torque
moment of inertia
parallel axis theorem
radius of gyration
electric charge
electric force
nucleus
atomic model
nucleons, protons,
neutrons
electronic charge
quarks
conservation of charge
magnetic force
electromagnetic forces
strong, weak forces
Coulomb's law

REVIEW QUESTIONS

Q5-1 Motion in a circular path with a constant speed is ______.
Q5-2 When an object moves along a circular path with a constant speed, it has an acceleration directed toward the ______.
Q5-3 An object undergoing uniform circular motion must have a net force on it directed toward ______.
Q5-4 Skids occur when the maximum frictional force of a flat road on a car is less than ______.
Q5-5 If an object moving along a circular path has its speed changing, it has a ______ equal to the rate of change of the speed.
Q5-6 A complete circle is ______ radians.
Q5-7 The angular velocity is the rate of change of the ______, and points along the ______.
Q5-8 The angular acceleration is the rate of change of the ______.
Q5-9 The angular acceleration of a rigid body about a fixed axis is proportional to the ______.
Q5-10 The moment of inertia of a point mass depends on its mass and on the ______.
Q5-11 For a given object, the moment of inertia depends on the location of the ______.
Q5-12 Atoms and molecules are held together by ______.
Q5-13 Nuclei are held together by ______.
Q5-14 Like charges ______, unlike charges ______.
Q5-15 A nucleus is made up of two types of ______, ______ and ______.
Q5-16 A nucleus is about ______ times smaller than an atom.
Q5-17 Nucleons are thought to be made up of ______.
Q5-18 The four fundamental forces are the ______.
Q5-19 The electric force between two charges is inversely proportional to the ______.

EXERCISES

Section 5.1 | Centripetal Acceleration

5-1 If the speed with which a car rounds a curve is doubled, by what factor does its centripetal acceleration change?
5-2 Cars moving at 100 km h^{-1} require a 0.5 m s^{-2} acceleration to go around a curve. (a) What is the radius of the curve? (b) How long will it take a car to go around the curve if the road direction changes from due north to due east?
5-3 A woman runs on a circular track of radius 100 m at a speed of 8 m s^{-1}. What is her acceleration?
5-4 A boy rides a bicycle at 10 m s^{-1} on a flat curve of radius 200 m. (a) What is his acceleration? (b) If the boy and the bike have a total mass of 70 kg, how large a force is needed to provide this acceleration?
5-5 A racing car rounds a turn at 60 m s^{-1}. If the force needed to provide the centripetal acceleration is equal to the weight of the car, what is the radius of the turn?
5-6 A man sits without a seat belt in a car. He tends to slide to the left as the car makes a right turn. Is there a force pushing the man to the left? Explain.
5-7 The speeds of centrifuges are limited in part by the strength of the materials used in their construction. A centrifuge spins a 10 g = 10^{-2} kg sample at a radius of 0.05 m at 60,000 revolutions per minute. (a) What force must the centrifuge exert on the sample? (b) What is the mass of a sample at rest with a weight equal to this force?
5-8 A child sits 4 m from the center of a merry-go-round, which turns completely each 10 s. What is the child's acceleration?
5-9 A jet fighter plane flying at 500 m s^{-1} pulls out of a dive on a circular path. What is the radius of the path if the pilot is subjected to an upward acceleration of $5g$?
5-10 The radius of the earth's orbit about the sun is 1.5×10^8 km, and its period is 365 days. what is the centripetal acceleration of the earth?
5-11 A trained pilot can pull out of a dive on a circular path with an upward acceleration of $5.5g$

at the bottom of the path. An untrained pilot can perform the same maneuver at the same speed but only with an acceleration of $3g$. What is the ratio of the minimum radii of the paths in which the two pilots can fly?

5-12 A centrifuge used for testing human tolerance to acceleration has a gondola at a distance of 16 m from the vertical axis of rotation. What speed is required to produce a horizontal acceleration of $11g$?

5-13 A car is traveling around a flat curve of radius 0.25 km. The coefficient of static friction between the tires and the road is 0.4. At what speed will the car begin to skid?

5-14 A woman of mass 60 kg runs around a flat, circular track of radius 200 m at 6 m s^{-1}. (a) What is her acceleration? (b) What force produces this acceleration? (c) How large is this force?

