# Chapter 8

Rotational Equilibrium and Rotational Dynamics

Quick Quizzes

1. (d). A larger torque is needed to turn the screw. Increasing the radius of the screwdriver handle provides a greater lever arm and hence an increased torque.

2. (b). Since the object has a constant net torque acting on it, it will experience a constant angular acceleration. Thus, the angular velocity will change at a constant rate.

3. (b). The hollow cylinder has the larger moment of inertia, so it will be given the smaller angular acceleration and take longer to stop.

4. (a). The hollow sphere has the larger moment of inertia, so it will have the higher rotational kinetic energy.

5. (c). The box. All objects have the same potential energy associated with them before they are released. As the objects move down the inclines, this potential energy is transformed to kinetic energy. For the ball and cylinder, the transformation is into both rotational and translational kinetic energy. The box has only translational kinetic energy. Because the kinetic energies of the ball and cylinder are split into two types, their translational kinetic energy is necessarily less than that of the box. Consequently, their translational speeds are less than that of the box, so the ball and cylinder will lag behind.

6. (c). Apply conservation of angular momentum to the system (the two disks) before and after the second disk is added to get the result: $I_1\omega_1 = (I_1 + I_2)\omega$.

7. (a). Earth already bulges slightly at the Equator, and is slightly flat at the poles. If more mass moved towards the Equator, it would essentially move the mass to a greater distance from the axis of rotation, and increase the moment of inertia. Because conservation of angular momentum requires that $\omega_z I_z = \text{const}$, an increase in the moment of inertia would decrease the angular velocity, and slow down the spinning of Earth. Thus, the length of each day would increase.

Answers to Even Numbered Conceptual Questions

2. If the bar is, say, seven feet above the ground, a high jumper has to lift his center of gravity approximately to a height of seven feet in order to clear the bar. A tall person already has his center of gravity higher than that of a short person. Thus, the taller athlete has to raise his center of gravity through a smaller distance.

4. The lever arm of a particular force is found with respect to some reference point. Thus, an origin for calculating torques must be specified. However, for an object in equilibrium, the calculation of the total torque is independent of the location of the origin.

6. We assume that the melt-water would form a thin shell of mass $m = 2.3 \times 10^{19}$ kg and radius $R_E = 6.38 \times 10^6$ m around the Earth. This shell would increase Earth's moment of inertia by an amount $\Delta I = \frac{2}{3} m R_E^2$. If we treat Earth as a uniform solid sphere, this would

    represent a fractional increase of $\dfrac{\Delta I}{I_0} = \dfrac{\frac{2}{3} m R_E^2}{\frac{2}{5} M_E R_E^2} = \dfrac{5}{3} \left(\dfrac{m}{M_E} \right)$. Thus, the fractional increase in

    the moment of inertial would be on the order of $\dfrac{10^{19} \text{ kg}}{10^{24} \text{ kg}} = 10^{-6}$. In this process, angular

    momentum would be conserved, so the quantity $I\omega = I\left(\dfrac{2\pi}{T} \right)$, where T is the rotation

    period or length of a day, must remain constant. Therefore, the length of the day must also experience a fractional increase on the order of 10^{-6}. This would give an increase in the length of the day of $\Delta T \sim 10^{-6} T_0 = 10^{-6} \left(86\ 400 \text{ s} \right) = 0.0864$ s , or $\Delta T \sim 10^{-1}$ s .

8. The critical factor is the total torque being exerted about the line of the hinges. For simplicity, we assume that the paleontologist and the botanist exert equal magnitude forces. The free body diagram of the original situation is shown on the left and that for the modified situation is shown on the right in the sketches below:

    Original Situation   Modified Situation
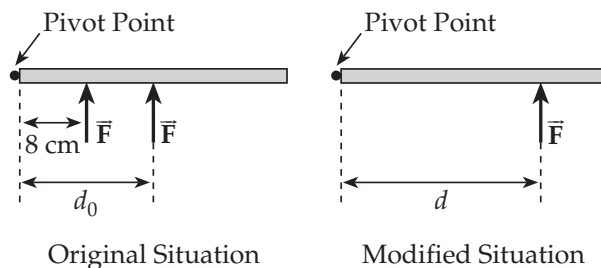
    In order for the torque exerted on the door in the modified situation to equal that of the original situation, it is necessary that $Fd = Fd_0 + F(8 \text{ cm})$ or $d = d_0 + 8 \text{ cm}$. Thus, the paleontologist would need to relocate about 8 cm farther from the hinge.

