Chapter 13 Fluids

PHYS-102

Conceptual 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.

No. If one material has a higher density, it can either be that, yes, it's heavier, but it could also be because they are packed closer together (less volume). Symbolic relationship of mass, density, and volume: $\rho = \frac{m}{V}$

8. Will an ice cube float in a glass of alcohol? Why or why not?

Alcohol is less dense than water so no. In order to float, the ice cube would have to displace a weight of alcohol = to its own weight; however, given that alcohol is less dense, this is impossible.

9. A submerged can of Coke® will sink, but a can of Diet Coke® will float. (Try it!) Explain.

As a baseline, all carbonated drinks hace a gas dissolved in them so their desnity is less than water causing them to float. However, normal Coke also has a bunch of sugar dissolved in it which increases density causing it to sink. On the other hand, Diet Coke has no sugar which, with only the gas dissolved in it, will float.

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.

As the weather balloon rises into the upper atmosphere, atmospheric pressure on it decreases, allowing the balloon to expand as the gas inside it expands. If filled to max, the balloon would burst shortly after take-off.

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
Question 17.

The papers will move toward each other. When you blow between the sheets of paper, you reduce the air pressure between them (Bernoulli's principle). The greater air pressure on the other side of each sheet will push the sheets toward each other.

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

As the water falls, it speeds up due to gravity. Because the volume flow rate ($Q = A\vec{v}$) must remain constant, the faster moving water's cross-sectional area must be smaller.

FIGURE 13–46
Question 18. Water coming from a faucet.

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

As the train travels, it pulls some air towards it Combine this with the lower air pressure around it because of its large velocity creating a force pulling toward the train from "high-pressure outer" to "low-pressure inner", $\therefore$ yes it can.

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

Taking off into the wind increases the velocity of the plane relative to the air, an important factor in the creation of lift. The plane will be able to take off with a slower ground speed, and a shorter runway distance

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

Due to the air moving fast outside the car, due to Bernoulli's Principle, the air pressure in the car will be greater than that of outside the car. $\therefore$ The air will try traveling outside the car causing the top to bulge out.

24. Roofs of houses are sometimes "blown" off (or are they pushed off?) during a tornado or hurricane. Explain using Bernoulli's principle.

Typically, the inside vs. outdoor air pressure is usually the same. However, at the event of a tornado or hurricane, the air pressure may suddenly drop outside causing the indoor air pressure to "push" the roof off.

Problems

13-2 Density and Specific Gravity

1. The approximate volume of the granite monolith known as El Capitan in Yosemite National Park (Fig. 13–47) is about $10^8\ m^3$. What is its approximate mass?

FIGURE 13–47 Problem 1.

The density of grantite is $\rho = 2.7 \times 10^3 \frac{kg}{m^3}$

$$m = \rho V$$
$$m = (2.7 \times 10^3 \frac{kg}{m^3})(10^8 m^3)$$
$$m \approx 2.7 \times 10^{11} kg$$

2. What is the approximate mass of air in a living room $5.6m \times 3.8m \times 2.8m$?

$$V = (5.6m)(3.8m)(2.8m)$$
$$V = 59.584m^3 \approx 60m^3$$

$$\rho_{air} = 1.29 \frac{kg}{m^3}$$

$$\therefore m = \rho V = (1.29 \frac{kg}{m^3})(60m^3)$$
$$m \approx 77\ kg$$

3. If you tried to smuggle gold bricks by filling your backpack, whose dimensions are $56cm \times 28cm \times 22cm$, what would its mass be?

The density of gold is $\rho_{gold} = 19.3 \times 10^3 \dfrac{kg}{m^3}$

$$V = (0.56m)(0.28m)(0.22m)$$
$$V \approx 0.034m^3 \ or \ 3.4 \times 10^{-2}m^3$$

$$\therefore m = \rho V = (19.3 \times 10^3 \frac{kg}{m^3})(3.4 \times 10^-2m^3)$$
$$m \approx 670 \ kg$$

13-3 to 13-6 Pressure; Pascal's Principle

9. 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).

a.