5-15 Show that v^2/r has the dimensions of an acceleration.

Section 5.2 | Examples of Circular Motion

5-16 At what angle should the track of Exercise 5-14 be banked so that there is no frictional force required?

5-17 A racing car travels around a curve of radius 1000 m. If the frictional force is zero and the speed is 50 m s^{-1}, at what angle is the curve banked?

5-18 A curved track has a radius of 336 m and is banked at 35°. At what speed is the frictional force zero?

5-19 Why might it be unsafe to drive on steeply banked curves at low speeds under very slippery conditions?

5-20 A swallow flies in a horizontal arc of radius 15 m at 18 m s^{-1}. (a) What is its acceleration? (b) What is the banking angle?

5-21 A curve is banked so that no friction is required at 60 km h^{-1}. If a car is moving at 40 km h^{-1} on the curve, in which direction is a frictional force exerted by the road?

5-22 An airplane climbs and then turns downward in a circular arc of radius R. If its speed is 400 m s^{-1}, at what radius will the pilot experience weightlessness at the top of the arc?

5-23 An ultracentrifuge spins samples so that their effective weight is 10^5 times their normal weight. If the sample is at a radius of 0.05 m, how many revolutions per minute does the machine make?

5-24 A bird of weight w flies at 15 m s^{-1} in a horizontal circle of radius 15 m. What is the bird's effective weight?

5-25 A Ferris wheel of radius 16 m rotates in a vertical circle uniformly once every 20 s. (a) What is the centripetal acceleration? (b) What is the effective weight of a 45-kg rider at the highest point of the ride? (c) What is the rider's effective weight at the lowest point of the ride?

Section 5.3 | Angular Variables

5-26 Convert to radians (a) 1°; (b) 53°; (c) 120°.

5-27 Convert to degrees (a) 0.1 rad; (b) $\pi/4$ rad; (c) 4π rad.

5-28 A point on a bicycle wheel moves a distance s = 1 m. If this point is 0.4 m from the wheel axis, through what angle has the wheel rotated in (a) radians; (b) degrees?

5-29 The following angles are given in radians. Find the corresponding angles in degrees, and sketch these angular coordinates on circles as in Fig. 5.13. (a) $\theta = \pi/3$ rad; (b) $\theta = 3\pi/4$ rad; (c) $\theta = 9\pi/4$ rad.

5-30 Figure 5.26 shows a right triangle with two of the angles given. (a) Find these two angles in radians. (b) The sum of the internal angles of any triangle is 180°; find the third angle in Fig. 5.26 in radians.

5-31 Figure 5.27 shows a sphere rotating about a vertical axis. What is the direction of the angular velocity in (a); in (b)?

5-32 If the sphere in Fig. 5.27a rotates at a constant rate, what is the direction and magnitude of ω if the angular displacement is (a) π rad in 0.4 s; (b) 270° in 0.6 s?

5-33 A bicycle rider moves past us from left to right. If her speed is 5 m s^{-1}, (a) what is the direc-

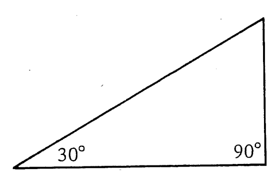

Figure 5.26. Exercise 5-30.

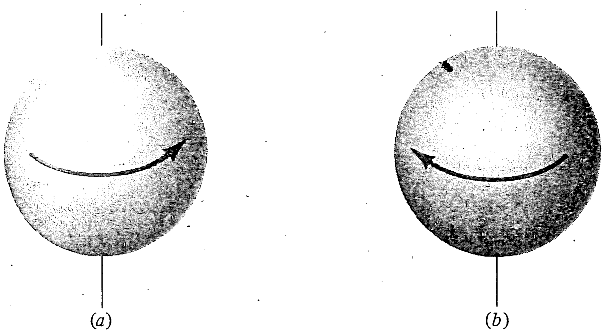

Figure 5.27. The colored arrows indicate the direction of rotation of the sphere about a vertical axis. Exercises 5-31 and 5-32.

tion and magnitude of the angular velocity of one of the wheels, which is 0.4 m in radius? (b) The rider is increasing her speed as she passes, and her acceleration is 1 m s^{-2}. What is the angular acceleration of a wheel?

