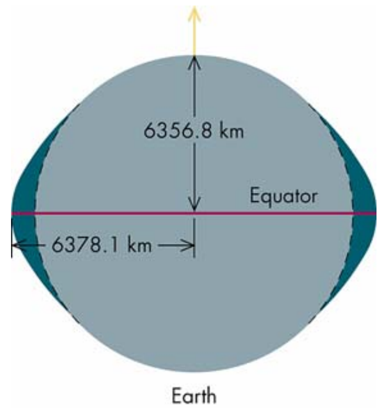
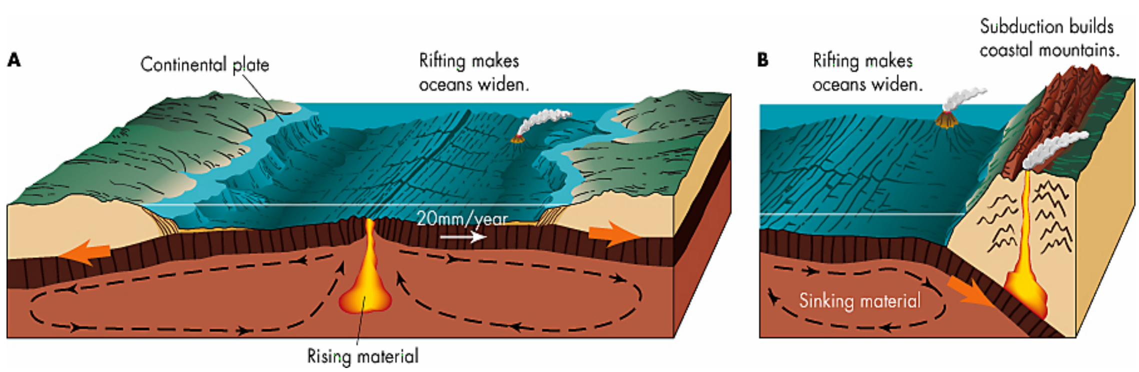
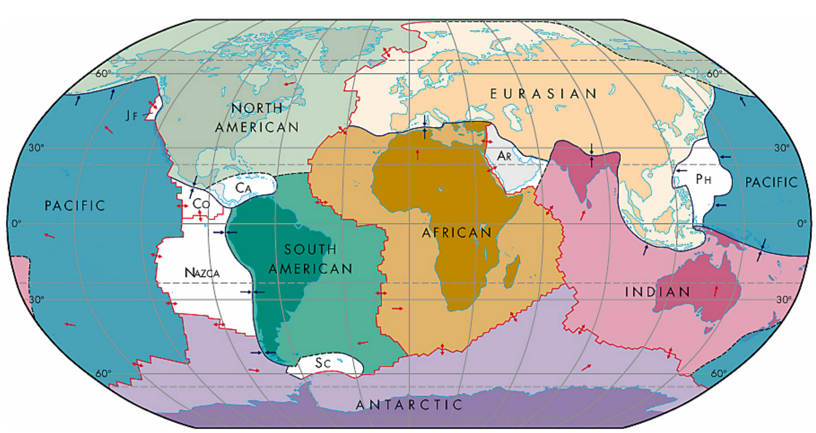
Third Rock from the Sun

Earth



- Earth is about 4.5 billion years old – same age as the sun.
- Earth is about 8000 miles (12,800km) in diameter. An oblate spheroid in shape.
- Earth is about 25,000 miles in circumference
- Earth has a great deal of internal heat from two sources: radioactive decay (fission) and leftover heat from the planetesimal era (heat from collisions). Because rocks are moderately poor conductors of heat the *in situ* heat is released very slowly. Thus the interior of the earth is very hot because of both trapped heat leftover from the formation of the planet and small amounts of heat being released due to radioactive decay.
- The earth radiates more energy than it receives from the sun (0.06 W/m^2) due to internal heat.
- The earth circulates rock from its lower levels to the surface (convection in the mantle). Has active geological processes including *erosion*, *plate tectonics*, *orogenisis*, and *volcanism*.





- Present composition of the earth: Oxygen (45.5%), Silicon (27.2%), Aluminum (8.3%), Iron (6.2%), Calcium (4.7%), Magnesium (2.8%), Sodium (2.3%), Potassium (1.8%), Titanium (0.6%), all others less than 1%

