Fluid flow can be characterized either as laminar, in which the layers of fluid flow smoothly and regularly along paths called streamlines, or as turbulent, in which case the flow is not smooth and regular but is characterized by irregularly shaped whirlpools.

Fluid flow rate is the mass or volume of fluid that passes a given point per unit time. The equation of continuity states that for an incompressible fluid flowing in an enclosed tube, the product of the velocity of flow and the cross-sectional area of the tube remains constant:

\[ \rho v = \text{constant.} \]  

Bernoulli's principle tells us that where the velocity of a fluid increases, the pressure decreases, and vice versa.

### Questions

1. If one material has a higher density than another, must the molecules of the first be heavier than those of the second? Explain.
2. An airplane travels sometimes note that its cosmetics bottles and other containers have leaked during a flight. What might cause this?
3. The three containers in Fig. 13–43 are filled with water to the same height and have the same surface area at the base; hence the water pressure, and the total force on the base of each, is the same. Yet the total weight of water is different for each. Explain this “hydrostatic paradox.”

![FIGURE 13–43](image)

**Question 3.**

4. Consider what happens when you push both a pin and the blunt end of a pen against your skin with the same force. Decide what determines whether your skin is cut—the net force applied to it or the pressure.
5. A small amount of water is boiled in a 1-gallon metal can. The can is removed from the heat and the lid put on. As the can cools, it collapses. Explain.
6. When blood pressure is measured, why must the cuff be held at the level of the heart?
7. An ice cube floats in a glass of water filled to the brim. What can you say about the density of ice? As the ice melts, will the water overflow? Explain.
8. Will an ice cube float in a glass of alcohol? Why or why not?
9. A submerged can of Coke® will sink, but a can of Diet Coke® will float. (Try it!) Explain.
10. Why don’t ships made of iron sink?
11. Explain how the tube in Fig. 13–44, known as a siphon, can transfer liquid from one container to a lower one even though the liquid must flow uphill for part of its journey. (Note that the tube must be filled with liquid to start with.)

![FIGURE 13–44](image)

**Question 11.** A siphon.

12. A barge filled high with sand approaches a low bridge over the river and cannot quite pass under it. Should sand be added to, or removed from, the barge? [ Hint: Consider Archimedes’ principle.]

13. Explain why helium weather balloons, which are used to measure atmospheric conditions at high altitudes, are normally released while filled to only 10–20% of their maximum volume.

14. A row boat floats in a swimming pool, and one of the water at the edge of the pool is marked. Consider the following situations and explain whether the level of water will rise, fall, or stay the same. (a) The boat is removed from the water. (b) The boat in the water holds an iron anchor, which is removed from the boat and placed on the shore. (c) The anchor is removed from the boat and dropped in the pool.

15. Will an empty balloon have precisely the same weight on a scale as a balloon filled with air? Explain.

16. Why do you float higher in salt water than in fresh water?

17. If you dangle two pieces of paper vertically, a few inches apart (Fig. 13–45), and blow between them, how do you think the papers will move? Try it and see. Explain.

![FIGURE 13–45](image)

**Question 17.**

18. Why does the stream of water from a faucet become narrower as it falls (Fig. 13–46)?

19. Children are told to avoid standing too close to a moving train because they might get sucked under it. Is this possible? Explain.

20. A tall Styrofoam cup is filled with water. Two holes are punched in the cup near the bottom, and water is being rushed out. If the cup is dropped so it falls freely, will the water continue to flow from the holes? Explain.

21. Why do airplanes normally take off into the wind?

22. Two ships moving in parallel paths close to one another colliding. Why?

23. Why does the canvas top of a convertible car come off when the car is traveling at high speed? [Hint: The wind deflects air upward, pushing streamlines closer together.

24. Roofs of houses are sometimes “blown” off (or are pushed off?) during a tornado or hurricane. Explain. Bernoulli’s principle.
1. (I) The approximate volume of the granite monolith known as El Capitan in Yosemite National Park (Fig. 13–47) is about \(10^3\) m\(^3\). What is its approximate mass?

2. (I) What is the approximate mass of air in a living room 5.6 m × 3.8 m × 2.8 m?

