Chapter 12: FLUID DYNAMICS AND ITS BIOLOGICAL AND MEDICAL APPLICATIONS

# 12.1 Flow rate and its relation to velocity

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| 1. | | *What is the average flow rate in  of gasoline to the engine of a car traveling at 100 km/h if it averages 10.0 km/L?* | | |
| Solution | |  | | |
| 2. | | *The heart of a resting adult pumps blood at a rate of 5.00 L/min. (a) Convert this to . (b) What is this rate in ?* | | |
| Solution | | (a)  (b) | | |
| 3. | | *Blood is pumped from the heart at a rate of 5.0 L/min into the aorta (of radius 1.0 cm). Determine the speed of blood through the aorta.* | | |
| Solution | |  | | |
| 4. | | *Blood is flowing through an artery of radius 2 mm at a rate of 40 cm/s. Determine the flow rate and the volume that passes through the artery in a period of 30 s.* | | |
| Solution | |  | | |
| 5. | | *The Huka Falls on the Waikato River is one of New Zealand’s most visited natural tourist attractions (see Figure 12.29). On average the river has a flow rate of about 300,000 L/s. At the gorge, the river narrows to 20 m wide and averages 20 m deep. (a) What is the average speed of the river in the gorge? (b) What is the average speed of the water in the river downstream of the falls when it widens to 60 m and its depth increases to an average of 40 m?* | | |
| Solution | | (a)  (b) | | |
| 6. | | *A major artery with a cross-sectional area of  branches into 18 smaller arteries, each with an average cross-sectional area of . By what factor is the average velocity of the blood reduced when it passes into these branches?* | | |
| Solution | |  | | |
| 7. | | *(a) As blood passes through the capillary bed in an organ, the capillaries join to form venules (small veins). If the blood speed increases by a factor of 4.00 and the total cross-sectional area of the venules is , what is the total cross-sectional area of the capillaries feeding these venules? (b) How many capillaries are involved if their average diameter is ?* | | |
| Solution | | (a)  (b) | | |
| 8. | | *The human circulation system has approximately  capillary vessels. Each vessel has a diameter of about . Assuming cardiac output is 5 L/min, determine the average velocity of blood flow through each capillary vessel.* | | |
| Solution | |  | | |
| 9. | | *(a) Estimate the time it would take to fill a private swimming pool with a capacity of 80,000 L using a garden hose delivering 60 L/min. (b) How long would it take to fill if you could divert a moderate size river, flowing at , into it?* | | |
| Solution | | (a)  (b) | | |
| 10. | | *The flow rate of blood through a -radius capillary is  (a) What is the speed of the blood flow? (This small speed allows time for diffusion of materials to and from the blood.) (b) Assuming all the blood in the body passes through capillaries, how many of them must there be to carry a total flow of ? (The large number obtained is an overestimate, but it is still reasonable.)* | | |
| Solution | | (a)  (b) total flow/single capillary flow = | | |
| 11. | | *(a) What is the fluid speed in a fire hose with a 9.00-cm diameter carrying 80.0 L of water per second? (b) What is the flow rate in cubic meters per second? (c) Would your answers be different if salt water replaced the fresh water in the fire hose?* | | |
| Solution | | (a)  (b)  (c) No, the flow rate and the velocity are independent of the density of the fluid. | | |
| 12. | | *The main uptake air duct of a forced air gas heater is 0.300 m in diameter. What is the average speed of air in the duct if it carries a volume equal to that of the house’s interior every 15 min? The inside volume of the house is equivalent to a rectangular solid 13.0 m wide by 20.0 m long by 2.75 m high.* | | |
| Solution | |  | | |
| 13. | | *Water is moving at a velocity of 2.00 m/s through a hose with an internal diameter of 1.60 cm. (a) What is the flow rate in liters per second? (b) The fluid velocity in this hose’s nozzle is 15.0 m/s. What is the nozzle’s inside diameter?* | | |
| Solution | | (a)  (b) | | |
| 14. | | *Prove that the speed of an incompressible fluid through a constriction, such as in a Venturi tube, increases by a factor equal to the square of the factor by which the diameter decreases. (The converse applies for flow out of a constriction into a larger-diameter region.)* | | |
| Solution | | If the fluid is incompressible, the flow rate through both sides will be equal:  , or | | |
