***University Physics Volume I***

**Unit 1: Mechanics**

**Chapter 14: Fluid Mechanics**

**Conceptual Questions**

1. Which of the following substances are fluids at room temperature and atmospheric pressure: air, mercury, water, glass?

Solution

Mercury and water are liquid at room temperature and atmospheric pressure. Air is a gas at room temperature and atmospheric pressure. Glass is an amorphous solid (non-crystalline) material at room temperature and atmospheric pressure. At one time, it was thought that glass flowed, but flowed very slowly. This theory came from the observation that old glass planes were thicker at the bottom. It is now thought unlikely that this theory is accurate.

3. Explain how the density of air varies with altitude.

Solution

The density of air decreases with altitude. For a column of air of a constant temperature, the density decreases exponentially with altitude. This is a fair approximation, but since the temperature does change with altitude, it is only an approximation.

5. How is pressure related to the sharpness of a knife and its ability to cut?

Solution

Pressure is force divided by area. If a knife is sharp, the force applied to the cutting surface is divided over a smaller area than the same force applied with a dull knife. This means that the pressure would be greater for the sharper knife, increasing its ability to cut.

7. Imagine that in a remote location near the North Pole, a chunk of ice floats in a lake. Next to the lake, a glacier with the same volume as the floating ice sits on land. If both chunks of ice should melt due to rising global temperatures, and the melted ice all goes into the lake, which one would cause the level of the lake to rise the most? Explain.

Solution

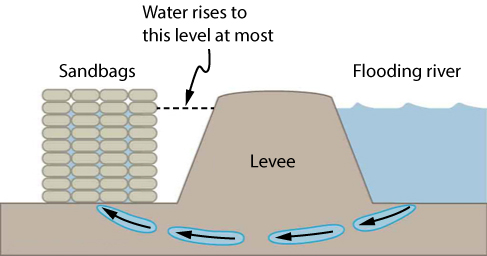
If the two chunks of ice had the same volume, they would produce the same volume of water. The glacier would cause the greatest rise in the lake, however, because part of the floating chunk of ice is already submerged in the lake, and is thus already contributing to the lake’s level.

9. Atmospheric pressure exerts a large force (equal to the weight of the atmosphere above your body—about 10 tons) on the top of your body when you are lying on the beach sunbathing. Why are you able to get up?

Solution

The pressure is acting all around your body, assuming you are not in a vacuum

11. The image shows how sandbags placed around a leak outside a river levee can effectively stop the flow of water under the levee. Explain how the small amount of water inside the column of sandbags is able to balance the much larger body of water behind the levee.



Solution

Because the river level is very high, it has started to leak under the levee. Sandbags are placed around the leak, and the water held by them rises until it is the same level as the river, at which point the water there stops rising. The sandbags will absorb water until the water reaches the height of the water in the levee.

13. Does atmospheric pressure add to the gas pressure in a rigid tank? In a toy balloon? When, in general, does atmospheric pressure not affect the total pressure in a fluid?

Solution

Atmospheric pressure does not affect the gas pressure in a rigid tank, but it does affect the pressure inside a balloon. In general, atmospheric pressure affects fluid pressure unless the fluid is enclosed in a rigid container.

15. Explain why the fluid reaches equal levels on either side of a manometer if both sides are open to the atmosphere, even if the tubes are of different diameters.

Solution

The pressure of the atmosphere is due to the weight of the air above. The pressure, force per area, on the manometer will be the same at the same depth of the atmosphere.

17. More force is required to pull the plug in a full bathtub than when it is empty. Does this contradict Pascal’s principle? Explain your answer.

Solution

Not at all. Pascal’s principle says that the change in the pressure is exerted through the fluid. The reason that the full tub requires more force to pull the plug is because of the weight of the water above the plug.

19. Will the same ship float higher in salt water than in freshwater? Explain your answer.

Solution

The buoyant force is equal to the weight of the fluid displaced. The greater the density of the fluid, the less fluid that is needed to be displaced to have the weight of the object be supported and to float. Since the density of salt water is higher than that of fresh water, less salt water will be displaced, and the ship will float higher.

21. Many figures in the text show streamlines. Explain why fluid velocity is greatest where streamlines are closest together. (*Hint:* Consider the relationship between fluid velocity and the cross-sectional area through which the fluid flows.)

