Physics 9, Fall 2018, Homework #8.

Due at start of class on Friday, November 8, 2018

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

Optics problem

1*. While looking through Mazur's chapter on fluids (from the book we used last fall), I stumbled upon this amazing photo. It is intended to illustrate that in the absence of gravity, even a large volume of water remains perfectly spherical, due to surface tension. But it is also a beautiful example of a spherical lens. $\boxed{\text{(a)}}$ What sort of lens would you expect a sphere of water to form (converging or diverging)? $\boxed{\text{(b)}}$ Using the lens maker's equation, estimate the focal length f of a lens made from a spherical blob of water of radius $R = 7$ cm. Is f postive or negative? $\boxed{\text{(c)}}$ Looking at the photo, estimate the magnification of the image that you see. (To me, the image looks about half as tall as the object.) Is h_i/h_o positive or negative? $\boxed{\text{(d)}}$ Using your values of f and h_i/h_o, estimate how far away the sphere is from the astronaut's face. Is your value of d_o larger than or smaller than f? $\boxed{\text{(e)}}$ Is the image real or virtual? Is the image located between the sphere and the camera, or is the image between the sphere and the astronaut?

Figure 18.26 Astronaut Kevin Ford watches a water bubble float freely between him and the camera aboard the International Space Station. When no large gravitational force is involved, even a large volume of liquid coalesces into a spherical shape.

Fluids problems

2. Poiseuille's equation accounts for viscosity, but it assumes *laminar* flow, i.e. it no longer works once the flow becomes *turbulent*. Laminar flow follows smooth, relatively straight flow lines, while turbulent flow often swirls around in circular vortices. In class, we mentioned turbulence as something that aerodynamic vehi-

cle designs try to minimize. Turbulence matters in architecture because turbulent flow is much noisier than laminar flow. The onset of turbulence occurs when the *Reynolds number*, defined as

$$\mathrm{Re} = \frac{2r\overline{v}\rho}{\eta} ,$$

exceeds approximately 2300, where $\overline{v}$ is the average speed of the fluid, ρ is its density, η is its viscosity, and r is the radius of the tube in which the fluid is flowing. $\boxed{\text{(a)}}$ At what speed does air flow through an HVAC duct of 0.100 m radius when turbulence just begins to appear? (The viscosity of air is about 2.0×10^{-5} Pa · s.) $\boxed{\text{(b)}}$ At what speed does water (at room temperature, $\eta = 1.01 \times 10^{-3}$ Pa · s) flow through a pipe of 7.0 mm radius when turbulence first appears? $\boxed{\text{(c)}}$ If I double the pipe diameter and maintain the same **flow rate** (not same speed), will the Reynolds number go up, go down, or stay the same? (A bigger Reynolds number increases turbulence.) $\boxed{\text{(d)}}$ For a given flow rate, will a wider or narrower pipe (or duct) be quieter (due to turbulent flow or lack thereof)?

3. We learned in mechanics that in the absence of air resistance, all objects near Earth's surface fall with the same constant acceleration $g = 9.8\ \mathrm{m/s^2}$. Yet as a student I once dropped a wadded-up tissue from the top of the Eiffel Tower and watched it take *minutes* to fall 300 m to Earth. (I retrieved it from the riverbank and put it in the poubelle.) In fluids, such as air or water, frictional drag forces grow larger as speed increases: often $F_{\mathrm{drag}} \propto v$ (for laminar flow), or $F_{\mathrm{drag}} \propto v^2$ (if turbulence is present). The result is that once a falling object reaches *terminal velocity*, where the upward drag force balances the downward gravitational force, the object no longer accelerates: it continues downward at constant speed. $\boxed{\text{(a)}}$ If an object falling downward at speed v feels an upward drag force $F_{\mathrm{drag}} = bv^2$ (where b is some constant that depends on the object's size and shape and the fluid properties), what is its terminal speed v_{term}? (Write v_{term} in terms of m, g, and b.) $\boxed{\text{(b)}}$ Using your expression for v_{term}, explain how it makes sense that a ping-pong ball dropped from a rooftop takes longer to fall to Earth than a steel ball of the same size and shape.