| 15. | | *Water emerges straight down from a faucet with a 1.80-cm diameter at a speed of 0.500 m/s. (Because of the construction of the faucet, there is no variation in speed across the stream.) (a) What is the flow rate in ? (b) What is the diameter of the stream 0.200 m below the faucet? Neglect any effects due to surface tension.* | | |
| Solution | | (a)  (b) | | |
| 16. | | ***Unreasonable Results*** *A mountain stream is 10.0 m wide and averages 2.00 m in depth. During the spring runoff, the flow in the stream reaches . (a) What is the average velocity of the stream under these conditions? (b) What is unreasonable about this velocity? (c) What is unreasonable or inconsistent about the premises?* | | |
| Solution | | (a)  (b) This velocity is much too high (speed of sound).  (c) The flow rate,, is much too large. | | |
| 12.2 bernoulli’s equation | | | | |
| 17. | | *Verify that pressure has units of energy per unit volume.* | | |
| Solution | |  | | |
| 18. | | *Suppose you have a wind speed gauge like the pitot tube shown in Figure 12.7(b). By what factor must wind speed increase to double the value of  in the manometer? Is this independent of the moving fluid and the fluid in the manometer?* | | |
| Solution | | Let  be the initial wind speed and  be the final wind speed.    Yes, the wind speed factor is independent of the moving fluid and the fluid in the manometer. | | |
| 19. | | *If the pressure reading of your pitot tube is 15.0 mm Hg at a speed of 200 km/h, what will it be at 700 km/h at the same altitude?* | | |
| Solution | |  | | |
| 20. | | *Calculate the maximum height to which water could be squirted with the hose in Example 12.2 if it: (a) Emerges from the nozzle. (b) Emerges with the nozzle removed, assuming the same flow rate.* | | |
| Solution | | (a) where    (b) | | |
| 21. | | *Every few years, winds in Boulder, Colorado, attain sustained speeds of 45.0 m/s (about 100 mi/h) when the jet stream descends during early spring. Approximately what is the force due to the Bernoulli effect on a roof having an area of ? Typical air density in Boulder is , and the corresponding atmospheric pressure is . (Bernoulli’s principle as stated in the text assumes laminar flow. Using the principle here produces only an approximate result, because there is significant turbulence.)* | | |
| Solution | | so that . Now, | | |
| 22. | | *(a) Calculate the approximate force on a square meter of sail, given the horizontal velocity of the wind is 6.00 m/s parallel to its front surface and 3.50 m/s along its back surface. Take the density of air to be . (The calculation, based on Bernoulli’s principle, is approximate due to the effects of turbulence.) (b) Discuss whether this force is great enough to be effective for propelling a sailboat.* | | |
| Solution | | (a)  (b) This force is small, but when the sails are large, the forces can be great enough to propel a sailboat. For larger sailboats, sometimes more than one sail is used to increase the surface areas thereby increasing the force applied. | | |
| 23. | | *(a) What is the pressure drop due to the Bernoulli effect as water goes into a 3.00-cm-diameter nozzle from a 9.00-cm-diameter fire hose while carrying a flow of 40.0 L/s? (b) To what maximum height above the nozzle can this water rise? (The actual height will be significantly smaller due to air resistance.)* | | |
| Solution | | (a)  (b) | | |
| 24. | | *(a) Using Bernoulli’s equation, show that the measured fluid speed  for a pitot tube, like the one in Figure 12.7(b), is given by , where  is the height of the manometer fluid,  is the density of the manometer fluid,  is the density of the moving fluid, and  is the acceleration due to gravity. (Note that  is indeed proportional to the square root of , as stated in the text.) (b) Calculate  for moving air if a mercury manometer’s  is 0.200 m.* | | |
| Solution | | (a) . Set  Because , the  and  terms cancel.  where  is the density of the fluid in the pitot tube. Thus,  (b) | | |
| 12.3 the most general applications of bernoulli’s equation | | | | |
| 25. | | *Hoover Dam on the Colorado River is the highest dam in the United States at 221 m, with an output of 1300 MW. The dam generates electricity with water taken from a depth of 150 m and an average flow rate of . (a) Calculate the power in this flow. (b) What is the ratio of this power to the facility’s average of 680 MW?* | | |
| Solution | | (a)  (b) | | |