Solution

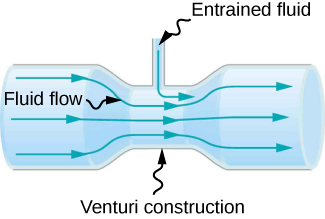
Consider two different pipes connected to a single pipe of a smaller diameter, with fluid flowing from the two pipes into the smaller pipe. Since the fluid is forced through a smaller cross-sectional area, it must move faster as the flow lines become closer together. Likewise, if a pipe with a large radius feeds into a pipe with a small radius, the stream lines will become closer together and the fluid will move faster.

23. Water is shot nearly vertically upward in a decorative fountain and the stream is observed to broaden as it rises. Conversely, a stream of water falling straight down from a faucet narrows. Explain why.

Solution

The mass of water that enters a cross-sectional area must equal the amount that leaves. From the continuity equation, we know that the density times the area times the velocity must remain constant. Since the density of the water does not change, the velocity times the cross-sectional area entering a region must equal the cross-sectional area times the velocity leaving the region. Since the velocity of the fountain stream decreases as it rises due to gravity, the area must increase. Since the velocity of the faucet stream speeds up as it falls, the area must decrease.

25. A tube with a narrow segment designed to enhance entrainment is called a Venturi, such as shown below. Venturis are very commonly used in carburetors and aspirators. How does this structure bolster entrainment?



Solution

When the tube narrows, the fluid is forced to speed up, thanks to the continuity equation and the work done on the fluid. Where the tube is narrow, the pressure decreases. This means that the entrained fluid will be pushed into the narrow area.

27. Is there a limit to the height to which an entrainment device can raise a fluid? Explain your answer.

Solution

The work done by pressure can be used to increase the kinetic energy and to gain potential energy. As the height becomes larger, there is less energy left to give to kinetic energy. Eventually, there will be a maximum height that cannot be overcome.

29. Roofs are sometimes pushed off vertically during a tropical cyclone, and buildings sometimes explode outward when hit by a tornado. Use Bernoulli’s principle to explain these phenomena.

Solution

Because of the speed of the air outside the building, the pressure outside the house decreases. The greater pressure inside the building can essentially blow off the roof or cause the building to explode.

31. Water pressure inside a hose nozzle can be less than atmospheric pressure due to the Bernoulli effect. Explain in terms of energy how the water can emerge from the nozzle against the opposing atmospheric pressure.

Solution

The air inside the hose has kinetic energy due to its motion. The kinetic energy can be used to do work against the pressure difference.

33. Based on Bernoulli’s equation, what are three forms of energy in a fluid? (Note that these forms are conservative, unlike heat transfer and other dissipative forms not included in Bernoulli’s equation.)

Solution

Potential energy due to position, kinetic energy due to velocity, and the work done by a pressure difference.

35. Water pressure inside a hose nozzle can be less than atmospheric pressure due to the Bernoulli effect. Explain in terms of energy how the water can emerge from the nozzle against the opposing atmospheric pressure.

Solution

The water has kinetic energy due to its motion. This energy can be converted into work against the difference in pressure.

37. When paddling a canoe upstream, it is wisest to travel as near to the shore as possible. When canoeing downstream, it is generally better to stay near the middle. Explain why.

Solution

The water in the center of the stream is moving faster than the water near the shore due to resistance between the water and the shore and between the layers of fluid. There is also probably more turbulence near the shore, which will also slow the water down. When paddling up stream, the water pushes against the canoe, so it is better to stay near the shore to minimize the force pushing against the canoe. When moving downstream, the water pushes the canoe, increasing its velocity, so it is better to stay in the middle of the stream to maximize this effect.

39. Doppler ultrasound can be used to measure the speed of blood in the body. If there is a partial constriction of an artery, where would you expect blood speed to be greatest: at or after the constriction? What are the two distinct causes of higher resistance in the constriction?

Solution

You would expect the speed to be slower after the obstruction. Resistance is increased due to the reduction in size of the opening, and turbulence will be created because of the obstruction, both of which will clause the fluid to slow down.

**Problems**

41. Gold is sold by the troy ounce (31.103 g). What is the volume of 1 troy ounce of pure gold?

Solution

1.610 

43. What is the mass of a deep breath of air having a volume of 2.00 L? Discuss the effect taking such a breath has on your body’s volume and density.

