**PHYSICS 101 SPRING 2000 HOMEWORK PROBLEMS**

**VERY IMPORTANT:** THE SOLUTIONS ASSUME $g = 10.0$ m/sec$^2$.

**Q1:** How many m/s equal 60 miles per hour?

**Q2:** What is your height in centimeters?

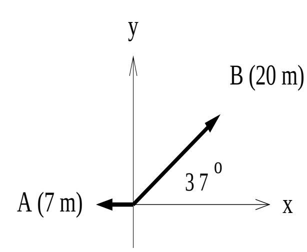
**Q3:** What is the displacement when a bicyclist travels from the East side of a circular race track of radius 500 meters to the West side? When she makes one complete circle around the track?

**Q4:** A certain atom vibrates ten million times a second. (This rate of vibration is unrealistically small: I'm trying to make this easy.) How many seconds is required for each vibration? Express the answer in scientific notation.

**P1:** Find the magnitude and direction of the vector represented by each of the following pairs of components:

a) $A_x = 3$ cm, $A_y = -4$ cm, b) $A_x = -5$ m, $A_y = -12$ m, c) $A_x = -2$ km, $A_y = 3$ km.

**P2:** Find the vector sum $\vec{A} + \vec{B}$ and the difference $\vec{A} - \vec{B}$ shown at right using a) components and b) graphically.




**P3:** A sailor sails 2 km East, then 4 km Southeast, and then an additional distance in an unknown direction. His final position is 3.5 km due East of his starting point. Find the magnitude and direction of the third leg of the voyage.

**P4:** When two vectors $\vec{A}$ and $\vec{B}$ are drawn from a common point, the angle between them is $\theta$. Show that the magnitude of their vector sum is given by

$$\sqrt{A^2 + B^2 + 2AB\cos\theta}\,. \tag{1}$$

Hint: Choose the $x$-axis to lie along $\vec{A}$.

**P5:** A "moving sidewalk" in an airport terminal building moves 1 m/s and is 150 m long. If a man steps on at one end and walks 2 m/s relative to the moving sidewalk, how long does it take him to reach the opposite end if he walks

a) in the same direction as the sidewalk is moving,

b) in the opposite direction.

**P6:** Two piers A and B are located one mile apart on the same side of a river. Two men make round trips starting from pier A, going to pier B and then returning to pier A. One man rows a boat at a speed 4 mi/hr relative to the water, and the other man walks on the shore at a speed of 4 mi/hr. The velocity of the river is 2 mi/hr in the direction from A to B. How long does it take each man to make the round trip?

**P7:** A postal employee drives a delivery truck 2 miles North, then 2 miles East, and then 5 miles $37^o$ South of West. After this, how far and in what direction relative to his starting point is he?

**P8:** A 1000 meter wide river flows due East with a speed of 2 m/s. A rower rows her boat across the river at a constant speed (relative to the water) of 3 m/s.

a) If the rowboat is aimed directly across the river (i. e. perpendicularly to the river banks) how far downstream relative to its starting point will the boat be when it reaches the opposite bank?

b) In what direction should the rowboat be aimed in order to reach a point on the opposite bank directly South from the starting pint?

c) What will be the velocity of the boat relative to the earth when it is aimed as in part b?

d) When aimed as in part b, how long does it take to cross the river.

**Q5:** Under what condition is the instantaneous velocity during a time interval equal to the average velocity over that time interval?

**Q6:** A car is traveling North. Can it have a velocity towards the North and at the same time have an acceleration towards the South? If so, explain how this can happen.

**Q7:** A ball is thrown straight up in the air. What is its acceleration at the instant it reaches its highest point?

**P9:** Starting from the initial time at $t = 0$, a body moves along a straight line, its distance, $x$, from the origin at any instant being given by the equation $x = 8t - 3t^2$, where $x$ is in cm and $t$ is in sec.

a) Find the average velocity of the body between $t = 0$ and $t = 1$ sec.

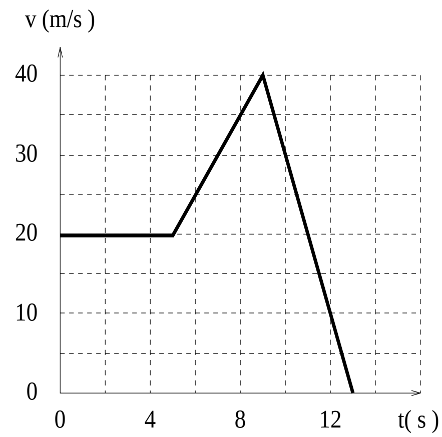
b) Find the average velocity of the body between $t = 0$ and $t = 4$ sec.

c) Give the body's instantaneous velocity at $t = 1$ sec.

d) What was the initial velocity of this object?

e) What is the acceleration of this object?

**P10:** The graph at right shows the velocity of a motorcyclist as a function of time.



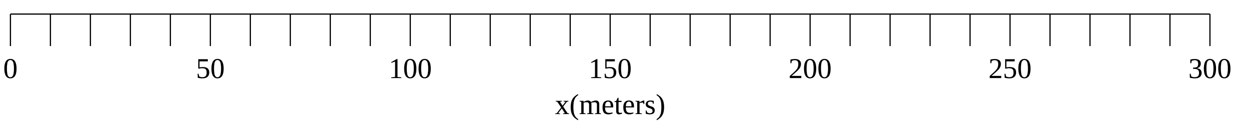

a) Find the instantaneous acceleration at $t = 3$ sec, at $t = 7$ sec, and at $t = 11$ sec.

b) How far does the motorcyclist go in the first 5 sec? In the first 9 sec? In the first 13 sec?

c) The area under the curve of $v$ versus $t$ between times $t_1$ and $t_2$ gives the displacement between times $t1$ and $t_2$. How much displacement does the area of one box in the graph at right correspond to?

d) Using the area principle stated in part c), count squares of area to find the displacement at $t = 5$ sec and the displacement at $t = 9$ sec.

e) On the axis given below, make a multiflash photograph (see Fig. 2-11 of the text) when images (which you represent by circular dots) are recorded every second.




**P11:** An airplane takes 20 sec to cover 400 m on the ground during a take off starting from rest. If the plane moves with constant acceleration, what was its speed when it became airborne?

**P12:** A leopard moving with constant acceleration covers the distance between two points 60 meters apart in 6 sec. Its speed as it passes the second point is 15 m/s.

a) What was the leopard's acceleration?

b) What was the leopard's speed as it passed the first point?

c) If the leopard started from rest, how long did it take to reach the first point.

**P13:** At the instant the traffic light turns green, an automobile that had been waiting at an intersection starts forward with a constant acceleration of 2 $m/s^2$. At the same instant a truck, traveling at a constant speed of 10 m/s passes the automobile at the traffic light.

a) How far beyond its starting point will the automobile overtake the truck?

b) When the automobile overtakes the truck, how fast will the automobile be traveling?

**P14:** The speed of an automobile going North is reduced from 30 m/s to 20 m/s over a distance of 125 meters. Find the magnitude and direction of the acceleration, assuming it to be constant.

**P15:** A hot-air balloonist, rising vertically with a speed of 10 m/s, releases a sandbag just when the balloon is 15 meters above the ground. (Remember: $g = 10$ $m/s^2$.)

a) Compute the position and velocity of the sandbag at the following times after its release: 1/2 sec, 1 sec, 2 sec, and 4 sec.

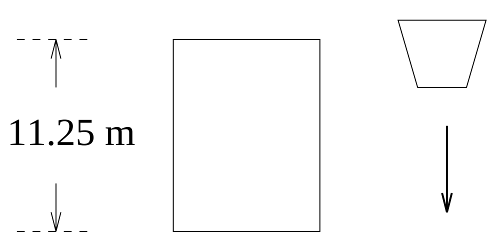
b) When, after its release, will the sandbag strike the ground?

c) With what velocity will the sandbag strike the ground?

d) A girl, standing underneath the balloon, throws a ball up into the air before the sandbag is released. It so happens that when the sandbag is released, the ball and the sandbag rise and fall exactly together. Obviously, this can only happen if the ball is thrown at exactly the right time before the sandbag is released, and also it must be thrown with exactly the right initial upward velocity. How long before the sandbag was released was the ball thrown?

**P16:** A stone is dropped from the top of a cliff and 1 sec later another one is thrown vertically downward with an initial speed of 20 m/s. How far below the top of the cliff will the second stone overtake the first?

**P17:** A flower pot falls off a window sill and falls past a large window below. It takes 0.5 sec to pass by the large window which is 11.25 meters in height.




a) How far is the top of the large window below the window sill? Use $g = 10$ $m/s^2$.

b) Calculate the instantaneous velocity of the pot as it passes the midpoint of the large window. Show that your answer is NOT the same as the average velocity, $\vec{v}$, during the time the pot passes by the large window.

**P18:** A ball is thrown vertically upward from a point near the cornice of a tall building. It just misses the cornice on the way down, and passes a point 160 ft below its starting point 5 sec after it leaves the thrower's hand. ($g = 32\text{ft/sec}^2$.)

a) What was the initial velocity of the ball?

b) How high did the ball rise above its starting point?

c) What were the magnitude and direction of its velocity at its highest point?

d) What were the magnitude and direction of its acceleration at its highest point?

e) What was the magnitude and direction of its velocity as it passed a point 64 ft below the cornice?

**Q8:** When one flies in an airplane at night in smooth air, there is no sensation of motion even though the plane may be moving 500 mi/hr. Why is this?

