Physics 9, Fall 2018, Homework #7.

Due at start of class on Friday, November 2, 2018

Problems marked with (*) must include your own drawing or graph representing the problem and at least one complete sentence describing your reasoning.

Fluids problems

1*. Since this year we have too large a group for the (fun!) buoyancy lab that we did with 2016's much smaller class, let's go through that lab's calculations here. You use a force-measuring scale to measure (in ordinary air) the weight (in newtons) of a heavy dark-grey nut (you measure 3.232 N) and a lightweight shiny wedge (you measure 0.572 N). (a) What is the mass (in kilograms) of the nut? (b) What is the mass (in kilograms) of the wedge? Now you use the same force-measuring scale to measure the apparent weight (i.e. the upward force exerted by the scale from which the nut or wedge is suspended on a string) of the nut, then the wedge, when each is fully immersed in water. The upward force exerted by the scale to suspend the fully-immersed nut is 2.818 N. The upward force exerted by the scale to suspend the fully-immersed wedge is 0.362 N. (c) What is the volume (in cubic meters) of the nut? (d) What is the density of the nut? (Should match that of a well-known metal structural material.) (e) What is the volume of the wedge? (f) What is the density of the wedge? (Should match that of a strong but lightweight metal.) Now you fully immerse the nut in a "mystery fluid" and find that the upward force exerted by the scale on the nut reads 2.710 N. (g) What is the density of the mystery fluid? (Should be just a little bit more dense than water — but noticeably so.)

2*. A hydraulic jack consists of an enclosed volume of oil, into which two cylindrical pistons are inserted. The first piston has radius 2.5 mm, while the second piston has radius 75.0 mm. The larger piston supports the weight of a 950 kg car. (a) What is the force in newtons corresponding to the weight of a 950 kg car? (b) What force in newtons must I exert on the smaller piston in order to hold (or lift) the weight of the car? (In practice, the smaller piston would be replaced by an oil pump that pumps oil in or out through a narrow tube at the necessary pressure.)

3*. A horizontal water pipe narrows in inner radius from 12.8 mm to 9.50 mm. The water flows at 1.2 m/s in the wide part of the pipe. (a) How fast is the water flowing in the narrow part of the pipe? (b) Ignoring viscosity, what is the pressure difference between the wide part and the narrow part? Which part is under higher pressure?

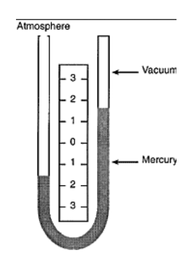
4*. Suppose that a house is 12 m wide, 14 m long, and has a flat (horizontal) roof. A storm passes through, with winds gusting to 25 m/s. (a) During a wind gust, how large is the vertical force that is trying to lift the roof off of the house? (b) How does this force compare with the weight of the roof, if the roof is made of 19 mm thick plywood, of density 720 kg/m^3? (I'm cheating somewhat by ignoring the mass of the roof shingles. And of course a real roof is held down by nails!)

5. Suppose that Ed Harris is re-making *The Abyss* and decides to equip himself to dive to 630 m below sea level. (a) What is the pressure at this depth, in pascals? (b) What is this pressure in atmospheres? (c) What is the pressure at a depth of zero meters below sea level? (Make sure your answers for (a) and (b) are not off by an atmosphere!)

6*. A lemonade dispenser is 0.75 m tall with a horizontal spigot near the bottom. It is sitting on a table that is 1.05 m tall, with the spigot at the edge of the table. A child wants to open the spigot and catch the lemonade in a cup on the ground. Assuming that the dispenser is completely full, how far from the table should the cup be placed to catch the lemonade?

7*. A firefighter carries a hose up a ladder to a height of 10.0 m, so that she can spray water onto a burning roof that is 9.00 m high. She holds the hose horizontally, and sees that the water strikes the roof 7.0 m in front of her position (i.e. horizontal component of displacement is 7.0 m). The hose is connected to a very large, pressurized chamber in the fire truck, which is sitting at ground level. What is the pressure in the large reservoir? (Ignore air resistance; don't be off by 1 atm.)

