Physics 81 Set 4 Solutions

1. A typical manhole (personhole?) cover is about $1m$ in diameter. If the sewer pipe below it were evacuated, how much force would you have to exert to lift the cover? You can assume that the cover itself has no mass. Remember that in the metric system, force is given in *Newtons*, where $1N = 1kg \cdot m/s^2$. Just for your own reference, $1N = 0.225lbs$

   Atmospheric pressure at ground level is $\sim 1000mbar = 1 \times 10^5 pa$. Thus, the weight of the atmosphere pushing down on the cover exerts a force of $10^5 N$ on every square meter of the surface. Since the cover has an area of $a = \pi \times (0.5m)^2 = .785m^2$, the total force is $7.9 \times 10^4 N$ (or $17,671lbs$!). If this is true (and it is), you might ask yourself how anyone ever does open a manhole.

2. If a parcel of dry air were carried adiabatically from sea level to an altitude equal to that of Boulder Colorado (5,400' or 1646m), how much would its temperature drop?

   The adiabatic lapse rate is $1°/100m$. Thus, we would expect the parcel to have its temperature drop by $16.46°$.

3. Complete the exercise given in appendix 5.3 (page 223) of Philander: How Many of Your Molecules Have Been to the Moon?

   Assuming you are in steady state (i.e. you take in $3l$ of water/day *and* you lose $3l$/day) then it would take you *at least*

$$75kg \times 0.7 \times \frac{1l}{1kg} \times \frac{\text{day}}{3l} = 17.5\text{days}$$

   to replace all of your water.

   The global reservoir contains $4 \times 10^{20} \times 3.324 \times 10^{25} = 1.33 \times 10^{46}$ molecules of water. Let's assume that since 1970, the astronauts' water moleculres have mixed in uniformly throughout this reservoir (a lousy assumption, but we have to start somewhere). These astronauts have between them a total of $18 \times 75 \times 0.7 \times 3.324 \times 10^{25} = 3.14 \times 10^{28}$ moon-voyaging molecules. Thus, the ratio

$$\frac{3.14 \times 10^{28}}{1.33 \times 10^{46}} = \frac{1}{4.2 \times 10^{17}}$$

   tells us that 1 out of every 4.2×10^{17} molecules in the global water reservoir has been to the moon.

   I have been alive since 1970. In the 31 years since then, I have flushed $3l/\text{day} \times 31\text{years} \times 365\text{days/year} \times 3.32 \times 10^{25}\text{molecules}/l = 1.13 \times 10^{30}$ molecules of water through my system. Thus, I have had

$$1.13 \times 10^{30} \times \frac{1}{4.2 \times 10^{17}} = 2.68 \times 10^{12}$$

   moon-going water molecules in my body. That's quite a few! Well, it seems that way until you calculate just how many grams of water that corresponds to.

4. Exercise 2 of Appendix 5 (page 223)

   Figure A5.1 shows that the *surface* of the earth is receiving $50+94 = 144$ units of energy in the form of radiation. Thus, it must also lose 144 units. However, it can (and does) lose energy in more ways than just radiating. In particular, 27 units are lost as latent heat (evaporation) and 7 as sensible heat (conduction/convection). From this balance, we conclude that $144 - 27 - 3 = 114$ units are lost through upward radiation. Thus, net *radiation* flow at the surface is $144 - 114 = 30$ units downward.

   You should realize that all of the greenhouse models of the earth's temperature that we discussed earlier in the semester assumed a dry and static atmosphere (i.e. the only form of heat transfer was radiative). This exercise should make it very clear to you just how much of a simplification those models were.

5. Exercise 3 of Appendix 5 (page 223)

   If the earth's surface receives $1m$ of rain per year, it must lose an equal amount of water through evaporation. Since the surface area of the earth is $4\pi(6.371 \times 10^6 m)^2 = 5.1 \times 10^{14} m^2$, this corresponds to a total evaporation rate of $5.1 \times 10^{14} m^3$/year.

   A liter of water fills a cube $0.1m$ on a side and has a mass of $1kg$. From this, you can conclude that each m^3 of water contains 10^3 liters with a mass of $10^3 kg$. Thus, every year, $5.1 \times 10^{17} kg$ of water evaporates from the earth's surface.

   Finally, we are told in A5.1 that the latent heat of vaporization for water is $2.5 \times 10^6 J/kg$. Thus, the hydrological cycle carries

$$5.1 \times 10^{17} kg \times 2.5 \times 10^6 J/kg = 1.27 \times 10^{24} J$$

   of energy (heat) away from the earth's surface.

   Just to give you a sense of how much energy this really is, you can think of this in terms of the energy released by atomic bombs. A 1-megaton explosion releases $1.42 \times 10^{15} J$ of energy. Therefore, you can see that the evaporation of water over the earth's surface is associated with an energy transfer equivalent to a billion 1-megaton explosions. That's a lot of energy!