Welcome back, Bill Wiecking

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Chapter 14: Fluid Mechanics

Conceptual problems

14.C.1 (5.00) You are standing in your driveway. You measure the pressure inside a bicycle tire with your tire gauge and get a reading of 60 psi. You then don your space suit, take the tire into outer space and repeat the measurement, this time getting a reading of 75 psi. Air was neither added to nor removed from the tire, and its temperature did not change. What explains this discrepancy?

14.C.2 (5.00) Scuba divers are instructed to exhale slowly but continuously as they rise to the surface in an emergency situation (such as losing a tank). How is it possible for them to do this?

14.C.4 (7.00) Lurid science fiction stories sometimes dramatize a deep-space event known as "explosive decompression": The villain ejects an innocent victim, without a spacesuit, from a spaceship's airlock, and the victim's eyes bug out and then he or she explodes. Such an event is enacted on the nearly airless surface of Mars in the Schwarzenegger film *Total Recall*. These scenes are inaccurate, but if you are suddenly ejected into space, you should be concerned about the danger of a sudden expansion of a substance in your body. What is this substance?

14.C.6 (5.00) A barometer is constructed using a closed-end tube containing a vacuum above a column of mercury, as described in the textbook. On a certain day, the pressure exerted solely by this column of mercury at the bottom of the tube is 1.024×10^5 Pa. Check each of the following quantities that are equal to this measurement.

- [ ] Absolute pressure at bottom
- [ ] Atmospheric pressure

14.C.7 **(7.00)** In a legendary and probably apocryphal story, a physics professor poses a question on a test, "How would you use a barometer to determine the height of a tall building?" In the story, a brilliant but rebellious physics student artfully avoids giving the "correct" answer but gives instead a long list of plausible alternative answers, including the following...

The kinematic answer: I would drop the barometer from the top of the building and time its fall. The equation $\Delta y = v_i t + (1/2)at^2$ would then tell me the building's height.

The pendulum answer: I would tie the barometer to a long string, lift it slightly above the ground, and swing it from the top of the building. The equation

would then tell me the building's height.

The geometric answer: On a sunny day, I would measure the height of the barometer, the length of its shadow, and the length of the building's shadow. I would then use similar triangles to compute the building's height.

The human-engineering answer: I would go to the building manager and say, "I have here a fine scientific instrument that I will give to you if you tell me the building's height!"

What answer was the professor really looking for?

14.C.8 **(5.00)** An empty boat is placed in a freshwater lake and a mark is painted on the hull at the waterline, a line corresponding to the surface of the water when the vessel is floating upright. The same boat is then transported to Jupiter, and placed into a pool of fresh water that has been prepared just for this comparison experiment. The acceleration due to gravity on Jupiter is 2.6 times what it is on Earth. The new waterline is noted on Jupiter. Compared to the waterline mark on Earth, where is the new waterline mark located on the hull of the boat? Ignore atmospheric effects.

The new waterline mark is ________ on the hull.

14.C.9 **(5.00)** An empty boat is placed in a freshwater lake and a mark is painted on the hull at the waterline, a line corresponding to the surface of the water when the vessel is floating upright. The boat is then transported to the Dead Sea, where the liquid density is about 1.2 times that of fresh water due to the high concentration of salts. A waterline mark is noted in the Dead Sea. Compared to the first waterline mark, where is the new waterline mark located on the hull of the boat?

The new waterline mark is [ ] on the hull.

14.C.10 **(5.00)** You hold a ping-pong ball and a steel ball bearing of the same diameter so that they are submerged underwater. Which one experiences the greater buoyant force? Explain your answer.

[ ].

14.C.11 **(5.00)** A ping-pong ball and a steel ball bearing of the same diameter are thrown into a swimming pool. The ball floats, while the bearing sinks. Which one experiences the greater buoyant force? Explain your answer.