Igneous, Sedimentary, Metamorphic Rocks

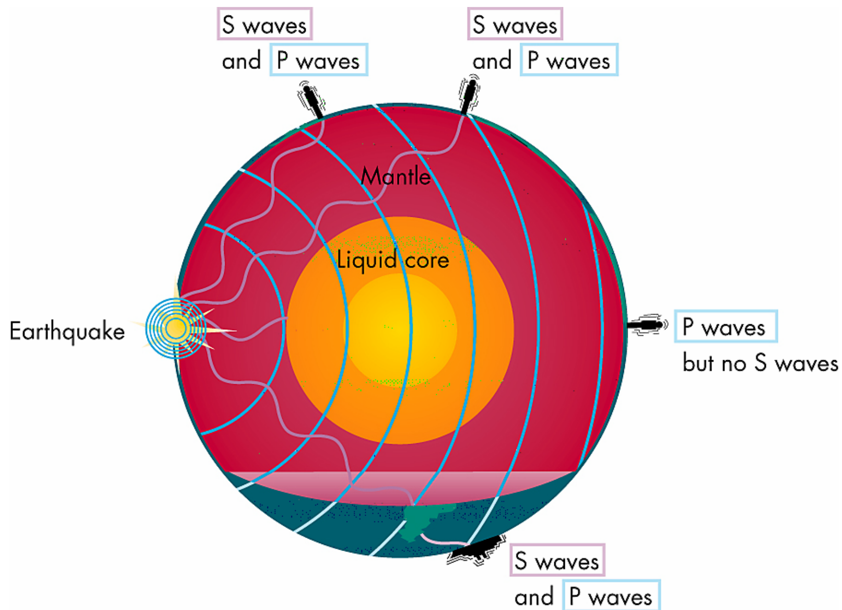
- Igneous rocks are made from the cooling of molten material (magma). There are two broad categories of igneous rocks: those associated with magma forced to the earth's surface through volcanic eruptions (lava) and those formed when magma invades intrusions beneath the earth's surface, cools and solidifies, and is later uncovered by uplift and/or erosion (plutonic rocks). Basalt is a common rock associated with lava flows and granite is a common plutonic rock.
- Sedimentary rocks are formed (lithified) from compressed sediments on the bottom of lakes or oceans. Sandstone and Limestone are common sedimentary rocks. Sedimentary rocks commonly contain fossils.
- Metamorphic rocks are formed when igneous or sedimentary rocks are changed to heat and/or pressure without being completely melted. Marble is highly metamorphosed limestone. Other common metamorphic rocks are quartzite, gneiss, schist.

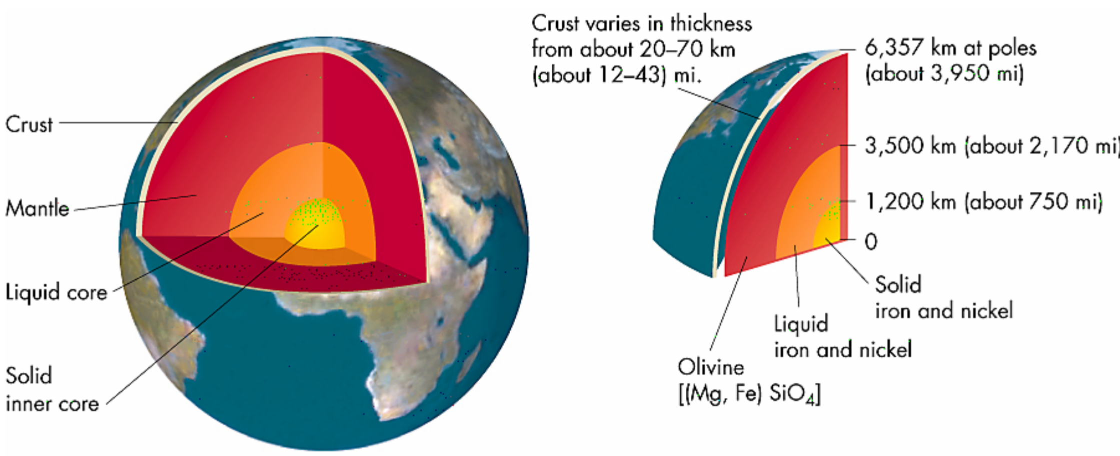
Determining the Age of Rocks

- Dating of the earth and its rocks is accomplished by measuring the ratios of radioactive elements "locked" into rocks as they condense and crystallize into solid form. The less of the older radioactive element, the younger the rock.
- Decay rates for radioactive elements are well known and obey the natural law of decay: $A = A_0 e^{-\alpha t}$, allowing us to date rocks with a good degree of accuracy.
- A radioactive isotope of the element Potassium (K^{40}) decays to the stable element Argon (Ar^{40}) at a rate such that half of any sample of Potassium 40 changes to Argon 40 in 1.28 billion years. By measuring the ratio of Potassium 40 to Argon 40 in a rock it is possible to estimate its age. A rock that contains a ratio of 50/50 ratio of K^{40} to Ar^{40}, for instance, is about 1.28 billion years old. A rock that contains a ratio of 25/75 ratio of K^{40} to Ar^{40} is about 2.56 billion years old.
- Radioactive dating indicates that the oldest rocks on Earth are about 4 billion years old.
- The oldest fossils are about 3.5 billion years old.

