Physics 2010 (Schroeder) Name ______________________________
spring 2004

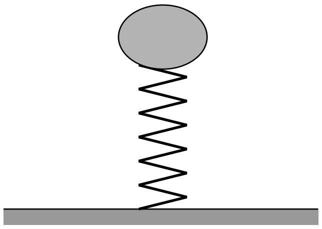
Problem Set 6

(due Monday, February 23)

1. A worker pushes a 250-kg piano up a ramp that is inclined 20° above the horizontal. The piano moves a total of 3.0 meters up the ramp and never accelerates significantly, so it is always in equilbrium. (a) Assuming that there is negligible friction and that the force exerted by the worker is parallel to the ramp, find the magnitude of this force. (Be sure to draw a force diagram.) (b) How much work does the worker perform? (c) How much work does the ramp perform? (d) How much work does gravity perform? (e) What is the total work performed by all three forces that act on the piano?
2. If the speed of an object is doubled, what happens to its kinetic energy?
3. Calculate the kinetic energies of the following objects moving at the given speeds: (a) a 110 kg football linebacker running at 8.1 m/s; (b) a 4.2 g bullet at 950 m/s; (c) the aircraft carrier *Nimitz*, 91,400 metric tons at 32 nautical miles per hour.
4. Reaching out a third-floor window, 10.0 meters above the ground, you drop a 2.0 kg textbook to a friend who catches it at a height of 1.5 m above the ground. (a) How much work is done by the earth (via gravity) on the book as it falls? (b) If we take the gravitational energy to be zero when the book is on the ground, what is its gravitational energy (b) when it is released and (c) when it is caught? (d) How are your answers to the three parts of this problem related?
5. For the same situation as in the previous problem, what is the speed of the textbook just before it is caught? If we substituted a second textbook with twice the mass, what would its speed be? (You may wish to use the Conservation Laws Worksheet.)
6. Three plums are launched from ground level, at the same initial speed. The first is launched straight upward; the second is launched at an angle, so it follows a parabolic arc; the third is launched up a frictionless incline, so it moves upward along a straight diagonal. When they reach an altitude of 5 meters above the ground, which has the greatest speed? Which has the smallest speed? What can you say about their velocities? (Please explain your reasoning.)
7. A pendulum consists of a 2.0 kg stone swinging from a 4.0 m string of negligible mass. The stone has a speed of 8.0 m/s when it passes its lowest point. (a) What is the speed when the string is at a 60° angle to the vertical? (b) What is the maximum angle of the swing of the pendulum? (c) If the system's gravitational energy is taken to be zero when the stone is at its lowest point, what is the total energy of the system? (You may wish to use the worksheet.)
8. I have a rubber band that stretches 10 cm when a 500 g mass hangs from it (motionless). (a) What is its "spring constant"? (b) How much would it stretch if I hang an additional 500 g from it, making 1 kg total? (c) How much elastic potential energy is stored in the rubber band in the second case?

9. During spring semester at MIT, residents of the parallel buildings of the East Campus dorms battle one another with large catapults that are made of surgical hose mounted on a window frame. A balloon filled with dyed water is placed in a pouch attached to the hose, which is then stretched across the room and released. Assume that the catapult obeys Hooke's law ($F_x = -kx$) and has a spring constant of 100 N/m. (a) How much force is needed to stretch the catapult 5.0 m from its relaxed position? (b) How much elastic potential energy is stored in the fully-stretched catapult? (c) If the balloon has a mass of 1.0 kg, to what speed is it accelerated by the catapult?

10. Shown below is an 8.0 kg stone resting on a spring. The spring is compressed by 10 cm by the stone. (a) What is the spring constant? (b) Suppose that you now push the stone down an additional 30 cm. What is the elastic potential energy of the spring? (c) If you now release the stone from this position, how much gravitational potential energy does it gain as it flies upward? (d) How high does the stone go, measured from the release point? (You may wish to use the worksheet.)



11. Consider again the original predicament of Paddy (mass 75 kg) and the barrel of bricks (mass 100 kg). Recall that both are initially at rest, then the bricks fall 25 m while Paddy rises 25 m until they collide. There is no friction in the pulley or elsewhere. Use conservation of energy to find Paddy's speed just before the collision. (You may wish to use the worksheet.)

12. Suppose that you wish to hike to the summit of Mt. Ogden, an elevation gain of 1500 meters. Assuming that your muscles can convert chemical energy into thermal energy with 25% efficiency, about how many jelly donuts should you eat for breakfast? (One jelly donut provides 250 kcal of energy.)

13. Measure the time it takes you to climb a flight of stairs (running or walking—your choice), then calculate the rate at which you are converting chemical energy into gravitational potential energy. Express the answer both in watts and in horsepower.

14. A news article states that during the California electricity crisis, utilities occasionally paid as much as $2000 per megawatt for electrical energy. Explain why this statement is literally nonsense, and guess what the article should have said.

Study Guide

Spring force: $|\vec{F}_s| = kx$, where x is the amount of stretch or compression. (Force and displacement are in opposite directions.)

(Work done by $\vec{F}$) $= |\vec{F}||\Delta\vec{r}|\cos\theta$. You should understand when W is positive, negative, and zero, according to this formula.

(If $\vec{F}$ or the direction of travel varies, we must break up path into tiny steps and add up all the little works to get the total work.)

Work-energy relation: The net work done on a particle by all forces acting on it equals the change in its kinetic energy. net $W = \text{KE}_{\text{final}} - \text{KE}_{\text{initial}}$. (A "particle" is any object whose internal structure is irrelevant to the situation at hand. The concept of work is ambiguous for an object whose shape can change.)

Types of potential energy: gravitational (mgy); elastic ($\frac{1}{2}kx^2$). (Next semester you'll learn about electrostatic potential energy. Any "conservative" force has an associated potential energy function. Friction, air resistance, and people pushing are examples of nonconservative forces.)

Total mechanical energy (kinetic plus all forms of potential) is conserved provided that all forces have been taken into account as types of potential energy, although forces that do no work can be neglected. If there are work-doing forces (such as friction or air resistance or people pushing) that do not have potential energy functions, then mechanical energy is *not* conserved.

Other forms of energy include thermal energy, chemical energy, nuclear energy, and magnetic energy. If *all* forms of energy are taken into account, then the total energy of an isolated system is *always* conserved. However, this principle is not very useful unless you know how to calculate all relevant forms of energy.

The SI unit of work or energy is the newton-meter or joule (J). Other common units of energy are the kilocalorie (4186 J), kilowatt-hour (kWh), British thermal unit (Btu), and electron-volt (eV). Don't worry for now about Btu's or electron-volts, but do memorize the number of joules in a kcal (to two significant figures). You should be able to figure out how many joules are in a kWh from the definition of a watt (below).

Power, in physics, is defined as the *rate* at which energy is converted or moved from place to place: Power = Energy / time. The SI unit of power is the J/s, also called a watt (W). One horsepower is now defined as 746 watts. (Whether *your* horse can produce one horsepower is your own problem!)