**Q9:** A sprinter accelerates from rest after the starter's gun is fired. What force causes this acceleration?

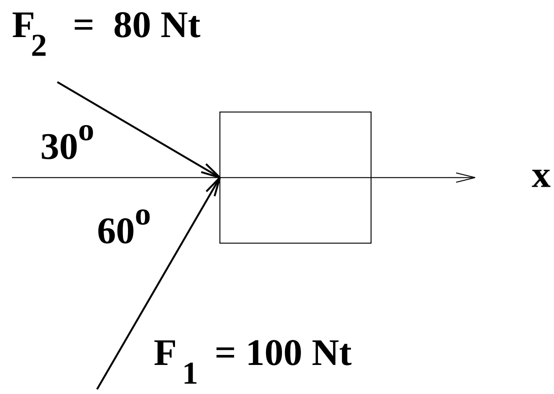
**Q10:** A horse is hitched to a wagon. Since the wagon pulls back on the horse just as hard as the horse pulls on the wagon, why doesn't the wagon remain in equilibrium, no matter how hard the horse pulls? Apply $F = ma$ assuming that no friction acts on the wagon wheels.

**Q11:** A car is driven up a steep hill at constant speed. Discuss all the forces acting on the car; in particular, what pushes it up the hill?

**Q12:** A block rests on an inclined plane with enough friction to prevent the block from sliding down. To start it moving, is it easier to push it up the plane, sideways, or down the plane? Explain.

**Q12.5:** In pushing a box up a ramp, is it better to push horizontally or to push parallel to the ramp?

**P19:** Two men and a boy want to push a crate in the direction marked $x$ in the diagram below. The two men push with forces $\vec{F}_1$ and $\vec{F}_2$, as shown in the diagram. Find the magnitude and direction of the smallest force the boy should exert.

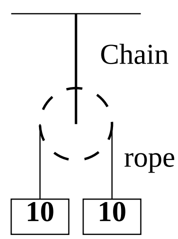



**P20:** A coin is given a push along a tabletop, and slides to the edge of the table and falls to the floor.

a) What forces act on the coin while it is falling from the tabletop to the floor?

b) Identify the reaction to each force which acts on the coin while it is falling. State on what body the reaction force acts and by what body the reaction force is exerted. Neglect air resistance.

**P21:** Two 10-Nt weights are suspended from opposite ends of a rope that passes over a light frictionless pulley. The pulley hangs from the end of a massless chain whose upper end is attached to the ceiling.



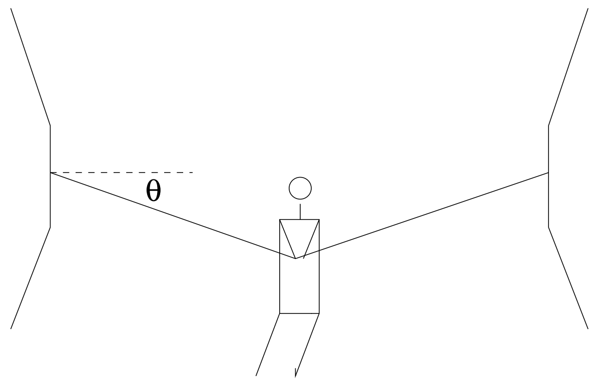

a) What is the tension in the rope?
b) What is the tension in the chain?

**P21.5** A shark is swimming under water at constant velocity 5 m/s, Eastward. Enumerate the forces acting on the shark, in particular stating by what body the force is exerted. Also give the reaction forces, putting each reaction force into the paradigm, a push or a pull exerted by _____ on _____.

**P22:** The mountaineering technique called a Tyrolean traverse is illustrated at right. A rope is stretched tightly between two points, and the climber slides across the rope. The climber is at the center and her weight is 800 N. The breaking strength of the rope is 20,000 N.

a) If the angle $\theta$ is 15°, find the tension in the rope.

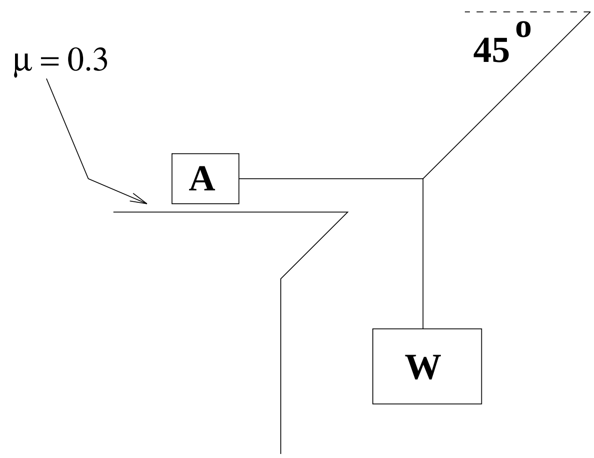
b) What is the smallest value the angle $\theta$ can have if the rope is not to break?




**P23:** In the diagram at right block A weighs 100 N. The coefficient of friction between the block and the surface underneath it is 0.3. The weight $W$ is 20 N and the system is in equilibrium.

a) Find the frictional force exerted on block A.

b) Find the maximum value of the weight $W$ for which the system will remain in equilibrium. For this maximum value of $W$ find the frictional force exerted on block A.

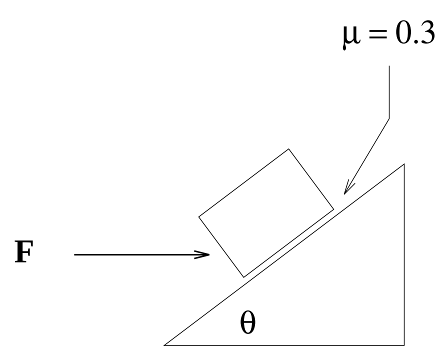



**P24:** A 200 Nt box of books on a $\theta = 37°$ ramp is being pushed by a horizontal force $\vec{F}$, as shown at right. The relevant coefficient of friction is 0.3.

a) Find the frictional force exerted by the ramp on the box if the box is stationary and $F = 160$ Nt. Repeat for $F = 120$ Nt.

b) What is the magnitude of $\vec{F}$ if the box moves up the ramp with constant speed?

c) What is the magnitude of $\vec{F}$ if the box moves down the ramp at constant speed?




**Q13:** When a heavy weight is lifted by a string that is barely strong enough, the weight can be lifted by a steady pull, but if the string is jerked it will break. Explain.

**Q14:** When a car accelerates, starting from rest, what is the force acting on the car which causes it to accelerate? By what body is this force applied?

**Q15:** When a car stops suddenly, the passengers are thrown forward, away from their seats. Explain this motion in terms of $F = ma$ as applied to a passenger.

**Q16:** If a man in an elevator drops his briefcase, but it does not fall to the floor, what can he conclude about the elevator's motion?

**Q17:** What is wrong with this argument: Since action and reaction are always equal in magnitude and opposite in direction, they always cancel each other. Thus the net force on any body is zero and and it does not accelerate.

**P25:** A constant horizontal force of 40 N acts on a body on a smooth horizontal plane. The body starts from rest and is observed to move 100 m in 5 s.

a) What is the mass of the body?

b) If the force is removed at $t = 5$ s, how far does the body move in the next 5 s?

**P26:** A .22 rifle bullet, traveling at 400 m/s, strikes a block of soft wood, which it penetrates to a depth of 0.1 m. The mass of the bullet is 2 g. Assume a constant retarding force.

a) How much time was required for the bullet to stop?

b) Give the force the block exerts on the bullet, both in newtons and in pounds.

**P27:** An elevator of mass 2000 kg rises with an upward acceleration of 1 m/s$^2$.

a) What is the tension in the supporting cable?

b) What would the tension in the supporting cable be if the elevator were descending and decelerating at a rate of 1 m/s$^2$?

**P28:** A body hangs from a spring balance supported from the roof of an elevator.

a) When the elevator has an upward acceleration of 2.5 m/s$^2$, the balance reads 50 N. What is the true weight of the body?

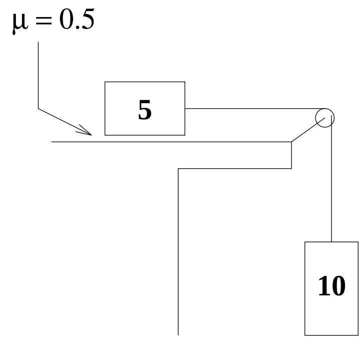
b) What is the acceleration of the elevator when the balance reads 30 N?

c) What will the balance read after the elevator cable breaks?

**P29:** A block of mass 5 kg on a horizontal surface is connected by a cord passing over a light frictionless pulley to a hanging block of mass 10 kg. The coefficient of friction between the block and the surface on which it can move is 0.5. If the hanging block is descending, find

a) the tension in the cord.

b) the acceleration of each block.




**P30:** A block of mass 5 kg is projected up a long 37° incline with an initial velocity of 20 m/s. The coefficient of friction between the block and the plane is 0.25.

a) Find the frictional force acting on the block as it moves up the plane.

b) How long does it take the block to reach its highest point?

c) What is the greatest distance up the plane that the block moves.

d) How long does it take the block to slide back down from its highest point to its starting point?

e) Find the velocity of the block as it passes its starting point on the way down.

f) If the mass of the block has been 2.5 kg rather than 5 kg, would the answers to the preceding parts be changed?

**P31:** A 20 kg block on a long horizontal frictionless table–top is attached by a cord passing over a light frictionless pulley to a hanging block originally at rest 0.1 meter above the floor. The hanging block strikes the floor 0.2 sec after the system is released from rest.

a) Determine the mass of the hanging block.

b) Find the tension in the string 0.1 sec after the system is released.

c) Find the tension in the string 0.3 sec after the system is released.

**P32:** The masses of blocks A and B in the diagram are 20 kg and 10 kg, respectively. They are initially at rest on the floor and are connected by a light inextensible string passing over a light frictionless pulley to which an upward force $\vec{F}$ is applied. (Hint: in this problem the tension in the string is the same on both sides of the pulley.)

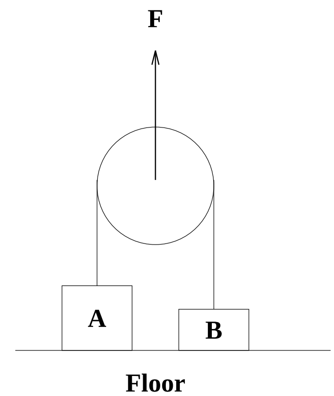
Find the accelerations of each block and the force the floor exerts on each body. when $F$ is

a) 80 N.

b) 120 N.

c) 240 N.

d) 480 N.