Internal Structure of the Earth

- Probed with seismic waves

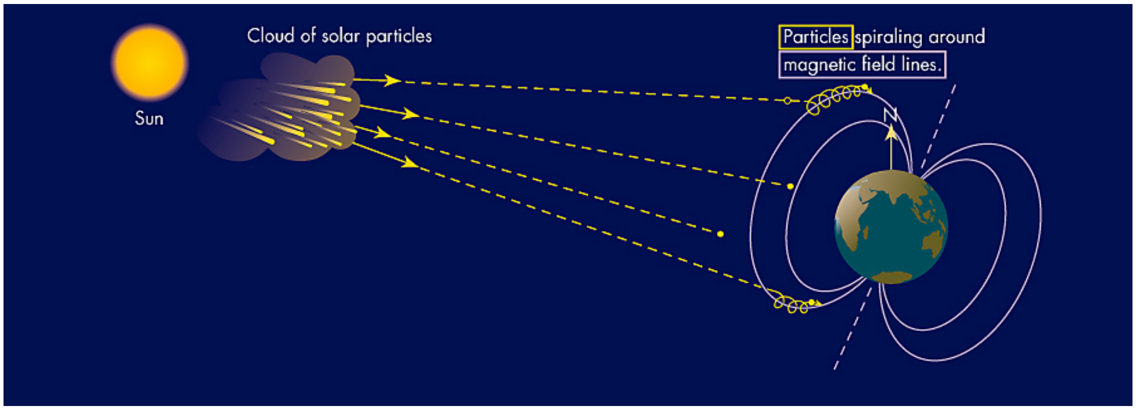




- Crust (silicates) solid, extends down to 20 – 70 km down
- Mantle (silicates - olivine rich) nearly molten solid, 3500 km down
- Liquid core (iron, nickel, sulfur?) molten, 4700 km down
- Solid core (iron, nickel) solid, 6400 km down
- Average density is about 5.5g/cm^3
- Inner core is solid even though it is hotter because of higher pressure and melting point. Temperature in the core is about 6500K (hotter than the surface of the sun!)
- The earth is *differentiated*: i.e., the materials from which it is composed are largely separated into layers by *density*.

Earth's Magnetic Field

Earth has a robust magnetic field due to the presence of charged particles moving within the mantle and cores. This magnetic field protects us from ionizing radiation in the solar wind.

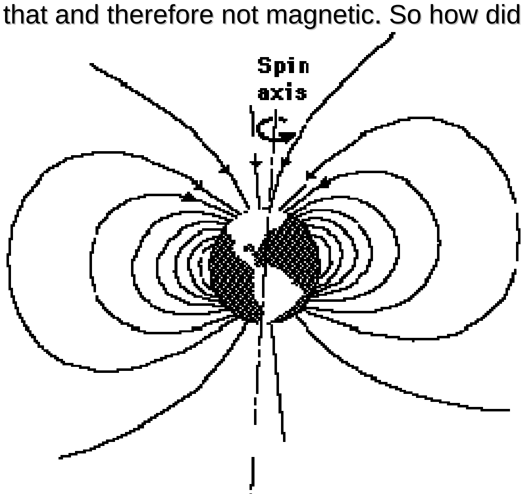


The earth's magnetic field shape is often warped by solar activity (see the solar storm link on our website courtesy of Briana Maas).

How the Earth's Magnetic Field is Formed

Courtesy of Rod Nave, Hyperphysics
http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magearth.html

The earth's magnetic field is similar to that of a bar magnet tilted 11 degrees from the spin axis of the earth. The problem with that picture is that the Curie temperature of iron is about 770 C (for a given ferromagnetic material the long range order (and magnetic properties – mhh) abruptly disappears at a certain temperature which is called the Curie temperature for the material). The earth's core is hotter than that and therefore not magnetic. So how did the earth get its magnetic field?



Magnetic fields surround electric currents, so we surmise that circulating electric currents in the Earth's molten metallic core are the origin of the magnetic field. A current loop gives a field similar to that of the earth.

The earth's magnetic field is attributed to a dynamo effect of circulating electric current, but it is not constant in direction. Rock specimens of different age in similar locations have different directions of permanent magnetization. Evidence for 171 magnetic field reversals during the past 71 million years has been reported.

Although the details of the dynamo effect are not known in detail, the rotation of the Earth plays a part in generating the currents which are presumed to be the source of the magnetic field. Mariner 2 found that Venus does not have such a magnetic field although its core iron content must be similar to that of the Earth. Venus's rotation period of 243 Earth days is just too slow to produce the dynamo effect.

Interaction of the terrestrial magnetic field with particles from the solar wind sets up the conditions for the aurora phenomena near the poles.

The Dynamo Effect

The simple question "how does the Earth get its magnetic field?" does not have a simple answer. It does seem clear that the generation of the magnetic field is linked to the rotation of the earth, since Venus with a similar iron-core composition but a 243 Earth-day rotation period does not have a measurable magnetic field. It certainly seems plausible that it depends upon the rotation of the fluid metallic iron which makes up a large portion of the interior, and the rotating conductor model leads to the term "dynamo effect" or "geodynamo", evoking the image of an electric generator.

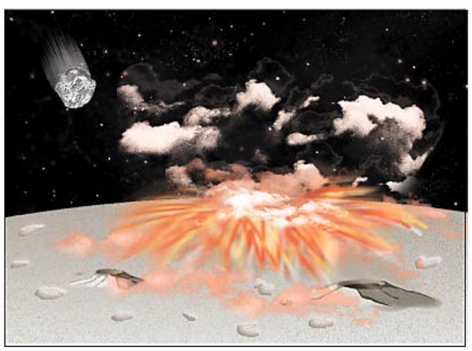
Convection drives the outer-core fluid and it circulates relative to the earth. This means the electrically conducting material moves relative to the earth's magnetic field. If it can obtain a charge by some interaction like friction between layers, an effective current loop could be produced. The magnetic field of a current loop could sustain the magnetic dipole type magnetic field of the earth. Large-scale computer models are approaching a realistic simulation of such a geodynamo.