| 26. | | *A frequently quoted rule of thumb in aircraft design is that wings should produce about 1000 N of lift per square meter of wing. (The fact that a wing has a top and bottom surface does not double its area.) (a) At takeoff, an aircraft travels at 60.0 m/s, so that the air speed relative to the bottom of the wing is 60.0 m/s. Given the sea level density of air to be , how fast must it move over the upper surface to create the ideal lift? (b) How fast must air move over the upper surface at a cruising speed of 245 m/s and at an altitude where air density is one-fourth that at sea level? (Note that this is not all of the aircraft’s lift—some comes from the body of the plane, some from engine thrust, and so on. Furthermore, Bernoulli’s principle gives an approximate answer because flow over the wing creates turbulence.)* | | |
| Solution | | (a) , so that    (b) | | |
| 27. | | *The left ventricle of a resting adult’s heart pumps blood at a flow rate of , increasing its pressure by 110 mm Hg, its speed from zero to 30.0 cm/s, and its height by 5.00 cm. (All numbers are averaged over the entire heartbeat.) Calculate the total power output of the left ventricle. Note that most of the power is used to increase blood pressure.* | | |
| Solution | |  | | |
| 28. | | *A sump pump (used to drain water from the basement of houses built below the water table) is draining a flooded basement at the rate of 0.750 L/s, with an output pressure of . (a) The water enters a hose with a 3.00-cm inside diameter and rises 2.50 m above the pump. What is its pressure at this point? (b) The hose goes over the foundation wall, losing 0.500 m in height, and widens to 4.00 cm in diameter. What is the pressure now? You may neglect frictional losses in both parts of the problem.* | | |
| Solution | | (a)  (b)  , so that | | |
| 12.4 viscosity and laminar flow; poiseuille’s law | | | | |
| 29. | | *(a) Calculate the retarding force due to the viscosity of the air layer between a cart and a level air track given the following information—air temperature is* *, the cart is moving at 0.400 m/s, its surface area is , and the thickness of the air layer is . (b) What is the ratio of this force to the weight of the 0.300-kg cart?* | | |
| Solution | | (a)  (b) | | |
| 30. | | *What force is needed to pull one microscope slide over another at a speed of 1.00 cm/s, if there is a 0.500-mm-thick layer of*  *water between them and the contact area is ?* | | |
| Solution | |  | | |
| 31. | | *A glucose solution being administered with an IV has a flow rate of . What will the new flow rate be if the glucose is replaced by whole blood having the same density but a viscosity 2.50 times that of the glucose? All other factors remain constant.* | | |
| Solution | |  | | |
| 32. | | *The pressure drop along a length of artery is 100 Pa, the radius is 10 mm, and the flow is laminar. The average speed of the blood is 15 mm/s. (a) What is the net force on the blood in this section of artery? (b) What is the power expended maintaining the flow?* | | |
| Solution | | (a)  (b) | | |
| 33. | | *A small artery has a length of  and a radius of . If the pressure drop across the artery is 1.3 kPa, what is the flow rate through the artery? (Assume that the temperature is .)* | | |
| Solution | |  | | |
| 34. | | *Fluid originally flows through a tube at a rate of . To illustrate the sensitivity of flow rate to various factors, calculate the new flow rate for the following changes with all other factors remaining the same as in the original conditions. (a) Pressure difference increases by a factor of 1.50. (b) A new fluid with 3.00 times greater viscosity is substituted. (c) The tube is replaced by one having 4.00 times the length. (d) Another tube is used with a radius 0.100 times the original. (e) Yet another tube is substituted with a radius 0.100 times the original and half the length, and the pressure difference is increased by a factor of 1.50.* | | |
| Solution | | (a)  (b)  (c)  (d)  (e) | | |
| 35. | | *The arterioles (small arteries) leading to an organ, constrict in order to decrease flow to the organ. To shut down an organ, blood flow is reduced naturally to 1.00% of its original value. By what factor did the radii of the arterioles constrict? Penguins do this when they stand on ice to reduce the blood flow to their feet.* | | |
| Solution | | If the flow rate is reduced to 1.00% of its original value, then  .  Since the length of the arterioles is kept constant and the pressure difference is kept constant, we can get a relationship between the radii: | | |
| 36. | | *Angioplasty is a technique in which arteries partially blocked with plaque are dilated to increase blood flow. By what factor must the radius of an artery be increased in order to increase blood flow by a factor of 10?* | | |
| Solution | |  | | |