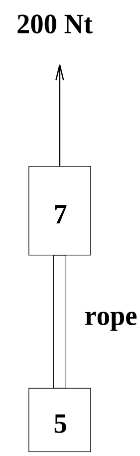



**P33:** The two blocks shown in the diagram are connected by a heavy uniform rope of mass 4 kg. An upward force of 200 N is applied to the upper mass as shown.

a) What is the acceleration of the system?

b) What is the tension in the top of the heavy rope?

c) What is the tension at the midpoint of the rope?




**P34:** A small body of mass $m = 2$ kg falls from rest into a viscous fluid (like water). The fluid exerts a viscous retarding force (or if you want, you can call it friction) on the body proportional to its speed and in newtons this force is equal to $5v$, where $v$ is the speed of the body in m/s. Only gravity and the viscous force act on the body.

a) Find the initial acceleration, $a_0$, of the body.

b) Find the acceleration of body when it is falling with speed 3 m/s.

c) Find the speed of the body when its acceleration is $0.1a_0$.

d) Find the terminal velocity, $v_t$.

e) Sketch (qualitatively) the velocity versus time.

**Q18:** An airplane in level flight drops a bomb. If air resistance is neglected, how does the motion of the bomb look to the pilot? To an observer on the ground?

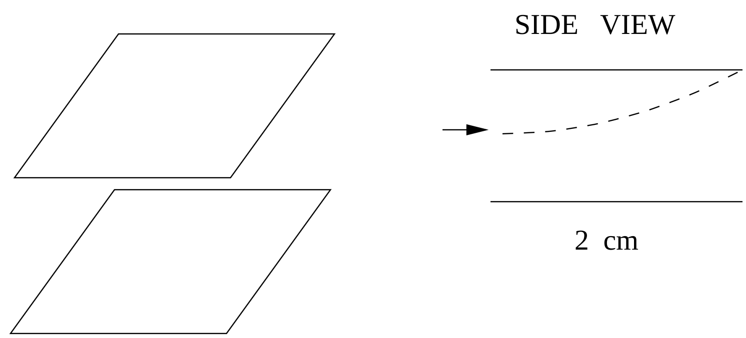
**Q19:** In uniform circular motion, what is the AVERAGE velocity over one revolution? The AVERAGE acceleration over one revolution? In what direction is the INSTANTANEOUS velocity? In what direction is the INSTANTANEOUS acceleration? What happens to the acceleration if the period is halved when the radius is held constant?

**P35:** A block sliding toward the edge of a horizontal tabletop has a speed of 4 m/s at a point 4 m from the edge. It slides off the edge of the table, which is 1.25 meter high, and strikes the floor 1 meter beyond a point directly below the edge of the table.

a) Determine the velocity vector of the block just after it left the tabletop.

b) Determine the coefficient of friction between the block and the tabletop.

**P35.2** An electron is fired with an initial horizontal velocity between two horizontal plates, one 2 cm directly above the other, and each is in the form of a square 2 cm on a side. The electron enters the region between the plates at a height midway between the plates. In the region between the plates the electron is subject to a uniform force upward (due to the electrical charges on the plate). After travelling a horizontal distance of 2 cm, the electron hits the upper plate. How far above the lower plate was the electron when it had travelled a horizontal distance of 1 cm?




**P35.5:** A canon ball is fired from the edge of a cliff of height $h$ with an initial velocity of 25 m/s in a direction 53° above the horizontal onto a horizontal plane. Neglect air resistance and take $g = 10\text{m/s}^2$.

a) To what maximum height above the firing point will the ball reach?

b) When the ball returns to the same height it had initially, what will its velocity vector be?

c) How long will it take the ball to reach its highest point?

d) If the ball hits the plane 5 seconds after being fired, what is the height $h$ of the cliff?

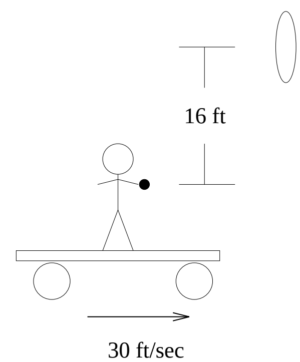
e) It what angle is canon ball moving just before it hits the ground? At what speed is it then moving?

f) Make a sketch which shows how the trajectory of the ball fired at an angle of 53° compares with that when the ball is fired at the same speed but at an angle of 37°.

**P36:** A boy kicks football at an angle of 53° (above the horizontal) at an initial speed of 40 ft/s towards a girl who is initially 80 ft from the boy. Just when the ball is kicked the girl runs to catch the ball. How fast and in which direction must she run in order to catch the ball (at the same height from which it was kicked)? Use $g = 32$ ft/s$^2$.

**P37:** A baseball leaves the bat at a height of 4 ft above the ground, initially traveling at an angle of $45^o$ above the horizontal and with an initial speed such that its horizontal range (the distance it would travel when it returns to its original height of 4 ft) would be 400 ft. At a distance of 360 ft from the batter is a fence 30 ft high. Will the ball go over this fence?

**P38:** A girl is riding on a flatcar traveling with a constant speed of 30 ft/s, as shown below. She wishes to throw the a ball through a stationary hoop in such a manner that the ball will move horizontally as it passes through the hoop. She throws the ball with an initial speed of 40 ft/s with respect to herself. ($g = 32$ ft/sec$^2$.)




a) What must the vertical component of the initial velocity of the ball be?

b) How many seconds after the ball is thrown will it pass through the hoop?

c) At what horizontal distance in front of the hoop must the ball be thrown?

d) At what angle does she aim her throw?

e) According to an observer on the ground, at what angle does the ball move just after it leaves the girl's hand.

**P38.5:** The moon moves in around the earth in an orbit which is approximately a circle of radius $3.8 \times 10^8$ meters in a time of 27.3 days. Calculate the acceleration of the moon. If I told you that the earth's acceleration of gravity was inversely proportional to the square of the distance from the CENTER of the earth, would that explain the moon's acceleration? (This is the beautiful calculation that Isaac Newton first did.)

**P39:** A highway curve of radius 500 m is to be banked so that a car traveling 25 m/s will have no tendency to skid sideways. At what angle should the curve be banked?

**P40:** A 20 gr coin placed on a record whose diameter is 30 cm will revolve with the record without slipping when it is brought up to a speed of $33\frac{1}{3}$ rev/min, provided the coin is not more than 10 cm from the axis.

a) What is the coefficient of static friction between the coin and the record.

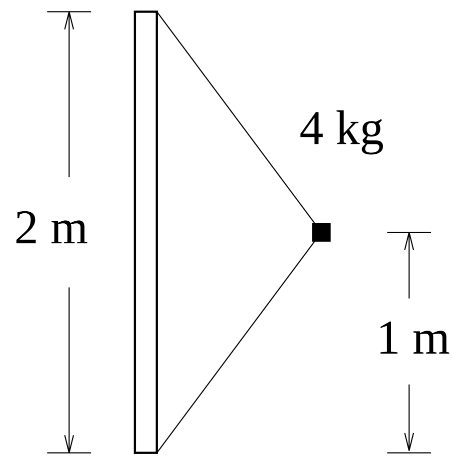
b) Find the magnitude of the frictional force exerted by the coin on the record if the coin is placed 5 cm from the axis and the record revolves at $33\frac{1}{3}$ rev/min. In what direction is this frictional force?

c) When the record revolves at 45 rev/min, what is the maximum distance from the axis that the coin can be placed so that it will not slip? In this case give the direction of the force exerted BY the coin ON the record.

**P41:** The 4–kg block shown in the diagram below is attached to a vertical rod by means of two strings, each 1.25 m long. When the system rotates about the axis of the rod, the strings are extended as shown in the diagram.

a) How many revolutions per minute must the system make in order that the tension in the upper cord shall be 60 N?

b) What is then the tension in the lower cord?




**P42:** The radius of a Ferris wheel is 5 m and it makes one revolution in 10 s.

a) Find the difference between the apparent weight of a passenger at the highest and lowest points, expressed as a fraction of his weight. (The apparent weight is what a bathroom scale would register under the actual conditions.)

b) What would the time of one revolution be if his apparent weight at the highest point were zero?

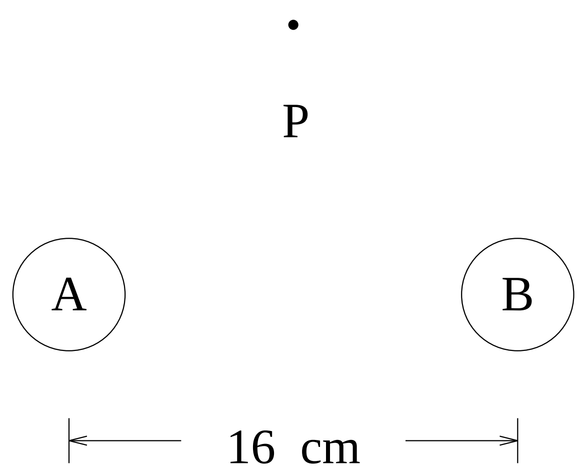
c) Under the conditions of part b) what would then be his apparent weight at the lowest point?

**Q20:** One can make precision measurements of the position, velocity, and acceleration of a man-made satellite in a circular orbit around the earth. For the purposes of this problem assume that all forces on the satellite from bodies other than the earth are completely negligible. From the measured data can one determine a) the mass of the satellite? b) the mass of the earth?

**P43:** Two spheres, each of mass 6.4 kg, are fixed at points A and B in outer space, as shown in the diagram below.

a) Find the magnitude and direction of the initial acceleration of a small sphere of mass 0.010 kg, if this sphere is released from rest at point P, which is 6 cm above the midpoint of AB. Neglect all forces on the small sphere other than the gravitational forces exerted by the two other spheres.

b) After release the small will NOT move with constant acceleration. Explain this statement?