[ ]

14.C.12 **(7.00)** A boat carrying a load of bricks is floating in a canal lock. One of the crew members throws a brick overboard, and it sinks. Does the level of the water in the lock rise or fall? Explain your answer.

○ It rises ○ It falls

14.C.14 **(7.00)** The string on a helium balloon is tied to the floor of a car. The car then makes a right turn. While the car is turning, how does the balloon sway according to observers inside the car? The windows are closed so there is no connection to the air outside.

The balloon [ ]

14.C.15 **(5.00)** Susie is out fishing on a calm, sunny day. She hooks an old tire that is resting on the lake bottom, and hauls it into her boat. In principle, how does the water level of the lake change?

The lake's water level [ ]

14.C.18 **(5.00)** People are warned not to stand near open doors on airplanes in flight, because they can get "sucked" out of the door. Explain how this might happen.

Section 2: Density

14.2.3 **(5.00)** If you have ever toured a facility (such as a cyclotron laboratory) where people have to be protected against radiation, there may have been lead bricks lying around, and you may have been given the opportunity to heft one. It is a surprising experience. The dimensions of a standard brick are 9.2 cm × 5.7 cm × 20 cm, and the density of lead is 11,300 kg/m^3. (a) What is the mass of a (standard) lead brick? (b) What is the weight of the brick, in pounds?

(a) ____ kg
(b) ____ lb

14.2.4 **(5.00)** In the opening sequence of the movie, *Raiders of the Lost Ark*, the intrepid explorer Indiana Jones deftly swipes a golden idol from a Mayan temple, instantly replacing it with a bag of sand of the same size to neutralize the ancient weight-based booby trap protecting it. (a) The density of gold is 19,300 kg/m$^{3.}$ If the idol's mass is 11.3 kg and it is solid gold, calculate its volume. (b) The density of silica sand is 1220 kg/m^3. What is the mass of a sandbag of equal volume? (c) Is the scene realistic?

(a) ____ m^3
(b) ____ kg
(c) ◯ Yes ◯ No

Section 3: Pressure

14.3.1 **(5.00)** (a) A fashionable spike heel has an area of 0.878 cm^2. When a 61.4 kg woman walking in this shoe sets her full weight down on the heel, what is the pressure it exerts on the floor? (b) The heel of a "sensible" shoe has an area of 38.3 cm^2. When the same woman sets her weight on this heel, what is the pressure?

(a) ____ Pa
(b) ____ Pa

14.3.5 **(5.00)** An advertisement for a certain portable vacuum cleaner shows off its power with a photograph of the vacuum-cleaner wand suspending a bowling ball by the strength of its suction. The vacuum cleaner can maintain a moderate vacuum inside the apparatus at an absolute pressure of 3.53×10^4 Pa (against an outside atmospheric pressure of 1.01×10^5 Pa) when the intake wand is closed. The wand is a hollow metal cylinder with an inside diameter of 3.19 cm. What is the weight of the heaviest ball the vacuum cleaner can lift?

N

14.3.6 **(7.00)** Water is generally said to be nearly incompressible. The deepest part of the ocean abyss lies at the bottom of the Marianas trench off the Philippines, at a depth of nearly eleven kilometers. At a depth of 10.0 km, the measured water pressure is an incredible 103 MPa (that's **mega**pascals). (a) If the density of seawater is 1030 kg/m^3 at the surface of the ocean, and its bulk modulus is $B = 2.34\times10^9$ N/m^2, what is its density at a depth of 10.0 km? (Hint: Use the *volume stress* equation from the study of elasticity, $\Delta P = -B\,(\Delta V/V_i)$, where the object undergoing the stress has an initial volume V_i, and experiences a change in volume, ΔV, when the pressure changes by ΔP.) (b) By what factor does the density increase?