5-34 (a) Find the radial acceleration at the edge of a phonograph record of radius 0.15 m rotating at 78 rev min^{-1}. (b) The record comes to a stop with a uniform angular acceleration in 2 s. Find the tangential acceleration at the edge and the angular acceleration.

5-35 An ultracentrifuge produces a radial acceleration of 300,000 times the acceleration of gravity at a distance of 0.05 m from the rotation axis. What is the angular velocity in radians per second and revolutions per minute?

5-36 A Ferris wheel at an amusement park rotates in a vertical circle once every 20 s. Its radius is 10 m. (a) What is its angular velocity in radians per second? (b) What is the radial acceleration of a passenger?

5-37 Pulsars are astronomical objects that rotate as fast as once every 0.03 s. Using the data in Table 3.2, determine whether they are (a) ordinary stars like our sun; (b) white dwarf stars; (c) neutron stars.

5-38 Assume a wheel has an initial angular velocity of $\omega_0 = 10$ rad s^{-1}. The angular acceleration is 2.5 rad s^{-2} directed opposite to $\boldsymbol{\omega}_0$. (a) How long does it take for the wheel to stop turning? (b) Through what angle has the wheel turned in this time?

5-39 A car accelerates uniformly from rest to 20 m s^{-1} in 15 s. The wheels have a radius of 0.3 m. (a) What is the final angular velocity of the wheels? (b) What is the angular acceleration of the wheels? (c) What is their angular displacement during the 15-s interval?

5-40 The flywheel of an automobile engine is turning at 700 revolutions per minute. The accelerator is depressed, and in 6 s the speed is 3500 rev min^{-1}. (a) Find the initial and final angular velocities in rad s^{-1}. (b) Find the average angular acceleration. (c) Assuming constant angular acceleration, find the angular displacement during the 6-s acceleration period. (d) Find the tangential acceleration of a point on the flywheel of the engine that is 0.2 m from the axis.

Section 5.4 | Torque, Angular Motion, and the Moment of Inertia

5-41 A bicycle wheel has a mass of 2 kg and a radius of 0.35 m. What is its moment of inertia?

5-42 Two wheels of mass m each have a radius R. Wheel A is a uniform disk, while wheel B has nearly all its mass at the rim. Find the ratio of the moments of inertia, I_B/I_A.

5-43 Is it easier to spin a bucket filled with water before or after it is frozen? Explain.

5-44 Compare a solid sphere and a solid cylinder with the same mass and radius. Which has the larger moment of inertia about the axes shown in Table 5.3? Give a qualitative explanation for your answer.

5-45 Find the radius of gyration of a rod of length l pivoted about an axis through its center.

5-46 What is the radius of gyration of a spherical shell of radius R rotating about an axis through its center?

5-47 A grinding wheel, a disk of uniform thickness, has a radius of 0.08 m and a mass of 2 kg. (a) What is its moment of inertia? (b) How large a torque is needed to accelerate it from rest to 120 rad s^{-1} in 8 s?

5-48 Assuming that the earth is a uniform sphere, find its moment of inertia about an axis through its center. (The mean radius of the earth is 6.38×10^6 m. Its total mass is 5.98×10^{24} kg.)

5-49 Two masses m_1 and m_2 hang on a pulley of mass M (Fig. 5.28). The pulley is a solid cylinder of radius R and rotates without friction. What is

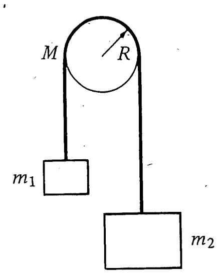

Figure 5.28. Exercises 5-49 and 5-50.

the tangential acceleration of the wheel if $M = m_2$ and $m_1 = \frac{1}{2}m_2$?

5-50 Two masses m_1 and m_2 hang on a frictionless pulley of mass M (Fig. 5.28). If all the mass of the pulley can be considered to be at its rim, and $M = 2m_2 = 3m_1$, find the acceleration of the masses m_1 and m_2.

5-51 Using the parallel axis theorem, find the moment of inertia of a rod of mass m and length l about an axis perpendicular to the rod at a distance $l/4$ from an end.

c5-52 Solve the preceding exercise using integration rather than the parallel axis theorem.