Solution

The mass is 2.58 g. The volume of your body increases by the volume of air you inhale. The average density of your body decreases when you take a deep breath because the density of air is substantially smaller than the average density of the body.

45. Suppose you have a coffee mug with a circular cross-section and vertical sides (uniform radius). What is its inside radius if it holds 375 g of coffee when filled to a depth of 7.50 cm? Assume coffee has the same density as water.

Solution

3.99 cm

47. A trash compactor can compress its contents to 0.350 times their original volume. Neglecting the mass of air expelled, by what factor is the density of the rubbish increased?

Solution

2.86 times denser

49. What is the density of 18.0-karat gold that is a mixture of 18 parts gold, 5 parts silver, and 1 part copper? (These values are parts by mass, not volume.) Assume that this is a simple mixture having an average density equal to the weighted densities of its constituents.

Solution

15.6 g/cm3

51. A glass tube contains mercury. What would be the height of the column of mercury which would create pressure equal to 1.00 atm?

Solution

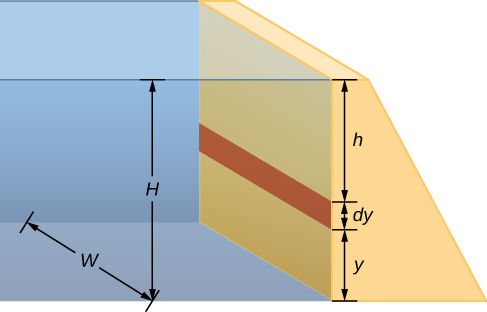


53. Verify that the SI unit of  is .

Solution

proof 

55. A dam is used to hold back a river. The dam has a height  and a width Assume that the density of the water is  (a) Determine the net force on the dam. (b) Why does the thickness of the dam increase with depth?



Solution

a. Pressureat:









b. The pressure increases as the depth increases, so the dam must be built thicker toward the bottom to withstand the greater pressure.

57. How tall must a water-filled manometer be to measure blood pressure as high as 300 mm Hg?

Solution

4.08 m

59. How much pressure is transmitted in the hydraulic system considered in Example: “Calculating Force on Wheel Cylinders: Pascal Puts on the Brakes”? Express your answer in atmospheres.

Solution

251 atm

61. A host pours the remnants of several bottles of wine into a jug after a party. The host then inserts a cork with a 2.00-cm diameter into the bottle, placing it in direct contact with the wine. The host is amazed when the host pounds the cork into place and the bottom of the jug (with a 14.0-cm diameter) breaks away. Calculate the extra force exerted against the bottom if he pounded the cork with a 120-N force.

Solution



63. Verify that work input equals work output for a hydraulic system assuming no losses due to friction. Do this by showing that the distance the output force moves is reduced by the same factor that the output force is increased. Assume the volume of the fluid is constant. What effect would friction within the fluid and between components in the system have on the output force? How would this depend on whether or not the fluid is moving?

Solution

If the system is not moving, the friction would not play a role. With friction, we know there are losses, so that  therefore, the work output is less than the work input. In other words, to account for friction, you would need to push harder on the input piston than was calculated.

65. If a person’s body has a density of 995 kg/m3, what fraction of the body will be submerged when floating gently in (a) freshwater? (b) In salt water with a density of 1027 kg/m3?

Solution

a. 99.5% submerged; b. 96.9% submerged

67. Archimedes’ principle can be used to calculate the density of a fluid as well as that of a solid. Suppose a chunk of iron with a mass of 390.0 g in air is found to have an apparent mass of 350.5 g when completely submerged in an unknown liquid. (a) What mass of fluid does the iron displace? (b) What is the volume of iron, using its density as given in the following table? (c) Calculate the fluid’s density and identify it.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Solids  (0.0 °C) | | Liquids  (0.0 °C) | | Gases  (0.0 °C, 101.3 kPa) | |
| Substance |  | Substance |  | Substance |  |
| Aluminum |  | Benzene |  | Air |  |
| Bone |  | Blood |  | Carbon dioxide |  |
| Brass |  | Ethyl alcohol |  | Carbon monoxide |  |
| Concrete |  | Gasoline |  | Helium |  |
| Copper |  | Glycerin |  | Hydrogen |  |
| Cork |  | Mercury |  | Methane |  |
| Earth’s crust |  | Olive oil |  | Nitrogen |  |
| Glass |  |  |  | Nitrous oxide |  |
| Gold |  |  |  | Oxygen |  |
| Granite |  |  |  |  |  |
| Iron |  |  |  |  |  |
| Lead |  |  |  |  |  |
| Oak |  |  |  |  |  |
| Pine |  |  |  |  |  |
| Platinum |  |  |  |  |  |
| Polystyrene |  |  |  |  |  |
| Tungsten |  |  |  |  |  |
| Uranium |  |  |  |  |  |

