General Astronomy (29:61)
Fall 2012
Lecture 27 Notes, November 5, 2012

1 The Earth as a Planet

As we start studying the planets, we begin with Earth. To begin with, it gives us a different perspective on the world we live in. Since the beginning of the Space Age, we have a direct way of visualizing this aspect of the Earth. Interplanetary probes can look back at the Earth and really show it as one of the other planets in the solar system.

$\longrightarrow$ look at online diagrams.

There are two ways in which study of the Earth contributes to a general study of the solar system.

1. We can obviously study the Earth better than any other astronomical object
2. We can establish a set of processes that are important for the Earth, then ask if those same processes occur on other planets. By "other planets" we generally mean the terrestrial planets, but we will also find these ideas relevant for some moons of the outer planets.

1.1 Basic facts about the Earth

Let's start with some numbers about the Earth. For the moment, we will talk about the big rock ball that forms the Earth. A little later we'll talk about the atmosphere.

- distance from the Sun: 1 astronomical unit
- radius: 6378 km (*How do we know that?*)
- mass: 5.974×10^{24} kg (*How do we know that?*)
- Important chemicals in composition?

With just the first two numbers, we can calculate an important number in planetary science, which is the *mean density* $\bar{\rho}$.

$$\bar{\rho} = \frac{M}{V} = \frac{3M}{4\pi R^3} \tag{1}$$

Let's calculate it out for the Earth

$$\bar{\rho} = \frac{3M}{4\pi R^3} \tag{2}$$

$$\bar{\rho} = \frac{3(5.97 \times 10^{24})}{4\pi(6.378 \times 10^6)^3} \tag{3}$$

$$\bar{\rho} = 5.49 \times 10^3 \tag{4}$$

The units are kg/m^3.

A more convenient unit is that of the cgs system, which is 5.49 gm/cc.

$\longrightarrow$ What do you have to say about this density?

A way of understanding what this is telling us to compare the density with that of some rocks that you can find on the surface of the Earth. This involves taking some information from the science of mineralogy and petrology, which are components of the study of rocks, and a part of the science of geology.

- quartz (SiO_2): 2600 kg/m^3
- feldspars ("by far the most common mineral in terrestrial surface rocks") ((K,Na,Ca)$AlSi_3O_8$): 2600 - 2800 kg/m^3
- pyroxenes (Mg, Fe, Ca, Na, Al, and Ti silicates (enstatite), "these minerals are common in meteorite as well as basic planetary igneous rocks): 2800 - 3700 kg/m^3

We could go on, but you should get the idea.

$\longrightarrow$ Given the above data, what can you conclude about the structure of the Earth?

1.2 The Interior Structure of the Earth

To begin with, it is probably true that we have a better picture of the interior of the Sun than the interior of the Earth. The picture we have is given in Figure 9.1 of the textbook.

$\longrightarrow$ Also look at diagram in online notes.

The thickness of the various layers are given below. Except for the innermost, which can be thought of as a spherical region, the others are the radial extents of spherical shells.

1. Solid, iron-nickel core: 1300 km

2. Molten iron-nickel core: 2250 km
3. mantle: 2900 km
4. crust: 8 - 40 km (thicker in the continents, thinner in ocean basins.

The combination of crust and outer mantle is referred to as the *lithosphere*

The structure of the Earth, in which a dense, metallic core lies at the center, with lighter (lower density) materials on the outside, is due to a process called *differentiation*. Generally speaking, it means that the Earth must have been in a molten state long enough for heavy elements to have settled deeper in the Earth, with relatively more buoyant materials floating to the top.

1.2.1 How do we know this?

We infer the interior structure of the Earth by the propagation of seismic waves through the interior of the Earth. There is a very interesting discussion of this on p210 and 211 of the textbook. *Read it!*.

1.3 Plate Tectonics

The lithosphere is broken into several plates. A map of these is shown in the ⟶ online notes.

These plates move over time. The spread apart in a process called *divergence* (mid-Atlantic ridge), the process of *subduction* occurs when one slides under another one (Juan de Fuca fault, Cascade Mountains). Finally, a *transform fault* is when one plate slides by another (San Andreas fault). ⟶ Also look at diagram in online notes.

