Oscillations and Waves Problems

1. *Oscillation:* You have been asked to evaluate the design for a simple device to measure the mass of small rocks on the Moon. The rock is attached to the free end of a lightweight spring which horizontal. The surface on which the rock slides is almost frictionless. You are worried that the kinetic energy of the rock may make this device dangerous in some situations. The device specifications state that a 150 gram rock will execute harmonic motion, with a frequency of 0.32 Hz, described by $x(t) = A \sin(bt - 35°)$ when the rock has an initial speed of 1.2 cm/s.

3. *Oscillations:* You and some friends are waiting in line for "The Mixer", a new carnival ride. The ride begins with the car and rider (150 kg combined) at the top of a curved track. At the bottom of the track is a 50 kg block of cushioned material which is attached to a horizontal spring whose other end is fixed in concrete. The car slides down the track ending up moving horizontally when it crashes into the cushioned block, sticks to it, and oscillates at 3 repetitions in about 10 seconds. Your friends estimate that the car starts from a height of around 10 feet. You decide to use your physics knowledge to see if they are right. After the collision, you notice that the spring compresses about 15 ft from equilibrium.

3. *Traveling Waves:* You've been hired as a technical consultant to the Minneapolis police department to design a radar detector-proof device that measures the speed of vehicles. (i.e. one that does not rely on sending out a radar signal that the car can detect.)

   You decide to employ the fact that a moving car emits a variety of characteristic sounds. Your idea is to make a very small and low device to be placed in the center of the road that will pick out a specific frequency emitted by the car as it approaches and then measure the change in that frequency as the car moves off in the other direction. The device will then send the initial and final frequencies to its microprocessor, and then use this data to compute the speed of the vehicle.

   You are currently in the process of writing a program for the chip in your new device. To complete the program, you need a formula that determines the speed of the car using the data received by the microprocessor. You may also include in your formula any physical constants that you might need.

   Because your reputation as a designer is on the line, you realize that you'll need find ways to check the validity of your formula, even though it contains no numbers.

4. *Traveling Waves:* You have the perfect summer job with a team of marine biologists studying dolphin communication off the coast of Hawaii. Massive boulders on the ocean floor can interrupt the reception of underwater sound waves from the dolphins. To reduce these disruptions, your team has decided to put several "transceivers" (a device that receives a signal, amplifies the signal, and then transmits it) at strategic locations on the ocean floor. A transceiver will receive sound waves from a dolphin and then retransmit them to the researchers on the ship. The ship's receiver is on a long cable so that it is at approximately the same depth as the dolphins. Because of your physics background, you worry that the frequency received at the moving ship will be different than that

emitted by the dolphin. To determine the size of this effect, you assume that the ship is moving at 35km/h away from the stationary transceiver. Meanwhile, the dolphin is moving at 60km/h towards the transceiver and at an angle of 63° to the ship's path when it emits a sound frequency of 660Hz.

5. *Wave Equation:* A friend of yours, a guitarist, knows you are taking physics this semester and asks for assistance in solving a problem. Your friend explains that he keeps breaking repeatedly the low E string (640 Hz) on his Gibson "Les Paul" when he tunes-up before a gig. The cost of buying new strings is getting out of hand, so your friend is desperate to resolve his Delia. Your friend tells you that the E string he is now using is made of copper and has a diameter of 0.063 inches. You do some quick calculations and, given the length of the neck of your friends guitar, estimate that the wave speed on the E string is 1900 ft/s. While reading about stringed instruments in the library, you discover that most musical instrument strings will break if they are subjected to a strain greater than about 2%. How do you suggest your friend solve his problem?

6. *Standing Waves:* Your friend, an artist, has been thinking about an interesting way to display a new wind sculpture she has just created. In order to create an aural as well as visual effect, she would like to use the wires needed to hang the sculpture as a sort of a string instrument. She decides that with three wires and some luck, the strings will sound a C-major dyad (C - 262Hz, G - 392 Hz) when the wind blows (note: A dyad is part of a chord.). Her basic design involves attaching a piece of wire from two eye-hooks on the ceiling that are approximately a foot-and-a-half apart and then hanging the 50 pound sculpture from another wire attached to the first wire forming a "y-shaped" arrangement. Your friend tells you that she has been successful in hanging the sculpture but not in "tuning" the sound. Desperate for success, she knows you are taking physics and asks for your help. Before you tackle the analysis, you use your knowledge of waves to gather some more information. You take a sample of the wire back to your lab and measure its linear mass density to be 5.0 g/m. You also determine that wire is some sort of iron or steel from its color. What is your advice?