(a) kg/m^3

(b)

Section 4: Pressure and fluids

14.4.1 **(5.00)** Seawater has a density of 1030 kg/m^3. The Marianas Trench is a deep undersea canyon in the Pacific Ocean off the Philippines. Assuming the seawater is incompressible, and ignoring the contribution of atmospheric pressure, what is the pressure in this trench (a) at a depth of 1.00 km? (b) at a depth of 5.00 km? (c) at a depth of 10.0 km? (Empirically measured pressures are a little larger than those given by these calculations because seawater compresses slightly at great depths.)

(a) Pa

(b) Pa

(c) Pa

14.4.2 **(5.00)** A photograph in the text in Section 14.4 shows how a Styrofoam® cup gets crushed by great pressure deep under the surface of the sea. Before the cup was crushed, experimenters used colored pens to write data on it, including the absolute pressure (3288 psi) at the depth to which they planned to submerge the cup. (You can inspect this data by right-clicking at a spot on the photograph and selecting Zoom In from the popup menu that appears.) At what depth below the ocean's surface is the pressure equal to 3288 psi? Use the value 1030 kg/m^3 for the density of seawater.

m

14.4.5 **(5.00)** To supply the plumbing system of a New York office building, water needs to be pumped to a tank on the roof, where its height will provide a "head" of pressure for all the floors. The vertical height between the basement pump and the level of the water in the tank is 95.3 m. What gauge pressure does the pump have to apply to the water to get it up to the tank?

Pa

Section 6: Sample problem: pressure at the bottom of a lake

14.6.1 **(5.00)** In the movie *Creature from the Black Lagoon*, the depth of the freshwater lagoon at its muddy and inscrutable bottom where the Creature lurks is 15.2 m. (a) What is the gauge pressure at the bottom of the lagoon? (b) What is the absolute pressure at the bottom of the lagoon? (c) Who played the Creature in this classic 1954 horror film?

(a) Pa

(b) Pa

(c)

Section 7: Physics at work: measuring pressure

14.7.1 **(5.00)** The gauge pressure at the bottom of a pint of beer, at a depth of 14.6 cm, is 1450 Pa. (a) What is the density of the beer? (b) What is the absolute pressure at the bottom of the pint?

(a) kg/m^3

(b) Pa

Section 9: Archimedes' principle

14.9.1 **(5.00)** The sizes of ships are commonly expressed in "tons displaced". If a naval vessel displaces *W* tons, this means it displaces that weight of water. What is the volume of the water displaced by this ship? Use the fact that 1 ton is equal to 8.90×10^3 N, and take the density of seawater to be 1030 kg/m^3.

m^3

Section 10: Sample problem: buoyancy in water

14.10.1 **(5.00)** You are fishing off a bridge. Suddenly you feel a tug on the vertical fishing line. Elated, you begin hauling in your catch at constant speed. The creature rears its head above the water and it is...a rubber tire! (a) If the tire is made entirely of hard rubber, with volume 6800 cm^3, and density 1190 kg/m^3, then what is the tension on your fishing line **after** you pull the tire out of the water? Assume that the tire is made entirely of rubber, it is a tire (not an inner tube), and it is punctured so you are not pulling up any water. (b) What is the tension on your fishing line **before** you pull the tire out of the water? Ignore any drag forces from the water.

(a) ____ N
(b) ____ N

Section 12: Sample problem: buoyancy in air

14.12.1 **(5.00)** In the motion picture *Danny Deckchair*, based on an actual event, a man attaches 42 helium-filled weather balloons to an aluminum deck chair, steps in, and takes off to experience a series of adventures. (Don't try this at home - or anywhere else!) The weight of the man plus the chair plus the balloons is *W* N. Each balloon is a sphere 1.60 meters in diameter. The density of air at sea level and 15°C is 1.23 kg/m^3. What is the net upward force on Danny and his vehicle right after he leaves the ground? Ignore the volume of the man and of the deckchair.

