Answers to Physics 176 One-Minute Questionnaires
Lecture date: January 13, 2011

Given the many students in the class and given my limited time to write answers, I will generally answer just some (although usually most) of your questions, the ones that seem more relevant or interesting for the class, or the questions that I can answer with a reasonable effort. My apologies to those who asked questions that I didn't answer.

I will however include all questions received—answered or not—so that you can see what your classmates wanted to know. Perhaps you can discuss some of these questions with your classmates and figure out some of the answers for yourselves.

Please also understand that the one-minute questionnaires are not intended to replace your meeting with me or with the TA if you have questions about the lectures, homeworks, or textbook. The purpose of the questionnaires is to help me get a sense of where a point in my lecture could use further discussion or what topic piqued your interest so you would like to know more.

Should we expect to see homework posted after every lecture?

The answer is no, homeworks will be posted only about once a week, with the new assignment usually being posted the day after the previous assignment was handed in. The next homework assignment will be posted on Friday, January 21.

Is thermal physics in any way related to thermodynamics?

The answer is yes.

"Thermal physics" is generally understood as encompassing two different subjects, thermodynamics and statistical physics.

Thermodynamics concerns the general properties of equilibrium systems, especially issues related to spontaneous processes, energy, work, heat, entropy, and efficiency (say how much work can an engine produce that gets its energy from some given temperature difference). One can discuss thermodynamics without ever worrying about what a substance is made of.

Statistical physics concerns the derivation of macroscopic equilibrium properties from a knowledge of the properties of the microscopic components. Although statistical physics began with the kinetic theory of gases in the late 19th century, it really became a vibrant and important subject after the discovery of quantum mechanics in the 1920s. About two thirds of 176 will involve statistical physics because of its greater ability to make useful predictions.

Why is this class cross-listed as ECE?

There was a time about ten years ago when the Physics Department and Electrical Engineering Department were taking turns teaching this course, which was a required course for engineers back then. Physics 176 is no longer a required course (I am shedding some tears here) but historically the cross-listing has continued.

How much will a knowledge of quantum physics aid in this course?

Only a little, and not enough to make a difference in your course grade. The course is self-contained in that I will explain all assumptions regarding quantum mechanics that we need for this course. But one thing I will not have time for (and is not really needed) is to derive some of the assumptions that I will use during the semester. If you have had Physics 143 or 211, you will have seen the derivations and so parts of the course will be more familiar to you and make a bit more sense. But you will not need to use the technical skills of 143 or 211.

What is temperature?

This is one of the key insights that you will gain from this course and it will take a while to explain enough details for you to understand the deeper definition, which you will learn about when we come to Chapter 3.

The technical definition you will soon learn is that temperature is related to how the entropy $S(U)$ of an equilibrium system (whatever entropy means) varies with the energy U of the system (whatever that means)

$$\frac{1}{T} = \left(\frac{\partial S}{\partial U}\right)_{V,N}, \tag{1}$$

for fixed volume V and fixed number of particles N. You will soon appreciate that it is entropy, not temperature, that is the deeper and more important concept in thermal physics.

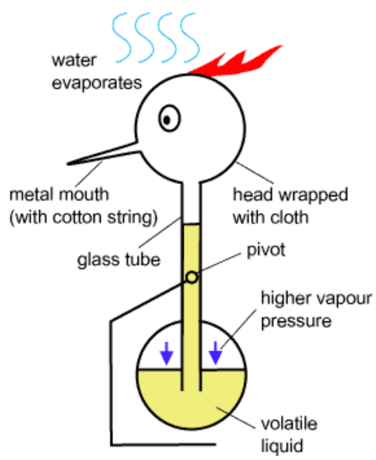
How the does the dippy bird work?

This was one of the most popular questions asked by the class. See the related links and papers that I put on the Answers web page

`http://www.phy.duke.edu/~hsg/176/answers/`

The most important insight for you to get from this demo is that the motion of the dippy bird is not driven by a difference in temperature (the bird and the cup of water were both at room temperature) but by a difference in concentration: because the surrounding air in the room was not saturated with water vapor, the water on the bird's beak could evaporate, causing a local drop in temperature that ends up driving the motion as explained below. If we had placed a tight glass cylinder over the dippy bird and its cup so that the air inside the cylinder soon became saturated with water vapor, the bird would stop moving. Similarly, if we were to place 100-foot-high dippy birds on the North Carolina seashore to generate energy, they would work poorly on rainy days, when the air is full of moisture.