**P44:** The mass of the moon is about one eighty-first and its radius one fourth, that of the earth.

a) What is the acceleration due to gravity on the surface of the moon.

b) If a high jumper can jump over a barrier of height 6 ft on earth, how high a barrier can he jump over on the moon? (Assume he has no problems in an oxygen-free environment.)

**Q21:** Two projectile are launched with the same initial kinetic energy, but at different angles with respect to the horizontal. Does the Conservation of Energy tell us that both projectiles will rise to the same maximum height?

**Q22:** An automobile jack is used to lift a heavy weight. In this process the operator exerts a force which is much smaller in magnitude than the weight being lifted. Does this mean that the operator does less work than if he had directly lifted the weight?

**P45:** A piano mover rolls a 200-kg piano at constant speed up a ramp 2 meters long at an angle of 30° with the horizontal. Assume that he pushes in a direction parallel to the plane of the ramp. (Because the piano rolls, you may neglect friction.)

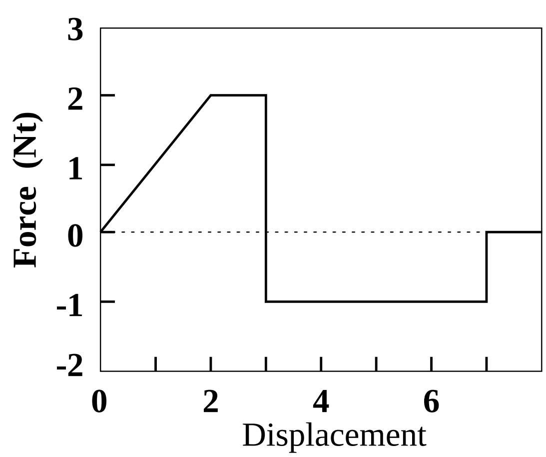
a) What force does the piano mover apply to the piano.

b) Calculate the work, $W$, the piano mover does. Use $W = Fs\cos\theta$.

c) By direct calculation verify the conservation of energy: $\mathrm{KE}_f + \mathrm{PE}_f = \mathrm{KE}_i + \mathrm{PE}_i + W_{\text{other}}$, where $W_{\text{other}}$ is the work done on the object by forces whose work is not already included in the potential energy.

**P46:** Compute the kinetic energy of a 2 gram rifle bullet traveling at 500 m/s.

**P47:** A 20 kg body, initially at rest at $x = 0$, moves horizontally to the right along the $x$-axis under the action of a force $\vec{F}$ parallel to the $x$-axis whose value (counting to the right as positive) is given in the graph at right.




a) In which range of $x$ is the work done by $F$ positive? Is the body speeding up or slowing down in this range? Explain.

b) In which range of $x$ is the work done by $F$ negative? Is the body speeding up or slowing down in this range? Explain.

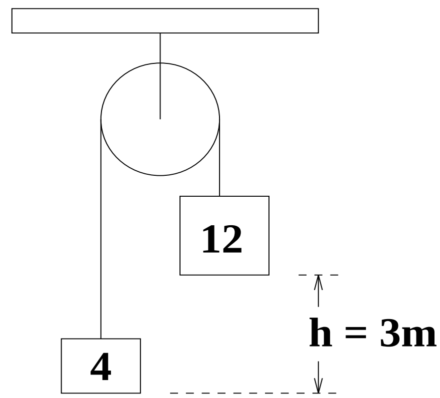
c) How much work does $\vec{F}$ do in the first 3 m of the motion?

d) Give the difference between the kinetic energy when the body is at $x = 7$m and the kinetic energy when the body is at $x = 3$m. Give the final velocity of the body.

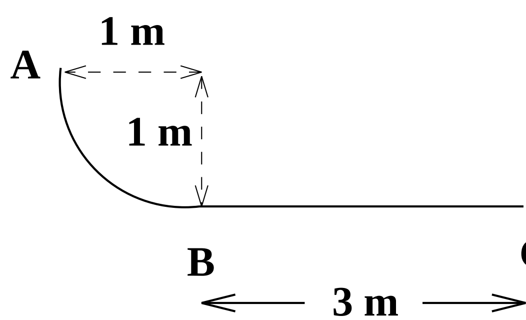
**P48:** Two blocks connected by a massless inextensible string are initially held in the positions shown at the right before being released from rest. Use the conservation of energy to find the speed $v_f$ at which the 12 kg block strikes the floor. The pulley is massless and frictionless. Using $F = ma$ we previously found

$$a = g\frac{(M-m)}{(M+m)} ,$$

where $M$ $(m)$ is the larger (smaller) mass. Obtain this result using the answer for $v_f$ you got using the conservation of energy.



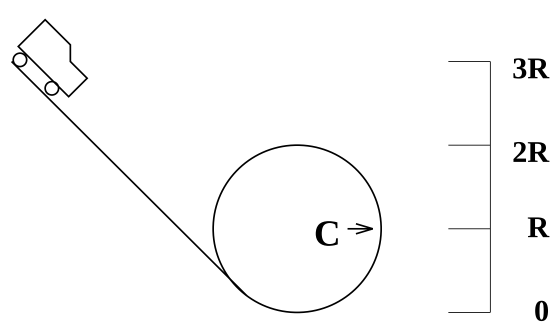

**P49:** In a truck–loading station at a post office, a 2 kg package is released from rest at point A on a track that is one quadrant of a circle of radius 1 meter, as shown below. It slides down the track and reaches point B with a speed of 4 m/s. From point B it slides on a level surface a distance of 3 m to point C where it comes to rest.




a) What is the coefficient of sliding friction, $\mu$, on the horizontal surface. Assume $\mu$ is constant over the entire distance between points B and C.

b) How much work was done by friction while the body slid down the circular arc from A to B?

**P50:** A car in an amusement-park ride rolls without friction around the loop-the-loop shown below. (Treat the car as a point mass moving in a circle of radius $R$.) It starts from rest at point A at a height $h = 3R$ ($R = 6$m) above the ground. When it reaches point C, at the the end of a horizontal diameter of the loop,




a) find the radial acceleration experienced by the passengers;

b) find their tangential acceleration; and

c) find their result acceleration vector.

Show these accelerations in a diagram, approximately to scale.

**P51:** In problem **P50**, suppose point A is at a height $h_A$ above the bottom of the loop. What is the minimum value of $h_A$ (in terms of $R$) so that the car moves around the loop without falling inward off the loop at the top?

**P51.5a:** A pendulum consists of a small ball of mass 2 kg suspended from a light inextensible string of length 9 m. Originally the ball is at rest at its lowest point. It is then hit by a hammer and given an initial speed of 6 m/s. (Use $g = 10\text{m/s}^2$.)
a) What is the largest angle the string makes with the vertical?
b) What is the tension in the string when it returns to its lowest point?
c) After hundreds of oscillations, the ball comes back to rest. What happened to its original kinetic energy?

**Q23:** Suppose you catch a baseball, and then someone invites you to catch a bullet with the either a) the same momentum or b) the same kinetic energy. Which option would you choose?

**Q24:** A machine gun is fired at a steel plate. Is the average force on the plate from the impact of the bullets greater if a) they bounce off or b) they are squashed and stick to the plate?

**P52:** a) What is the momentum of a 10,000 kg truck whose velocity is 20 m/s?

What velocity must a 5,000 kg truck attain in order to have

b) the same momentum?

c) the same kinetic energy?

**P53:** A bullet emerges from the muzzle of a gun with a speed of 300 m/s. The force on the bullet while it is inside the gun barrel is given by

$$F = 400 - (4/3) \times 10^5 t\ , \tag{2}$$

where $F$ is the force in newtons and $t$ the time in seconds, and $t = 0$ is the time the trigger is pulled.

a) Construct a graph of $F$ versus $t$.

b) Compute the time required for the bullet to travel the length of the barrel, assuming the force becomes zero just at the end of the barrel.

c) Find the impulse associated with this force over the time the bullet traversed the barrel.

d) Determine the mass of the bullet.

**P54:** A tennis ball approaches a player's racket horizontally at 10 m/s. After it is stuck, its velocity is 20 m/s horizontally in the opposite direction. The ball has mass 0.060 kg, and is in contact with the racket for 0.01 s. What is the average force exerted by the racket on the ball?

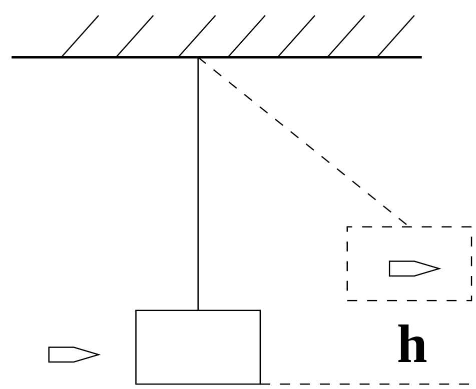
**P55:** An empty freight car of mass 10,000 kg rolls at 3 m/s along a level track and collides with a loaded car whose mass (including its contents) is 20,000 kg. The loaded car is initially standing at rest with its brakes released.

a) If the cars couple together, find their speed after the collision.

b) Calculate the amount of kinetic energy dissipated in the collision.

c) With what speed should the loaded car be rolling toward the empty car, in order that both shall be brought to rest by the collision?

**P56:** When a bullet of mass $m = 20$ grams strikes a small wooden block of mass $M = 10$ kg initially hanging at rest at the end of a string of length $L = 2$ meters, the center of gravity of the block is observed to rise through a vertical distance of $h = 5$ cm. The bullet remains embedded in the block.




a) Calculate the original speed of the bullet.
b) What fraction of the original kinetic energy of the bullet remains as kinetic energy of the system just after the collision?

c) What fraction of the original momentum remains as momentum of the system just after the collision.

d) True or false: All the original kinetic energy of the bullet is converted into the potential energy of the pendulum (with the bullet embedded in it).

**P57:** A bullet of mass 5 grams passes horizontally THROUGH a small 1 kg wood block suspended from a string 2 meters long. The center of gravity of the block is observed to rise through a height of 5 cm. Find the speed of the bullet as it emerges from the block if its initial speed is 300 m/s.