Solution

a. 39.5 g; b. ; c. 0.79 g/cm3; ethyl alcohol

69. What is the density of a woman who floats in fresh water with  of her volume above the surface? (This could be measured by placing her in a tank with marks on the side to measure how much water she displaces when floating and when held under water.) (b) What percent of her volume is above the surface when she floats in seawater?

Solution

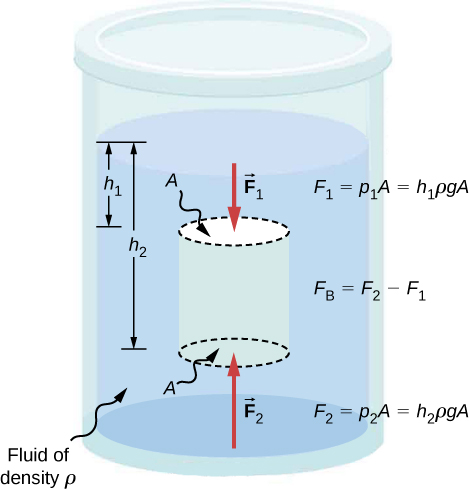
a. 960 kg/m3; b. 6.34%; She floats higher in seawater.

71. A simple compass can be made by placing a small bar magnet on a cork floating in water. (a) What fraction of a plain cork will be submerged when floating in water? (b) If the cork has a mass of 10.0 g and a 20.0-g magnet is placed on it, what fraction of the cork will be submerged? (c) Will the bar magnet and cork float in ethyl alcohol?

Solution

a. 0.24; b. 0.72; c. Yes, the cork will float in ethyl alcohol.

73. Referring to the following figure, prove that the buoyant force on the cylinder is equal to the weight of the fluid displaced (Archimedes’ principle). You may assume that the buoyant force is  and that the ends of the cylinder have equal areas *A.* Note that the volume of the cylinder (and that of the fluid it displaces) equals 



Solution



75. 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

2.78 

77. The Huka Falls on the Waikato River is one of New Zealand’s most visited natural tourist attractions. 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. 0.75 m/s; b. 0.13 m/s

79. 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. 12.6 m/s; b. ; c. No, the flow rate and the velocity are independent of the density of the fluid.

81. 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 

83. Verify that pressure has units of energy per unit volume.

Solution



85. 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

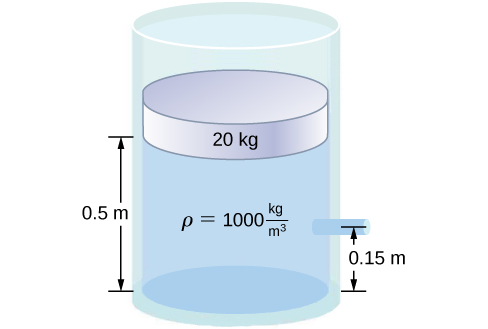
–135 mm Hg

87. 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. 163 m

89. A container of water has a cross-sectional area of *A* = 0.1 m2. A piston sits on top of the water (see the following figure). There is a spout located 0.15 m from the bottom of the tank, open to the atmosphere, and a stream of water exits the spout. The cross sectional area of the spout is  (a) What is the velocity of the water as it leaves the spout? (b) If the opening of the spout is located 1.5 m above the ground, how far from the spout does the water hit the floor? Ignore all friction and dissipative forces.



Solution

a.





;

b.



91. 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 20 °C, the cart is moving at 0.400 m/s, its surface area is 2.50 × 10–2 m2, and the thickness of the air layer is 6.00 × 10–2 m. (b) What is the ratio of this force to the weight of the 0.300-kg cart?