5-53 A thin ring of radius R and mass m lies on a horizontal plane. Find its moment of inertia for rotation about a vertical axis passing through the edge of the ring.

c5-54 (a) Show that a cone of mass m and length l (Fig. 5.29) has a mass per unit length which is proportional to $(l - x)^2$. (b) Find its moment of inertia for rotation about the y axis.

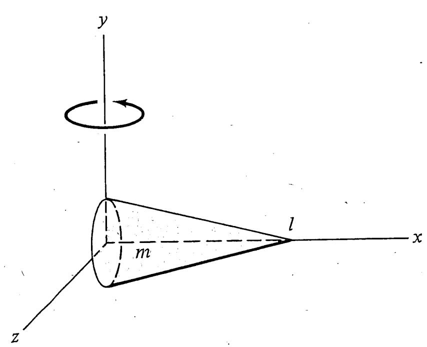

Figure 5.29. Exercise 5-56.

Section 5.6 | Coulomb's Law

5-55 An electric current is measured in amperes; a 1-A (ampere) current is a flow of 1 coulomb of charge per second. How many electrons per second pass through a wire carrying a 10-A current?

5-56 A proton and a neutron in a nucleus are separated by a distance of 2×10^{-15} m. What is the electrical force between them?

5-57 Objects can be given a net charge by rubbing, as is observed by people walking on woolen rugs in dry weather. How many electrons must be transferred to give an object a net charge of $+10^{-6}$ C? Must electrons be added or taken away?

5-58 A gram of hydrogen contains about 6×10^{23} atomic electrons. What fraction of the electrons must be removed to give the sample a net charge of 10^{-3} C?

5-59 Two identical charges 0.1 m apart exert electrical forces of 10 N on each other. (a) What is the magnitude of one of the charges? (b) Find the ratio of this charge to that on an electron.

5-60 Cosmic ray protons strike the upper atmosphere at an average rate of 1500 protons per square metre each second. How much charge is received by the earth in a 24-hour day? (The radius of the earth is 6.38×10^6 m.)

5-61 A kilogram of molecular hydrogen contains 3.01×10^{26} molecules, each consisting of two hydrogen atoms. (a) What is the total charge on the electrons in 1 kg of hydrogen? (b) What is the total charge on the protons? (c) If all the electrons were removed and placed 1 m away from the protons, what would be the electric force between them?

5-62 In a nucleus the minimum separation between two protons is about 10^{-15} m. (a) Find the electrical force between two protons at this distance. (b) Find the ratio of this force to the force between a proton and an electron separated by 10^{-10} m.

5-63 A salt crystal is made up of Na^+ ions, which are lacking one electron, and Cl^- ions, which have one extra electron. What is the force between a Na^+ ion and a Cl^- ion separated by 5×10^{-10} m?

5-64 In a simple model of the normal hydrogen atom, the radius of the circular electronic orbit is 5.29×10^{-11} m and the speed of the electron is 2.19×10^6 m s^{-1}. Find (a) the acceleration of the electron; (b) the number of orbits completed per second.

PROBLEMS

5-65 A car travels on a curve of radius 100 m banked at 20° at a speed such that no friction is needed. (a) What is the speed of the car? (b) Find the ratio of the normal force to the weight.

***5-66** A car of weight w travels on a curve of radius 200 m banked at 10°. (a) At what speed is no friction required? (b) What frictional force is required if the car travels 5 m s^{-1} faster than this speed?

***5-67** A curve of radius 300 m is banked at an angle of 10°. (a) At what speed is no friction required? (b) If the coefficient of friction is 0.8, what are the maximum and minimum speeds at which the curve can be traveled?

5-68 A bird of mass 0.3 kg flies in a horizontal curve of radius 20 m at 15 m s^{-1}. (a) What is the banking angle? (b) What is the lift force exerted by the air on the bird?

5-69 The earth's radius is 6.38×10^6 m and it rotates on its axis once every 24 h. (a) What is the centripetal acceleration at the equator? (b) If a man weighs 700 N at the North Pole, what is his effective weight at the equator? (c) The earth is actually not quite spherical; it is flattened slightly at the poles and broadened at the equator. What qualitative effect does this have on your answer to part (b)?