3. (I) If you tried to smuggle gold bricks by filling your backpack, whose dimensions are 56 cm × 28 cm × 22 cm, what would its mass be?

4. (I) State your mass and then estimate your volume. [Hint: Because you can swim on or just under the surface of the water in a swimming pool, you have a pretty good idea of your density.]

5. (II) A bottle has a mass of 35.00 g when empty and 98.44 g when filled with water. When filled with another fluid, the mass is 89.22 g. What is the specific gravity of this other fluid?

6. (II) If 50 L of antifreeze solution (specific gravity = 0.80) is added to 4.0 L of water to make a 9.0-L mixture, what is the specific gravity of the mixture?

7. (III) The Earth is not a uniform sphere, but has regions of varying density. Consider a simple model of the Earth divided into three regions—inner core, outer core, and mantle. Each region is taken to have a unique constant density (the average density of that region in the real Earth):

<table>
<thead>
<tr>
<th>Region</th>
<th>Radius (km)</th>
<th>Density (kg/m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Core</td>
<td>0–1220</td>
<td>13,000</td>
</tr>
<tr>
<td>Outer Core</td>
<td>1220–3480</td>
<td>11,100</td>
</tr>
<tr>
<td>Mantle</td>
<td>3480–6371</td>
<td>4,400</td>
</tr>
</tbody>
</table>

(a) Use this model to predict the average density of the entire Earth. (b) The measured radius of the Earth is 6371 km and its mass is 5.98 × 10\(^{24}\) kg. Use these data to determine the actual average density of the Earth and compare it (as a percent difference) with the one you determined in (a).

8. (I) Estimate the pressure needed to raise a column of water to the same height as a 35-m-tall oak tree.

9. (I) Estimate the pressure exerted on a floor by (a) one pointed chair leg (66 kg on all four legs) of area = 0.020 cm\(^2\), and (b) a 1300-kg elephant standing on one foot (area = 800 cm\(^2\)).

10. (I) What is the difference in blood pressure (mm-Hg) between the top of the head and bottom of the feet of a 1.70-m-tall person standing vertically?

11. (II) How high would the level be in an alcohol barometer at normal atmospheric pressure?

12. (II) In a movie, Tarzan evades his captors by hiding underwater for many minutes while breathing through a long, thin reed. Assuming the maximum pressure difference his lungs can manage and still breathe is −85 mm-Hg, calculate the deepest he could have been.

13. (II) The maximum gauge pressure in a hydraulic lift is 17.0 atm. What is the largest-size vehicle (kg) it can lift if the diameter of the output line is 22.5 cm?

14. (II) The gauge pressure in each of the four tires of an automobile is 240 kPa. If each tire has a “footprint” of 220 cm\(^2\), estimate the mass of the car.

15. (II) (a) Determine the total force and the absolute pressure on the bottom of a swimming pool 28.0 m by 8.5 m whose uniform depth is 1.8 m. (b) What will be the pressure against the side of the pool near the bottom?

16. (II) A house at the bottom of a hill is fed by a full tank of water 5.0 m deep and connected to the house by a pipe that is 110 m long at an angle of 58° from the horizontal (Fig. 13–48). (a) Determine the water gauge pressure at the house. (b) How high could the water shoot if it came vertically out of a broken pipe in front of the house?

17. (II) Water and then oil (which don’t mix) are poured into a U-shaped tube, open at both ends. They come to equilibrium as shown in Fig. 13–49. What is the density of the oil? [Hint: Pressures at points a and b are equal. Why?]

18. (II) In working out his principle, Pascal showed dramatically how force can be multiplied with fluid pressure. He placed a long, thin tube of radius \( r = 0.30 \) cm vertically into a wine barrel of radius \( R = 21 \) cm, Fig. 13–50. He found that when the barrel was filled with water and the tube filled to a height of 12 m, the barrel burst. Calculate (a) the mass of water in the tube, and (b) the net force exerted by the water in the barrel on the lid just before rupture.

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**Figure 13–47** Problem 1.

