Topics: particle speeds in gases (brief), formation of the Solar System, Earth's interior, (begin) Earth's atmosphere (including perfect gas law and hydrostatic equilibrium)

Reading:

- Read the last paragraph on p. 201 of Ryden and Peterson, Ch. 8 (don't even bother going to p. 202).
- Read Ryden and Peterson, §8.3, on the formation of the Solar System.
- Read Ryden and Peterson, Ch. 9, from the beginning up through the middle of p. 216.

Summary of work to submit:

- Nothing to submit for Tuesday's class.

Overview:

We will start by taking a quick look at particle speeds in a gas (as a function of the temperature of the gas). This has broad relevance, beyond the physical properties of planetary atmospheres. We'll not go in depth into that, but just think about the basics. Then we'll wrap up the overview of the Solar System by seeing what we think we know about its formation. The reading highlights the important processes that gave us the Solar System properties we see today. Then we move on to looking at individual objects in the Solar System and what object could be more important than the Earth? Our reading covers what we know (and how we know) about the interior of the Earth while the second section is about the Earth's atmosphere. The concepts of hydrostatic equilibrium (HSEQ) and the perfect gas law are introduced here for the first time. HSEQ is super-important (it describes stars as well as planetary atmospheres) and we will go through its derivation, meaning, and utility in some detail in class. This is one derivation you should read carefully and try hard to understand.

Commentary on the reading, viewing, and other preparation:

Rather than discuss themes, here, let me just provide a few specific bits of information that will be useful as you do the reading and think about what you'd like to talk about in class on Tuesday.

Eqn. 8.17 on p. 201 expresses that average ("rms" is a particular kind of average – the square root of the average of the squares or *root mean square*) speed of particles in a gas as a function of the gas's temperature and the mass of each particle (m). Note that $\frac{3}{2}kT$ is the average thermal energy of a particle, where k is Boltzmann's constant. Given that, can you see that this equation simply comes from saying that the thermal energy of a gas is manifest as kinetic energy of the particles?

You might compute the average speed of a molecule of nitrogen (2 atoms, each with seven protons and seven neutrons) at room temperature. Fast!

(We'll talk about mean free paths and optical depths...some other time.)

The basic idea of the information at the bottom of p. 201 is that if atoms (or molecules) of a species of gas are moving faster than the planet's escape velocity, they will eventually escape from the planet and that gas won't be present in the planet's atmosphere. That's why we have no hydrogen or helium in our atmosphere (do you see how lighter atoms move faster than heavier ones and so it's the lighter ones that a planet has a harder time holding on to?).

The escape velocity (eqn. 8.18) is derived simply from equating kinetic energy of a particle to its gravitational potential energy. If the KE is bigger than the PE, then it will escape. (Think about whether we should talk about this in class on Tuesday).

In §8.3, the basic fact conveyed is that planets form in a *protoplanetary disk* which is a flattened distribution of gas and small solids each individually orbiting the Sun (much like Saturn's rings are a bunch of individual particles, each orbiting Saturn). We will talk about why a spherical cloud collapsing under its own gravity will naturally flatten into a disk. The book – at least in Ch. 8 – does not explain the physical mechanism of the formation of the disk, but we'll talk about it in class.

The important concepts in this section are bold-faced; pay special attention to them. But also, there's a narrative of planet formation that's conveyed in this chapter. See if you can outline the key points.

And note terms and concepts in this part of the reading that are confusing (perhaps because they were introduced in earlier parts of the book, which we haven't read). Be ready to ask about them in class.

The first section of Ch. 9 is about the Earth's interior. The details of seismic waves are maybe not so important, but what structure they reveal inside the Earth is. Note the heat flux stuff at the end of the section. Flux is just energy per area per time (just like the flux of light that shows up in the inverse square law).

The last part of our reading is about the Earth's atmosphere. Please read carefully about hydrostatic equilibrium (HSEQ). Have you ever wondered what holds up the atmosphere? I mean, the Earth's gravity is pulling down on it. What prevents it from settling into a very thin, very dense layer along the Earth's surface?

Another thing to think about: pressure and force are related (pressure is force per unit area). So, if you're in a room with air in it, there's air pressure. But is there an associated force? If so, shouldn't the air be moving? (Since forces lead to acceleration.)

The perfect gas law in its most useful form for astronomy is eqn. 9.9 on p. 215. But it probably doesn't look familiar to you. Another simple form of the gas pressure is $P = nkT$, where n is the number density of particles (particles per cubic meter). But the form in the book has the mass density, ρ (kilograms per cubic meter). What is the relationship between number density and mass density? See if you can figure it out. Looking at the units will help. So, the "mean molecular mass" given by the Greek letter μ is the average particle's mass expressed in units of the proton mass. Note that protons and neutrons have virtually the same mass and electrons weigh only 1/2000 as much, so we can generally ignore their mass. A hydrogen atom has one proton and one electron so it has $\mu = 1$. While helium has two protons, two neutrons, and two electrons, for $\mu = 4$.

Where does gas pressure come from, physically? I like to think of a balloon. It is inflated because of the high pressure inside it. What does that mean, physically? It means gas molecules inside the balloon are constantly colliding with the skin of the ballon and transferring momentum to it (pushing on it). The amount of momentum transferred must be proportional to the particle density (more particles, more pushes) and the temperature (faster particles, stronger pushes). So $P \propto nT$ makes sense.

Finally, the equation of HSEQ (eqn. 9.12) is a differential equation (an equation with variables but also at least one derivative of a variable). You solve it by integrating both sides. The book does it for a special case (gravity and temperature both constant). We'll go over that at the end of class, but you should read it carefully, see if it makes sense to you, and note that once you solve the HSEQ equation, you have an equation for pressure as a function of height in the atmosphere (eqn. 9.14). From that, you can calculate, for example, what the air pressure is on the top of Mt. Everest.

So...the answer is that atmospheres hold themselves up against gravity not by pressure itself, but by the *gradient* of the pressure (that is, the spatial derivate of the pressure, or crudely, pressure differences). Air pressure makes air move only when there is a pressure *difference*.