8*. Imagine a U-shaped tube filled with liquid mercury ($\rho = 13534\ \mathrm{kg/m^3}$, about 13.5$\times$ the density of water). The left end of the tube is open to atmospheric pressure ($P_{\mathrm{atm}} = 101325\ \mathrm{N/m^2}$), while the right end is evacuated ($P \approx 0$). (a) How much higher is the mercury level on the right side than on the left side? (b) A storm passes through, reducing the outside air pressure from 1.000 atm to 0.975 atm. Now how much higher is the mercury level on the right side than on the left side?



9. You are so annoyed that it takes you 12 minutes to fill up your bathtub with

the faucet fully open that you decide to replace the water pipes in your house, which all have 1.0 cm diameter, with new pipes of 2.0 cm diameter. Now how long will it take to fill the tub? (For this question, it matters that water has finite viscosity, i.e. we're no longer neglecting energy dissipation by friction. That means Bernoulli's equation, which assumed constant energy, cannot be used. Assume that the water flow is laminar and that the water pipes are cylindrical tubes. With these assumptions, you can use Poiseuille's equation, which states that the flow rate is proportional to the fourth power of the radius of the tube through which it flows. We demonstrated this effect in class, though even there we saw that the assumption of laminar (vs. tubulent) flow was not perfect.)

10*. You want water to flow through a 75 m length of garden hose, of radius 8.0 mm, at a flow rate of 1.0 liter per minute. (a) What is this flow rate in m^3/s? (b) If the water emerges from the downstream end of the hose at atmospheric pressure, what pressure is required at the upstream end of the hose, to maintain this flow rate? (Assume that the flow is laminar. The viscosity of room-temperature water is $1.01 \times 10^{-3}\ \mathrm{Pa \cdot s}$.) (c) How tall a water tower would provide the needed pressure? (Be careful not to get answers that are off by 1 atm anywhere.) For this problem, Poiseuille's equation is again relevant:

$$Q = \frac{\pi R^4\ (P_1 - P_2)}{8 \eta L}$$

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XC1*. Optional/extra-credit. A sphere of diameter 15 cm floats in water with its bottom-most point 11 cm below the water line. What is the mass of the sphere? (Hint: use calculus!)

XC2*. Optional/extra-credit. You're designing a dam to hold back a 25 m depth of water in a canyon 45 m wide. The dam will be a rectangular block of concrete ($\rho = 2300\ \mathrm{kg/m^3}$), $H = 25$ m high, $W = 45$ m wide, and of thickness T to be determined. Only static friction ($\mu_s = 0.33$) between the ground and the bottom face of the dam will hold it in place. (a) What is the pressure difference ΔP between the inside and outside of the dam, as a function of height y above the ground ($0 < y < H$)? (b) What net horizontal force on the dam does this pressure difference cause? (Hint: $\int_0^H (H-y)\mathrm{d}y = \frac{1}{2}H^2$.) (c) What is the minimum required thickness T if friction alone (with the ground beneath) will keep the dam from sliding horizontally?

XC3*. Optional/extra-credit. I want to make sure that the dam in Problem XC2 won't tip over, i.e. rotate about its outside bottom edge, under the water pressure. (a) Show that the torque caused by the pressure difference ΔP is $\frac{1}{6}\rho g W H^3$. (Hint: $\int_0^H (H-y)y\mathrm{d}y = \frac{1}{6}H^3$.) (b) To keep the dam from toppling over (rotational static equilibrium), this torque must be balanced by the torque of gravity pulling the dam's center of mass downward. A thicker dam increases both the force of gravity and gravity's lever arm about the pivot axis. What is the minimum thickness T to keep the dam from toppling over? (c) If the dam is even thicker than required, will it still be in static equilibrium about this pivot axis? (Maybe there is a third torque, so that all three add up to zero?) (d) Why do real dams tend to be thicker on the bottom than on the top?

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