$$P = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$

The force would be $\frac{1}{4}$ the weight of the chair since it is standing on just one leg

$$P = \frac{\frac{1}{4}mg}{A}$$
$$P = \frac{\frac{1}{4}(66\ kg)(9.8\frac{m}{s^2})}{0.00020\ m^2}$$
$$P \approx 808500\frac{N}{m^2}$$

b.

$$P = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$
$$P = \frac{mg}{A}$$
$$P = \frac{(1300\ kg)(9.8\frac{m}{s^2})}{8m^2}$$
$$P \approx 1593\frac{N}{m^2}$$

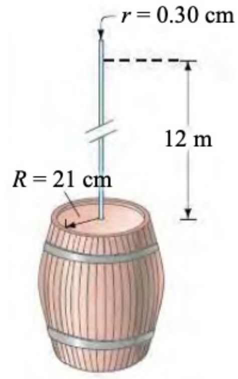
14. The gauge pressure in each of the four tires of an automobile is 240 kPa. If each tire has a "footprint" of 220 cm^2, estimate the mass of the car.

$$P = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$
$$P = \frac{mg}{A}$$
$$m = \frac{PA}{g}$$

Since each of the tires is exerting a pressure within their respective area, this would be $4PA$

$$m = \frac{4PA}{g} = \frac{4(240000\frac{\frac{kg\cdot m}{s^2}}{m^2})(0.022m^2)}{9.8\frac{m}{s^2}}$$
$$m = 2155\ kg \approx 2200\ kg$$

18. 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.



a. We use the definition of density and notice the shape of the tube is a cylinder

$$m = \rho V = \rho(\pi r^2 h)$$
$$m = (1000\frac{kg}{m^3})(\pi)(0.003m)^2(12m)$$
$$m \approx 0.34\ kg$$

b. The net force exerted on the lid is the gauge pressure of the water times the area of the lid. The gauge pressure is found from Eq. 13-3.

$$F = PA \quad (P = \rho g h)(A = \pi r^2)$$
$$F = \rho g h \pi r^2$$
$$F = (1000\frac{kg}{m^3})(9.8\frac{m}{s^2})(12m)(\pi)(0.21m)^2$$
$$F \approx 1.6 \times 10^4\ N$$

13-7 Buoyancy and Archimedes' Principle

27. A geologist finds that a Moon rock whose mass is 9.28 kg has an apparent mass of 6.18 kg when submerged in water. What is the density of the rock?

Recall, Archimedes' Principle states that the buoyant force is equal to the weight of the fluid displaced

$$\begin{aligned}
F_B &= \Delta\vec{w} \\
F_B &= [(9.28\ kg)(9.8\frac{m}{s^2})] - [(6.18\ kg)(9.8\frac{m}{s^2})] \\
F_B &\approx 30.38\ N
\end{aligned}$$

We can equate the buoyant force we found to the weight of the displaced fluid

$$\begin{aligned}
F_B &= mg = \rho_{H_2O}V_{rock}g = \rho_{H_2O}(\frac{m_{rock}}{\rho_{rock}})g \\
F_B &= \rho_{H_2O}(\frac{m_{rock}}{\rho_{rock}})g
\end{aligned}$$

so,

$$\begin{aligned}
\rho_{rock} &= \frac{\rho_{H_2O}m_{rock}g}{F_B} \\
\rho_{rock} &= \frac{(1000\ \frac{kg}{m^3})(9.28\ kg)(9.8\frac{m}{s^2})}{30.38\frac{kg\cdot m}{s^2}} \\
\rho_{rock} &\approx 2994\frac{kg}{m^3}
\end{aligned}$$

35. 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?

The buoyant force on the ice is equal to the weight of the ice, since it floats.

$$\begin{aligned}
F_B &= \vec{w}_{ice} \\
m_{sea}g &= m_{ice}g \\
\rho_{sea}V_{sea} &= \rho_{ice}V_{ice}
\end{aligned}$$

Let SG = Specific Gravity

$$\begin{aligned}
SG_{sea}\rho_{sea}V_{sea} &= SG_{ice}\rho_{ice}V_{ice} \\
V_{sub.\ ice} &= \frac{SG_{ice}}{SG_{sea}}V_{ice} \\
V_{sub.} &= \frac{0.917}{1.025}V_{ice} \\
V_{sub.\ ice} &\approx 0.895V_{ice} \\
V_{above} &= V_{ice} - V_{sub.\ ice} = 0.105 \\
V_{above} &\approx 10.5\%
\end{aligned}$$

13-8 to 13-10 Fluid Flow, Bernoulli's Equation

45. 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.

