

Density of Earth Materials Lab

Purpose: Many of Earth's processes are due to different densities of materials within the Earth. These processes include

- Formation of the solar system
- Formation of compositional layers within the earth,
- Convection currents within the outer core, the asthenosphere, the oceans, and the atmosphere
- Subduction of crust through plate tectonics.
- Isostasy, or "floating" of continental and oceanic lithosphere on top of the asthenosphere.

Getting a feel for the average densities of different earth materials will give you an understanding of the driving factor behind some of these processes.

Background:

Earth is a layered planet. Its layers are the core, mantle, and crust. Each layer is a different composition. Note: with Plate Tectonics Theory, different layers are classified according to the way they deform. These layers are the **lithosphere**, a rigid outer layer containing the crust and upper-mantle; the **asthenosphere**, a weaker, semi-molten layer in the mantle; and the **mesosphere**, a stronger layer in the lower mantle.

Earth's crust is the most accessible to study, but also more complex, with many more variations in composition. The crust of Earth is divided into two types: **oceanic** and **continental**. Most oceanic crust is composed of the rock **basalt**. Basalt is **mafic** (which means it has a high magnesium and iron content), composed of the minerals: calcium-rich plagioclase feldspar, olivine, amphibole, and pyroxene. Continental crust has more range in composition, but for our purposes we will assume that its average composition is similar to the rock **granite**. Granite is a **felsic** rock (which means it has a high feldspar and silica content), composed of quartz, potassium-rich feldspar, and mica. Mafic rocks contain denser minerals and therefore, oceanic crust is denser than continental crust (the average density of basalt is 3.0 g/cm^3 and granite is 2.7 g/cm^3). On average, continental crust is much thicker and older than oceanic crust.

Laboratory experiments indicate that the rocks **peridotite** and **dunite**, largely made up of minerals olivine and pyroxene, has similar physical properties to account for observed speeds of seismic waves that travel through Earth's upper mantle. Peridotite and Dunite are more dense than crustal rocks (with average densities between $3.2 - 3.4 \text{ g/cm}^3$). Additional observations come from the field which show peridotites below crustal rocks in areas of deformation where rocks have been uplifted and exposed at the surface.

Peridotite inclusions are also found in **kimberlite pipes**, cone-shaped bodies of rock where magma has been volcanically emplaced into pre-existing rocks. Kimberlite deposits contain certain minerals (one of which is diamond) which can only form under the high temperature and pressure conditions found between 100-300 km depth. The inclusions of peridotite in the kimberlites are thought to represent pieces of the mantle brought up to the surface during eruptions. A final piece of evidence used to determine the mantle's composition comes from **stony meteorites** (chondrites), since they are thought to be remnants of material left over from the formation of the solar system, and have

peridotitic composition. In earth's lower mantle, below the transition zone, greater pressures cause rock of the same composition as peridotite to undergo phase changes to become higher in density.

The core is believed to be composed of mostly iron and nickel. The evidence for this comes from the existence of Earth's magnetic field, **metallic meteorites**, and seismic waves. The density of the liquid outer core is between 9.9-12.2 g/cm³, and the density of the inner core is 12.8-13.1 g/cm³.

Materials:

Graduated cylinders, different sizes	Electronic balance	Water
Beakers	Various Earth materials	

Procedures:

1. Use the balance to find the mass of the material.
2. Pour enough water into the large beaker for the rock samples. Measure and record the volume of just the water. This is the initial volume.
3. Carefully place the material being tested in the graduated cylinder. Find the volume of the water plus the material. This is the final volume. Subtract the initial volume from the final volume. This is the volume of the material. Note that 1 ml = 1 cm³.
4. For rock samples that require a beaker, place the rock carefully into the beaker. Make a mark on the side of the beaker with a water soluble pen. This is the final volume. Carefully remove the rock.
5. Measure out 100 ml with the graduated cylinder and slowly pour into the beaker until you reach the line where the volume reached when the rock was in the water. Subtract the amount you used from 100 ml. This is the volume of the rock. If you need more than 100 ml, fill the cylinder with another 100 ml, keeping track of the total volume of water you pour in.
6. Divide mass by the volume to find the density.
7. Calculate the percent error: $\% \text{ error} = \left| \frac{\text{Your Value} - \text{Actual Value}}{\text{Actual Value}} \right| \times 100$

Data:

	Mass of material (g)	Initial water vol. (ml)	Final water vol. (ml)	Volume of material (ml)	Density of material (g/ml) or g/cm ³	% Error
Iron Nails (core)						
Nickel Spheres (core)						
Dunite (mantle rock)						
Basalt (oceanic crust)						
Granite (continental crust)						

Analysis:

1. How do the densities you measured for your rock samples (granite, basalt, and dunite) compare with the values presented in the discussion? What do you think are some sources of error with your measurements?

2. Earth's core is believed to be composed primarily of an iron-nickel alloy. Compare the values you got for the densities of iron and nickel to the density of the core. Why is there such a difference?

3. Earth is round, although not exactly spherical in shape (it's slightly bulging at the equator and flattened at the poles), but we can approximate its volume by using that of a sphere:

$$V = \frac{4}{3} \times \pi \times r^3$$

where:

V = Earth's volume = *calculated value*

r = Earth's average radius = 6371 km

π = 3.1415...

Calculate the volume of Earth in km³.

Convert the volume of Earth from km³ to cm³. 1 km = 100,000 cm.

Here's the conversion factor:

$$\frac{1 \text{ km}^3}{1} \times \frac{100,000 \text{ cm}}{1 \text{ km}} \times \frac{100,000 \text{ cm}}{1 \text{ km}} \times \frac{100,000 \text{ cm}}{1 \text{ km}} = \text{_____ cm}^3$$

Using the mass of Earth as: 5.98×10^{27} g, compute the average density in g/cm³.

4. Crustal rocks on Earth have an average density between $2.7 - 3.0 \text{ g/cm}^3$. How does this compare with the average density of Earth that you calculated? What does this imply about Earth's density structure?

5. Go to. <http://nineplanets.org/data1.html>. Using data showing planetary density data, which planets have densities similar to the Earth? Which have densities much different from that of Earth? Using the positions of the planets relative to the sun, do you see any patterns with average density and distance from the sun?

Which planet would be able to float on water? (Density of water is 1 g/cm^3 .)

6. A theory of planetary formation is that in the early history of a planet, a certain process called **differentiation** occurs where denser matter sinks under its own weight toward the center of the planet, and lighter matter floats to the surface. How do the observations from this lab relate to this theory?

7. Earth's moon has an average density of 3.3 g/cm^3 . The prevailing theory of its formation is that a very large impactor (the size of Mars) collided with Earth, and the material that was thrown out into space coalesced to form the moon. Based upon our observations and this theory, would you think that the moon formed before or after Earth's differentiation? Please explain your answer.

8. Recent surveys from NASA reveal Earth's moon has no magnetic field. What might be an explanation for this observation?
9. At a convergent plate boundary, usually one plate will subduct (go beneath) the other. If an oceanic plate meets a continental plate, which one do you think will subduct and why?
10. If an oceanic plate collides with another oceanic plate, which plate do you think will subduct and why? **Hint:** They will both be composed of basalt, so density differences will not be based on composition. What are other factors that affect density?
11. Within the Earth System, there are also layers of air and water which surround the solid Earth. Look up the density of Earth's atmosphere and oceans. How do the densities of air and ocean water compare with the values for Earth's core, mantle and crust? Why are gases and water still trapped within the Earth when the density differences are so great?
12. Why is seismic data necessary to infer Earth's interior structure and composition? Why cannot direct observation be used?