10.
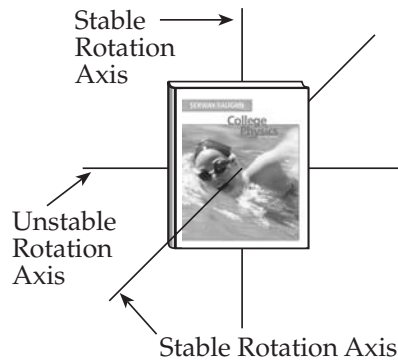
12. After the head crosses the bar, the jumper should arch his back so the head and legs are lower than the midsection of the body. In this position, the center of gravity may pass under the bar while the midsection of the body is still above the bar. As the feet approach the bar, the legs should be straightened to avoid hitting the bar.

14. **(a)** Consider two people, at the ends of a long table, pushing with equal magnitude forces directed in opposite directions perpendicular to the length of the table. The net force will be zero, yet the net torque is not zero.

   (b) Consider a falling body. The net force acting on it is its weight, yet the net torque about the center of gravity is zero.

16. As the cat falls, angular momentum must be conserved. Thus, if the upper half of the body twists in one direction, something must get an equal angular momentum in the opposite direction. Rotating the lower half of the body in the opposite direction satisfies the law of conservation of angular momentum.

18. All solid spheres reach the bottom of the hill at the same time. The speed at the bottom does not depend on the sphere's mass or radius, but only on how its mass is distributed and the height of the hill.

Chapter 9
Solids and Fluids

Quick Quizzes

1. (c). The mass that you have of each element is:

    $m_{gold} = \rho_{gold}V_{gold} = \left(19.3 \times 10^3 \text{ kg/m}^3\right)\left(1 \text{ m}^3\right) = 19.3 \times 10^3 \text{ kg}$

    $m_{silver} = \rho_{silver}V_{silver} = \left(10.5 \times 10^3 \text{ kg/m}^3\right)\left(2 \text{ m}^3\right) = 21.0 \times 10^3 \text{ kg}$

    $m_{aluminum} = \rho_{aluminum}V_{aluminum} = \left(2.70 \times 10^3 \text{ kg/m}^3\right)\left(6 \text{ m}^3\right) = 16.2 \times 10^3 \text{ kg}$

2. (a). At a fixed depth, the pressure in a fluid is directly proportional to the density of the fluid. Since ethyl alcohol is less dense than water, the pressure is smaller than P when the glass is filled with alcohol.

3. (c). For a fixed pressure, the height of the fluid in a barometer is inversely proportional to the density of the fluid. Of the fluids listed in the selection, ethyl alcohol is the least dense.

4. (b). The blood pressure measured at the calf would be larger than that measured at the arm. If we imagine the vascular system of the body to be a vessel containing a liquid (blood), the pressure in the liquid will increase with depth. The blood at the calf is deeper in the liquid than that at the arm and is at a higher pressure.

    Blood pressures are normally taken at the arm because that is approximately the same height as the heart. If blood pressures at the calf were used as a standard, adjustments would need to be made for the height of the person, and the blood pressure would be different if the person were lying down.

5. (c). The level of floating of a ship is unaffected by the atmospheric pressure. The buoyant force results from the pressure differential in the fluid. On a high-pressure day, the pressure at all points in the water is higher than on a low-pressure day. Because water is almost incompressible, however, the rate of change of pressure with depth is the same, resulting in no change in the buoyant force.

6. (b). Since both lead and iron are denser than water, both objects will be fully submerged and (since they have the same dimensions) will displace equal volumes of water. Hence, the buoyant forces acting on the two objects will be equal.

7. (a). When there is a moving air stream in the region between the balloons, the pressure in this region will be less than on the opposite sides of the balloons where the air is not moving. The pressure differential will cause the balloons to move toward each other. This is demonstration of Bernoulli's principle in action.

Answers to Even Numbered Conceptual Questions

2. We approximate the thickness of the atmosphere by using $P = P_0 + \rho g h$ with $P_0 = 0$ at the top of the atmosphere and $P = 1$ atm at sea level. This gives an approximation of

$$h = \frac{P - P_0}{\rho g} \sim \frac{10^5 \text{ Pa} - 0}{\left(1 \text{ kg/m}^3\right)\left(10^1 \text{ m/s}^2\right)} = 10^4 \text{ m} \quad \text{or} \quad h \sim 10 \text{ km}$$

Because both the density of the air, ρ, and the acceleration of gravity, g, decrease with altitude, the actual thickness of the atmosphere will be greater than our estimate.

4. Both must have the same strength. The force on the back of each dam is the average pressure of the water times the area of the dam. If both reservoirs are equally deep, the force is the same.