Destination Check: The reason for bringing up all of these interesting bits of information is that we will be interested in knowing if other planets have these properties.

These plates are carried over the surface of the Earth by convection currents in the underlying mantle. One important aspect of this plate motion is that the surface of the Earth is being reformed by subduction of plates, the creation of new crust at divergence zones, and by volcanism. As the book states, "Plate tectonics and volcanism are constantly renewing the surface of Earth, which has the youngest surface of any of the terrestrial planets".

The second interesting point is that the arrangements of the continents has changed drastically over geological time. There are some movies that show this. Look at youtube under "Continental Drift".

2 The Earth's Atmosphere

When we study solar system objects, we are very interested in atmospheres of planets. So what are the properties of the Earth's atmosphere, and how do they compare with the those of the atmospheres of other planets? First, let's look at a picture of the Earth's atmosphere for inspirational purposes. $\longrightarrow$ Also look at diagram in online notes.

Let's begin by looking at the chemical composition of the Earth's atmosphere, given in a very interesting Table 9.1. It shows that 78.1 % of the molecules are N2, 20.9 % are O2, 0.93 % are Argon atoms, and 0.040 % are CO2 molecules. Water vapor is about the same as Argon, but highly variable.

This chemical composition is unlike the Sun, and also is unlike any other planet, including the terrestrial planets. So the question in, how did our atmosphere come into existence. The answer to this is that the present atmosphere of Earth is really the third generation. Read the discussion on p213; it is one of the most interesting things you will read in your science education. A short summary of this is:

1. Primeval atmosphere formed with the planet. Rapidly lost because Earth couldn't retain it.

2. Secondary atmosphere formed by outgassing from the planetary interior. Large amounts of CO2 and H20. H2O could also have arrived from space. The secondary atmosphere of Earth was almost certainly like the present atmospheres of Venus and Mars.

3. Present atmosphere. The atmosphere of Earth now has a significant component of molecular oxygen. Oxygen is not a major atmospheric constituent in any other planet. The origin of this is life itself. It began with cyanobacteria that gave off oxygen as a byproduct. Over billions of years, the level of oxygen in the atmosphere built up. It probably did not reach a significant level like today until about 500 million years ago.

2.1 The Physics of the Earth's Atmosphere

The Perfect Gas Law says

$$PV = Nk_BT \tag{5}$$

so

$$P = nk_BT \tag{6}$$

If we are dealing with a gas consisting of one kind of atom or molecule, then $\rho = nm$, so $n = \rho/m$. We can write the mass of the atom or molecule as $m = \mu m_p$ where μ is the *mean molecular weight* of the molecule, and m_p is the mass of a hydrogen atom. If we substitute this into the Perfect Gas Law, we have

$$P = \frac{\rho k_B T}{\mu m_p} \tag{7}$$

In the case of N2, $\mu = 28$, and for O2, $\mu = 32$. If we form an average weighted by their abundances in the atmosphere, we have $\mu = 29$ (see book, p216).

Let's work out the case for the surface of the Earth. The density of air at sea level is 1.3 kg/m^3. Let's pick 290K as a typical temperature. We then have

$$P = \frac{\rho k_B T}{\mu m_p} \tag{8}$$

$$P = \frac{1.3(1.381 \times 10^{-23})290}{29(1.67 \times 10^{-27}} \tag{9}$$

$$P = \frac{5.22 \times 10^{-21}}{4.84 \times 10^{-26}} \tag{10}$$

$$P = 1.078 \times 10^5 \text{ N/m}^2 \tag{11}$$

$$\tag{12}$$

A unit of pressure in the SI system is also called a *Pascal*. By convention, a pressure of 1.013×10^5 N/m^2 is referred to as one atmosphere, and is taken as the average pressure at sea level.

The atmospheric pressure at the same altitude above sea level is remarkably constant across the Earth. Variations of 1 percent are associated with major weather systems. A strong hurricane would have a pressure in the eye of about 92 % of an atmosphere.