____ N

14.12.2 **(7.00)** The Von Hindenburg airship was a famous lighter-than-air vehicle that met a fiery end at its moorage in Lakehurst, New Jersey, in 1937. Called a "dirigible" because, unlike traditional hot-air balloons, it was "directable," the craft used hydrogen, the lightest gas, for buoyancy. The hydrogen capacity of the craft was 200,000 m^3, and together with its cabin, access spaces, and navigation surfaces it displaced 205,000 m^3 of air. Its fully-loaded weight, including hydrogen gas, engines, diesel fuel, crew, 72 passengers, and 76 kg of luxury items such as caviar, was 1.95×10^5 kg. When the ship was safely docked, it was held down by two angled lines, each 20.6 meters long, at a height of 14.2 m above their attachment points on two mooring towers. What was the tension on each mooring line? Assume that the density of air is 1.23 kg/m^3. (Of course, hydrogen is not only the lightest gas, it is also highly flammable, which makes it risky to use in airships.)

____ N

Section 13: Sample problem: buoyancy of an iceberg

14.13.1 **(5.00)** A shipwrecked mariner is stranded on a desert island. He seals a plea for rescue in a 1.00 liter bottle, corks it up, and throws it into the sea. If the mass of the bottle, plus the message and the air inside, is *m* kg, what percentage of the volume of the bottle is submerged as it bobs away? Take the density of seawater to be 1030 kg/m^3. For simplicity, assume the bottle and its contents have a uniform density.

%

Section 14: Interactive problem: Eureka!

14.14.1 **(5.00)** Use the information given in the interactive problem in Section 14.14 to determine which crown is not made of pure gold. Confirm your answer by using the simulation.

- The 3.20 kg crown
- The 2.70 kg crown

Section 15: Pascal's principle

14.15.1 **(5.00)** An automobile having a mass of 1750 kg is placed on a hydraulic lift in a garage. The piston lifting the car is *D* m in diameter. A mechanic attaches a pumping mechanism to a much smaller piston, 1.50 cm in diameter, which is connected by hydraulic lines to the lift. She pumps the handle up and down, slowly lifting the car. What is the force exerted on the small piston during each downward stroke?

N

Section 18: Fluid continuity

14.18.1 **(5.00)** An incompressible fluid flows through a circular pipe at a speed of 15.0 m/s. The radius of the pipe is 5.00 cm. There is a constriction of the pipe where the radius is only 3.20 cm. How fast must the fluid flow through the constricted region?

m/s

Section 19: Sample problem: water flowing from a tap

14.19.1 **(7.00)** The illustration shows water flowing from a tap. The diameter of the end of the tap is $2R$, and the water emerges from the tap at speed v_i, subsequently falling under the acceleration due to gravity. The right-hand side of the water column is emphasized with a dark curve. Using an analysis similar to the one in the textbook, write an equation for this curve in the form $y = f(x)$. Note the orientations of the x and y axes.

Submit answer on paper.

Section 20: Bernoulli's equation

14.20.1 **(5.00)** A stream of water is flowing through the horizontal configuration shown. The speeds v_1 and v_2 are *v1* m/s and 5.35 m/s, respectively. The pressure P_2 is 7.36×10^4 Pa. What is P_1? (Hint: the numbers on the pressure dials are not correct - that would be too easy!)

Pa

Section 24: Laminar flow

14.24.2 **(5.00)** A paramedic treats an accident victim lying on the ground, transfusing her with a saline solution that has a coefficient of viscosity of $\eta = 1.002\ \mathrm{mPa\cdot s}$, and a density of $1025\ \mathrm{kg/m^3}$. The flexible plastic pouch containing the saline solution is 1.85 m above the patient's arm, the needle through which the fluid is being transfused has an inside radius of 0.15 mm and a length of 1.90 cm, and the average gauge pressure of the blood in the patient's vein is $1.33\times10^4\ \mathrm{Pa}$. (a) What is the average volume flow rate of the saline solution into the patient? (b) If this flow rate is too low, what is the first adjustment a paramedic is likely to make in the transfusion apparatus?

(a) m^3/s

(b)

- Replace the needle with a shorter one
- Use a needle with a larger diameter
- Raise the height of the saline bag

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