6. The external pressure exerted on the chest by the water makes it difficult to expand the chest cavity and take a breath while under water. Thus, a snorkel will not work in deep water.

8. A fan driven by the motor removes air and hence decreases the pressure inside the cleaner. The greater air pressure outside the cleaner pushes air in through the nozzle toward this region of lower pressure. This inward rush of air pushes or carries the dirt along with it.

10. The larger the density of a fluid, the higher does an object float in it. Thus, an object will float lower in low density alcohol.

12. The water level on the side of the glass stays the same. The floating ice cube displaces its own weight of liquid water, and so does the liquid water into which it melts.

14. A breeze from any direction speeds up to go over the mound, and the air pressure drops at this opening. Air then flows through the burrow from the lower to the upper entrance.

16. No. The somewhat lighter barge will float higher in the water.

18. Although the area and pressures is the same at the base of each vessel, the volumes of the vessels differ, so the weight of the liquid in each vessel increases as its volume increases.

Chapter 10
Thermal Physics

Quick Quizzes

1. (c). When two objects having different temperatures are in thermal contact, energy is transferred from the higher temperature object to the lower temperature object. As a result, the temperature of the hotter object decreases and that of the cooler object increases until thermal equilibrium is reached at some intermediate temperature.

2. (b). The glass surrounding the mercury expands before the mercury does, causing the level of the mercury to drop slightly. The mercury rises after it begins to get warmer and approach the temperature of the hot water, because its coefficient of expansion is greater than that for glass.

3. (c). Gasoline has the highest coefficient of expansion so it undergoes the greatest change in volume per degree change in temperature.

4. (c). A cavity in a material expands in exactly the same way as if the cavity were filled with material. Thus, both spheres will expand by the same amount.

5. (a). It expands. Imagine the balloon rising into air at uniform temperature. The air cannot be uniform in pressure because the lower layers support the weight of all the air above them. The rubber in a typical balloon stretches or contracts until interior and exterior pressures are nearly equal. So as the balloon rises, it expands; this can be considered as constant temperature expansion with V increasing as P decreases by the same factor in $PV = nRT$. If the rubber wall is strong enough, the buoyant force will eventually match the total weight of the balloon and helium so the balloon will stop rising. It is more likely that the rubber will stretch and rupture, releasing the helium, which in turn will escape from Earth's atmosphere.

6. (b). Since the two containers are at the same temperature, the average kinetic energy per molecule is the same for the argon and helium gases. However, helium has a lower molar mass than does argon, so the rms speed of the helium atoms must be higher than that of the argon atoms.

Answers to Even Numbered Conceptual Questions

2. As the moment of inertia of the balance wheel increases, the angular acceleration the spring can give the wheel will decrease. Thus, the wheel will not oscillate as rapidly as it should, causing the watch to run slow.

4. This is very good advice. As the engine heats, pressure builds up in the radiator causing most of the water in the system to remain liquid even at temperatures above the normal boiling point of water. Opening the radiator cap while the engine is still hot would result in an explosive release of this pressure and very rapid boiling of the water. This will cause steam and superheated water to spew from the radiator, and can result in serious burns to the person opening the cap.

6. The temperature of the bearing can be increased until its diameter becomes large enough to slip over the axle.

8. The lower temperature will make the power line decrease in length. This increases the tension in the line to the point that it is near breaking.

10. At high temperature and pressure, the steam inside exerts large forces on the pot and cover. Strong latches hold them together, but they would explode apart if you tried to open the hot cooker.

12. The measurements are too short. At 22°C the tape would read the width of the object accurately, but an increase in temperature causes the divisions ruled on the tape to be farther apart than they should be. This "too long" ruler will, then, measure objects to be shorter than they really are.

14. The existence of an atmosphere on a planet is due to the gravitational force holding the gas of the atmosphere to the planet. On a small planet, the gravitational force is very small, and the escape speed is correspondingly small. If a small planet starts its existence with atmosphere, the molecules of the gas will have a distribution of speeds, according to kinetic theory. Some of these molecules will have speeds higher than the escape speed of the planet and will leave the atmosphere. As the remaining atmosphere is warmed by radiation from the Sun, more molecules will attain speeds high enough to escape. As a result, the atmosphere bleeds off into space.

Energy in Thermal Processes

Quick Quizzes

1. (a) Water, glass, iron. Because it has the highest specific heat $(4186 \text{ J/kg} \cdot °C)$, water has the smallest change in temperature. Glass is next $(837 \text{ J/kg} \cdot °C)$, and iron $(448 \text{ J/kg} \cdot °C)$ is last. (b) Iron, glass, water. For a given temperature increase, the energy transfer by heat is proportional to the specific heat.