**P58:** On a frictionless table a 3 kg block moving 4 m/s to the right collides with an 8 kg block moving 1.5 m/s to the left.

a) If the two blocks stick together, what is their common final velocity?

b) If the two blocks make a completely elastic head-on collision, what are their final velocities?

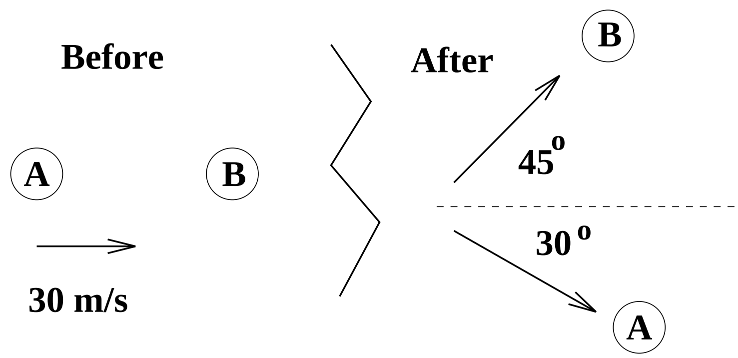
c) How much mechanical energy is dissipated in the collision of part a)?

**P59:** A stone whose mass is 100 grams rests on a horizontal frictionless surface. A bullet of mass 2.5 grams, traveling horizontally at 400 m/s, strikes the stone and rebounds horizontally at right angles to its original direction with a speed of 300 m/s.

a) Compute the magnitude and direction of the velocity of the stone just after it was struck.

b) Is the collision perfectly elastic?

**P60:** A hockey puck B rests on a smooth ice surface and is struck by a second puck A of equal mass. Puck A was originally traveling at 30 m/s and was deflected through an angle of 30 ° from its original direction, as shown at right. After the collision puck B acquires a velocity at 45° with respect to the original velocity of puck A, as shown.




Compute the speed of each puck just after the collision.

**P61:** A railroad handcar is moving along a straight frictionless track. In each of the following cases the car initially has a total mass (car and contents) of 200 kg and is traveling with a speed of 4 m/s. Find the final speed of the car in each of the three following cases.

a) A 20 kg mass is thrown sideways out of the car with a velocity of 2 m/s relative to the car.

b) A 20 kg mass is thrown backwards out of the car with a velocity of 6 m/s with respect to the car's initial velocity.

c) A 20 kg mass is thrown into the car with a velocity of 6 m/s relative to the ground and opposite in direction to the velocity of the car.

**P62:** A machine gun is firing 120 shots per minute. The mass of each bullet is 10 grams, the muzzle velocity is 800 m/s.

a) Find the average recoil force on the machine gun.

b) Consider the reaction force which by Newton's Third Law is equal and opposite to the recoil force exerted on the gun. What object does this reaction force cause to accelerate?

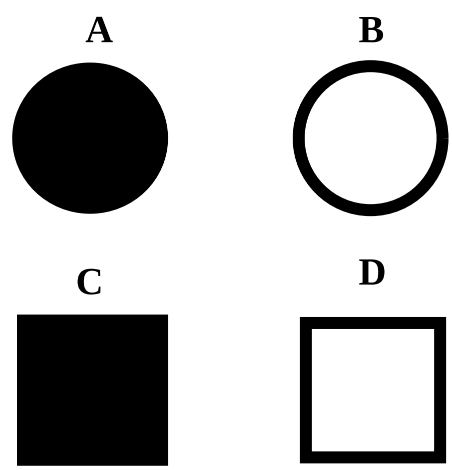
**Q25:** A flywheel rotates with constant angular velocity $\omega$. What are the mks units of $\omega$? Does a point on its rim have a tangential acceleration? A radial acceleration? Are these accelerations constant in magnitude? Are they constant in direction?

**Q26:** In order to maximize the moment of inertia of a flywheel whose weight is fixed, what shape should it have?

**P63:** A circular saw 0.6 meters in diameter starts from rest and accelerates with constant angular acceleration to an angular velocity of 100 radians/second in 20 seconds. Find the angular acceleration and the angle through which the saw has turned in this 20 second interval.

**P64:** An electric motor is turned off, and its angular velocity decreases uniformly from 1000 rev/min to 400 rev/min in 5 sec. Find a) the angular acceleration, b) the number of revolutions made by the motor in the 5 sec interval, and c) the additional time required for the motor to come to rest?

**P65:** The four bodies shown at right all have the same mass $m$. Body A is a solid cylinder of radius $R$. Body B is a hollow cylinder whose outer radius is $R$ and whose inner radius is slightly smaller than $R$. Body C is a solid square having sides of length $2R$. Body D is a hollow square whose outside length is $2R$ and whose inside length is slightly smaller than $2R$. In this problem we discuss the moments of inertia of these bodies when rotated about an axis passing through their center and which is perpendicular to the page. In all cases the bodies consist of a uniform distribution of mass.




a) Which body has the smallest moment of inertia?

b) Which body has the largest moment of inertia?

c) Do the answers to the above parts a) and b) depend on what you assume about the value of the thickness $h$ of the objects perpendicular to the page?

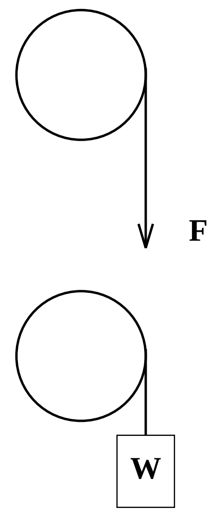
**P66:** A disc, initially at rest on a frictionless axle, has a mass of 300 kg and a moment of inertia of 500 kg-m$^2$. Then a constant torque of 2000 N-m is applied to the disc.

a) What is the angular acceleration of the flywheel?

b) What will the angular velocity of the flywheel after it has turned through 4 revolutions?

c) How much work is done by the motor during the first 4 revolutions?

**P67:** A cord is wrapped around the rim of a flywheel 0.5 meters in radius, and a steady pull of 40 newtons is exerted on the cord, as shown at right. The wheel is mounted on frictionless bearings on a horizontal shaft through its center. The moment of inertia of the wheel is 4 kg-m$^2$.



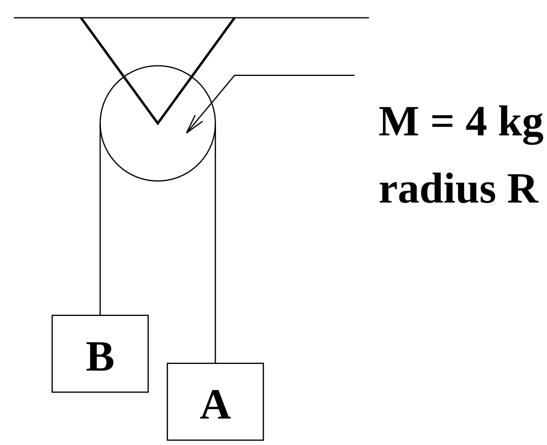

a) What is the angular acceleration of the wheel?

b) Show that the work done in unwinding 5 meters of cord equals the gain in kinetic energy of the wheel up to that point.

c) If a mass having a weight $W = 40$ Nt hangs from the cord, as shown on the right, compute the angular acceleration of the wheel.

d) Why is the answer to part c) not the same as in part a?

**P68:** Previously we considered an Atwood's machine with a massless pulley rotating on a frictionless axle. Now we consider the case where the pulley is not massless. The mass of the pulley is 4 kg and you may treat it as a uniform disc of radius $R$.




A massless rope passes around this pulley. Block A of mass $M_A = 4$ kg is suspended from the right-hand side of the pulley and block B of mass $M_B = 2$ kg is suspended from the left–hand side of the pulley. Assume that there is no slipping between the rope and the surface of the pulley.

a) Calculate the acceleration of the masses when they are free to move.

b) Determine the tension in the rope just above each block.

c) Why are these two tensions NOT the same?

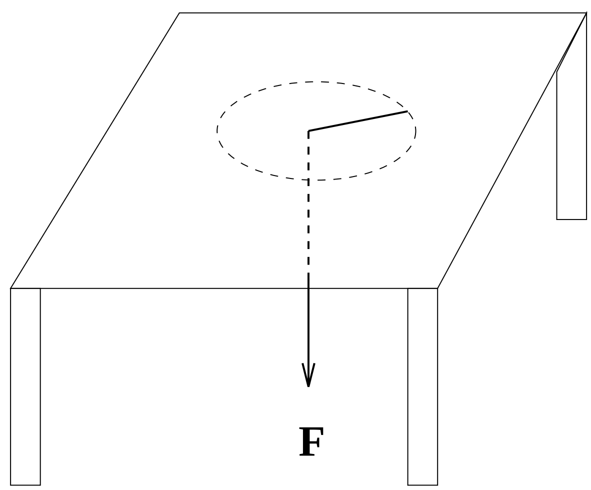
**P69:** A man sits on an old–fashioned rotating piano stool holding a pair of dumbbells at a distance of 0.5 meters from the axis of rotation of the stool. He is given an angular velocity of 4 rad/sec, after which he pulls the dumbbells in until they are only 0.2 meters from the axis. The moment of inertia of the man about the axis of rotation is 8 kg–m$^2$ and may be considered to be independent of how he holds his arms. Neglect the mass of that part of the piano stool which is rotating. Each dumbbell has a mass of 4 kg and may be considered to be a point mass. Neglect friction.

a) What is the initial angular momentum of the system, consisting of the dumbbells, the man, and that part of the piano stool which is rotating?

b) What is the angular velocity of the system after the dumbbells are pulled in toward the axis?

c) Compute the kinetic energy of the system before and after the dumbbells are pulled in. Account for the difference, if any.

**P70:** A block on a frictionless table top has a mass of 0.05 kg and is attached to a cord passing through a hole in the surface, as shown below. The block is originally moving in a circle of radius 0.2 meters about the hole with an angular velocity of 3 rad/sec. The cord is then pulled from below, shortening the radius of the circle in which the block is moving to 0.1 meters. The block may be considered to be a point mass. Neglect any possible friction between the cord and the sides of the hole.




a) What is the final angular velocity at the radius of 0.1 meters?

b) Find the change in the kinetic energy of the puck.

c) Use the force required to hold the string to estimate the work done (via Work $= Fs\cos\theta$) in pulling down the cord and show that this estimate is approximately the same as the answer to part b. (To calculate the work done using the force exactly requires the use of calculus.)

**P71:** A turntable of radius 5 meters rotates about a fixed frictionless vertical axis, making one revolution in 10 sec. The moment of inertia of the turntable about this axis is 1200 kg-m$^2$. A man of mass 80 kg, initially standing at the center of the turntable, walks out along a radius painted on the surface of the turntable. What is the angular velocity of the turntable when the man is 2 meters from its center?

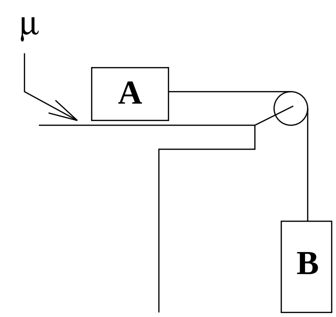
**P72:** A man of mass 100 kg stands at the rim of a turntable of radius 2 meters and moment of inertia 4000 kg-m$^2$, mounted on a frictionless vertical shaft at its center. The whole system is initially at rest. The man now walks along the outer edge of the turntable with a velocity of 1 meter/sec relative to the earth.

a) With what angular velocity and in what direction does the turntable rotate?

b) Through what angle will it have rotated when the man first returns to his initial position on the turntable?

c) Through what angle will it have rotated when the man returns to his initial position relative to the earth?

**P73:** Consider the system shown at right. Block A has mass $m_A$ and block B has mass $m_B$. The pulley has a radius $R$ and a moment of inertia, $I$. The rope does not slip over the pulley. The relevant coefficient of friction between the block A and the tabletop is $\mu$. The system is released from rest and block B falls.




a) Find the speed of block as a function of the distance $d$ through which it falls using the conservation of energy.

b) Using your answer to part a) deduce the acceleration with which it falls.

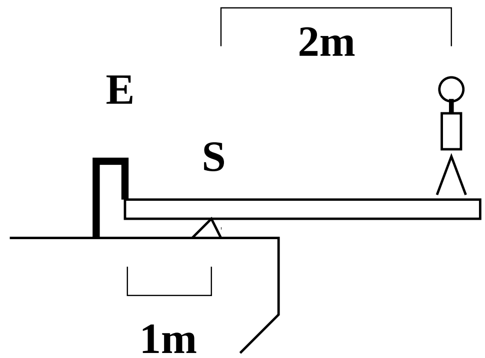
c) Rederive the acceleration with which the mass falls using Newton's Laws of translational and rotational motion.

**P74:** A thin wooden bar of length 0.2 meters and mass 2.5 kg is suspended from the ceiling in such a way that it can oscillate back and forth like a pendulum without friction. Initially the bar is hanging vertically at rest just before a 5 gr bullet traveling horizontally at 300 m/s strikes and is embedded in the bar at the midpoint of the bar. Through what angle does the bar rise after this collision?

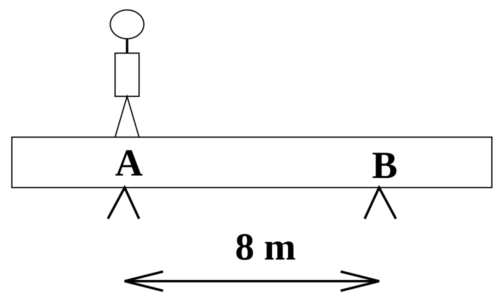
**Q27:** Manuals for car–engine repair always specify the torque to be applied when tightening the cylinder-head bolts. Why is the torque specified, rather than the force to be applied to the wrench handle?

**Q28:** Why is it easier to hold a 10 kg body in your hand at your side than to hold it with your arm extended horizontally? Does it matter if you hold your arm not horizontally, but vertically?

**P75:** A diving board 3 meters long is supported at a point 1 meter from the end, and a diver weighing 800 newtons stands at the free end, as shown below. Find the forces which act on the board i) at the support point and ii) at the end that is held down, if the weight of the board is negligible.



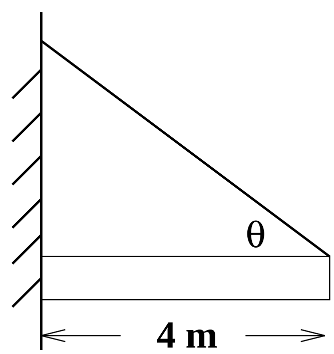

**P76:** A uniform plank, 15 meters long, weighing 400 newtons, rests symmetrically on two supports 8 meters apart, as shown below. A boy weighing 640 newtons starts at point A and walks toward the right. How far beyond point B can the boy walk before the plank tips?



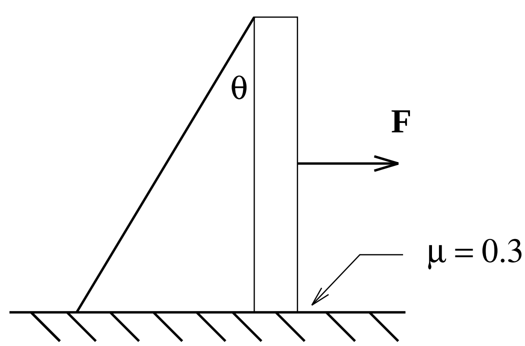

**P77:** The uniform 4 meter long beam shown at right weighs 200 newtons. It is attached to the wall by a hinge and held by a 5 meter long light cable. Find

a) The tension in the cable.

b) The horizontal and vertical components of the force exerted on the beam by the hinge.



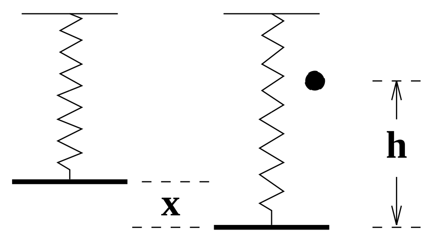

**P78:** One end of a post weighing 500 newtons rests on a rough horizontal surface with respect to which the relevant coefficient of friction is $\mu = 0.3$. The upper end is held by a rope fastened to the surface and making an angle $\theta = 37^o$ with the post, as shown at right. A horizontal force, $\vec{F}$ is exerted on the post as shown. If the force $\vec{F}$ is applied at the midpoint of the post, what is the largest value it can have without causing the post to slip?



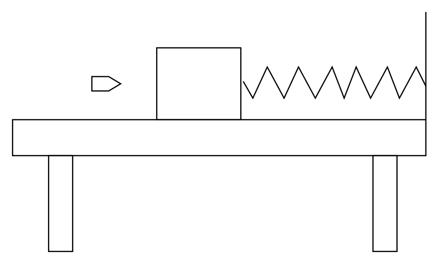
**Q29:** Does a tuning fork undergo simple harmonic motion? Why is this a crucial question to musicians?

**Q30:** A pendulum is mounted in an elevator that accelerates upward with constant acceleration. Does the period, $T$, of the pendulum increase, decrease, or remain the same? Hint: a proper answer to this question may be based on the formula $T = 2\pi\sqrt{L/g}$, where $L$ is the length of the pendulum, providing you know what to use for $g$.

**P79:** The pan of a spring balance has a mass of 200 grams. When suspended from the coil spring shown in the diagram at right, it is found that the spring is $x = 10$ cm longer than when the pan is not attached. A lump of putty of mass 200 grams is dropped from rest onto the pan from a height, $h$, of 30 cm. Find the maximum distance the pan moves downward in its subsequent motion.




**P80:** A rifle bullet of mass 0.01 kg strikes and embeds itself in a block of mass 0.99 kg which rests on a horizontal frictionless surface and is attached to a wall via a coil spring, as shown at right. After this collision the maximum compression of the spring is 10 cm. In a separate experiment it is found that a force of 1.0 Nt will compress the spring 1 cm.



a) Find the maximum potential energy stored in the spring after the collision.

b) Find the velocity of the block just after the impact.

c) What was the initial velocity of the bullet?

d) Find the initial kinetic energy of the bullet.

e) Why are answers a) and d) different?

**P81:** A body is vibrating in simple harmonic motion of amplitude 15 cm at a frequency of 4 Hz. Compute

a) the maximum magnitudes of the acceleration and velocity,

b) the acceleration and velocity when the displacement from equilibrium is 9 cm,

c) the time required to move from the equilibrium position to a point 12 cm away from the equilibrium point.

**P82:** A body of mass 10 grams moves in simple harmonic motion with an amplitude of 24 cm and a period of 4 sec. The displacement from equilibrium is +24 cm at time $t = 0$. Compute

a) the position of the body when $t = 0.5$ sec.

b) the magnitude and direction of the force acting on the body when $t = 0.5$ sec.

c) the minimum time required for the body to move from its initial position to the point where $x = -12$ cm.

d) the velocity of the body when $x = -12$ cm for the first time.

**P83:** A small block is executing simple harmonic motion in a horizontal plane with an amplitude of 10 cm. At $t = 0$ the block is at a point 6 cm away from the equilibrium point, E, and is moving with velocity 24 cm/s towards E.

a) What is the period?

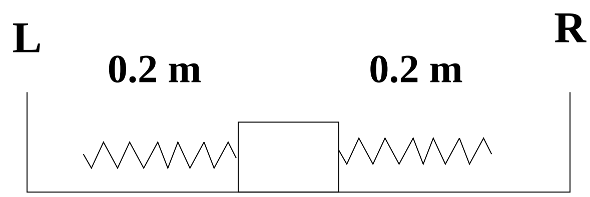
b) What can you say about the displacement if the speed of the block is known to be 12 cm/sec?

c) When does the block first reach point E.

d) A small coin is placed atop the oscillating block. How large must the coefficient of friction, $\mu$, be if the coin is not to slip off the block.