| 37. | | *(a) Suppose a blood vessel’s radius is decreased to 90.0% of its original value by plaque deposits and the body compensates by increasing the pressure difference along the vessel to keep the flow rate constant. By what factor must the pressure difference increase? (b) If turbulence is created by the obstruction, what additional effect would it have on the flow rate?* | | |
| Solution | | (a)  (b) Turbulence will decrease the flow rate of the blood, which would require an even larger increase in the pressure difference, leading to higher blood pressure. | | |
| 38. | | *A spherical particle falling at a terminal speed in a liquid must have the gravitational force balanced by the drag force and the buoyant force. The buoyant force is equal to the weight of the displaced fluid, while the drag force is assumed to be given by Stokes Law, . Show that the terminal speed is given by* ***,*** *where  is the radius of the sphere,  is its density, and  is the density of the fluid and  the coefficient of viscosity.* | | |
| Solution | | The net force is zero, so . Now,, , and . Therefore, | | |
| 39. | | *Using the equation of the previous problem, find the viscosity of motor oil in which a steel ball of radius 0.8 mm falls with a terminal speed of 4.32 cm/s. The densities of the ball and the oil are 7.86 and 0.88 g/mL, respectively.* | | |
| Solution | |  | | |
| 40. | | *A skydiver will reach a terminal velocity when the air drag equals their weight. For a skydiver with high speed and a large body, turbulence is a factor. The drag force then is approximately proportional to the square of the velocity. Taking the drag force to be  and setting this equal to the person’s weight, find the terminal speed for a person falling “spread eagle.” Find both a formula and a number for , with assumptions as to size.* | | |
| Solution | | An adult male skydiver with gear might have a weight of about 100 kg, and a surface area of . The critical velocity is about | | |
| 41. | | *A layer of oil 1.50 mm thick is placed between two microscope slides. Researchers find that a force of  is required to glide one over the other at a speed of 1.00 cm/s when their contact area is . What is the oil’s viscosity? What type of oil might it be?* | | |
| Solution | | Based on the values in Table 12.1, the lubricant oil appears to be olive oil. | | |
| 42. | | *(a) Verify that a 19.0% decrease in laminar flow through a tube is caused by a 5.00% decrease in radius, assuming that all other factors remain constant, as stated in the text. (b) What increase in flow is obtained from a 5.00% increase in radius, again assuming all other factors remain constant?* | | |
| Solution | | (a)  (b) | | |
| 43. | | *Example 12.8 dealt with the flow of saline solution in an IV system. (a) Verify that a pressure of  is created at a depth of 1.61 m in a saline solution, assuming its density to be that of sea water. (b) Calculate the new flow rate if the height of the saline solution is decreased to 1.50 m. (c) At what height would the direction of flow be reversed? (This reversal can be a problem when patients stand up.)* | | |
| Solution | | (a)  (b)  (c) | | |
| 44. | | *When physicians diagnose arterial blockages, they quote the reduction in flow rate. If the flow rate in an artery has been reduced to 10.0% of its normal value by a blood clot and the average pressure difference has increased by 20.0%, by what factor has the clot reduced the radius of the artery?* | | |
| Solution | | The radius reduced to 53.7% of its normal value. | | |
| 45. | | *During a marathon race, a runner’s blood flow increases to 10.0 times her resting rate. Her blood’s viscosity has dropped to 95.0% of its normal value, and the blood pressure difference across the circulatory system has increased by 50.0%. By what factor has the average radii of her blood vessels increased?* | | |
| Solution | | The radii of her blood vessels increased by 58.6%. | | |
| 46. | | *Water supplied to a house by a water main has a pressure of  early on a summer day when neighborhood use is low. This pressure produces a flow of 20.0 L/min through a garden hose. Later in the day, pressure at the exit of the water main and entrance to the house drops, and a flow of only 8.00 L/min is obtained through the same hose. (a) What pressure is now being supplied to the house, assuming resistance is constant? (b) By what factor did the flow rate in the water main increase in order to cause this decrease in delivered pressure? The pressure at the entrance of the water main is , and the original flow rate was 200 L/min. (c) How many more users are there, assuming each would consume 20.0 L/min in the morning?* | | |