Atmosphere/Oceans of the Earth

- The primordial atmosphere was rich in nitrogen, carbon dioxide, hydrogen rich compounds such as methane and ammonia and water vapor
- The primordial atmosphere formed when these gasses were liberated from the earth's interior due to collisions and volcanic activity. Comets may have also contributed water to the primordial atmosphere. Methane and ammonia were broken down into hydrogen, carbon and nitrogen by sunlight. Most of the nitrogen and carbon remains while the hydrogen long ago escaped into space.

A

B



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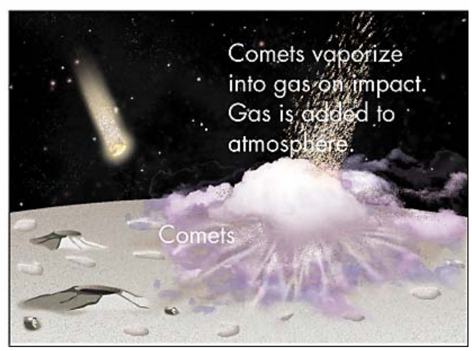
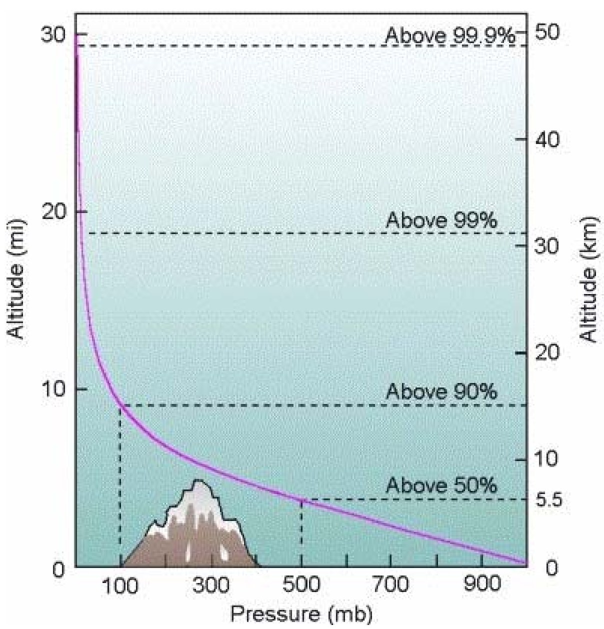
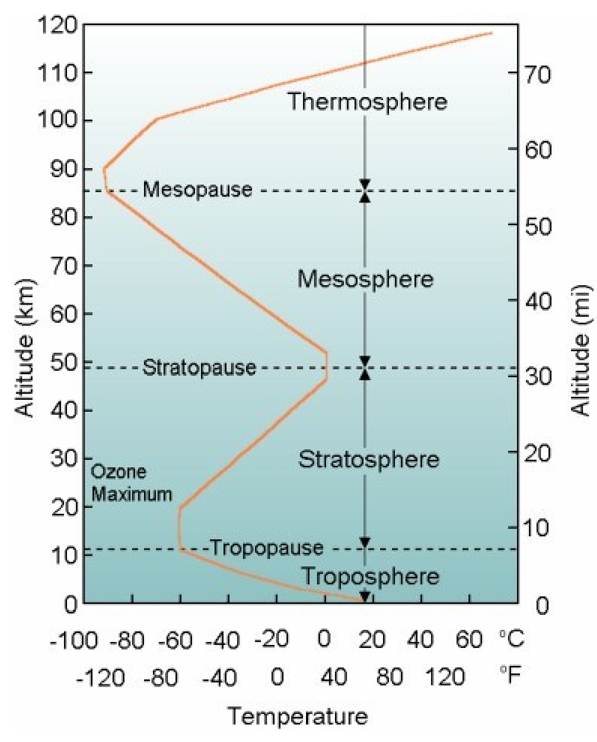


- The modern atmosphere is relatively oxygen rich (about 78% nitrogen and 21% oxygen). Oxygen came from the rise of organisms (plants).
- The earth has oceans. Primordial oceans formed when water vapor in the atmosphere cooled as the planet cooled and condensed into liquid water.

Details of Earth's Atmosphere

- Earth's atmosphere has four layers: the *Troposphere, Stratosphere, Mesosphere and Thermosphere.*
- The lowest layer of Earth's atmosphere, the one in which all weather (and life) exists is the *troposphere*. The troposphere extents from the surface to about 10 kilometers above the ground. Temperature decreases with increasing height in the troposphere. This *lapse rate* is about 5.5^0F per 1000 feet on average. The troposphere is capped by the *tropopause* which is notable for being the layer of Earth's atmosphere containing *jet streams*.
- The *stratosphere* lies above the troposphere and is important to life because stratospheric ozone (O_3) is largely responsible for absorbing ultraviolet radiation from the sun. The stratosphere extends to about 50 kilometers above the earth's surface. There is a temperature inversion in the stratosphere (although this inversion is weakening due to *global warming*). The stratosphere is capped by the *stratopause*.
- The *mesosphere* extends to about 85 kilometers above the earth's surface. The mesosphere also cools with increasing height.
- The *thermosphere* fades gradually into outer space 120 kilometers up. The thermosphere is also characterized by a strong temperature inversion and is the warmest layer of Earth's atmosphere.
- Temperature decreases with height in the earth's atmosphere in the troposphere and mesosphere but *increases* with height in most of the stratosphere and all of the thermosphere.