Using Torricelli's Theorem,

$$\vec{v}_1 = \sqrt{2g\Delta y}$$
$$\vec{v}_1 = \sqrt{2(9.8\frac{m}{s^2})(5.3m)}$$
$$\vec{v}_1 \approx 10.19\frac{m}{s} \approx 10\frac{m}{s}$$

49. 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 $6.2m \times 12.4m$ in size, estimate the weight of the roof. Assume the roof is not nailed down.

First converting the given information: $\vec{v} = (\frac{180km}{1h})(\frac{1h}{3600s})(\frac{1000m}{1km}) = 50\frac{m}{s}$ and $A = 77m^2$

Using Bernoulli's Equation,

$$P_{inside} + \frac{1}{2}\rho\vec{v}_{inside}^2 + \rho g y_{inside} = P_{outside} + \frac{1}{2}\rho\vec{v}_{outside}^2 + \rho g y_{outside}$$

We are left with, (assuming no velocity in the house and no Δy.)

$$P_{in} - P_{out} = \frac{1}{2}\rho\vec{v}_{out}^2$$

We see that $P_{in} = P_{out}$ can be rewritten as ΔP

Using Pascal's Principle, (net force on the roof due to air is the difference in pressure on the two sides of the roof $\times$ the area of the roof)

$$\Delta P = \frac{F_{air}}{A_{roof}}$$
$$F_{air} = \Delta P A_{roof}$$
$$F_{air} = \frac{1}{2}\rho_{air}\vec{v}_{out}^2 A_{roof}$$
$$F_{air} = \frac{1}{2}(1.29\frac{kg}{m^3})(50\frac{m}{s})^2(77m^2)$$
$$F_{air} \approx 1.2 \times 10^5\ N$$

52. 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?

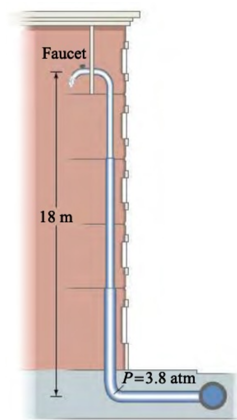
Using Bernoulli's Equation,

$$P_{top} + \frac{1}{2}\rho\vec{v}_{top}^2 + \rho g y_{top} = P_{bot} + \frac{1}{2}\rho\vec{v}_{bot}^2 + \rho g y_{bot}$$
$$P_{bot} - P_{top} = \frac{1}{2}\rho(\vec{v}_{top}^2 - \vec{v}_{bot}^2)$$

Using Pascal's Principle,

$$
\begin{aligned}
P_{bot} - P_{top} &= \frac{F_{lift}}{A_{wing}} \\
F_{lift} &= \Delta P A_{wing} \\
F_{lift} &= \frac{1}{2}\rho(\vec{v}_{top}^2 - \vec{v}_{bot}^2)A_{wing} \\
F_{lift} &= \frac{1}{2}(1.29\frac{kg}{m^3})\left[(280\frac{m}{s})^2 - (150\frac{m}{s})^2\right](88m^2) \\
F_{lift} &\approx 3.2 \times 10^6\ N
\end{aligned}
$$

54. 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.



$A_1\vec{v}_1 = A_2\vec{v}_2$ continuity of flow rate

$$
\begin{aligned}
\vec{v}_2 &= \frac{A_1}{A_2}\vec{v}_1 \\
\vec{v}_2 &= \frac{\pi(0.05m)^2}{\pi(0.028m)^2}(0.68\frac{m}{s}) \\
\vec{v}_2 &\approx 2.17\frac{m}{s} \quad \text{flow velocity}
\end{aligned}
$$