| Solution | | (a) Let pressure at end of hose, pressure at hose for home use, and  pressure at main water works. At the hose,    (b) To find *R*, use  where  and are given. For the main,  Thus,      Thus, the flow rate in the main increases by 90%.  (c) In the afternoon, the number of users =  In the morning, the number of users =  There are approximately 38 more users in the afternoon. | | |
| 47. | | *An oil gusher shoots crude oil 25.0 m into the air through a pipe with a 0.100-m diameter. Neglecting air resistance but not the resistance of the pipe, and assuming laminar flow, calculate the pressure at the entrance of the 50.0-m-long vertical pipe. Take the density of the oil to be  and its viscosity to be  (or ). Note that you must take into account the pressure due to the 50.0-m column of oil in the pipe.* | | |
| Solution | | The pressure at the bottom of the pipe, , will be greater than that obtained for a horizontal pipe by amount of the pressure, , due to the 50-m column of oil.    The pressure at the top of the gusher,, will be equal to atmospheric pressure, which is 0 gauge pressure.  , where *P2* is the pressure at the top of the vertical pipe | | |
| 48. | | *Concrete is pumped from a cement mixer to the place it is being laid, instead of being carried in wheelbarrows. The flow rate is 200 L/min through a 50.0-m-long, 8.00-cm-diameter hose, and the pressure at the pump is . (a) Calculate the resistance of the hose. (b) What is the viscosity of the concrete, assuming the flow is laminar? (c) How much power is being supplied, assuming the point of use is at the same level as the pump? You may neglect the power supplied to increase the concrete’s velocity.* | | |
| Solution | | (a) . The pressure at the exit of the hose,, is atmospheric pressure (0 gauge pressure).    (b)  (c) | | |
| 12.5 the onset of turbulence | | | | |
| 51. | | *Verify that the flow of oil is laminar (barely) for an oil gusher that shoots crude oil 25.0 m into the air through a pipe with a 0.100-m diameter****.*** *The vertical pipe is 50 m long. Take the density of the oil to be  and its viscosity to be  (or ).* | | |
| Solution | | . To find  Now,  Since is the approximate upper value for laminar flow, the flow of oil is laminar (barely). | | |
| 52. | | *Show that the Reynolds number  is unitless by substituting units for all the quantities in its definition and cancelling.* | | |
| Solution | |  | | |
| 53. | | *Calculate the Reynolds numbers for the flow of water through (a) a nozzle with a radius of 0.250 cm and (b) a garden hose with a radius of 0.900 cm, when the nozzle is attached to the hose. The flow rate through hose and nozzle is 0.500 L/s. Can the flow in either possibly be laminar?* | | |
| Solution | | Hose:  Flow is not laminar.  Nozzle:  Flow is not laminar. | | |
| 54. | | *A fire hose has an inside diameter of 6.40 cm. Suppose such a hose carries a flow of 40.0 L/s starting at a gauge pressure of . The hose goes 10.0 m up a ladder to a nozzle having an inside diameter of 3.00 cm. Calculate the Reynolds numbers for flow in the fire hose and nozzle to show that the flow in each must be turbulent.* | | |
| Solution | | Hose:  Flow is turbulent.  Nozzle:  Flow is turbulent. | | |
| 55. | | *Concrete is pumped from a cement mixer to the place it is being laid, instead of being carried in wheelbarrows. The flow rate is 200 L/min through a 50.0-m-long, 8.00-cm-diameter hose, and the pressure at the pump is . Verify that the flow of concrete is laminar taking concrete’s viscosity to be , and given its density is .* | | |
| Solution | | (a) . The pressure at the exit of the hose,, is atmospheric pressure (0 gauge pressure).    (b)  (c) | | |
| 56. | | *At what flow rate might turbulence begin to develop in a water main with a 0.200-m diameter? Assume a*  *temperature.* | | |
| Solution | | At  flow will be turbulent, whereas for , flow may either be laminar or turbulent. We use  to calculate the flow rate at which turbulence might begin to develop. | | |
| 57. | | *What is the greatest average speed of blood flow at*  *in an artery of radius 2.00 mm if the flow is to remain laminar? What is the corresponding flow rate? Take the density of blood to be .* | | |
| Solution | | Use as the limit of laminar flow. Then, | | |
| 58. | | *In Take-Home Experiment: Inhalation, we measured the average flow rate  of air traveling through the trachea during each inhalation. Now calculate the average air speed in meters per second through your trachea during each inhalation. The radius of the trachea in adult humans is approximately . From the data above, calculate the Reynolds number for the air flow in the trachea during inhalation. Do you expect the air flow to be laminar or turbulent?* | | |