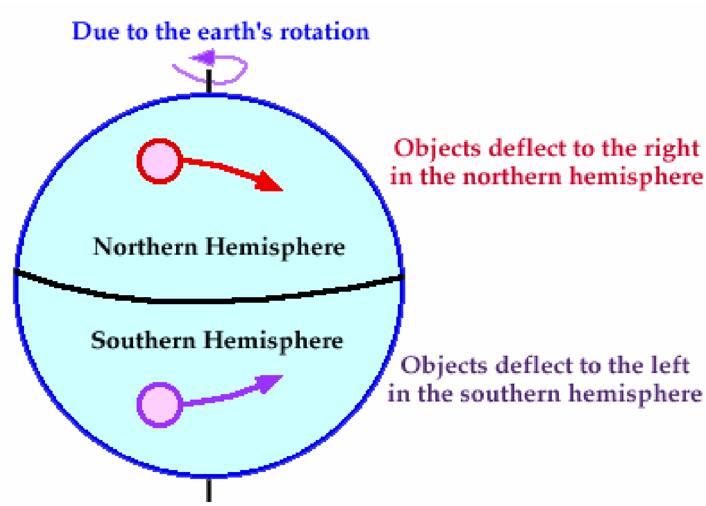


How the Sun Transmits Energy to Earth

- There are three mechanisms by which energy is transmitted: *conduction, convection and radiation*.
- Conduction is a mechanism of energy transfer that occurs when two objects that have different temperatures are placed in direct contact with one other. Heat energy flows from the hotter object to the cooler object.
- Convection is a mechanism of energy transfer that occurs in fluids. Convection occurs when a fluid begin a "roiling" motion when part of it is heated like that seen in a pot of boiling water on a stove. The roiling motion distributes heat from the hotter regions of the fluid to the cooler regions of the fluid.
- Radiation is energy transfer via electromagnetic waves. The infrared heat from an electric heater is an example of heat transfer via radiation as is the warmth you feel outside from the sun on a clear day.
- Energy in the sun is created in the thermonuclear core and is transmitted outward to the surface of the sun (the *photosphere*) via radiation and convection.
- The sun is a blackbody whose surface temperature may be determined from its color via Wiens Law (about 5800K).
- The sun pumps out an amazing 4×10^{26} watts of power. This energy is radiated away from the sun in all directions.
- Energy from the surface of the sun reaches the top of the earth's atmosphere via electromagnetic radiation (sunlight). Due to the inverse square law, the amount of power from the sun which reaches the top of earth's atmosphere is about 1400 watts/m^2.
- Earth's atmosphere generally absorbs very little sunlight. About 1000 watts/m^2 of power from the sun eventually reaches the earth's surface in the middle latitudes (under ideal conditions).
- Since the atmosphere is nominally transparent to visible light it is the presence of aerosols and clouds that reflect and scatter the 30% of sunlight that does not penetrate the atmosphere.
- The average amount of sunlight that reaches the earth's surface worldwide is about 340 w/m^2.
- Of the sunlight that reaches the earth's surface, approximately 1/3 is absorbed and converted to IR (blackbody effect) – about 110 watts/m^2. The remaining sunlight is reflected/scattered back into the atmosphere from the earth's surface.
- The earth warms all during the day (while it is being illuminated) and radiates well after sunset.
- Earth's atmosphere absorbs and scatters IR (the greenhouse effect), thus heating the environment. Greenhouse gasses include water vapor, carbon dioxide and methane.
- The atmosphere is also heated by conduction in the *boundary layer*. The boundary layer is the layer of air within a meter of so of the ground. Although air is generally

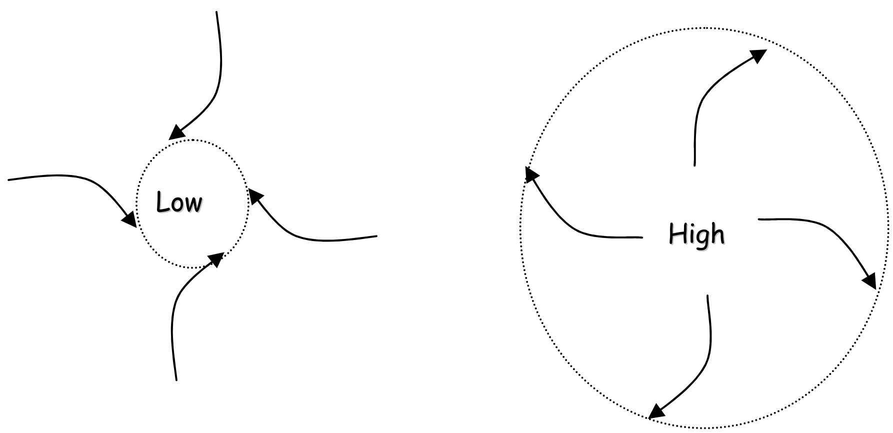
not a good conductor of heat, the amount of air in contact with large patches of ground eventually becomes heated due simply to the large areas involved.