5-70 A 2-kg rock is tied to a light rope 1 m long and is swung in a horizontal circle. The rope is at an angle of 30° to the horizontal. (a) What is the tension in the rope? (b) What is the speed of the rock?

5-71 An airplane moving at 400 m s^{-1} can safely be subjected to an $8g$ acceleration when banking. How long will it take for the plane to turn 180°?

5-72 On an Olympic bobsled course, a sled goes through a horizontal turn at 120 km h^{-1}, subjecting the crew to an effective weight 5 times their actual weight. What is the radius of the turn?

5-73 An amusement park ride rotates its occupants in a vertical circle at a constant speed. At the top of the circle, a rider has an effective weight that is directed upward and has a magnitude of twice his actual weight, w. (a) What is his effective weight at the bottom of the circle? (b) How large is his effective weight when he is halfway to the top of the circle?

5-74 A thin washer of mass m is made by drilling a hole of radius $0.4R$ in the center of a circular disk of radius R. Find its moment of inertia.

***5-75** A wheel of radius R has a thickness a from $r = 0$ to $r = R/2$, and a thickness $2a$ from $r = R/2$ to $r = R$. If its density is ρ, what is its moment of inertia?

5-76 A person stands on the earth halfway between the equator and the North Pole. Find his speed in m s^{-1} due to the daily rotation of the earth. (The radius of the earth is 6.38×10^6 m.)

5-77 A grinding wheel is a uniformly thick disk of mass 3 kg and radius 10 cm. It is initially moving at 2400 revolutions per minute. A tool is pressed against the wheel with a normal force of 10 N. If the coefficient of friction is 0.7 and no other torques act on the wheel, how long will it take for the wheel to come to rest?

5-78 A block of mass 10 kg rests on a horizontal surface. The coefficient of sliding friction is 0.1. A massless horizontal string attached to this block passes over a frictionless pulley and is tied to a hanging block of mass 20 kg. When released, the system moves 2 m in 1 s. What is the mass of the pulley if it is a solid cylinder?

5-79 Blocks of mass 10 kg and 30 kg hang on either side of a pulley on a massless string. The pulley has a mass of 3 kg, a radius of 0.1 m, and a radius of gyration of 0.08 m. If the system has an acceleration of 3 m s^{-2}, what torque is exerted by the frictional forces in the bearings of the pulley?

5-80 Two lead balls of mass 5 kg have a distance of 1 m between their centers. (a) A lead atom has a mass of 3.44×10^{-25} kg. How many atoms are there in each ball? (b) If each atom has 82 elec-

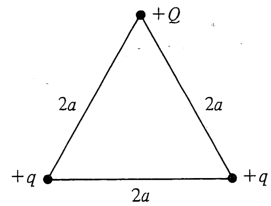

Figure 5.30. Problem 5-81 (b).

trons, what fraction of the electrons must be transferred from one ball to the other so that their gravitational and electrical attractions are equal? (Neglect the mass of the transferred electrons.)

5-81 Two identical positive charges q are separated by a distance $2a$. (a) If a third positive charge Q is placed midway between them, what is the net force on Q? (b) If the charge Q is instead placed a distance $2a$ from each of the other charges, as in Fig. 5.30, find the magnitude and direction of the net force on it.

5-82 Positive charges q and $2q$ are a distance a apart. Where can we place a third charge so that the forces due to these two charges will cancel?

5-83 Two identical solid spheres have radii R and masses m. They are attached to the ends of a bar of mass $m/5$ and length $5R$ to form a dumbbell. Find the moment of inertia of the dumbbell about an axis perpendicular to the bar through its center.

5-84 A uniformly dense rod of length L can pivot freely about its left end. (a) When the rod makes an angle θ with the horizontal direction, what is its angular acceleration? (b) What is the tangential acceleration of a point on the rod at a distance x from the pivot? (c) What is the tangential acceleration of the right end when the rod is horizontal? (Note: Your answer should be greater than g! Does this violate any physical laws?)

c**5-85** A square plate of side b has a mass m. (a) Find its moment of inertia about an axis perpendicular to the plate and passing through its center. (b) Find the moment of inertia about an axis perpendicular to the plate and passing through a corner.

c**5-86** Derive the formula in Table 5.3 for the moment of inertia of a thin circular disk. [*Hint:* Break up the disk into thin rings.]