**Figure 13–48** Problem 16.

**Figure 13–49** Problem 17.

**Figure 13–50** Problem 18 (not to scale).
28. (II) A crane lifts the 16,000-kg steel hull of a sunken ship out of the water. Determine (a) the tension in the crane's cable when the hull is fully submerged in the water, and (b) the tension when the hull is completely out of the water.

29. (II) A spherical balloon has a radius of 7.35 m and is filled with helium. How large a cargo can it lift, assuming that the skin and structure of the balloon have a mass of 930 kg?

Neglect the buoyant force on the cargo volume itself.

30. (II) A 74-kg person has an apparent mass of 54 kg (because of buoyancy) when standing in water that comes up to the hips. Estimate the mass of each leg. Assume the body has SG = 1.00.

31. (II) What is the likely identity of a metal (see Table 12-1) if a sample has a mass of 63.5 g when measured in air and an apparent mass of 55.4 g when submerged in water?

32. (II) Calculate the true mass (in vacuum) of a piece of aluminum whose apparent mass is 3.0000 kg when weighed in air.

33. (II) Because gasoline is less dense than water, drums containing gasoline will float in water. Suppose a 230-L steel drum is completely full of gasoline. What total volume of steel can be used in making the drum if the gasoline-filled drum is to float in fresh water?

34. (II) A scuba diver and her gear displace a volume of 6500 cm³ and have a total mass of 68.0 kg. (a) What is the buoyant force on the diver in seawater? (b) Will the diver sink or float?

35. (II) The specific gravity of ice is 0.917, whereas that of seawater is 1.025. What percent of an iceberg is above the surface of the water?

36. (II) Archimedes’ principle can be used not only to determine the specific gravity of a solid using a known liquid (Example 13-10); the reverse can be done as well. (a) As an example, a 3.80-kg aluminum ball has an apparent mass of 2.10 kg when submerged in a particular liquid; calculate the density of the liquid. (b) Derive a formula for determining the density of a liquid using this procedure.

37. (II) (a) Show that the buoyant force \( F_B \) on a partially submerged object such as a ship acts at the center of gravity of the fluid before it is displaced. This point is called the center of buoyancy. (b) To ensure that a ship is in stable equilibrium, would it be better if its center of buoyancy was above, below, or at the same point as, its center of gravity? Explain. (See Fig. 13–52.)

38. (II) A cube of side length 10.0 cm and made of an unknown material floats at the surface between water and oil. The cube has a density of 810 kg/m³. If the cube floats so that 72% in the water and 28% in the oil, what is the mass of the cube and what is the buoyant force on the cube?

39. (II) How many helium-filled balloons would it take to lift a person? Assume the person has a mass of 75 kg and each helium-filled balloon has a weight of 0.3 N.

40. (II) A board of density \( 0.60 \text{ g/cm}^3 \) has a thickness of 0.5 cm, a width of 30 cm, and a length of 1.5 m. How many such boards can be placed on top of each other without the bottom one having more than half of its cross section above the surface of water, assuming the boards float and do not touch each other?
40. (II) A scuba tank, when fully submerged, displaces 15.7 L of seawater. The tank itself has a mass of 14.0 kg and, when “full,” contains 3.00 kg of air. Assuming only a weight and buoyant force act, determine the net force (magnitude and direction) on the fully submerged tank at the beginning of a dive (when it is full of air) and at the end of a dive (when it no longer contains any air).

41. (III) If an object floats in water, its density can be determined by tying a sinker to it so that both the object and the sinker are submerged. Show that the specific gravity is given by \( w/(w_1 - w_2) \), where \( w \) is the weight of the object alone in air, \( w_1 \) is the apparent weight when a sinker is tied to it and the sinker only is submerged, and \( w_2 \) is the apparent weight when both the object and the sinker are submerged.

42. (III) A 3.25-kg piece of wood (SG = 0.50) floats on water. What minimum mass of lead, hung from the wood by a string, will cause it to sink?

13–8 to 13–10 Fluid Flow, Bernoulli’s Equation

43. (I) A 15-cm-radius air duct is used to replenish the air of a room 8.2 m \( \times \) 5.0 m \( \times \) 3.5 m every 12 min. How fast does the air flow in the duct?

