Physics 81 Exam 2

Administered 4/11/05 Name: Official Solutions

1. Imagine that you go out early on a sunny morning and you take some measurements of the atmospheric temperature using a thermometer attached to a balloon. You discover that the temperature at the ground is 20°C, at 500m it is 18°C, at 1000m it is 16°C, at 1500m it is 14°C, and at 2000m it is 12°C.

   On a morning like this, would you expect air quality near the local power plant to be good or poor? Justify your answer.

   Based on the numbers I give above, you can see that the actual lapse rate for the atmosphere is $4°C/km$. This is a slower drop in temperature than the adiabatic lapse rate ($9.8°C/km$), so the atmospheric profile represents an inversion (probably left over from the cool of the night before).

   When the observed lapse rate is less than the adiabatic lapse rate, (the case here) the atmosphere is stably stratified and pollutants emitted at ground level will tend to stay at ground level, and you can expect air quality in the immediate vicinity of a power plant to be poor.

2. Imagine I give you a can filled with a gas mixture. I tell you that the presure of the mixture in the can is 1000mb. The gas is a mixture of O_2, N_2 and H_2O (and nothing else).

   (a) If the partial pressure of O_2 is 200mb and the partial pressure of N2 is 790mb, what is the water vapor pressure (e)?

   Partial pressures sum to total pressure, so...

   $$1000mb = 200mb + 790mb + e$$

   From this, $e = 10mb$

   (b) If the saturation vapor pressure e_s is 42mb, what is the relative humidity? You should use your answer from part **a**. If you didn't know how to answer part **a**, just pick a number for e and tell me what you used.

   Relative humidity is given by $RH = e/e_s$ so in our case

   $$RH = 10/42 = 0.24 = 24\%$$

   (c) If I cool the can a little bit (just a couple of °C), what would you expect to happen to the pressure? Justify your answer.

   From the ideal gas law ($PV = NRT$) it is clear that if T drops, P will drop too. This will be true as long as we don't get any condensation, and since we start with pretty dry air ($RH = 24\%$), a little cooling isn't going to bring the air to the dew point.

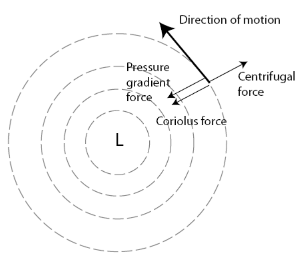
   In short, we expect a small pressure drop to accompany the small cooling.

   (d) If I cool the can a lot (perhaps 20°C or more), what would you expect to happen to the pressure in the can? Compare this pressure change to the one in part **c** and be sure to justify your answer.

If the ideal gas law holds, the pressure drop with 20 degrees of cooling should be 10 times as large as the pressure drop with 2 degrees of cooling. However, with so much cooling, the chances are very good that we will reach the dew point and condensation will occur. Once condensation occurs, you can no longer apply the ideal *gas law. Furthermore, the water vapor will have largely condensed, and liquids occupy much less volume than gases. Thus, when the water vapor condenses, the volume (and hence the pressure) of the remaining gas drops dramatically (much more than just the 10-fold drop expected from the ideal gas law).*

3. Imagine you look at a weather map of Australia and see a strong low pressure center. The winds around it are cyclonic (counter-clockwise).

   (a) Draw a picture depicting this situation, showing the pressure center, some isobars around it, the direction of motion, and arrows indicating the forces acting on a moving air parcel.



   (b) Is it possible for these forces to balance? In just a few words, justify your answer.

   These forces can balance. For a given pressure gradient force (inward), there exists a speed at which the sum of the coriolus and centrifugal forces (both outward) will be equal in magnitude.

   (c) If the low pressure center were to intensify (i.e. the low becomes lower), what would you expect to happen to the circulation? Be sure to explain your answer.

   If the pressure intensifies, the forces will only balance if the speed increases (thereby increasing both the coriolus and centrifugal terms).