- On a warm sunny day temperature gradients in the boundary layer can be as great as 40^0 F in less than a meter!
- Warm air is less dense than cool air, is more buoyant, and will rise. On clear, calm days thermal bubbles of warm air rise over portions of the earth's surface warmed by direct sunlight.
- These thermal bubbles contain air and water vapor. As they rise they cool at approximately the lapse rate of 5.5^0 F per 1000 feet in the troposphere. As they cool the water vapor in these air masses condenses to water droplets. This begins the process of cloud formation.
- Condensation liberates *latent heat*. The release of latent heat is a significant contributor to Earth's overall temperature. Latent heat is also a significant energy source for thunderstorms as the release of latent heat from condensation enhances thermal activity and results in large amounts of vertical air movement in the atmosphere. Hurricanes are examples of large weather systems fueled by the release of latent heat.
- Thermal activity in Earth's atmosphere distributes heat from the sun vertically and from the equatorial regions northward where warming of the surface is less efficient.
- Vertical motion of air creates High and Low Pressure regions. Horizontal movement of air both near the surface and at higher elevations creates fronts, long waves, and jet streams. All of these features distribute heat throughout the atmosphere.
- Most large (mesoscale or greater) weather systems rotate due to the *Coriolis Force*. The Coriolis force is an apparent deflection to the right that affects all air masses due to the rotation of the earth.



http://ww2010.atmos.uiuc.edu/(Gh)/guides

High and low pressure systems



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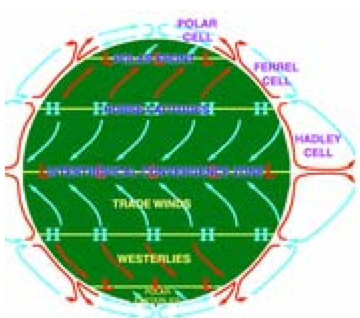
Coriolis Influenced Three Cell Circulation Model



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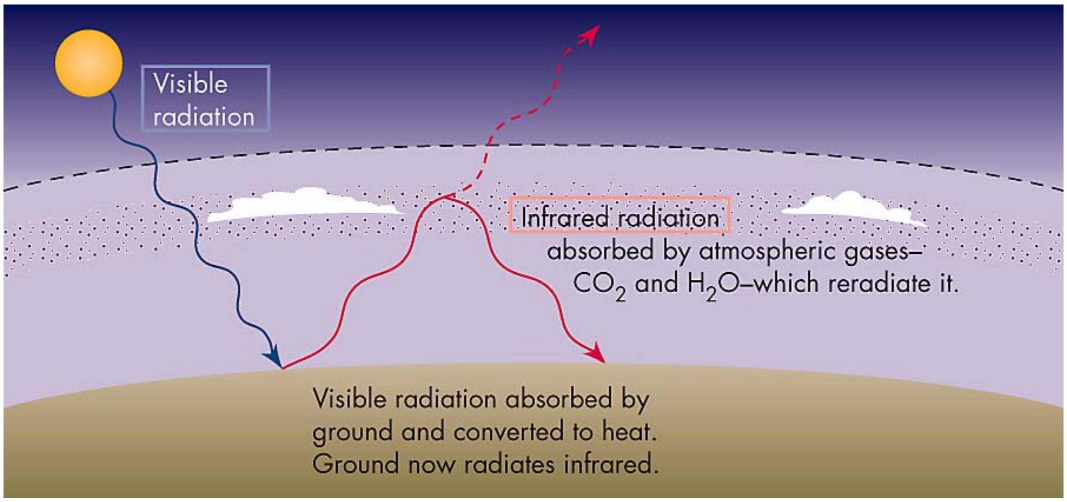
Greenhouse Effect

- Earth, Venus, Mars all have greenhouse gasses in their respective atmospheres
- A greenhouse effect, due to the partial opacity of the atmosphere to infrared light, helps moderate temperature on earth.



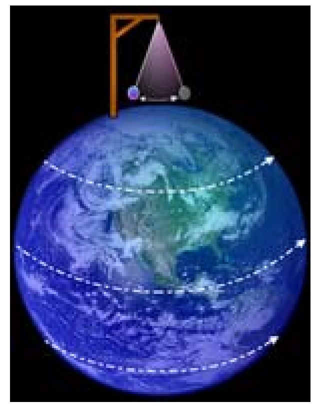
- Although Earth has always had a "greenhouse effect", human activities are increasing both the amount of greenhouse gasses in Earth's atmosphere and the infrared signature of Earth's surface, thus enhancing the existing greenhouse effect
- Global warming is a well- established scientific fact
- Increasing CO_2 levels (and other greenhouse gasses) have been thoroughly documented.
- Increase of Earth's infrared signature has been thoroughly documented
- Increasing global temperatures have been thoroughly documented

