CHAPTER 12
FLUID MECHANICS

Discussion Questions

Q12.1 For a submerged cube the buoyant force is the difference between the downward force exerted by the water at the top face of the cube and the upward force exerted by the water at the bottom face of the cube. The pressure at these two locations is different so the forces are different. If there is truly no water under the cube, between the bottom face of the cube and the bottom of the tank, then there is no upward force due to the water pressure there and the block doesn't rise to the surface when released. But in practice this would be very unstable and difficult to achieve. At the bottom face of the cube there are large horizontal forces due to the water pressure there that tend to push water under the block. If only a thin film of water gets under the block the buoyant force returns to its normal value and the block floats to the surface.

Q12.2 The pressure at a given point depends only on the height of the fluid surface above that point. Therefore, the pressure at a given depth below the surface for water in the hose is the same as the pressure at the same depth below the surface in the funnel. The upward force that supports the weight of the water in the funnel comes partly from the upward force due to the pressure in the water at the bottom of the funnel and partly from the sloped sides of the funnel.

Q12.3 The force on the floor is not due just to the weight of the air in the room, but is due to the entire column of the earth's atmosphere above the floor.

Q12.4 The distance the small piston moves is a factor of A_2 / A_1 larger than the distance the large piston moves. So the work done by F_1 equals the work done by F_2 and energy is conserved.

Q12.5 The total force of the pavement on the tires must equal the weight of the car. $F = pA$ so smaller pressure p requires a larger area A.

Q12.6 Hot air has a smaller density than the surrounding air so the buoyancy force is larger than the weight when the balloon is filled with hot air. The density of the air in the balloon depends on the temperature of this air; the ascent or descent is controlled by varying the temperature of the air in the balloon.

Q12.7 This is the weight of the water displaced by the floating ship. This equals the buoyant force and must equal the weight of the ship.

Q12.8 No. As the elevator accelerates upward, more upward force on the sphere is needed to make the sphere accelerate upward with the elevator. The sphere continues to sit on the bottom of the bucket no matter how great the upward acceleration of the elevator is. The buoyant force is $\rho_{\text{fl}} V_{\text{sp}} (g + a)$, where ρ_{fl} is the density of the water and V_{sp} is the volume of the sphere. Newton's 2nd law applied to the sphere gives $n + B - mg = ma$, where n is the normal force the bottom of the bucket exerts on the sphere. This gives

$$n = m(g + a) - B = \rho_{\text{sp}} V_{\text{sp}} (g + a) - \rho_{\text{fl}} V_{\text{sp}} (g + a) = V_{\text{sp}} (g + a)(\rho_{\text{sp}} - \rho_{\text{fl}}),$$

where ρ_{sp} is the density of the sphere. As a increases, the upward normal force n that the bottom of the bucket exerts on the sphere also increases.

Q12.9 The density of the atmosphere decreases with altitude so the buoyant force on the dirigible decreases with altitude. The dirigible rises until the density of the surrounding air equals the average density of the dirigible (frame plus cargo plus helium).

Q12.10 Assume that in each case the liquid is the same. The buoyant force is equal to $\rho_{\text{liquid}} V_{\text{submerged}} g$. For the piece of iron the volume submerged is $(25\text{ cm})^3$. For the floating piece of wood the volume submerged is less than $(25\text{ cm})^3$. Therefore, the buoyant force on the iron is greater. The buoyant force on the piece of wood equals the weight of the piece of wood and the buoyant force on the piece of iron is less than the weight of the piece of iron. But the density of iron is much larger than the density of wood so for equal volumes the weight of the piece of iron is much larger than that of the piece of wood.

Q12.11 The weight in air is $w_{\text{air}} = mg = \rho_{\text{obj}} V_{\text{obj}} g$, where ρ_{obj} and V_{obj} are the density and volume of the object. The "weight" in water is $w_{\text{w}} = w_{\text{air}} - B = \rho_{\text{obj}} V_{\text{obj}} g - \rho_{\text{w}} V_{\text{obj}} g = (\rho_{\text{obj}} - \rho_{\text{w}}) V_{\text{obj}} g$, where ρ_{w} is the density of water. $w_{\text{air}} / w_{\text{w}} = \rho_{\text{obj}} / (\rho_{\text{obj}} - \rho_{\text{w}})$ so if w_{air} and w_{w} are measured, ρ_{obj} can be calculated. The density of the object measured in this way can be compared to the density of pure gold. To make your fake brick pass this test the average density of the brick would have to equal that of gold. Table 12.1 shows that few materials have a density as large as that of gold. You could gold-plate a platinum-brass alloy brick, for example, but to have the same density of gold it would have to be mostly platinum, and platinum is very expensive.

Q12.12 Pressure varies with depth so the force on each square centimeter of levee is greatest at the bottom.

Q12.13 In each case the buoyant force B must equal the weight of the floating ship. $B = \rho_{\text{fl}} V_{\text{displ}} g$, where ρ_{fl} is the density of the fluid and V_{displ} is the volume of the ship that is beneath the surface of the water. The density of fresh water is a bit less than the density of sea water, so V_{displ} must be greater in fresh water to produce the same buoyant force.