4. Here's a quote from a recent publication that uses the 2nd law of thermodynamics to justify a position in environmental economics:

> What Mr. Ben-Ami overlooks is the second law of thermodynamics, which tells us that all transformations of energy and matter – in other words, all economic activities – produce an increase in entropy, more commonly known as waste, pollution, disorder, externalities, side effects or unintended consequences. Therefore, the second law tells us, the ultimate limit on economic growth is the unintended consequences that it creates in the form of waste and disorder – not the shortage of materials or energy. On a finite planet, there is only so much waste and disorder that can be tolerated before the place becomes intolerably degraded – and that's the kind of limit that is peeking over the horizon in modern times.

Do you agree with this application of the second law, or is the author of this quote mistaken? Be sure to justify your answer.

Note: I am *not* asking if you agree with his conclusion about impending degradation. I am instead asking specifically about the applicability of the second law in this context.

> This quote comes from an editorial by Peter Montague, published in "Rachel's Environment & Health News #805" (http://www.rachel.org).
>
> Montague makes one minor error and one major error.
>
> The minor error is the statement that entropy always increases. Strictly speaking, entropy increases or stays the same (it just never decreases).
>
> The major error is much more important. The writer concludes that the ultimate limit to productivity and economic growth is the increase in entropy. He says "On a finite planet, there is only so much [entropy] that can be tolerated." However, as we discussed in class, the Second Law only applies to a closed system. The earth is not a closed system: the sun is steadily adding energy, and this energy can be used to reduce the entropy of the planet. I don't think anyone would argue with my claim that the earth is more highly ordered now than it was in its early history. The planet may be finite, but it isn't closed.
>
> Two personal comments: First, I find it ironic that religious fundamentalists have incorrectly invoked the second law to support their creationist views, and here someone on the opposite end of the political spectrum is making the same mistake. Secondly, I actually agree with Montague's basic point that an unfettered free market will lead to major environmental problems, but his invocation of the 2nd law to justify this conclusion is embarassingly wrong.
>
> Here is some more of the flawed rant:
>
> > The second law tells us that everything we do leaves behind a mess, and the more we do, the bigger the mess becomes. Want more coal? Then someone is going to remove more mountain tops in West Virginia and dump them in the nearest creek. Want to burn more oil? Then someone is going to cut roads and move heavy equipment into unspoiled areas and eventually warm the whole planet, leading to more floods and hurricanes and malaria and yellow fever...
> >
> > ... To summarize: Based on his misinterpretation of the second law of thermodynamics, Mr. Ben-Ami says there are no real limits on human activity because we are such an ingenious species that we can always figure out some way to get around any limits that nature may impose. Economists may claim this is true, but physicists know it's not. That's what the second law is about – there really ARE limits to growth, limits imposed by the unintended mess we make whenever we do anything useful. Physicists call the mess "entropy" – and it take the form of chemical wastes, heapes of mine spoils, polluted water, unhealthy air, eroded hillsides, and sick children. For any beneficial activity, the mess can be reduced, but it cannot be eliminated.

Again, I don't disagree with Montague's list of consequences associated with energy production. However, I argue that these come about because there is no economic incentive to avoid these consequences. They do represent an increase in entropy, but they are not inevitable, and the second law is simply not applicable to the planet as a whole.

5. **Bonus Question:** Speaking of Australia, what (or who) is a monotreme? If you don't know, make something up. As usual, creativity will be generously rewarded.

   There were lots of great answers (a one-celled Australian organism, a one-stringed Australian instrument, a person who believes in one extreme or another, an earthquake with only one tremor, etc.) but in truth "monotreme" is the scientific name for an egg-laying mammal. They only live in Australia and New Guinea, and the only examples are the duck-billed platypus and the echidna (spiny anteater).

   Interestingly, one of you (who must know latin) said that it was a strange Australian inscect that eats and excretes from a single hole. This rather revolting image isn't so far from the true origin of the name. Monotremes are so named because they have a single opening that serves as a common exit for the unrinary tract, the anus and the reproductive tract. However, this opening is *not used for food intake.*