The key physics behind the dippy bird is the ideal gas law $PV = NkT$, and in fact the dippy bird is a nice application of the ideal gas law. The dippy bird can be thought of as two gaseous regions separated by fluid, gas in its body and gas in its neck and head:



Evaporation at the beak lowers the vapor pressure in the neck and head (via $P = (Nk/V)T$ with fixed number of particles N and fixed volume V) relative to the pressure in the body and the pressure difference pushes the fluid in the body up the neck. With a careful choice of fluid (one with a high vapor pressure such as methylene chloride), one can get a large pressure difference with a small temperature change. The fluid rising up the neck shifts the center of mass of the bird, causing it to tip over more and more until the bird's beak enters the cup of water. At the same time that the beak dips into the water, the glass tube connecting the head to the body empties of fluid, causing the vapor pressure to equilibrate everywhere and shifting the center of mass such that the bird rises vertically again. The bird continues to dip until the surrounding air is saturated with water or until the cup of water has evaporated to a level below which the beak can reach.

Based on this explanation, you could try several simple experiments to test your understanding. For example, you could try cooling the body and see if that slows down the motion, you could try swapping a cup of water with a cup of rubbing alcohol which should cause a greater degree of cooling by evaporation and so cause the bobbing to speed up, and you could try different fluids inside the dippy bird to see what happens.

Some other questions asked by students about the dippy bird:

1. "What role does the chemical composition of the fluids in the bird play?" A quick answer: the chemical composition is only important to the extent that it affects the vapor pressure. Chemicals with weaker bonding (such as alcohols or ethers) have a higher vapor pressure and so cause a larger affect. Chemicals with strong bonding (say water, with its strong hydrogen bonds), would lead to a wimpy dippy bird.

2. "Was the dipper filled with mercury? And does it run based on how water radiates heat?"

3. "Why can't the dipping bird by used as a perpetual motion device?" The above discussion answers this question, the bird is driven by a difference in water concentration and stop when the surrounding air is saturated with water vapor. Sorry, no perpetual motion machine.

What makes the radiometer spin around?

Another popular question. I have put a paper about radiometers on the above Answers webpage that should hopefully answer most of your questions. There are also many websites that offer explanations (most unclear, some just wrong).

Radiometers are rather subtle devices, it took a while for people to understand what was going on and even some famous scientists like Maxwell got the wrong answer the first time around. In particular, it turns out that it is the *edges* of the vanes, not the surfaces of the vanes, that turns out to be the key to understanding why radiometers spin and how their spinning depends on gas density and temperature.

Some other questions that students asked were:

1. "How does the color of the flaps of the radiometer vanes affect their motion?" A brief answer is that the colors affect the amount of light absorbed and so the temperature of the vane of a given color, with darker colors generally causing increased absorption and increased temperature and so causing an increased speed. A complete answer would require knowing something about the spectrum of the light illuminating the radiometer.

Is there ambient electromagnetic radiation in intergalactic space?

The answer is yes and this fact is an exceedingly important one in 20th- and 21st-century science. Two Nobel prizes in physics have so far been awarded related to this discovery (to Penzias and Wilson in 1978 and to Smoot in 2006) and one or two more are likely to follow.

Briefly: experimental observations have confirmed to high accuracy that the space between galaxies is not empty but filled with light in the form of an equilibrium gas of photons (quantized light particles) with a temperature of 2.7 K. (We will discuss this in substantial detail later in the course, e.g., what does it mean for a gas of photons to be in equilibrium?) Theory and experiment strongly support the idea that this photon gas is a remnant of matter-antimatter annihilations that took place about one millisecond after the Big Bang (which experiment showed took place about 14 billion years ago). The extremely few particles that did not annihilate turned out to be the stuff that you and the planets and stars are made of. No one yet knows why there was a tiny excess of matter (about one extra proton for every ten billion protons and ten billion antiprotons), which remains a central question in physics and the reason why we exist as material creatures in the first place.

