Name(s) ____ Per ______

Heat Transfer in the Earth's Interior

Initial model

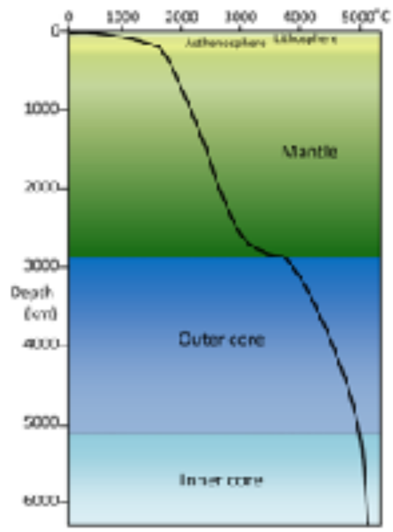
In the space below please draw what you think would happen if you were to look through the center of the Earth (for example, imagine looking at the cutaway of an apple). Include an explanation of your model.

Name(s) ____ Per ______

Determining the Structure of the Earth's Interior

Two students are having a discussion about heat within the Earth System. A student states that the hottest temperature on the Earth is at the surface because this is where the sun radiates all the heat (which is why a snowman like Olaf would melt in the summer). This student found the table below.

Depth (km)	Temperature (ºC)
660	1900
2900	3000
5150	5000
5370	6000



1. Does the evidence support the student's claim? Why or why not?

2. What does this evidence tell us about the interior of the Earth?

3. Now that we know that the interior of the Earth is at different temperatures, let's discuss energy and matter. What happens when matter at two different temperatures meets?

Name(s) ____ Per ______

Reading #1

What is the Source of the Heat in Earth's Interior?

By **EarthSky** *in* **EARTH** | September 6, 2010

The heat inside Earth moves continents, builds mountains and causes earthquakes. Where does all this heat come from?If you think about a volcano, you know Earth must be hot inside. The heat inside Earth moves continents, builds mountains and causes earthquakes. Where does all this heat inside Earth come from?

Earth was hot when it formed. A lot of Earth's heat is leftover from when our planet formed, four-and-a-half billion years ago. Earth is thought to have arisen from a cloud of gas and dust in space. Solid particles, called "planetesimals" condensed out of the cloud. They're thought to have stuck together and created the early Earth. Bombarding planetesimals heated Earth to a molten state.

So Earth *started out* with a lot of heat.

Earth makes some of its own heat. Earth is cooling now – but very, very slowly. Earth is close to a *steady temperature state*. Over the past several billion years, it might have cooled a couple of hundred degrees. Earth keeps a nearly steady temperature, because it *makes* heat in its interior.

In other words, Earth has been losing heat since it formed, billions of years ago. But it's producing almost as much heat as it's losing. The process by which Earth makes heat is called *radioactive decay.* It involves the disintegration of natural radioactive elements inside Earth – like uranium, for example. Uranium is a special kind of element because when it decays, heat is produced. It's this heat that keeps Earth from cooling off completely.

Many of the rocks in Earth's crust and interior undergo this process of *radioactive decay* . This process produces subatomic particles that zip away, and later collide with surrounding material inside the Earth. Their energy of motion is converted to heat.

Without this process of radioactive decay, there would be fewer volcanoes and earthquakes – and less building of Earth's vast mountain ranges.

How hot is it inside Earth? No one has come close to exploring Earth's interior directly. So not all geophysicists agree on how hot it is at Earth's core. But the rate of travel of waves from earthquakes – called "seismic waves" – tells scientists a lot about what materials make up the planet. Seismic data also reveal whether these materials are liquid, solid or partially solid. Meanwhile, laboratory data indicate at what temperatures and pressures the materials inside Earth should begin to melt.

From this evidence, Earth's core temperature is estimated to be around 5,000 to 7,000 degrees Celsius. That's about as hot as the surface of the sun, but vastly cooler than the sun's interior.

Name(s) ____ Per ______

4. According to the reading, make a claim about each of the two sources of energy within the Earth

Claim #1: ____

Claim #2: ____

5. What evidence do we have to support those claims?

Evidence #1: ____

Evidence #2: ____

6. Is the Earth more like the inside of an onion or the inside of an apple? Use evidence from the packet to explain your answer.

Name(s) ____ Per ______

Reading #2

How Earthquakes Tell Us Information About the Structure of the Earth

Earthquakes and S-Waves

The seismic waves released by earthquakes provide scientists with several forms of measurable evidence that supports the idea of the Earth's outer core being liquid. Two particular types of waves, compressional waves and shear waves — known commonly as P-waves and S-waves, respectively, provide direct evidence. Geologists use seismometers — wave-sensing and data-collecting units placed at different points on the Earth's surface — to measure these waves as they pass through the planet during earthquakes. Both P- and S-waves travel easily through solids, but S-waves cannot pass through liquids. S-wave propagation requires strong bonds between affected molecules. The wave moves because one row of atoms moves sideways and pulls the next row with it, until the bonds between the rows pulls the second row back with an elastic-type recoil. This process continues down the rows, propagating the shaking wave. Liquids don't have strong bonds, so the molecules don't recoil.

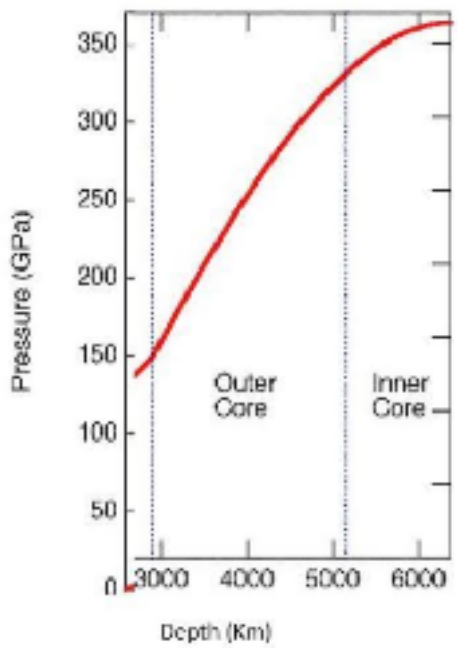
7. Based on the information in the text, what might be a reason that the S-waves are "stopped"

8. Using this knowledge of S-wave shadows and the layers of the Earth, make a prediction about the state of matter of the outer core

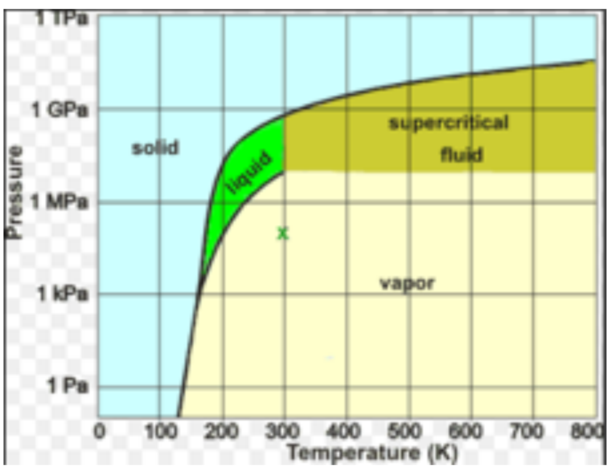
Name(s) ____ Per ______

9. Normally, when you heat a solid, what happens to that solid? What scientific evidence or everyday experience do you have to support this claim? Use scientific reasoning to explain what happens to the molecules when you heat the solid.

Scientists have determined that the pressure within the inner and outer core are different according to the chart to the **right**:



Below is a phase diagram that shows what happens if you change the pressure when you are heating a solid.



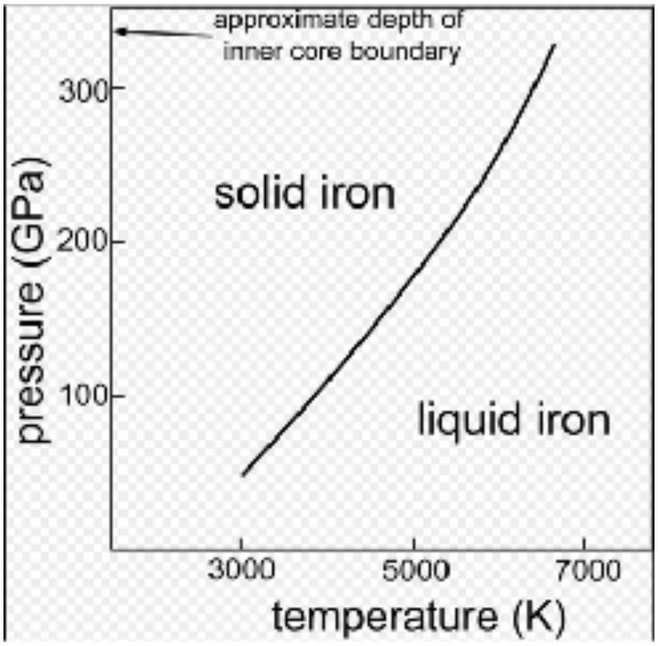
10.At high temperatures and low pressure what state of matter do you expect? ______________

11.At low temperature and low pressure what state of matter do you expect? ________________

12.At high temperature and high pressure what state of matter do you expect? ______________

Name(s) ____ Per ______

Scientists have studied the composition of the core of the Earth and determined that it has mostly Iron and some Nickel within it. In particular the inner core is composed of mostly Iron. These scientists have studied the conditions of temperature and pressure that exist within the core within the laboratory and they have found the following data in regards to how pressure and temperature affects the state of matter of iron.