Possible Effects of Human Enhancement of Earth's Atmosphere

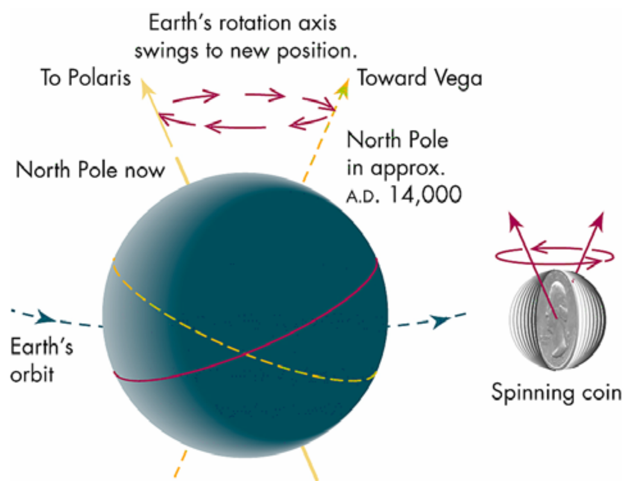
- Increase in sea levels
- Climate change
- Increases in storm energy
- Increases in disease
- Global cooling

Motions of the Earth

- Earth spins on its own axis. This gives rise to a *diurnal* cycle. The period is a day. A *solar* day varies slightly from a *sidereal* day.
- The spin of the earth gives rise to the *Coriolis Force*. This may be measured with a Foucault Pendulum (Fig 5.26, p 173 – the greatest photo in your textbook). The Coriolis Force is responsible for jet streams and the rotation of large weather systems.



- Earth orbits the sun in along an elliptical path. The period is 1 year. The elliptical nature of the earth's orbit has very little to do with the change of seasons. The earth is closest to the sun at *perihelion* and farthest from the sun at *aphelion*. The earth's speed changes along its orbital path in accordance with Kepler's laws.
- Earth precesses, i.e., its rotational axis "wobbles" like that of a top. The period is about 26,000 years.

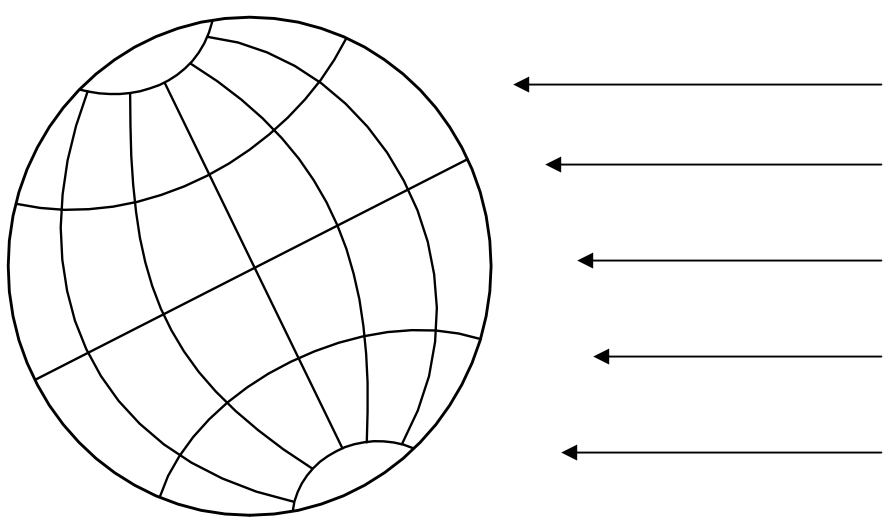


- Forces generated by collisions or gravity can affect the spin of planets. Precession occurs due to the presence of such outside. forces
- The Earth's axis precesses because of the attraction of the Sun, the Moon and the planets.
- Superimposed on the Earth's normal precession is a slow oscillation of the Earth's axial tilt over a period of about 41,000 years.

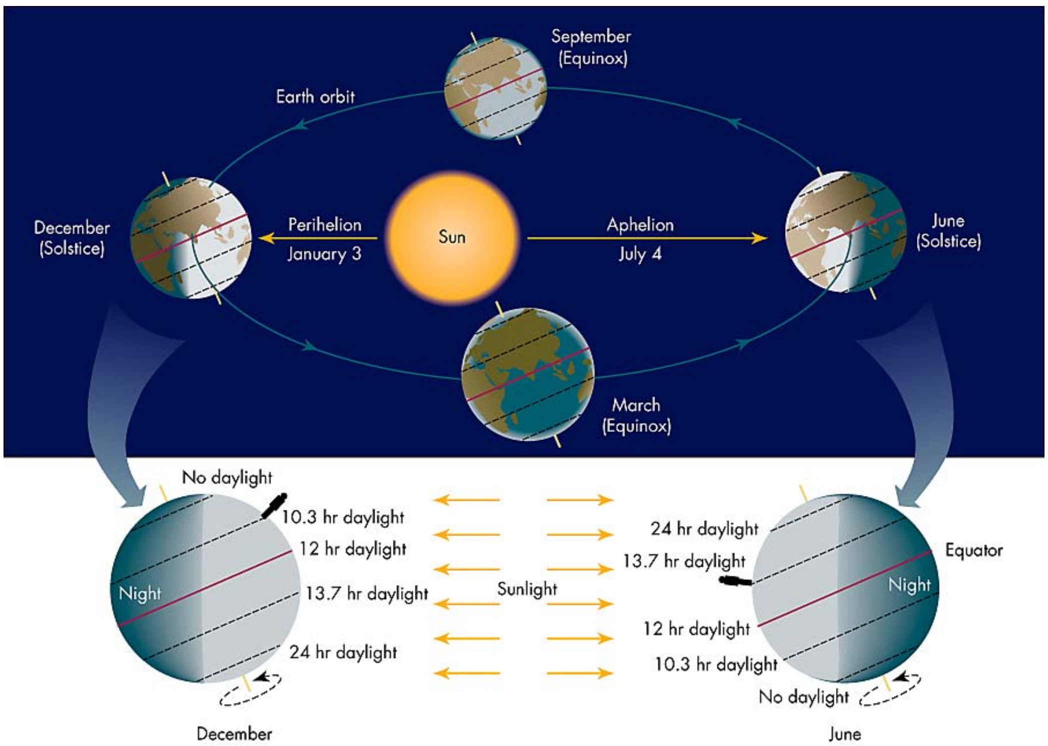
- Right now the Earth's axial tilt is decreasing. The tropics are moving toward the equator at about 15 meters a year.
- The Earth, which is not perfectly spherical, wobbles as it spins. Even weather systems can affect the wobble. This causes the precession of the earth's rotational axis to be fairly complex
- The Moon acts to keep the earth's axis tilt within moderate limits. Planets like Mars and Venus that lack moons can precess wildly due to the gravitational pull of other planets and the sun.