Using Bernoulli's Equation,

$$P_1 + \frac{1}{2}\rho_{H_2O}\vec{v}_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho_{H_2O}\vec{v}_2^2 + \rho g y_2$$

$$P_2 = P_1 + \frac{1}{2}\rho(\vec{v}_1^2 - \vec{v}_2^2) - \rho g y_2$$

$$P_2 = (3.8atm)(\frac{1.013 \times 10^5 \frac{N}{m^2}}{1atm}) + \frac{1}{2}(1000\frac{kg}{m^3})\left[(0.68\frac{m}{s})^2 - (2.17\frac{m}{s})^2\right] - (1000\frac{kg}{m^3})(9.8\frac{m}{s^2})(-18m)$$

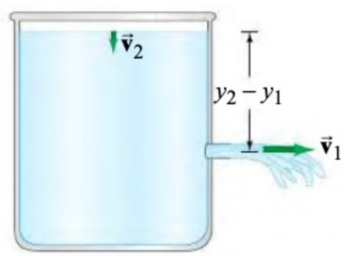
$$P_2 \approx 2.06410^5\frac{N}{m^2}\left(\frac{1atm}{1.013 \times 10^5\frac{N}{m^2}}\right)$$

$$P_2 \approx 2.0atm \text{ gauge pressure}$$

55. n 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

$$v_1 = \sqrt{\frac{2gh}{(1 - \frac{A_1^2}{A_2^2})}}$$

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 $A_1 << A_2$ so that the flow remains nearly steady and laminar



$A_1\vec{v}_1 = A_2\vec{v}_2$ continuity of flow rate

$$\vec{v}_2 = \frac{A_1}{A_2}\vec{v}_1$$

Using Bernoulli's Equation,

$$P_1 + \frac{1}{2}\rho\vec{v}_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho\vec{v}_2^2 + \rho g y_2$$

$P_1 = P_2 = P_{atmosphere}$

$$\frac{1}{2}\rho\vec{v}_1^2 - \frac{1}{2}\rho\vec{v}_2^2 = \rho g y_2 - \rho g y_1$$
$$\frac{1}{2}\rho(\vec{v}_1^2 - \vec{v}_2^2) = \rho g(y_2 - y_1)$$
$$\vec{v}_1^2 - \vec{v}_2^2 = 2gh$$
$$\vec{v}_1^2 - \left(\frac{A_1}{A_2}\vec{v}_1\right)^2 = 2gh$$
$$\vec{v}_1^2 - \left(\frac{A_1^2}{A_2^2}\vec{v}_1^2\right) = 2gh$$
$$\vec{v}_1^2\left(1 - \frac{A_1^2}{A_2^2}\right) = 2gh$$
$$\vec{v}_1 = \sqrt{\frac{2gh}{1 - \frac{A_1^2}{A_2^2}}}$$

General Problems

97. An airplane has a mass of 1.7×10^6 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 plane is to stay in the air?

$$\begin{aligned}
F_{top} + mg &= F_{bot} \\
P_{top}A + mg &= P_{bot}A \\
(P_{bot} - P_{top}) &= \frac{mg}{A}
\end{aligned}$$

Using Bernoulli's Equation,

$$\begin{aligned}
P_0 + P_{bot} + \frac{1}{2}\rho\vec{v}^2_{bot} + \rho g y_{bot} &= P_0 + P_{top} + \frac{1}{2}\rho\vec{v}^2_{top} + \rho g y_{top} \\
P_{bot} - P_{top} + \frac{1}{2}\rho\vec{v}^2_{bot} &= \frac{1}{2}\rho\vec{v}^2_{top} \\
\vec{v}^2_{top} &= \frac{2(P_{bot} - P_{top})}{\rho} + \vec{v}^2_{bot} \\
\vec{v}_{top} &= \sqrt{\frac{2(P_{bot} - P_{top})}{\rho} + \vec{v}^2_{bot}} \\
\vec{v}_{top} &= \sqrt{\frac{2mg}{\rho A} + \vec{v}^2_{bot}} \\
\vec{v}_{top} &= \sqrt{\frac{2(1.7 \times 10^6\ kg)(9.8\frac{m}{s^2})}{(1.29\frac{kg}{m^3})(1200m^2)} + (95\frac{m}{s})^2} \\
\vec{v}_{top} &\approx 174.8\frac{m}{s} \approx 170\frac{m}{s}
\end{aligned}$$