Heat problems

4. Suppose that the insulating properties of the 100 m^2 roof of a house come mainly from an "R-49" layer of insulation. (R-49 means 49 $\frac{\mathrm{foot^2 \cdot hour \cdot {}^\circ F}}{\mathrm{Btu}}$, which in metric units is 8.6 $\frac{\mathrm{m^2 \cdot {}^\circ C}}{\mathrm{W}}$.) $\boxed{\text{(a)}}$ If the inside-outside temperature difference is 25°C, how much heat per unit time (in watts) is lost through the roof? $\boxed{\text{(b)}}$ How

thick a layer of fiberglass would achieve this R-value? $\boxed{\text{(c)}}$ How thick would a single layer of glass have to be to achieve the same R-value? $\boxed{\text{(d)}}$ How thick would a single layer of trapped air (for example, trapped between two thin layers of glass, so that convection is minimized) have to be to achieve the same R-value? (See Giancoli's table 14-4 for thermal conductivities.)

5. The specific heat capacity of water that people find easiest to remember is that 1 calorie ($= 4.18$ J) of heat is required to raise 1 cm^3 ($= 10^{-6}$ m^3, or 10^{-3} kg) of water by 1°C. $\boxed{\text{(a)}}$ How long does it take a 1500 watt tea kettle to heat 0.5 L ($=$ 500 cm^3, or 0.5×10^{-3} m^3) of water from 25°C (room temperature) to 99°C (just below the boiling point)? Assume that all 1500 W go into heating the water. $\boxed{\text{(b)}}$ If electrical power costs ten cents per kilowatt hour, how much does the electric company charge you to make your 0.5 L cup of tea?

6*. $\boxed{\text{(a)}}$ If the Sun is a perfect black body ($e = 1$) at $T = 5780$ K, with radius 6.96×10^8 m, what is the total power output that the Sun should radiate? (You can look up the Sun's luminosity in the Wikipedia to check your answer.) $\boxed{\text{(b)}}$ If the intensity varies with distance r like $\mathbf{power}/(\mathbf{4\pi r^2})$, what intensity (in W/m^2) of radiated heat from the Sun do you expect to arrive at Earth (at normal incidence), which is about 1.5×10^{11} m away from the Sun? (Your answer should compare pretty well with the "solar constant.")

7*. On a clear day, about 1000 W/m^2 of intensity from the Sun reaches Earth's surface (at normal incidence, e.g. when the Sun is directly overhead at noon in the summer). $\boxed{\text{(a)}}$ How large an area of land would you need to match (instantaneously, with the Sun directly overhead) the power output of a 1 gigawatt (10^9 W) power plant? (If this is a square, how long is each side?) $\boxed{\text{(b)}}$ How large an area of land would you need to collect (instantaneously, in direct sunlight) the 3 terawatts (3×10^{12} W) of power consumed on average by the entire U.S.? $\boxed{\text{(c)}}$ If the area for part (b) is a square, how long is each side of the square? $\boxed{\text{(d)}}$ It turns out that Earth intercepts only πR^2 of the Sun's rays, compared with the $4\pi R^2$ surface area of Earth. What is the total power from the Sun that reaches Earth? $\boxed{\text{(e)}}$ If Earth were a perfect ($e = 1$) black body, what temperature would Earth need to be so that the power radiated away by Earth equals the incident power from the Sun? $\boxed{\text{(f)}}$ What feature of Earth provides the "blanket" or "greenhouse" that keeps Earth's surface warmer than your calculated temperature? (Mars no longer has this feature!)

8. How many atoms are there in a 52.00 kilogram copper awning?

9. A concrete highway is build of slabs that are 8.5 meters long at 20°C. How wide should the expansion cracks between the slabs be (at 20°C) to prevent buckling if the range of temperatures is −30°C to +50°C?

10. The Eiffel Tower is built of wrought iron and is approximately 300 meters tall. Estimate how much the tower's height changes between July (average temperature 25°C) and January (average temperature 2°C). Ignore the angles of the iron members, and treat the tower as a vertical column.

11. $\boxed{\text{(a)}}$ A brass plug is to be placed in a ring made of iron. At 20°C, the diameter of the plug is 8.753 cm, and the inner diameter of the ring is 8.743 cm. They must both be brought to what common temperature in order to fit? $\boxed{\text{(b)}}$ What if the plug were iron and the ring brass?

12. An aluminum bar has the desired length when it is at 15°C. How much stress is required to keep it at this length if the temperature increases to 35°C?

Remember **online response** at `positron.hep.upenn.edu/wja/jitt/?date=2018-11-08`