Seasons

- The earth is at perihelion in early January each year. This is when its orbital speed is greatest. It gradually slows down until reaching aphelion in July when its orbital speed is at its minimum.
- The earth is actually closer to the sun when temperatures are coldest in the northern hemisphere. This is possible because even though the sun is much closer to the earth during our winter months, the sun's rays travel a greater distance through the atmosphere and strike the earth at a more oblique angle in the northern hemisphere due to the $23\frac{1}{2}^0$ tilt of the earth about its rotational axis.
- The eccentricity of the Earth's orbit around the sun is so small ($\varepsilon = 0.017$) that it has virtually nothing to do with the change of seasons.
- At each equinox the sun is at a declination of 0^0 and the lengths of day and night are 12 hours at all points on the Earth's surface. At noon on the equator the sun is directly overhead (zenith or 90^0 above the horizon) and at the poles it is at 0^0.
- During the solstices the Sun has its greatest declination ($\pm 23.5^0$). The Sun is at the zenith for a latitude of $\pm 23.5^0$.
- Arctic and Antarctic circles – 66.5^0. Constant sun or darkness from solstice to equinox.

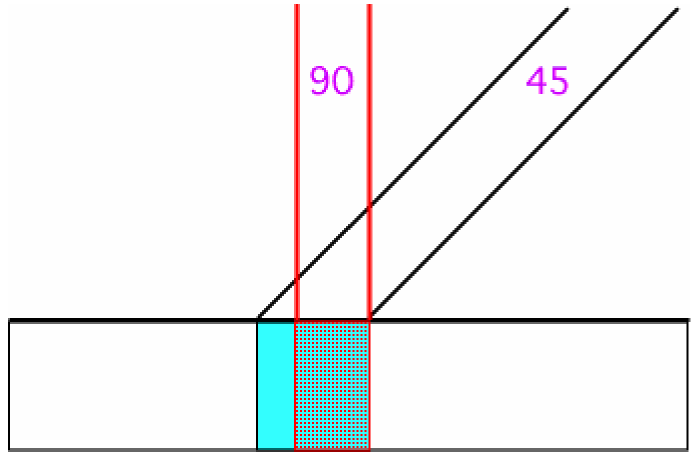


- Even though the difference between the earth's perihelion and aphelion distances is less than 3%. The amount of solar energy striking the earth is 7% greater at perihelion (in January) than at aphelion (in July).
- The previous statement would lead one to conclude that summer in the southern hemisphere, which occurs at perihelion, is warmer than summer in the northern hemisphere. This, however, is not the case.



- Most of the land mass of the earth is concentrated in the northern hemisphere. The southern hemisphere, by contrast, is 80% covered by water. Water has the ability to absorb large amounts of heat without changing temperature very much.
- The additional solar energy supplied by the sun at perihelion is absorbed by the large bodies of water in the southern hemisphere. The result is that temperatures are actually more moderate during summers in the southern hemisphere. On Mars, which does not have any oceans to absorb heat, the temperature fluctuations are much greater due to perihelion and aphelion.

- Energy from the sun that strikes the earth from directly overhead is more intense than energy that strikes the earth at an angle because the light at an angle is spread out over a greater area.
- *Solar Insolation* – heating effectiveness
- As the angle that sunlight strikes the earth changes with the progression of seasons the heating effectiveness of solar radiation changes.
- The amount of time the sun is in the sky also effects heating effectiveness.
- There is both a diurnal and a seasonal time lag in temperature response to solar insolation.



If the area irradiated by the sun is A and the angle the sun makes with respect to the surface is θ then the area irradiated increases as A/sinθ as sunlight strikes the surface at lower angles of incidence. At an angle of 30^0 the available sunlight is spread out over twice the area as at normal incidence.

Illustration courtesy of
http://www.physicalgeography.net/fundame

- Spring and summer are shorter in the southern hemisphere than in the northern. This is because of the earth's varying orbital speed. The number of days from the *vernal equinox* (March 20) to the *autumnal equinox* (September 22) is about a week longer than from autumnal to vernal.