44. (I) Using the data of Example 13–13, calculate the average speed of blood flow in the major arteries of the body which have a total cross-sectional area of about 2.0 cm\(^2\).

45. (I) How fast does water flow from a hole at the bottom of a very wide, 5.3-m-deep storage tank filled with water? Ignore viscosity.

46. (II) A fish tank has dimensions 36 cm wide by 1.0 m long by 0.50 m high. If the filter should process all the water in the tank once every 4.0 h, what should the flow speed be in the 3.0-cm-diameter input tube for the filter?

47. (II) What gauge pressure in the water mains is necessary if a firehose is to spray water to a height of 18 m?

48. (II) A \( \frac{3}{8}\)-in. (inside) diameter garden hose is used to fill a round swimming pool 6.1 m in diameter. How long will it take to fill the pool to a depth of 1.2 m if water flows from the hose at a speed of 0.40 m/s?

49. (II) A 180-km/h wind blowing over the flat roof of a house causes the roof to lift off the house. If the house is 6.2 m \( \times \) 12.4 m in size, estimate the weight of the roof. Assume the roof is not nailed down.

50. (II) A 6.0-cm-diameter horizontal pipe gradually narrows to 4.5 cm. When water flows through this pipe at a certain rate, the gauge pressure in these two sections is 32.0 kPa and 24.0 kPa, respectively. What is the volume rate of flow?

51. (II) Estimate the air pressure inside a category 5 hurricane, where the wind speed is 300 km/h (Fig. 13–53).

52. (II) What is the lift (in newtons) due to Bernoulli’s principle on a wing of area 88 m\(^2\) if the air passes over the top and bottom surfaces at speeds of 280 m/s and 150 m/s, respectively?

53. (II) Show that the power needed to drive a fluid through a pipe with uniform cross-section is equal to the volume rate of flow, \( Q \), times the pressure difference, \( P_1 - P_2 \).

54. (II) Water at a gauge pressure of 3.8 atm at street level flows into an office building at a speed of 0.68 m/s through a pipe 5.0 cm in diameter. The pipe tapers down to 2.8 cm in diameter by the top floor, 18 m above (Fig. 13–54), where the faucet has been left open. Calculate the flow velocity and the gauge pressure in the pipe on the top floor. Assume no branch pipes and ignore viscosity.

55. (II) In Fig. 13–55, take into account the speed of the top surface of the tank and show that the speed of fluid leaving the opening at the bottom is

\[
v_1 = \sqrt{\frac{2gh}{(1 - A_1/A_2)}},
\]

where \( h = y_2 - y_1 \), and \( A_1 \) and \( A_2 \) are the areas of the opening and of the top surface, respectively. Assume \( A_1 \ll A_2 \) so that the flow remains nearly steady and laminar.

56. (II) Suppose the top surface of the vessel in Fig. 13–55 is subjected to an external gauge pressure \( P_2 \). (a) Derive a formula for the speed, \( v_1 \), at which the liquid flows from the opening at the bottom into atmospheric pressure, \( P_0 \). Assume the velocity of the liquid surface, \( v_2 \), is approximately zero. (b) If \( P_2 = 0.85 \text{ atm} \) and \( y_2 - y_1 = 2.4 \text{ m} \), determine \( v_1 \) for water.

57. (II) You are watering your lawn with a hose when you put your finger over the hose opening to increase the distance the water reaches. If you are pointing the hose at the same angle, and the distance the water reaches increases by a factor of 4, what fraction of the hose opening did you block?
94. A bucket of water is accelerated upward at 1.8 g. What is the buoyant force on a 3.0-kg granite rock (SG = 2.7) submerged in the water? Will the rock float? Why or why not?

95. The stream of water from a faucet decreases in diameter as it falls (Fig. 13–58). Derive an equation for the diameter of the stream as a function of the distance y below the faucet, given that the water has speed \( v_0 \) when it leaves the faucet, whose diameter is \( d \).

**FIGURE 13–58** Problem 95.
Water coming from a faucet.

96. You need to siphon water from a clogged sink. The sink has an area of 0.38 m\(^2\) and is filled to a height of 4.0 cm. Your siphon tube rises 45 cm above the bottom of the sink and then descends 85 cm to a pail as shown in Fig. 13–59. The siphon tube has a diameter of 2.0 cm.