7. *Standing Waves:* You have a summer job in a biomedical engineering laboratory studying the technology to enhance hearing. You have learned that the human ear canal is essentially an air filled tube approximately 2.7 cm long which is open on one end and closed on the other. You wonder if there is a connection between hearing sensitivity and standing waves so you calculate the lowest three frequencies of the standing waves that can exist in the ear canal. From your trusty Physics textbook, you find that the speed of sound in air is 343 m/s.

8. *Standing Waves:* You have joined a team designing a new skyway that is to link the Physics Building to the Mechanical Engineering Building. To make sure it will be stable in gusts of wind, you need to find the lowest frequency that sets up a standing wave in the skyway structure. Your group has decided to make a scale model of the skyway and put it into a wind tunnel to determine the frequency. Unfortunately the wind tunnel cannot be pulsed at a very low frequency. While the model is in the wind tunnel you pulse the wind until you find a frequency which sets up a standing wave in the model. You then slowly increase the frequency until you get the next standing wave

pattern. Using the two frequencies you have measured together with the length of the skyway model you then calculate the lowest frequency which will set up a standing wave.

9. *Energy, Frequency:* You have an exciting summer job working on an oil tanker in the waters of Alaska. Your Captain knows that the ship is near an underwater outcropping of land and wishes to avoid running into it. He estimates that it is about 6 km straight ahead of the ship and asks you to use the sonar to check how fast the ship is approaching it. The ship's instruments tell you the ship is moving through still water at a speed of 31 km/hr but the captain cannot take any chances. A sonar signal is sent out with a frequency of 980 Hz, bounces off the underwater obstacle, and is detected on the ship. If the ship's speed indicator is correct, what frequency should you detect? You use your trusty Physics text to find the speed of sound in seawater is 1522 m/s.

10. *Rotations:* You are helping a friend build an experiment to test behavior modification techniques on rats. She needs to build an obstacle that swings across a path every 1.0 second. To keep the experiment as inexpensive as possible, she wants to use a meter stick as the swinging obstacle. She asks you to determine where to drill a hole in the meter stick so that, when it is hung by a nail through that hole, it will do the job for small swings.

11. *Rotations:* Your friend is trying to construct a clock for a craft show and asks you for some advice. She has decided to construct the clock with a pendulum. The pendulum will be a very thin, very light wooden bar with a thin, but heavy, brass ring fastened to one end. The length of the rod is 80 cm and the diameter of the ring is 10 cm. She is planning to drill a hole in the bar to place the axis of rotation 15 cm from one end. She wants you to tell her the period of this pendulum.

12. *Rotations:* The child of a friend has asked you to help with a school project. She wants to build a clock from common materials. She has found a meter stick which has a mass of 300g and asks you to determine where to drill a hole in it so that when it is hung by a nail through that hole it will be a pendulum with a period of 2.0 seconds for small oscillations. A quick calculation tells you that the moment of inertia of the meter stick about its center of mass is 1/12 of its mass times the square of its length.

13. *Rotations:* You have a part time job at a software company that is currently under contract to produce a program simulating accidents in the modern commuter railroad station being planned for downtown. Your task is to determine the response of a safety system to prevent a railroad car from crashing into the station. In the simulation, a coupling fails causing a passenger car to break away from a train and roll into the station. Furthermore, the brakes on the passenger car have failed. It cannot stop on its own so it keeps on rolling. The safety system at the end of the track is a large horizontal spring with a hook that will grab onto the car when it hits preventing the car from crashing into the station platform. After the car hits the spring, your program must calculate the frequency and amplitude of the car's oscillation based on the specifications of the passenger car, the specifications of the spring, and the speed of the passenger car. In your simulation, the wheels of the car are disks with a significant mass and a moment of inertia half that of a ring of the same mass

and radius. At this stage of your simulation, you ignore any energy dissipation in the car's axle or in the flexing of the spring, and the mass of the spring.

14. *Rotations:* You have been asked to help design an automated system for applying a resistive paint to plastic sheeting in order to mass produce containers to protect sensitive electronic components from static electric charges. The object used to apply the paint is a solid cylindrical roller. The roller is pushed back and forth over the plastic sheeting by a horizontal spring attached to a yoke, which in turn is attached to an axle through the center of the roller. The other end of the spring is attached to a fixed post. To apply the paint evenly, the roller must roll without slipping over the surface of the plastic. The machine simultaneously paints two narrow strips of plastic that lay side by side parallel to the axle of the roller. While the roller is in contact with one strip, a feed mechanism pulls the other strip forward to expose unpainted surface. In order to determine how fast the process can proceed, you have been assigned to calculate how the oscillation frequency of the roller depends on its mass, radius and the stiffness of the spring. You know that the moment of inertia of a solid cylinder with respect to an axis through its center is 1/2 that of a ring.

Additional Problems: