Part I. *Answer each question with a brief statement, using a mathematical equation where appropriate.*

1. State Newton's three laws of motion.

2. Under what conditions is the total linear momentum of a system conserved?

3. Define a conservative force and state the law of conservation of mechanical energy.

4. State the law of universal gravitation.

5. State the first and second laws of thermodynamics.

6. A fireman of mass m slides at constant speed down a vertical pole. The coefficient of (kinetic) friction between his hands and the pole is μ. With what normal force is he squeezing the pole?

7. A railroad car is at rest on a level track, on which it can roll freely. A terrorist in the rear of the car fires his gun toward the front and the bullet embeds itself in the front wall. Describe the motion of the car while the bullet is in flight and after it is stopped.

8. To turn on a level road, a bicyclist must make the vehicle lean toward the center of the curve. Sketch the forces on the system (bicycle plus rider) and explain why.

9. Show that for a satellite in a circular orbit around the earth the kinetic energy is minus one-half of the gravitational potential energy. (Take potential energy to vanish at infinite distance from the earth.)

10. Write a function $f(x,t)$ describing a harmonic wave travelling in the x direction with amplitude 0.1 m, wavelength 0.5 m, and speed 500 m/s.

11. A traveling wave carries intensity I. If a second wave, identical to the first except that by itself it carries intensity $4I$, is added in the same medium, what are the maximum and minimum possible resulting intensities?

12. The water in a hose moves at speed 10 cm/s. It emerges from a nozzle opening with diameter 1/40 that of the hose. How fast will the water move as it leaves the nozzle?

13. It is easy to distinguish between the sounds of a flute and a violin when they are playing the same musical note (same fundamental frequency). What aspect of the sound is different?

14. One mole of an ideal gas starts at pressure P_0 and volume V_0. It expands to volume $2V_0$. Sketch the process on a P-V diagram, if the expansion is: (a) at constant pressure; (b) isothermal; (c) adiabatic. (Show all three on the same graph.)

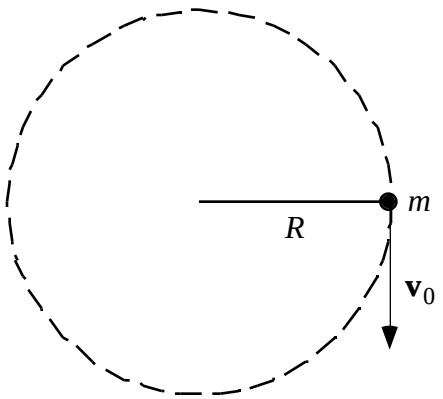
15. A certain object radiates heat at a rate of 5 W when its temperature is 500 K. At what rate will it radiate if the temperature is 1000 K?

Part II. *Work the problems in the space provided, indicating your method clearly.*

1. A small mass m is attached to a string of length R, fixed so that the mass can move in a vertical circle as shown. Initially the string is horizontal and the mass is propelled downward with speed v_0.

   (a) What is the minimum value of v_0 for the mass to describe the complete circle? [Hint: What is the minimum possible speed at the top of the circle?]

   (b) For that case, what is the tension in the string when the mass is at the bottom?

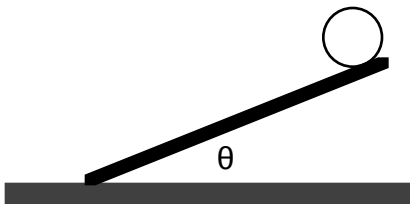


2. A hoop of radius R, mass m, and moment of inertia $I = mR^2$ is at rest at the top of a plank of length L inclined as shown at angle θ. The static friction coefficient is μ.

   (a) Find the maximum value of θ for which the hoop will roll without slipping down the plank.

   (b) For this angle, what will be the linear speed of the hoop's CM at the bottom?

   (c) If the hoop were replaced by one with radius $R/2$, how would your answers change?

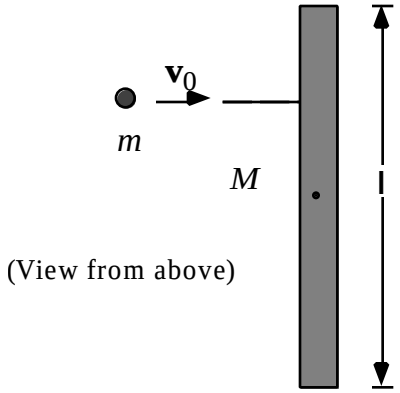


3. A small steel ball of mass m slides across a smooth horizontal surface and collides elastically with a steel rod of mass M and length l, pivoted at its center. The ball strikes the rod halfway between the pivot and one end, as shown. The collision brings the ball to rest. The moment of inertia of the rod about the pivot is $I = Ml^2/12$.

(a) What quantities are conserved in the collision?

(b) Find the angular speed ω of the rod after the collision.

(c) Find the ratio m/M.

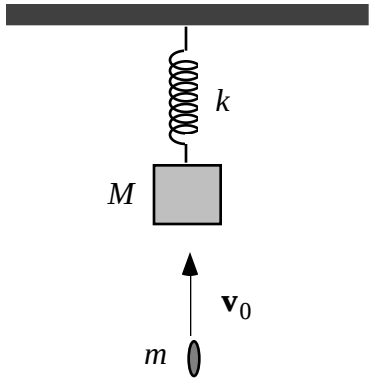


4. A block of mass M hangs at rest supported by a spring of stiffness k. A bullet of mass m travels upwards, striking the block with speed v_0 and embedding itself in the block. Assume the collision time is very small.

(a) What is the kinetic energy of the system (block plus bullet) just after the collision?

(b) What is the amplitude of the resulting oscillation?

(c) What is its frequency?



5. A rocket is sent vertically up from the earth's surface with just sufficient initial kinetic energy to escape to infinite distance.

   (a) What is that initial kinetic energy?

   (b) Suppose the same rocket had been launched with 1/4 enough kinetic energy to escape. How high would it rise (measured from the center of the earth)?

   [Express answers in terms of the rocket's mass m, the mass M and radius R of the earth, and G.]

6. One mole of an ideal monatomic gas ($c_V = 3R/2$) is used in a reversible engine, following the cycle shown and proceeding clockwise $A \to B \to C \to A$. Pressures are in units of 10^6 Pa, and volumes are in 10^{-3} m^3. The gas constant is $R = 8.3$.

   (a) Find the temperatures at the corners of the cycle.

   (b) For each step in the cycle, calculate the heat put in, the work output, and the change in internal energy.

   (c) What is the total heat taken in? What is the efficiency of an engine using this cycle?