Assignment I, PHYS 308
Fall 2014
Due 8/29/14 at start of class

NOTE: If you have had me for classes before, you know that normally I want you to leave answers symbolically. In *THIS* class, however, leave answers numerically if you can. (In other words, give me a number at the end of the problem). The reason is that this class is more directly applied to a particular subfield than most of the other upper-level classes you may have had from me (like Mechanics, E&M, or Modern) and, as such, we want to get you a sense of the magnitude of these things. Note – this also means you will be allowed to use calculators on exams.

Please provide full, legible, easy to follow solutions to the following problems. I can't give you credit if I can't read it (or I can't follow your reasoning). Extensive exposition on your thought process or strategy is always appreciated.

1. We'll get you warmed up with one that isn't so bad. In class, I gave you a breakdown of the constituents of dry air in the atmosphere. Although I said that these fractions were based on "percentage by volume", they are very close to "percentage by particle number". (E.g. since about 21% of the volume of air is Oxygen, it is also fair to say about 21% of all molecules in the air are O_2 molecules.) Based on this information, complete the following computations:

   a) Find the ratio $\frac{\text{number of N}_2\text{ molecules in the Earth's Atmosphere}}{\text{number of CO}_2\text{ molecules in the Earth's Atmosphere}}$.

   b) Find the ratio $\frac{\text{mass of N}_2\text{ molecules in the Earth's Atmosphere}}{\text{mass of CO}_2\text{ molecules in the Earth's Atmosphere}}$.

   c) Assume that the number of particles per unit volume of air can be treated as a constant. Would air with 5% of its particles as water vapor be heavier or lighter than air with only 1% of its particles as water vapor? (Note that if water vapor composes 5% of the particles in the atmosphere, N_2 is only $78.08\% \times (1 - 0.05) \approx 74.176\%$ of the atmosphere. You'll have to modify all the rest of the non-water constituent percentages accordingly as well to make this work.

   d) It is often said (by "people") that moist air feels "heavy". Explain/comment.

2. In class, I argued that acceleration charges emit energy. This is true, but many of you haven't had enough E&M yet to know this. For a moment, let's posit that – yes – accelerating charges do emit energy. Given this assumption, it seems sensible enough to suggest that the amount of power emitted is related to the acceleration of the charges. It probably also probably isn't totally absurd to suggest that Coulomb's law (governing forces between charges) might also play a role in determining this power released. Finally, since electrodynamic fields travel at the speed of light, c might get into the picture somehow as well.

   Let's see if we can combine these quantities together to obtain an estimate of the power released by an accelerating charge. Assume that the power released follows the basic form:

$$P \propto a^{\alpha} c^{\beta} \left[\frac{q^2}{4\pi\epsilon_\circ}\right]^{\gamma}$$

with α, β, and γ unknown constants. (I'm not including the r^2 in the Coulomb's law part of the expression intentionally). Your task – find α, β, and γ so that the units in the above equation work out. It turns out that (other than a numerical factor of 2/3 that comes from an integration) this method actually gives you the radiated power from an accelerating charge!

3. Calculate the number of molecules in the Earth's atmosphere. (Hint: Remember, standard pressure is 101325 Pa).

4. This question is about energy balance of a blackbody.

   a) If you were a perfect blackbody in a vacuum, about how much total power would you radiate? (Use reasonable values for your surface area and surface temperature).

   b) If you have a 3000 kcal daily diet (3 million calories, or 12552000 J – a realistic number) and had to have your body in radiative equilibrium, what would your body temperature have to be in order to balance the energy of the food you eat. (Assume you are a perfect blackbody and don't expend any energy except through radiation. No biological processes, no motion, no beating heart, no brain activity, nada. Just floating space debris that "somehow" gets fed).

   c) Based on your answer to part (a), how many calories would you have to eat each day just to make up for the energy you radiate away?

   d) Your answers to parts (b) and (c) should have been rather silly. Explain why this whole calculation went haywire.

5. The Planck distribution law is written:

$$I(\nu, T)\mathrm{d}\nu = \frac{2h\nu^3}{c^2} \frac{\mathrm{d}\nu}{e^{\frac{h\nu}{kT}} - 1}$$

   Where ν is the frequency of the radiation and h is Planck's constant. Rewrite this expression in terms of λ and $\mathrm{d}\lambda$ to show:

$$|I(\lambda, T)\mathrm{d}\lambda| = \frac{2hc^2}{\lambda^5} \frac{\mathrm{d}\lambda}{e^{\frac{hc}{\lambda kT}} - 1}$$

   (Hint: $c = \lambda\nu$).