Careful observations of tiny deviations of the photon gas from thermodynamic equilibrium have yielded amazing insights about the universe such as the amounts of dark matter and dark energy, and the overall geometric shape of the universe (whether it is flat like Euclidean space or curved like a the surface of a four-dimensional sphere).

I want to know how the balloon demo worked, why did the little balloon empty into the big one?

Try looking up "Laplace's law" via Google or in Landau and Lifshitz's book "Statistical Physics", there are numerous discussions, deviations, and pictures, especially because the law is so important for medicine (it explains why aneurysms form in blood vessels).

In its simplest form, Laplace's law has the mathematical form:

$$P_{\text{inside}} - P_{\text{outside}} = \frac{2\sigma}{r}, \tag{2}$$

where P_{inside} is the pressure inside an elastic sphere of radius r, P_{outside} is the pressure external to the sphere, and σ is the surface tension of the sphere. (The more general formula treats a surface of general shape with a known local mean curvature.) This law implies that, for a fixed surface tension σ, the smaller the sphere, the greater the internal pressure, which explains why a small balloon empties into a large balloon.

If you mastered your freshman physics, you should be able to derive this formula by considering an infinitesimal patch on the sphere and by requiring force equilibrium on the patch.

Can you briefly explain why the tungsten filament acts as a blackbody but the fluorescent lights do not?

Only an opaque warm body can reach thermodynamic equilibrium and so generate a universal blackbody light spectrum. The tungsten filament is indeed opaque to radiation and so acts like a blackbody, as does the Sun and your body (which emits mainly in the infrared range of light).

A fluorescent lamp works on a different principle, it uses electricity to excite gaseous mercury atoms, that then deexcite and emit photons of a precise wavelength. These photons collide with and excite a phosphor coating on the inside of the fluorescent bulb and the resulting fluorescence causes the light that we see. (A good thing that there is a phosphor since the mercury emissions are in the ultraviolet range and would cause blindness and bad sunburns.) There is no mechanism for the phosphor to reach thermodynamic equilibrium and so the light emitted by fluorescent lights have a rather different spectrum (largely less pleasing to humans) than that emitted by a tungsten filament.

How did they figure out that human ears are related to fish gills?

I don't remember the exact sequence of logic, but this was evidently a fairly straightforward deduction based on comparative anatomy of many species of fish and mammals. A similar strangeness is that an elephant's "nose" is really a highly evolved upper lip and has nothing to do with a real nose. Evolution finds strange ways to solve practical problems.

How does the speed of electrons travel through a wire differ from a lead battery?

Sorry if I confused you: what I tried to explain briefly in my lecture is that some important aspects of chemistry come from the relativistic speed of the outermost valence electrons, which are moving rapidly even at absolute zero. A recent paper in Physical Review Letters summarizes a theoretical calculation which suggests that about 80% of the energy of a lead-acid battery comes from the specific fact that lead electrons are moving relativistically (close to the speed of light).

Earlier you described how processes in modern computers rivals the "speed of light" $\times$ "the size of the computer". Where do you see the next advances in computers?

I am puzzled by this question since I don't remember mentioning anything about computers during the class, where did this come from?

I am not an expert in computer technology and so am not qualified to make predictions. From my "lay person" understanding, I see three different frontiers:

1. nanoscience, in which computer component like transistors will eventually be just a few molecules in size
2. optical computing, in which logical operations will be done by the interaction of light beams in a three-dimensional nonlinear medium, allowing massively parallel computations,
3. quantum computing, in which the massively parallel properties of quantum mechanics superpositions will be exploited.

I am afraid I have no stocks of companies to recommend at this point regarding these technologies.

How does the spectrophotometer work?

I am confused by this question, there were no spectrophotometers mentioned in my first lecture. Do you mean the hand-held spectroscopes? Those are based on splitting light into separate colors by a plastic diffraction grating, the principles of which I hope you learned about in your intro physics course.

I would like to know more about your current research. Are there any papers or journal articles you can provide links to?

You can try this article:

`http://link.aps.org/doi/10.1103/PhysRevE.74.011918`

But I would especially encourage you to meet with me so I can explain the big picture in person, the articles will be hard to read and you likely won't appreciate the context that motivated them. I am also working on some projects for which I have not yet published any papers, on olfaction and connectomics.