| Solution | | This is an open-ended problem based on a take home experiment using your own numbers:  (a)  (b) | | |
| 59. | | *Gasoline is piped underground from refineries to major users. The flow rate is  (about 500 gal/min), the viscosity of gasoline is , and its density is . (a) What minimum diameter must the pipe have if the Reynolds number is to be less than 2000? (b) What pressure difference must be maintained along each kilometer of the pipe to maintain this flow rate?* | | |
| Solution | | (a) . First, we need to get an expression for the velocity:  . Giving:  so that the minimum diameter is  (b) , so | | |
| 60. | | *Assuming that blood is an ideal fluid, calculate the critical flow rate at which turbulence is a certainty in the aorta. Take the diameter of the aorta to be 2.50 cm. (Turbulence will actually occur at lower average flow rates,, because blood is not an ideal fluid. Furthermore, since blood flow pulses, turbulence may occur during only the high-velocity part of each heartbeat.)* | | |
| Solution | | At  flow will be turbulent. We thus use this value as the Reynolds number at which turbulence is a certainty.    (Note  for blood at  is used.) | | |
| 61. | | ***Unreasonable Results*** *A fairly large garden hose has an internal radius of 0.600 cm and a length of 23.0 m. The nozzleless horizontal hose is attached to a faucet, and it delivers 50.0 L/s. (a) What water pressure is supplied by the faucet? (b) What is unreasonable about this pressure? (c) What is unreasonable about the premise? (d) What is the Reynolds number for the given flow? (Take the viscosity of water as .)* | | |
| Solution | | (a)    (b) This pressure is unreasonably high.  (c) The flow rate is very high for a garden hose.  (d)  This flow is turbulent, contrary to the assumption of laminar flow when using this equation. | | |
| 12.7 molecular transport phenomena: diffusion, osmosis, and related processes | | | | |
| 62. | | *You can smell perfume very shortly after opening the bottle. To show that it is not reaching your nose by diffusion, calculate the average distance a perfume molecule moves in one second in air, given its diffusion constant  to be .* | | |
| Solution | |  | | |
| 63. | | *What is the ratio of the average distances that oxygen will diffuse in a given time in air and water? Why is this distance less in water (equivalently, why is  less in water)?* | | |
| Solution | | is less in water because there are more collisions in water due to the closer spacing of molecules in a liquid vs. in a gas. | | |
| 64. | | *Oxygen reaches the veinless cornea of the eye by diffusing through its tear layer, which is 0.500-mm thick. How long does it take the average oxygen molecule to do this?* | | |
| Solution | |  | | |
| 65. | | *(a) Find the average time required for an oxygen molecule to diffuse through a 0.200-mm-thick tear layer on the cornea. (b) How much time is required to diffuse  of oxygen to the cornea if its surface area is ?* | | |
| Solution | | (a)  (b) | | |
| 66. | | *Suppose hydrogen and oxygen are diffusing through air. A small amount of each is released simultaneously. How much time passes before the hydrogen is 1.00 s ahead of the oxygen? Such differences in arrival times are used as an analytical tool in gas chromatography.* | | |
| Solution | | From Table 12.2, we know:  .  We want the distance traveled to be the same, where.  Setting the two distance equations equal and squaring gives  and substituting for oxygen time gives .  Solving for the hydrogen time gives: | | |
| Test Prep For AP® Courses | | | |
| 1. | *Water flows through a small horizontal pipe with a speed of 12 m/s into a larger part of the pipe for which the diameter of the pipe is doubled. What is the speed of the water in the larger part of the pipe?*   1. 0.75 m/s 2. 3.0 m/s 3. 6.0 m/s 4. 12 m/s | |
| Solution | (b) | |
| 2. | *A popular pool toy allows the user to push a plunger to compress water in a barrel with a diameter of 3.0 cm. The water is compressed with a speed of 1.2 m/s and emerges from a small opening with a speed of 15 m/s. What is the diameter of the opening? Assume the toy is oriented horizontally.* | |
| Solution | . | |
| 3. | *At what depth beneath the surface of the lake is the pressure in the water equal to twice atmospheric pressure?*   1. 10 m 2. 100 m 3. 1000 m 4. 10,000 m | |
| Solution | (a) | |