*c**5-87** Using the formula in Table 5.3 for the moment of inertia of a disk, derive the formula for the moment of inertia of a sphere rotating about an axis through its center. [*Hint:* Slice the sphere into thin disks.]

ANSWERS TO REVIEW QUESTIONS

Q5-1, uniform circular motion; **Q5-2**, center of the circle; **Q5-3**, the center of the circle; **Q5-4**, mv^2/r; **Q5-5**, tangential acceleration; **Q5-6**, 2π; **Q5-7**, angular position, axis of rotation; **Q5-8**, angular velocity; **Q5-9**, net torque about that axis; **Q5-10**, position of the rotation axis; **Q5-11**, axis of rotation; **Q5-12**, electric forces; **Q5-13**, strong nuclear forces; **Q5-14**, repel, attract; **Q5-15**, nucleons, protons, neutrons; **Q5-16**, 10,000; **Q5-17**, quarks; **Q5-18**, strong, electromagnetic, weak, gravitational; **Q5-19**, distance squared.

SUPPLEMENTARY TOPICS

5.7 | SATELLITES; TIDES

Newton's great triumph was his demonstration that, with the laws of motion and the universal law of gravitation, the motion of the planets about the sun and of the moon about the earth could be understood in detail. He was also able to use these laws to give a qualitative explanation of the tides.

We can see what is involved in the motion of satellites by considering an artificial satellite in a circular earth orbit. Like a water pail swung in a vertical circle, the satellite has an acceleration due to gravity toward the earth. It is falling just fast enough to stay in that orbit (Fig. 5.31). We can find a formula relating the orbital radius r to the *period* T, the time needed for one full orbit.

If the satellite mass is m and the earth mass is M_E, the gravitational force on the satellite has a magnitude GmM_E/r^2. Since $F = ma_r$, we have

$$\frac{GmM_E}{r^2} = \frac{mv^2}{r}$$

In the period T the satellite travels a distance $2\pi r$, so its speed is $v = 2\pi r/T$, and the equation above

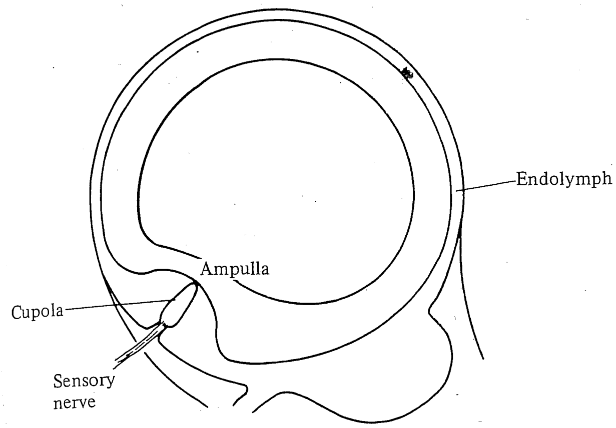

Figure 5.35. A semicircular canal of a human ear. The endolymph is a fluid that can flow around the canal. The ampulla is a swelling into which the cupola projects. The cupola can block the entire canal, but it is elastic and will bend when the fluid moves. When the cupola is pushed aside by the flowing fluid, the sensory nerve detects this motion and the information is transmitted to the brain.

and bucket is now opposite to that when the bucket was first set into motion.

In the inner ear, it takes a second for the endolymph to start moving at about the speed of the canal, so initially the cupola is deflected by its motion relative to the fluid. This deflection is sensed by the nerve, and information is transmitted to the brain. Once the canal, fluid, and cupola are all rotating at the same rate, the cupola starts to return to its normal position. However, the elastic or spring force on the cupola is so weak that it takes about 20 s for this return to be completed. The perception of rotation persists during this 20-s period, but afterward the ear can no longer detect rotation.

If the rotation rate is now reduced, the canal slows while the fluid continues to move briefly at the higher speed. Thus the cupola is deflected in the opposite direction, and the subject perceives a change in the direction of rotation. If this slower rotation continues for about 20 s, the cupola once more returns to its normal position, and the subject again perceives no rotation. Finally, if the rotation is stopped, the cupola is again deflected, and the subject perceives a rotation opposite to the original direction.