The pressure of the inner core/outer core boundary is approximately 300 GPa. Using the graph above, and the evidence about temperature within the Earth from earlier within the packet answer the following questions:

13.What state of matter would you predict the inner core to be? ______________________

14.What state of matter would you predict the outer core to be? ______________________

Name(s) ____ Per ______

Reading #3

Evidence that Heat Transfer Occurs Within the Earth

In the first reading, the first line stated “The heat inside Earth moves continents, builds mountains and causes earthquakes.” We are now going to explore the scientific evidence that suggests that heat transfer occurs within the Earth.

WHAT DRIVES EARTH'S MAGNETIC FIELD?

When an electric current passes through a metal wire, a magnetic field forms around that wire. Likewise, a wire passing through a magnetic field creates an electric current within the wire. This is the basic principle that allows electric motors and generators to operate. In the Earth, the liquid metal that makes up the outer core passes through a magnetic field, which causes an electric current to flow within the liquid metal. The electric current, in turn, creates its own magnetic field—one that is stronger than the field that created it in the first place. As liquid metal passes through the stronger field, more current flows, which increases the field still further. This self-sustaining loop is known as the geomagnetic dynamo.

Energy is needed to keep the dynamo running. This energy comes from the release of heat from the surface of the solid inner core. Although it may seem counterintuitive, material from the liquid outer core slowly "freezes" onto the inner core, releasing heat as it does so. (High pressures within the Earth cause material to freeze at high temperatures.) This heat drives convection cells within the liquid core, which keeps the liquid metal moving through the magnetic field. The so-called Coriolis force also plays a role in sustaining the geomagnetic dynamo. Our planet's spinning motion causes the moving liquid metal to spiral, in a way similar to how it affects weather systems on the surface. These spiraling eddies allow separate magnetic fields to more or less align and combine forces. Without the effects caused by the spinning Earth, the magnetic fields generated within the liquid core would cancel one another out and result in no distinct north or south magnetic poles.—*R.G.*

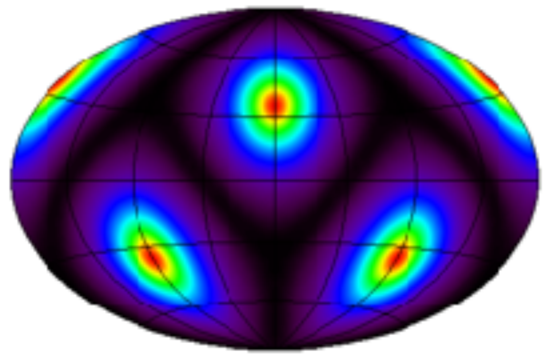
15.How is the Earth’s magnetic field evidence that convection is occurring?

Name(s) ____ Per ______

Now we will explore a second form of convection, within the mantle of the Earth.

Thermal evolution and mantle convection

The thermal evolution of terrestrial bodies is strongly influenced by the way heat is transported from the interior to the surface. Heat can be transported by either conduction and/or convection. The conductive heat transport dominates in the stagnant outer layer of a planet, i.e. the lithosphere, whereas convective heat transport usually dominates in the interior, i.e. the mantle and the core.



Moving the interior

Thermal convection occurs due to density changes of the material caused by temperature variations: heated material rises towards the surface because of its reduced density relative to the density of the surrounding material and cooled material sinks toward the centre because of its increased density. This convective heat transport is more efficient than the conductive heat transport and as long as the planet is sufficiently hot inside and cool outside, a global-scale circulation of the interior can be sustained. In addition to thermal convection also chemical convection can take place in a terrestrial planet. Chemical convection is caused by density variations due to compositional differences: dense material sinks and light material rises.

Fluid rocks

The mantles of terrestrial planets consist of rock, which can be partially molten in small regions, but the vast majority of the mantle material is solid. In response to short-term (~ 1s) force, e.g. seismic waves, the mantle behaves like an elastic solid body. However, in geological time scales (~100 Ma) the rock behaves like a viscous fluid and allows the above described global-scale circulation. These interior movements can leave behind some fingerprints on the surface, for instance in the form of tectonic structures likes faults and mountains, horizontal plate movements or volcanoes.

Driving energy sources

Thermal convection in terrestrial bodies is driven by internal heat sources. This heat stems from accretion, the decay of radioactive elements, tidal dissipation, and the gravitational energy, which is released during the differentiation into core, mantle, and crust. The relative importance of each of these heat sources is a function of time and can vary from one terrestrial body to another. It should be noted that, although solar irradiation can be orders of magnitude bigger than internal heat, it has no effects on deep internal dynamics. Solar irradiation indeed penetrates less than a few hundred meters and only drives processes close to the surface.

Thermal and chemical convection provides a framework to reconcile observations of planetary magnetic and gravity fields, surface heat flow, distribution of volcanoes and tectonic structures, geo- & cosmochemistry, and mineral physics.

Name(s) ____ Per ______

16.Construct an explanation for how convection moves the Earth's interior

17.Please go to Google classroom to view a few videos about convection within the mantle.

18.From today's activity what are three new ideas/piece of evidence to incorporate into our model?