| 4. | *A pump provides pressure to the lower end of a long pipeline that supplies water from a reservoir to a house located on a hill 150 m vertically upward from the lower end of the pipe (where the water is initially at rest before being pumped). The pipeline has a constant diameter of 3.5 cm, and the upper end of the pipeline is open to the atmosphere. What pressure must the pump provide for water to flow from the upper end of the pipeline at a rate of 5.0 m/s?* | |
| Solution | Take the surface of the lake to be at a height of 0. | |
| 5. | *According to Bernoulli’s equation, if the pressure in a given fluid is constant and the kinetic energy per unit volume of a fluid increases, which of the following is true?*   1. The potential energy per unit volume of the fluid decreases. 2. The potential energy per unit volume of the fluid increases. 3. The fluid must no longer be considered incompressible. 4. The flow rate of the fluid increases. | |
| Solution | (a) | |
| 6. | *Consider the following circumstances within a fluid, and determine the answer using Bernoulli’s equation. (a) The pressure and kinetic energy per unit volume along a fluid path increases. What must be true about the potential energy per unit volume of the fluid along the fluid path? Explain. (b) The pressure along a fluid path increases, and the kinetic energy per unit volume remains constant. What must be true about the potential energy per unit volume of the fluid along the fluid path? Explain.* | |
| Solution | (a) Since Bernoulli’s equation represents energy conservation, we can write it as:    If the pressure increases and the kinetic energy per unit volume increases along a fluid path, then the first two terms of Bernoulli’s equation must both be positive. For the equation to be true, then the third term must be negative. This means that the potential energy per unit volume is lower at location 2 in the fluid, so the potential energy per unit volume must decrease.  For (b), if the pressure increases and the kinetic energy per unit volume remains constant, then the first term of the equation must be positive and the second term is zero. This means again that the third term must be negative. So again, potential energy per unit volume must decrease. | |
| 7. | *A horizontally oriented pipe has a diameter of 5.6 cm and is filled with water. The pipe draws water from a reservoir that is initially at rest. A manually operated plunger provides a force of 440 N in the pipe. Assuming that the other end of the pipe is open to the air, with what speed does the water emerge from the pipe?*   1. 12 m/s 2. 19 m/s 3. 150 m/s 4. 190 m/s | |
| Solution | (a) Reasoning: By using Bernoulli’s equation and ignoring the potential energy terms: | |
| 8. | *A 3.5-cm-diameter pipe contains a pumping mechanism that provides a force of 320 N to push water up into a tall building. Upon entering the piston mechanism, the water is flowing at a rate of 2.5 m/s. The water is then pumped to a level 21 m higher where the other end of the pipe is open to the air. With what speed does water leave the pipe?* | |
| Solution |  | |
| 9. | *A large container of water is open to the air, and it develops a hole of area 10 cm2 at a point 5 m below the surface of the water. What is the flow rate () of the water emerging from this hole?*   1. 99 2. 9.9 3. 0.099 4. 0.0099 | |
| Solution | (d) Reasoning: We start with Bernoulli’s equation:    Since the top of the container and the hole are both open to the air, the two pressures are equal and subtract equally from both sides. In addition, since the tank is very large, we can assume that the speed with which the water level moves downward in the large tank is very small compared to the speed with which water is moving out of the hole. This means Bernoulli’s equation can be greatly simplified as follows, taking the hole to be part 2 of the flow: | |
| 10. | *A pipe is tapered so that the large end has a diameter twice as large as the small end. What must be the gauge pressure (the difference between pressure at the large end and pressure at the small end) in order for water to emerge from the small end with a speed of 12 m/s if the small end is elevated 8 m above the large end of the pipe?* | |
| Solution | We will treat the large end of the pipe as part 1 of the pipe and apply Bernoulli’s equation as follows:    Since the gauge pressure and the initial velocity are both unknown, we need another equation to solve for one of these unknowns, namely, the continuity equation:        The gauge pressure can now be found:    The pressure at the lower, larger end of the pipe () must be 146,000 greater than the pressure at the upper, smaller end of the pipe (). | |

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