec{r}||\vec{F}|\sin\theta = r_\perp|\vec{F}| = F_\perp|\vec{r}|.$$

In these formulas, $\vec{r}$ is the position of the point where the force acts, with respect to the (arbitrarily chosen) origin. By convention, counter-clockwise torques are considered positive, clockwise torques negative.

Torque is important because when an object is in equilbrium (no part of it is accelerating), both the net force and the net torque on it must be zero.

Center of mass

For a system of two particles in one dimension, the location of the center of mass is

$$x_{\text{cm}} = \frac{m_1x_1 + m_2x_2}{m_1 + m_2}.$$

Think of this as the *weighted* average of x_1 and x_2. This equation generalizes to multiple particles and multiple dimensions in the ways you would expect. For the purpose of computing the torque on an object due to gravity, you can pretend that the entire force acts at the object's center of mass (or technically, its center of gravity, which is the same thing unless the object is so large that g varies from one end to the other).

Other concepts

You should understand the concept of mechanical advantage (section 5.6).

You should understand the concepts of elasticity (section 5.8), but you needn't memorize any of the equations.