2. (b). The slopes are proportional to the reciprocal of the specific heat, so larger specific heat results in a smaller slope, meaning more energy to achieve a given change in temperature.

3. (c). The blanket acts as a thermal insulator, slowing the transfer of energy by heat from the air into the cube.

4. (b). The rate of energy transfer by conduction through a rod is proportional to the difference in the temperatures of the ends of the rod. When the rods are in parallel, each rod experiences the full difference in the temperatures of the two regions. If the rods are connected in series, neither rod will experience the full temperature difference between the two regions, and hence neither will conduct energy as rapidly as it did in the parallel connection.

5. **(a)** 4. The From Stefan's law, the power radiated from an object at absolute temperature T is proportional to the surface area of that object. Star A has twice the radius and four times the surface area of star B. **(b)** 16. From Stefan's law, the power radiated from an object having surface area A is proportional to the fourth power of the absolute temperature. Thus, $\mathscr{P}_A = \sigma A e (2T_B)^4 = 2^4 (\sigma A e T_B^4) = 16 \mathscr{P}_B$. **(c)** 64. When star A has both twice the radius and twice the absolute temperature of star B, the ratio of the radiated powers is

$$\frac{\mathscr{P}_A}{\mathscr{P}_B} = \frac{\sigma A_A e T_A^4}{\sigma A_B e T_B^4} = \frac{\sigma (4\pi R_A^2)(1) T_A^4}{\sigma (4\pi R_B^2)(1) T_B^4} = \frac{(2R_B)^2 (2T_B)^4}{R_B^2 T_B^4} = (2^2)(2^4) = 64$$

Answers to Even Numbered Conceptual Questions

2. In winter the produce is protected from freezing. The specific heat of Earth is so high that soil freezes only to a depth of a few inches in temperate regions. Throughout the year the temperature will stay nearly constant day and night. Factors to be considered are the insulating properties of the soil, the absence of a path for energy to be radiated away from or to the vegetables, and the hindrance of the formation of convection currents in the small, enclosed space.

4. The high thermal capacity of the barrel of water and its high heat of fusion mean that a large amount of energy would have to leak out of the cellar before the water and produce froze solid. Evaporation of the water keeps the relative humidity high to protect foodstuffs from drying out.

6. Yes, if you know the specific heat of zinc and copper, you can determine the relative fraction of each by heating a known weight of pennies to a specific initial temperature, say 100° C, then dump them into a known quantity of water, at say 20° C. The equation for conservation of energy will be

    $$m_{pennies} \left[x \cdot c_{Cu} + (1-x) c_{Zn} \right] (100°C - T) = m_{water} c_{water} (T - 20°C)$$

    The equilibrium temperature, T, and the masses will be measured. The specific heats are known, so the fraction of metal that is copper, x, can be computed.

8. Convection is the dominant energy transfer process involved in the cooling of the bridge surface. Air currents can flow freely around all parts of the bridge, making convection particularly effective.

10. The black car absorbs more of the incoming energy from the Sun than does the white car, making it more likely to cook the egg.

12. Keep them dry. The air pockets in the pad conduct energy slowly. Wet pads absorb some energy in warming up themselves, but the pot would still be hot and the water would quickly conduct a lot of energy to your hand.

14. Write $m_{water} c_{water} (1°C) = (\rho_{air} V) c_{air} (1°C)$, to find

    $$V = \frac{m_{water} c_{water}}{\rho_{air} c_{air}} = \frac{(1000 \text{ kg})(4186 \text{ J/kg} \cdot °C)}{(1.3 \text{ kg/m}^3)(1000 \text{ J/kg} \cdot °C)} = 3.2 \times 10^3 \text{ m}^3$$

16. (c). The ice and the liquid water have the same mass and both undergo a 5°C rise in temperature, but the ice requires less energy to accomplish this. Thus, the specific heat, $c = Q/m(\Delta T)$, of ice is less than that of the liquid water.

The Laws of Thermodynamics

Quick Quizzes

1. (b). The work done on a gas during a thermodynamic process is the **negative** of the area under the curve on a PV diagram. Processes in which the volume decreases do positive work on the gas, while processes in which the volume increases do negative work on the gas. The work done on the gas in each of the four processes shown is:

    $$W_a = -4.00 \times 10^5 \text{ J} \text{, } W_b = +3.00 \times 10^5 \text{ J} \text{, } W_c = -3.00 \times 10^5 \text{ J} \text{, and } W_d = +4.00 \times 10^5 \text{ J}$$

    Thus, the correct ranking (from most negative to most positive) is a,c,b,d.