Q12.14 With the wood completely submerged the buoyant force is equal to $\rho_{\text{water}} V_{\text{wood}} g$, where ρ_{water} is the density of the water and V_{wood} is the volume of the piece of wood. The buoyant force increases very slightly with depth because the density of the water increases slightly with depth, due to the increase of pressure with depth. But for the depth of a swimming pool the increase in density from near the surface to the bottom of the pool is very small and to a good approximation the buoyant force on the piece of wood remains constant as the wood is pushed deeper under the water.

Q12.15 A mass of feathers for which the weight is one pound has a much larger volume than a mass of lead for which the weight is one pound. The larger volume for the feathers would have a much larger buoyant force from the air and the net downward force on the feathers would be less than that on the lead. It would take more than a pound of feathers to balance a pound of lead.

Q12.16 The pressure difference would be $(0.01)(1.0\times10^5\text{ Pa}) = 1.0\times10^3\text{ Pa}$. For a door with area 2 m^2 the net force keeping the door closed would be 2×10^3 N. This is about 450 pounds. It would take a very strong person to pull the door open. But all that would be required would be to open it slightly, so air can move from the high pressure to the low pressure side. Once the pressure is equalized the door will easily open the rest of the way.

Q12.17 The pressure at depth h in an incompressible fluid is given by $p = p_0 + \rho g h$, where

p_0 is the pressure at the surface. When the depth h is doubled, the ρgh term doubles. But p doesn't double, because of the p_0 term. The gauge pressure doubles but the absolute pressure is less than $2p$.

Q12.18 When the block floats, the weight of water displaced equals the total weight of the block. Since it floats, the average density of the block plus iron must be less than the density of the water. The block still floats when the block is turned over. In either case the same amount of water is displaced, an amount whose weight equals that of the block, so the water level in the bucket doesn't change.

Q12.19 As the jar is pushed deeper the water pressure increases and the air inside the jar is compressed to a smaller volume. More water enters the jar so less water is displaced by the jar plus air bubble and the buoyant force on the jar decreases.

Q12.20 When the bowling ball is sitting in the floating canoe it must cause an amount of water to be displaced that is equal to the weight of the bowling ball. When the bowling ball is sitting at the bottom of the pool the buoyant force on it is less than its weight, since it sinks, so it is displacing less than its weight of water. The bowling ball causes less water to be displaced when it has been dropped over the side, so the water level in the pool falls.

Q12.21 The buoyant force is increased by an amount equal to the weight of the bird so the canoe sinks lower to displace more water and the level of water in the pool rises.

Q12.22 Consider a bucket full of water. When the piece of wood is placed in the water the buoyant force on the floating piece of wood equals its weight. This buoyant force also equals the weight of the water displaced by the piece of wood. Therefore, the weight added by placing the piece of wood in the water equals the weight of the water that flows over the side of the bucket and the weight of the contents of the bucket doesn't change. The two buckets weigh the same.

Q12.23 When the ice cube is floating it displaces an amount of water whose weight equals its weight. The amount of water produced from the melted ice has a weight equal to that of the ice cube; the mass doesn't change during the melting. These two amounts of water are the same, so the water level in the glass doesn't change.

Q12.24 The balloons move forward toward the front of the car. The air in the car has the same acceleration as the car. The force that produces this acceleration for a volume of air is exerted by the surrounding air. When this volume is replaced by a helium-filled balloon, the force on the balloon exerted by the surrounding air is the same as when just air was in the volume. But the helium-filled balloon has less mass that the same volume of air (the balloon rises if released), so the same force produces a greater acceleration when applied to the balloon and the balloon has a greater forward acceleration than does the air inside the car.

Q12.25 The velocity of the fluid at a given point in space is constant in time but the velocity at different points can be different. A fluid particle accelerates when it moves to a point where the velocity is different.

Q12.26 The pressure is less in the moving stream of air than it is in the surrounding stationary air.

Q12.27 The pressure is less in the rapidly rotating air, where the air is moving at high speed. The air pressure difference gives rise to large forces, since normal air pressure is large.

Q12.28 Atmospheric pressure is less at higher elevations so for the same wing speed and shape the pressure difference between points above and below the wing is less at higher elevations.

Q12.29 See Problem 12.84. As the water falls it gains speed due to gravity. The continuity equation says that the cross-sectional area decreases when the fluid speed increases.

Q12.30 "Identical-sized" means the two cubes have equal volumes. But lead has a greater density than aluminum so the mass of the lead cube will be greater than the mass of the aluminum cube. (a) The buoyant force on each cube is given by $B = \rho_{\text{water}} V_{\text{water}} g$. Since the cubes have equal volumes the buoyant force is the same on each. (b) The tension in the wire is given by $T = mg - B$. B is the same for both but mg is greater for the lead cube and therefore the tension in the wire is greater for the lead cube. (c) The force on the lower face of each cube is $F = p_1 A$, where A is the area of the lower face and $p_1 = p_0 + \rho g h$ is the pressure at the lower face. Figure Q12.30 shows that the lead cube is suspended at a greater depth in the water. So, the pressure at its lower face is greater than for the aluminum block and the force on its lower face is greater than for the aluminum block. But, the pressure at the upper face is also greater and the difference between the upward force on the bottom and the downward force on the top face is the same for the two blocks. (d) The difference in depth between the top and bottom faces is the same for both blocks so the difference in pressure between the upper and lower faces is also the same for both blocks.