**P84:** A body of mass 5 kg hangs from a vertical spring and oscillates with a period of 0.5 sec. How much will the spring shorten when the body is removed?

**P85:** Two springs, each of unstretched length 0.2 meters, but having different force constants, $k_\ell$ and $k_r$, are attached to opposite ends of a block of mass $m$ on a level frictionless surface, as shown below. The outer ends of the springs are now attached to two pins, L and R, each of which is 10 cm from the end of a spring when it is unstretched. Take $k_\ell = 1$ Nt/m, $k_r = 3$ Nt/m, and $m = 0.1$ kg.




a) Find the length of each spring when the block is in its new equilibrium position after the springs have been attached to the pins.

b) Find the period of vibration of the block if it is slightly displaced from its new equilibrium position and then released. Hint: you have to find how the force on the block depends on its displacement from its new equilibrium.

**P86:** A block of mass 0.1 kg is oscillating on a frictionless horizontal surface with an amplitude of 5 cm at the end of a spring whose force constant is 4 Nt/m. At the instant the block passes through its equilibrium position, a lump of putty of mass 0.1 kg is dropped onto the block from a height of 10 cm and sticks to the block.

a) Find the new period and amplitude in the motion after the putty is dropped on the block.

b) Was there a loss of mechanical energy (i. e. PE + KE)? If so, what happened to this energy?

c) Would the answers to part a) be the same if the putty had been dropped on the block when it was at one end of its orbit?

**P87:** The balance wheel of a watch vibrates with an angular amplitude, $\theta_0 = \pi$ rads and with a period of 0.5 sec.

a) Find its maximum angular velocity, $\Delta\theta/\Delta t$.

b) Find its angular velocity when its angular displacement is $\frac{1}{2}\theta_0$.

c) Find its angular acceleration, $\alpha$, when its angular displacement is 45°.

**Q31:** Why are very narrow heels (found on some women's shoes) more likely to make dents in a soft wood floor than wider heels, even though both heels might be supporting the same weight?

**Q32:** If you drive a car into a lake 10 meters deep, do you have a better chance of escaping from the car if you try to open a door, or if you open a window and crawl out? Why?

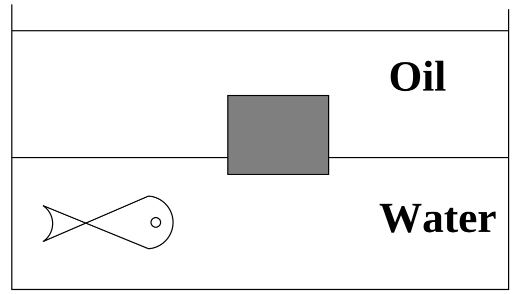
**P88:** A diving bell is to be designed to withstand the pressure of water at a depth of 2000 ft.

a) If sea water weighs 64 lb per cubic foot, what is the pressure at this depth?

b) What force must the window frame exert to hold a circular glass window 6 inches in diameter in place at a depth of 2000 ft?

**P89:** A slab of ice floats on a fresh-water lake. What is the minimum volume the slab must have so that an 80-kg man can stand on it without getting his feet wet?

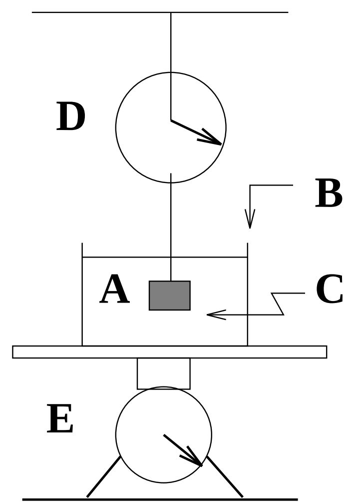
**P90:** A cubical block of wood 10cm on a side floats at the interace between oil and water as shown below. Between depths 0 and 15 cm the liquid is oil and between depths 15 cm and 30 cm the liquid is water. The lower surface of the wood is 2cm below the interface. The density of the oil is $0.6 \text{gr/cm}^3$.




a) What is the mass of the block?

b) What is the gauge pressure at the bottom of the block?

**P91:** Block A in the diagram below hangs by a cord from spring balance D and is submerged in liquid C contained in beaker B. The mass of the beaker is 1 kg and the mass of the liquid is 1.5 kg. Balance D reads 2.5 kg and scale E reads 7.5 kg. The volume of block A is $0.003 \text{ m}^3$.



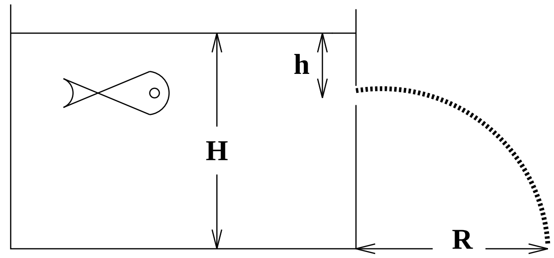

a) What is the mass density, $\rho$, of the liquid?

b) What will each balance read if the support from which the spring is suspended is raised so that block A is no longer in the liquid?

**Q33:** You are driving a car South on an expressway which has three Southbound lanes. There is a huge traffic jam and you are moving at 20 mph because up ahead there is a construction zone (CZ) where only two Southbound lanes are open. When you get to the CZ, do you expect to go slower or faster? Explain.

**P92:** Estimate the maximum rate (in cars per hour) that cars can pass through a two–lane (in each direction) tunnel through a mountain. Is is necessary to make some assumption about how long a typical tunnel is, in order to answer this question?

**P93:** Water stands at a depth $H$ in a large open tank, as shown below. A small hole is made in one of the walls at a depth $h$ below the water surface.




a) At what distance $R$ from the foot of the wall does the emerging stream of water strike the floor?

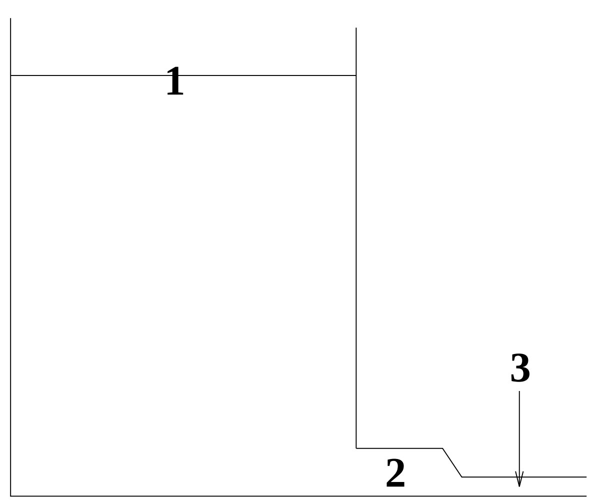
b) At what height above the bottom of the tank could a second hole be drilled so that the stream emerging from it would hit the floor in the same place?

**P94:** A cylindrical vessel, open at the top, is 20 cm high and 10 cm in diameter. A circular hole whose cross–sectional area is 1 $cm^2$ is cut in the center of the bottom of the vessel. Water flows into the vessel from a tube above it at the rate of 140 $cm^3$/sec. How high will the water in the vessel rise when steady state is established?

**P95:** A pipeline 0.2 meters in diameter, flowing full of water, has a constriction where its diameter is 0.1 meters. If the water flows with a speed of 2 m/s in the unconstricted part of the pipe find (a) the speed of flow in the constricted part of the pipe, and (b) the volume rate of discharge in cubic meters per second.

**P96:** At point, $P_1$, in a pipeline carrying water the speed of flow is 10 m/s and the gauge pressure is $3 \times 10^5$ Pa. Find the gauge pressure at a second point in the line which is at a height 20 meters lower than the first point. The cross-sectional area at the second point is one half the cross-sectional area at the first point.

**P97:** Water flows steadily from a reservoir, as shown at right. The elevation of point #1 is 10 m, that of points #2 and #3 is 1 m. The cross-sectional area of the pipe at point #2 is $0.04 m^2$ and at point #3 is $0.02 m^2$. The area of the reservoir is $400 m^2$. a) Compute the gauge pressure at point #2.

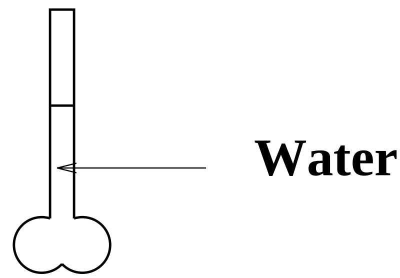



b) Compute the discharge rate in $m^3$/sec.

c) Suppose the exit pipe is closed and the water level is at point #1. What is the pressure at points #2 and #3. Compare to part a.

**Q34:** A student claimed claimed that thermometers are useless because a thermometer always registers ITS OWN temperature. How would you respond?

**Q35:** Could a thermometer similar to that shown at right be made using water as the liquid? What unsatisfactory feature would such a thermometer possess, besides not being good for $T < 0°$C.




**P98:** A glass flask whose volume is exactly 1000 cm$^3$ at 0C is filled full of mercury at that temperature. When the flask and the mercury in it are heated to 100C, 15.2 cm$^3$ of mercury overflows. If the coefficient of volume expansion of mercury is $1.82 \times 10^{-4}/°$C, compute the linear expansion coefficient of the glass.

**P99:** A steel ring whose inside diameter at 20°C is 3.000 cm is to be heated and slipped over a brass shaft whose diameter at 20°C is 3.002 cm.

a) To what temperature should the ring be heated. (Assume that the temperature of the brass shaft is held fixed at 20°C.)

b) Now the shaft and the ring on it are both cooled (by some means such as liquid air). At what temperature will the ring just slip off the shaft?

**P100:** Steel railroad rails 60 ft long are laid on a winter day when the temperature is 20°F. How much space must be left between the rails if they are to just touch on a summer day when the temperature is 110°F?

**Q36:** A student claimed that when two bodies not initially in thermal equilibrium are placed in contact, the temperature rise of the cooler body must always equal the temperature drop of the warmer. Do you agree? Is there a principle of conservation of temperature, or something like that?