When a subject is put through the same sequence but is not blindfolded, the eyes do not normally stare directly outward at passing objects. Instead, the eyes focus briefly on a given object, then fix on another object, and so on. This is called the *nystagmus reflex*. The flicking of the eyes will continue as long as the sensory nerve detects a bending of the cupola. When the cupola resumes its normal position, the reflex action of the eyes stops and the subject, if untrained, sees objects streaking by. Then balance is lost.

When the rotation is stopped, the cupola is again deflected and the nystagmus reflex acts, this time in the opposite direction. Objects at rest appear to be moving steadily and then moving back again. The postural muscles are then trying to respond to nonexistent motion, resulting in staggering.

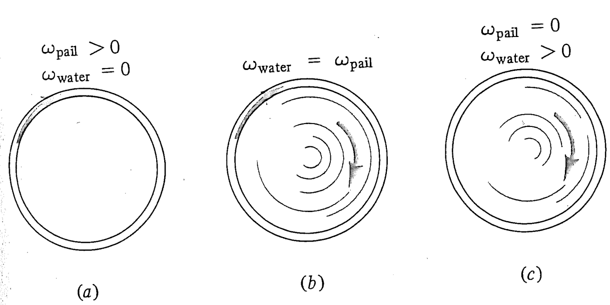

Figure 5.36. (*a*) A bucket of water is spun, with the water initially at rest. (Small scraps of paper on the surface make its motion more readily visible.) The water remains nearly at rest for a few seconds, and the pail is moving *clockwise* relative to the water. (*b*) After a while the frictional torques have increased the angular velocity of the water, and it has the same angular velocity as the bucket. (*c*) When the bucket is stopped, the water continues to move for some time until slowed by the frictional torques. Relative to the water, the pail is now moving *counterclockwise*.

EXERCISES ON SUPPLEMENTARY TOPICS

Section 5.7 | Satellites; Tides

5-88 An artificial earth satellite moves in a circular orbit with a radius one-fourth that of the moon's orbit. What is its period?

5-89 An artificial satellite is to be placed in an orbit around the sun so that its period is 8 earth years. By definition, the radius of the earth's orbit is 1 astronomical unit (A.U.). What is the radius of the satellite's orbit in A.U.?

5-90 The distance from the sun to the earth is 1 A.U. What is the length of a "year" on a planet 9 A.U. from the sun?

5-91 The average distance from Mars to the sun is 1.524 times the distance from the earth to the sun. How long does it take for Mars to go around the sun?

5-92 Using the data on the inside back cover, find the time an artificial satellite would need to go once around the sun in an orbit whose radius is twice that of the sun.

5-93 The period of the moon's orbit around the earth is 27.3 days, and its mean distance is 3.84×10^8 m. From these data, determine the mass of the earth.

5-94 Newton's theory of the tides predicts that the difference in the height of the oceans at high and low tides should be $h = 3GMR_E^2/2gr^3$, where G is the gravitational constant, M is the mass of the moon, R_E is the average radius of the earth, g is the acceleration due to gravity at the surface of the earth, and r is the earth–moon distance. Using the numerical values listed on the inside back cover, evaluate h.

PROBLEMS ON SUPPLEMENTARY TOPICS

5-95 The orbital radius of the moon is 3.84×10^5 km and its period is 27.3 days. (a) Find its acceleration a_m. (b) The gravitational acceleration at the earth's surface, which is 6380 km from its center, is $g = 9.81$ m s^{-2}. Using the $1/r^2$ dependence of the gravitational force law, what gravitational acceleration g' would one expect at the radius of the moon's orbit? (c) Compare g' and a_m. (This was one of Newton's original tests of the universal law of gravitation.)

5-96 Suppose the gravitational force were proportional to $1/r^3$ instead of $1/r^2$. What would be the relation between the period of a planet and its orbital radius? Compare this result with the observed relation $T^2 = Cr^3$.

Additional Reading

D. E. Goldman and H. E. von Gierke, in Cyril M. Harris and Charles E. Crede (eds.), *Shock and Vibration Handbook*, McGraw-Hill Book Co., New York, 1961. Chapter 44 is entitled Effects of Shock and Vibration on Humans.

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