BASIC EARTH PARAMETERS

We will begin our study of the Earth as a planet by reviewing some of the most important basic facts regarding the Earth, its shape, size and mass. At the end, we will combine this knowledge to make a stunning and important conclusion about the nature of the interior of the Earth.

Shape of Earth All your students will know that the Earth is roughly spherical in shape, but how many of them will be able to suggest any of the ways that we know the Earth is spherical (the Earth is actully not perfectly spherical. Due to forces generated by the Earth's rotation, the Earth is slightly **oblate**, meaning the Earth is slightly wider across the equator than it is from North Pole to South Pole. The amount of oblateness is small for the Earth, but if you look at full images of the larger outer planets, they are noticeably oblate. Saturn, in fact, is 10% wider across the equator than it is pole to pole.)

The ancient Greeks knew that the Moon was spherical because the terminator, the line that separated illuminated and non-illuminated regions of the Moon was a curved line, and they understood that only a spherical object could show a curved terminator (a hockey puck for instance, is either completely in light or completely in darkness, only a sphere shows the curved terminator we see at different lunar phases). If the Moon were spherical, argued the ancients, then surely the Earth must be. Moreover, the Greeks understood that lunar eclipses were caused when the Moon entered the shadow of the Earth. By watching the shape of the Moon as it entered and left the Earth's shadow, they could conclude that the Earth must be spherical to produce the curved shadow lines on the Moon. Visit this wonderful site from Florida State University to see what the Moon looks like during an eclipse. Change the button to "manual", and slowly move the Moon through an eclipse. Notice how the shadow of the Earth is curved; only a spherical object casts such a shadow.

Size of Earth

One of the most remarkable intellectual achievements in human history was the accurate determination of the circumference of the Earth long before anyone travelled over long distances of the Earth. Before explainint to your students how this was done, ask them when they think people first had an accurate understanding of the size of the Earth. The circumference of the Earth was determined to a high degree of accuracy over 2200 years ago! The calculation was made by the librarian at Alexandria, Eratosthenes. He heard from travelers of a remarkable well in southern Egypt, near the current town of Aswan, then named Syene. He heard that on the first day of summer, the sun's rays reached the bottom of a deep, vertical well. Eratosthenes realized that this meant that the sun was directly overhead at Syene, something he never observed from his more northerly city of Alexandria. Eratosthenes, like all educated Greeks, understood the Earth was spherical. Therefore, he knew that if he could measure the altitude of the sun (remember, altitude means angle in the sky) in Alexandria at the moment it was overhead in Syene, he could begin to determine the circumference of the Earth. When he did this measurement, Eratosthenes found that at the moment the sun was overhead in Syene, the sun made a

7.2^o angle from the vertical in Alexandria. See figure below:

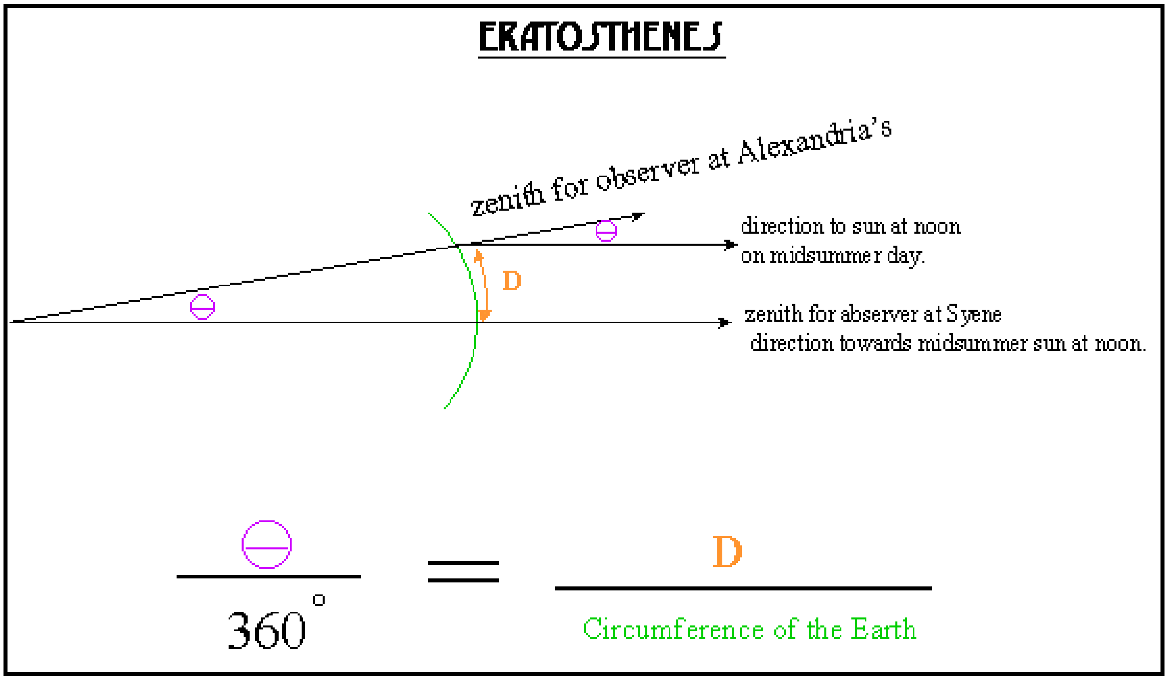

image courtesy Cornell Univ. Astronomy Dept.