(a) Assuming that the water level in the sink has almost zero velocity, estimate the water velocity when it enters the pail.

(b) Estimate how long it will take to empty the sink.

**FIGURE 13–59**
Problem 96.

97. An airplane has a mass of \( 1.7 \times 10^4 \) kg, and the air flows past the lower surface of the wings at 95 m/s. If the wings have a surface area of 1200 m\(^2\), how fast must the air flow over the upper surface of the wing if the airplane is to stay in the air?

98. A drinking fountain shoots water about 14 cm up in the air from a nozzle of diameter 0.60 cm. The pump at the base of the unit (1.1 m below the nozzle) pushes water into a 1.2-cm-diameter supply pipe that goes up to the nozzle. What gauge pressure does the pump have to provide? Ignore the viscosity; your answer will therefore be an underestimate.

99. A hurricane-force wind of 200 km/h blows across the face of a storefront window. Estimate the force on the 2.0 m \( \times \) 3.0 m window due to the difference in air pressure inside and outside the window. Assume the store is airtight so the inside pressure remains at 1.0 atm. (This is why you should not tightly seal a building in preparation for a hurricane).

100. Blood from an animal is placed in a bottle 1.30 m above a 3.8-cm-long needle, of inside diameter 0.40 mm, from which it flows at a rate of 4.1 cm\(^3\)/min. What is the viscosity of this blood?

101. Three forces act significantly on a freely floating filled balloon: gravity, air resistance (drag), and buoyant force. Consider a spherical helium-filled balloon of radius \( r \) = 15 cm rising upward through air and \( m = 2.8 \) g is the mass of the (deflated) balloon. For all speeds \( v \), except the very slowest ones, the air past a rising balloon is turbulent, and the drag force is given by the relation

\[
F_D = \frac{1}{2} C_D \rho \pi r^2 v^2
\]

where the constant \( C_D = 0.47 \) is the “drag coefficient” of a smooth sphere of radius \( r \). If this balloon is released it will accelerate very quickly (in a few tenths of a second) to its terminal velocity \( v_T \), where the buoyancy force is cancelled by the drag force and the balloon’s total acceleration is zero. Assuming the balloon’s acceleration takes place in a negligibly small amount of time and distance, how long does it take for a released balloon to rise a distance \( h = 12 \) m?

*102. If cholesterol buildup reduces the diameter of an artery by 15%, by what % will the blood flow rate be reduced, assuming the same pressure difference?*

103. A two-component model used to determine percent fat in a human body assumes that a fraction \( f \) of the body’s total mass \( m \) is composed of fat with a density of 0.90 g/cm\(^3\), and that the remaining mass of the body is composed of fat-free tissue with a density of 1.1 g/cm\(^3\). If the specific gravity of the entire body’s density is 1.0, what percent body fat (\( = f \times 100 \)) is given by

\[
\% \text{ Body fat} = \frac{495}{X} - 450.
\]

*Numerical/Computer*

*104. (III) Air pressure decreases with altitude. The following table shows the air pressure at different altitudes. Show how the air pressure changes with altitude. (b) Determine the best-fit quadratic equation that describes how the air pressure changes with altitude. (c) Use each fit to find the air pressure at the summit of the mountain K2 at 8611 m.*

<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>Pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>101.3</td>
</tr>
<tr>
<td>1000</td>
<td>89.88</td>
</tr>
<tr>
<td>2000</td>
<td>79.50</td>
</tr>
<tr>
<td>3000</td>
<td>70.12</td>
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<tr>
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<td>61.66</td>
</tr>
<tr>
<td>5000</td>
<td>54.05</td>
</tr>
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<td>9000</td>
<td>30.80</td>
</tr>
<tr>
<td>10,000</td>
<td>26.50</td>
</tr>
</tbody>
</table>

(a) Determine the best-fit quadratic equation that describes how the air pressure changes with altitude. (b) Determine the best-fit exponential equation that describes how the air pressure changes with altitude. (c) Use each fit to find the air pressure at the summit of the mountain K2 at 8611 m.