**Q37:** Why do you think the heat of vaporization for water is so much larger than its heat of fusion?

**P101:** In a physics lab experiment, a student immersed 100 copper pennies (each of mass 3 grams) in boiling water. After they reached thermal equilibrium, they were dropped into 0.2 kg of water at 20°C. Assuming no heat was transferred to the surroundings, what was the final temperature of the water.

**P102:** A piece of ice at 0°C falls from rest into a lake at 0°C and one half of one percent of the ice melts. Compute the minimum height from which the ice must have fallen. (Why is it important in asking this question that the word "minimum" should be included?)

**P103:** A thermos bottle of negligibly small mass contains 500 gr of water at a temperature of 80°C. How many grams of ice at temperature −20°C must be dropped into the water so that the final temperature of the system will be 50°C?

**P104:** The nominal food-energy value of butter is about 6 kcal/gr, where 1 kcal = 4186 joules. If all this energy could be converted completely into mechanical energy, how much butter would be required to enable a mountaineer to climb a mountain 2000 meters high? In reality will it require more or less butter than our calculation predicts?

**Q38:** A cold block of metal feels colder than a block of wood at the same temperature. Is there any temperature at which they feel equally hot or cold.

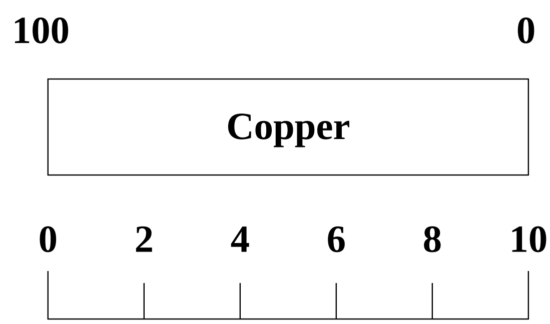
**P105:** A slab of a thermal insulator is 100 cm$^2$ in cross section and 2 cm thick. Its thermal conductivity is 0.1 J/(m-sec °C). If the temperature difference between opposite faces is 100°C, how much heat flows through this slab in one day?

**P106:** Suppose that the rod shown is made of copper and has length 10 cm and cross-sectional area 1 cm$^2$. The left–hand temperature is $T_2 =$ 100°C and the right–hand temperature is $T_1 =$ 0°C.

a) What is the final steady-state temperature gradient along the rod?

b) What is the steady-state heat current in the rod?

c) What is the final steady-state temperature at a point in the rod 2cm from its left end?




**P107:** A long rod of uniform cross–sectional area of 5 cm$^2$ and which is insulated to prevent heat losses from its side, consists of a section of length 100 cm made of copper and a section of length $L_2$ made of steel. The copper end is in contact with boiling water and the steel end is in contact with a mixture of ice and water, everything being at atmospheric pressure. In steady–state conditions the temperature of the copper–steel junction is found to be 60°C.

a) How much heat per second flows from the steam bath into the ice-water mixture?

b) What is the value of $L_2$?

c) Sketch a graph of temperature ($T$) versus position ($x$) in the rod.

**P108:** The emissivity of tungsten is approximately 0.35. A tungsten sphere 1 cm in radius is suspended within a large evacuated enclosure whose walls are at 300°K. What power input to the sphere is required to maintain its temperature at 3000°K, if heat conduction along its supports are neglected?

**P109:** A small blackened solid copper sphere of radius 2 cm is placed in an evacuated enclosure whose walls are kept at 100°C. At what rate must energy be supplied to the sphere to keep its temperature constant at 127°C?

**Q39:** Comment on this statement: "Equal masses of two different gases, placed in containers of equal volume at equal temperatures, must exert equal pressures."

**P110:** A helium storage tank has a capacity of 0.05 $m^3$. If the gas pressure is 100 atm at 27°C, determine

a) the number of moles of helium in the tank

b) the mass of helium in the tank.

**P111:** A hot-air balloon makes use of the fact that hot air at atmospheric pressure is less dense than cooler air at the same pressure; the buoyant force is the difference between the weight of the hot air inside the balloon and that of an equal volume of the cooler surrounding air. If the volume of the balloon is 500 $m^3$ and the surrounding air is at 0°C, what must be the temperature of the air in the balloon in order for it to lift a total mass of 200 kg?

**Q40:** Which has more atoms, a kilogram of hydrogen or a kilogram of lead? Which has more mass?

**Q41:** Chlorine is a mixture of two isotopes, one having atomic mass 35 gr/mole, the other 37 gr/mole. Molecules of chlorine consist of two atoms. Arrange in order of decreasing average speed: molecules having two of the heavier isotopes, two of the lighter isotopes, or one each of the two isotopes.

**Q42:** Comment on this statement: "When two gases are mixed, if they are to be in thermal equilibrium, they must have the same average molecular speed."

**P112:** Consider an ideal gas at 0°C and at 1 atm pressure. Imagine each molecule to be at the center of a small cube.

a) What is the length of an edge of this small cube?

b) How does this distance compare the the diameter of a molecule?

**P113:** A mole of liquid water occupies a volume of 18 $cm^3$. Imagine each molecule to be at the center of a small cube.

a) What is the length of an edge of this small cube?

b) How does this distance compare the the diameter of a molecule?

**P114:** At what temperature is the rms speed of oxygen molecules equal to the rms speed of hydrogen molecules at 0°C?

**P115:**

a) What is the average translational kinetic energy of a molecule of oxygen at a temperature of 300°K?

b) What is the average value of the square of its speed at 300°K?

c) What is its rms speed at 300°K?

d) What is the momentum of an oxygen molecule traveling at the speed of part c)?

e) Suppose a molecule traveling at the speed of part c) bounces back and forth between opposite walls of a cubical vessel 10cm on a side. What is the time averaged force this molecule exerts on the walls of the container? (Assume that the molecule's velocity is perpendicular to the two sides that it strikes.)

f) What is the average force per unit area exerted by the molecule of part e) on one wall?

g) How many such molecules, traveling at the speed of part e), are necessary to produce an average pressure of 1 atmosphere?

h) Compare the answer to part g) with the number of oxygen molecules actually contained in a vessel of the size given at 300K and at atmospheric pressure.

i) Your answer in part g) should be three times smaller than the actual number requested in part h). Explain this discrepancy.

**P116:** It can be shown that a projectile of mass $m$ can "escape" from the earth's gravitational field if it is launched vertically upward with a kinetic energy greater than $mgR$, where $g$ is the acceleration of gravity at the earth's surface and $R$ is the radius of the earth.

a) At what temperature would an average oxygen molecule have this much energy? An average hydrogen molecule?

b) Can you explain on this basis why the earth's atmosphere contains very little hydrogen.

**NOTE FOR THE FOLOWING PROBLEMS:**
**the speed of propagation of light in vacuo is $3 \times 10^8$ m/s.**

**Q43:** A two–slit interference experiment is set up, and the fringes are displayed on a screen. Then the whole apparatus is submerged in water. How does the fringe pattern change? (Note that there is no change in the frequency of the light emitted by the laser used to illuminate the two slits. However, the speed of propagation of light in water is somewhat less than it is in vacuo.)

**Q44:** Would the headlights of a distant car form a two-source interference pattern? Explain your answer.

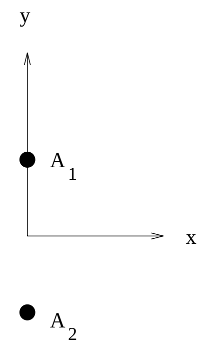
**Q45:** Light from a mercury arc appears to be white but is actually a mixture of only a few discrete wavelengths. The most important wavelengths in nm ( $1\text{nm} = 10^{-9}$ m) present are 578 (yellow), 546 (green), 436 (blue-violet), and 405 (violet). Suppose this light is used in a two slit diffraction experiment. How would the result compare to the same experiment when only one wavelength is present?

**Q46:** A student claimed that it is impossible to observe interference fringes in a two-source experiment if the distance between sources is less than helf the wavelength of the light being used. Do you agree? Explain.

**Q47:** Following up on the previous question: Do you think it is sensible to try to study crystals (in which the separation between atoms if of order a few Angstroms) by observing the diffraction lines of visible light?

**Q48:** Does a microscope have better resolution with red light or with blue light?

**P117:** An FM radio station broadcasts at a frequency of 100 MHz using two identical antennae, $A_1$ and $A_2$, mounted 12 meters apart, as shown at right. The resulting radiation pattern has maximum intensity along the $x$-axis. This problem concerns the signal an observer would receive at distances several kilometers from the radio station.




a) At what other angles measured from the $x$-axis is the observed intensity a maximum.

b) At what angles is the observed intensity zero?

**P118:** Light from a mercury arc is passed through a filter that only allows light of one wavelength to be transmitted. This emergent monochromatic light illuminates two slits separated by 0.600 mm. The resulting interference pattern is observed on a screen 2.50 m away from the slits. Both the slits and the screen are positioned as usual, e. g. in a plane perpendicular to the initial axis of propagation of light. The separation between adjacent bright fringes on the screen is found to be 2.27 mm.

a) Determine the wavelength of the light in the interference pattern. What color is this?

b) If the wavelength of light used is increased, the separation between fringes will (increase/decrease). Choose one.

c) If the distance between the two slits is increased, the separation between fringes will (increase/decrease). Choose one.

**P119:** Monochromatic light of wavelength 589 nm passes through a single slit of width 1 mm and the result is viewed on a screen 2 m behind the slit. Both the slit and the screen lie in a plane perpendicular to the initial direction of the light beam. How wide is the central fringe of light on the screen? To answer this question calculate the distance between the places on the screen on either side of the central maximum where the intensity of light first falls to zero.

**P120:** Monochromatic light of wavelength 600 nm illuminates (at normal incidence) a diffraction grating consisting of 500 lines per mm. The diffraction grating has 5000 lines.

a) Calculate ALL angles relative to the initial axis of propagation at which the grating transmits light.

b) Using the discussion in class estimate the width in angle of the light beam transmitted in the forward (undiffracted) beam of transmitted light.