2. A is isovolumetric, B is adiabatic, C is isothermal, D is isobaric.

3. (c). The highest theoretical efficiency of an engine is the Carnot efficiency given by $e_c = 1 - T_c/T_h$. Hence, the theoretically possible efficiencies of the given engines are:

    $$e_A = 1 - \frac{700 \text{ K}}{1\,000 \text{ K}} = 0.300 \text{, } e_B = 1 - \frac{500 \text{ K}}{800 \text{ K}} = 0.375 \text{, and } e_C = 1 - \frac{300 \text{ K}}{600 \text{ K}} = 0.500$$

    and the correct ranking (from highest to lowest) is C, B, A.

4. (b). $\Delta S = \dfrac{Q_r}{T} = 0$ and $Q = 0$ in an adiabatic process. If the process was reversible, but not adiabatic, the entropy of the system could undergo a non-zero change. However, in that case, the entropy of the system's surroundings would undergo a change of equal magnitude but opposite sign, and the total change of entropy in the universe would be zero. If the process was irreversible, the total entropy of the universe would increase.

5. The number 7 is the most probable outcome because there are six ways this could occur: 1-6, 2-5, 3-4, 4-3, 5-2, and 6-1. The numbers 2 and 12 are the least probable because they could only occur one way each: either 1-1, or 6-6. Thus, you are six times more likely to throw a 7 than a 2 or 12.

Answers to Even Numbered Conceptual Questions

2.   Either statement can be considered an instructive analogy. We choose to take the first view. All processes require energy, either as energy content or as energy input. The kinetic energy which it possessed at its formation continues to make Earth go around. Energy released by nuclear reactions in the core of the Sun drives weather on Earth and essentially all processes in the biosphere. The energy intensity of sunlight controls how lush a forest or jungle can be and how warm a planet is. Continuous energy input is not required for the motion of the planet. Continuous energy input is required for life because energy tends to be continuously degraded, as energy is transferred by heat into lower-temperature sinks. The continuously increasing entropy of the Universe is the index to energy-transfers completed.

4.   Shaking opens up spaces between the jelly beans. The smaller ones have a chance of falling down into spaces below them. The accumulation of larger ones on top and smaller ones on the bottom implies an increase in order and a decrease in one contribution to the total entropy. However, the second law is not violated and the total entropy of the system increases. The increase in the internal energy of the system comes from the work required to shake the jar of beans (that is, work your muscles must do, with an increase in entropy accompanying the biological process) and also from the small loss of gravitational potential energy as the beans settle together more compactly.

6.   Temperature = A measure of molecular motion. Heat = the process through which energy is transferred between objects by means of random collisions of molecules. Internal energy = energy associated with random molecular motions plus chemical energy, strain potential energy, and an object's other energy not associated with center of mass motion or location.

8.   A higher steam temperature means that more energy can be extracted from the steam. For a constant temperature heat sink at T_c and steam at T_h, the maximum efficiency of the power plant goes as $\dfrac{T_h - T_c}{T_h} = 1 - \dfrac{T_c}{T_h}$ and is maximized for high T_h.

10. $e_{max} = \dfrac{\Delta T}{T_h} = \dfrac{80 \text{ K}}{373 \text{ K}} \approx 22\%$ (Assumes atmospheric temperature of 20°C.)

12.   An analogy due to Carnot is instructive: A waterfall continuously converts mechanical energy into internal energy. It continuously creates entropy as the organized motion of the falling water turns into disorganized molecular motion. We humans put turbines into the waterfall, diverting some of the energy stream to our use. Water flows spontaneously from high to low elevation and energy is transferred spontaneously from high to low temperature by heat. Into the great flow of solar radiation from Sun to Earth, living things put themselves. They live on energy flow. A basking snake diverts high-temperature energy through itself temporarily, before it is inevitably lost as low-temperature energy radiated into outer space. A tree builds organized cellulose molecules and we build libraries and babies who look like their grandmothers, all out of a thin diverted stream in the universal flow of energy crashing down to disorder. We do not violate the second law, for we build local reductions in the entropy of one thing within the inexorable increase in

the total entropy of the Universe. Your roommate's exercise increases random molecular motions within the room.

14. Even at essentially constant temperature, energy must be transferred by heat out of the solidifying sugar into the surroundings. This action will increase the entropy of the environment. The water molecules become less ordered as they leave the liquid in the container to mix with the entire atmosphere.

16. A slice of hot pizza cools off. Road friction brings a skidding car to a stop. A cup falls to the floor and shatters. Any process is irreversible if it looks funny or frightening when shown in a videotape running backward. At fairly low speeds, air resistance is small and the flight of a projectile is nearly reversible.