Solution

a. ; b. 

93. 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 *R* is the radius of the sphere,  is its density, and  is the density of the fluid, and  the coefficient of viscosity.

Solution

proof

95. A skydiver will reach a terminal velocity when the air drag equals his or her weight. For a skydiver with a large body, turbulence is a factor at high speeds. 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 skydiver’s weight, find the terminal speed for a person falling “spread eagle.”

Solution

40 m/s

97. 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 is reduced to 53.7% of its normal value.

99. 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 8.00 × 106 N/m2. (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. ; b. ; c. 

101. 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

(a. Nozzle: 



Flow is not laminar.

b. Hose: 



Flow is not laminar.

103. At what flow rate might turbulence begin to develop in a water main with a 0.200-m diameter? Assume a  temperature.

Solution



**Additional Problems**

105. Water towers store water above the level of consumers for times of heavy use, eliminating the need for high-speed pumps. How high above a user must the water level be to create a gauge pressure of 3.00 × 105 N/m2?

Solution

30.6 m

107. (a) Convert normal blood pressure readings of 120 over 80 mm Hg to newtons per meter squared using the relationship for pressure due to the weight of a fluid  rather than a conversion factor. (b) Explain why the blood pressure of an infant would likely be smaller than that of an adult. Specifically, consider the smaller height to which blood must be pumped.

Solution

a. ;

b. Since an infant is only approximately 20 inches tall, while an adult is approximately 70 inches tall, the blood pressure for an infant would be expected to be smaller than that of an adult. The blood only feels a pressure of 20 inches rather than 70 inches, so the pressure should be smaller.

109. Bird bones have air pockets in them to reduce their weight—this also gives them an average density significantly less than that of the bones of other animals. Suppose an ornithologist weighs a bird bone in air and in water and finds its mass is 45.0 g and its apparent mass when submerged is 3.60 g (assume the bone is watertight). (a) What mass of water is displaced? (b) What is the volume of the bone? (c) What is its average density?

Solution

a. 41.4 g; b. 41.4 cm3; c. 1.09 g/cm3. This is clearly not the density of the bone everywhere. The air pockets will have a density of approximately 1.29 × 10–3 g/cm3, while the bone will be substantially denser.

111. Some fish have a density slightly less than that of water and must exert a force (swim) to stay submerged. What force must an 85.0-kg grouper exert to stay submerged in salt water if its body density is 1015 kg/m3?

Solution

12.3 N

113. The flow rate of blood through a -radius capillary is . (a) What is the speed of the blood flow? (b) Assuming all the blood in the body passes through capillaries, how many of them must there be to carry a total flow of ?

Solution

a. . (This small speed allows time for diffusion of materials to and from the blood.) b.  capillaries. (This large number is an overestimate, but it is still reasonable.)

115. 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 3.00 × 105 N/m2. (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. *P*2 = 2.81 × 105 N/m2

117. A small artery has a length of 1.1 × 10–3 m and a radius of 2.5 × 10–5 m. 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

8.7 × 10–2 mm3/s

119. 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.1.52; b. Turbulence would decrease the flow rate of the blood, which would require an even larger increase in the pressure difference, leading to higher blood pressure.

**Challenge Problems**

121. The temperature of the atmosphere is not always constant and can increase or decrease with height. In a neutral atmosphere, where there is not a significant amount of vertical mixing, the temperature decreases at a rate of approximately 6.5 K per km. The magnitude of the decrease in temperature as height increases is known as the lapse rate  (The symbol is the upper case Greek letter gamma.) Assume that the surface pressure is  where and the lapse rate is . Estimate the pressure 3.0 km above the surface of Earth.

Solution





















123. Logs sometimes float vertically in a lake because one end has become water-logged and denser than the other. What is the average density of a uniform-diameter log that floats with 20.0% of its length above water?

Solution

800 kg/m3

125. The inside volume of a house is equivalent to that of a rectangular solid 13.0 m wide by 20.0 m long by 2.75 m high. The house is heated by a forced air gas heater. The main uptake air duct of the 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 minutes?

Solution

11.2 m/s

127. 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 as , 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. 71.8 m/s; b. 257 m/s

129. 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. 

131. 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. ; b. The flow rate in the main increases by 90%. c. There are approximately 38 more users in the afternoon.

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