This diagram shows that the Sun is overhead at Syene, but makes an angle of 7.2^{o}with overhead at Alexandria. Looking at the Earth in this diagram, we can see that this observation means that Alexandria is 7.2^o north of Syene along the surface of the Earth. Since the Earth is a sphere (already known by the Greeks) and the whole trip around a sphere is 360^o (also known by the Greeks), then Eratosthenes' measurement of the Sun told him that the distance between these two cities represented **7.2/360 of the circumference of the Earth**. Now, all he had to do was get some measurement of the actual distance between the two cities and he could find the circumference of the Earth. To do this, he spoke with caravan drivers who routinely made the trip from Syene to Alexandria and back. He asked them how long it took a caravan to traverse the cities, and asked them for information on the average distance covered by caravans in a day. By obtaining this information, he could estimate the distance between the two cities. By using a simple ratio:

Dist between cities/Circumference of Earth = 7.2^o/360^o

He could determine the circumference of the Earth. The result he found was within 2% of the currently accepted value of the circumference of the Earth.

You can use your quadrants to do the same experiment! Suppose you and a friend are in cities sufficiently far apart (in a north/south direction). If you each had quadrants, and measured the altitude of the Sun at exactly the same time, you should get different values for your reading of the altitude of the Sun. The difference between your measurements represents how many degrees of distance you are along the surface of the Earth. It is important, though, to make sure the measurements are made at the same time, and that there is little to no east-west separation between the two observers. If you make your measurements of the North Star (Polaris) at the same time, you will be able to complete the experiment even if the two observers are not exaclty north-south aligned.

The Mass of the Earth

Many students are amazed that we can determine the mass of the Earth. Many students have an image of trying to find a scale set large enough where we could place the Earth, and figure out its mass by direct measurement. Of course this is impossible. However, by understanding the force of gravity, we are able to determine how much gravity the Earth generates. Since gravity is the force generated by mass, measuring how much gravity an object generates enables us to figure out how much mass caused that much gravity.

We recall from last summer that gravity is the force that causes any two objects to be attracted to each other. The famous equation Newton determined to describe this is:

$$F = GMm/d^2$$

Where F is the force between the two masses, M is the larger mass, m is the smaller mass, d is the distance between them, and G is what we call the Newtonian Gravitational Constant. G is a constant of nature, that means it has the same value everywhere in the universe, but it also means that we have to measure the exact value of this constant to know how much gravitational force exists between two objects a certain distance apart.

Suppose we wanted to know the gravitational force between the Earth and some mass on the surface of the Earth. In this case, the larger mass is the mass of the Earth, the smaller mass is the mass of the object, and the distance between them is the radius of the Earth. However, we also know from our physics course that the gravitational force between two objects is the *weight* of the object, and we remember from last summer that weight is given by:

$$W = mg$$

where g is the acceleration due to gravity, and is well measured to be 9.8 meters/sec/sec.

So, if the weight of an object is merely the force between the Earth and itself, we can combine our two equations and obtain:

$$GMm/R^2 = mg$$

where now we use R to mean radius of the Earth.

Dividing through by the common factor of m gives us:

$$g = GM/R^2$$

, or, by rearranging terms:

$$M = gR^2/G$$

Since we can measure g via a number of means, and R was determined for us 2200 years ago, all we need is a measurement of G and we can acutally determine the mass of the Earth! This was first done in 1798 by one of the great experimental physicists of his (or any other day), Henry Cavendish. You can read up on the details of this experiment doing a google search on "cavendish earth mass", but the details of the experiment are beyond the scope of this course or of your courses. However, it is good to know the basics of how this was done.

Thus, once we had a reasonable estimate for the value of G (and this was in 1798), we could measure the mass of the Earth accurately!!

Now, we know the shape, size, and mass of the Earth. This enables us to determine the volume of the Earth (since we know the volume of a sphere and we know the radius of this particular sphere). And, since we know the mass of the Earth, we should realize immediately that we can determine the **density** of the Earth!! All we need to do is divide the total mass (you would have to provide this to your students or have them look it up) by the volume of the Earth, and you should obtain the correct result (which is 5.5 grams/cm^3 if you use grams and cm, or 5500 kg/m^3. It is better to use grams and cm, as you will see immediately.

Your students can immediately put this density in context by measuring the density of rocks and pebbles they find around school and their homes. Remember how we found density of common objects: determine the mass of one (or several) of them by measuring with a balance; determine volume by measuring the volume of dispaced water using a graduated cylinder, and dividing the two to determine density.

If your students perform this experiment, they should find that ALL the surface rocks they find have densities in the 2.5-3.0 g/cm^3 range (and finding densities at the upper end of this range will be rare). You can then assure them that if they could roam the Earth and measure the density of rocks taken anywhere, including the ocean crust, they will find densities of surface rocks to be in the range of 2.5-slightly over 3 grams/cm^3.

What is this result screaming at you? It is telling you that the surface rocks are less dense than the average density of the Earth. The only possible conclusion is that the Earth gets denser as you go down. This is a significant result for a few reasons. First, you have made use of data to understand something important about the Earth. Second, you will show your students how planetary scientists combine obeservation, theory, and logic to draw conclusions about regions of the Earth we will never directly investigate.