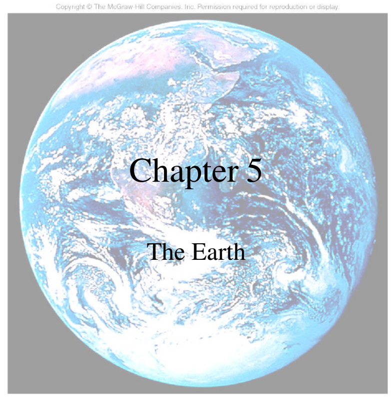
Tuesday, 10/7/08

- Project Part 1 (due 10/16)
- Return tests
- Chapter 5



Chapter 5

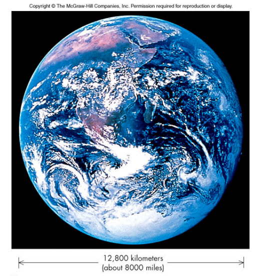
The Earth

Our Home, The Earth

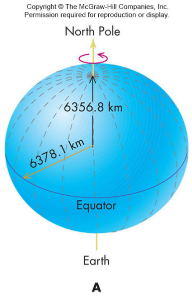
- Earth's beauty is revealed from space through blue seas, green jungles, red deserts, and white clouds.
- From our detailed knowledge of Earth, astronomers hope to understand what properties shape other worlds
- Earth is a dynamic planet with its surface and atmosphere having changed over its lifetime.
- Slow and violent motions of the Earth arise from heat generated within the planet
- Volcanic gases accumulate over billions of years creating an atmosphere conducive to life, which in turn together with water affects the air's composition

Size and Shape of the Earth

- In simple terms, the Earth is a huge, rocky sphere spinning in space and moving around the Sun at a speed of about 100 miles every few seconds
- Earth also has a blanket of air and a magnetic field that protects the surface from the hazards of interplanetary space



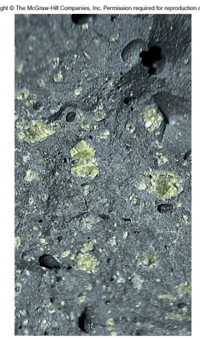
Size and Shape of the Earth



- The Earth is large enough for gravity to have shaped it into a sphere
- More precisely, Earth's spin makes its equator bulge into a shape referred to as an oblate spheroid – a result of inertia

Composition of the Earth

- The most common elements of the Earth's surface rocks are:
  - oxygen (45.5% by mass),
  - silicon (27.2%),
  - aluminum (8.3%),
  - iron (6.2%),
  - calcium (4.66%), and
  - magnesium (2.76%)
- Silicon and oxygen usually occur together as ***silicates***
- Ordinary sand is the silicate mineral quartz and is nearly pure silicon dioxide



Density of the Earth

- ***Density*** is a measure of how much material (mass) is packed into a given volume
- Typical unit of density is grams per cubic centimeter
- Water has a density of 1 g/cm^3, ordinary <u>surface</u> rocks are 3 g/cm^3, while iron is 8 g/cm^3
- For a spherical object of mass M and radius R, its <u>average density</u> is given by

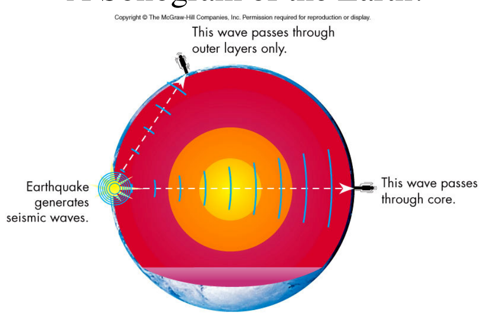
$$\frac{M}{\frac{4}{3}\pi R^3}$$

- For Earth, this density is found to be 5.5 g/cm^3
- Consequently, the Earth's interior (core) probably is iron (which is abundant in nature and high in density)

The Earth's Interior

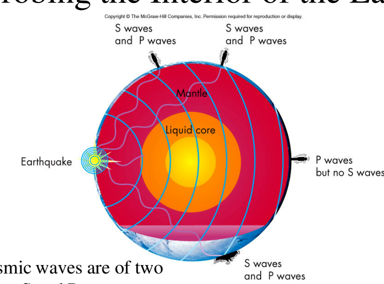
- Earthquakes generate ***seismic waves*** that move through the Earth with speeds depending on the properties of the material through which they travel
- These speeds are determined by timing the arrival of the waves at remote points on the Earth's surface
- A seismic "picture" is then generated of the Earth's interior along the path of the wave

A Sonogram of the Earth!



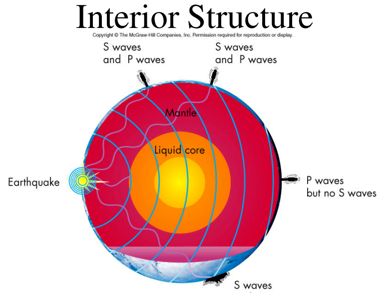
- This is the only way we have to probe the Earth's interior!

Probing the Interior of the Earth



- Seismic waves are of two types: S and P
  - P waves compress material and travel easily through liquid or solid
  - S waves move material perpendicular to the wave direction of travel and only propagate through solids

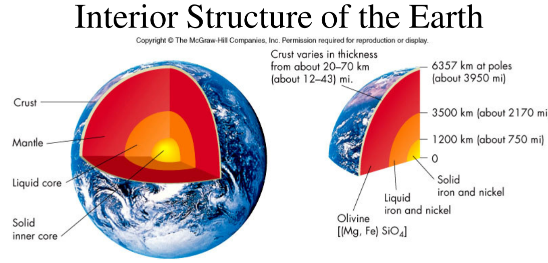
Interior Structure



- Observations show P waves but no S waves at detecting stations on the opposite side of the Earth from the origin of an Earthquake

  ⇒ the Earth has a liquid core!

Interior Structure of the Earth

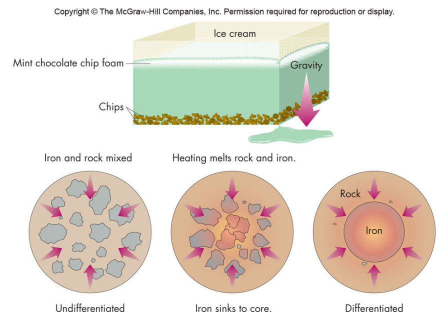


- A solid, low-density and thin ***crust*** made mainly of silicates
- A hot, thick, not-quite-liquid ***mantle*** with silicates
- A ***liquid, outer core*** with a mixture of iron, nickel and perhaps sulfur
- A ***solid, inner core*** of iron and nickel

Layers of the Earth

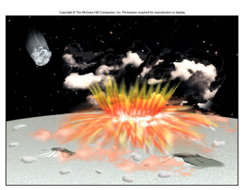
- The Earth is layered in such a fashion that the densest materials are at the center and the least dense at the surface – this is referred to as ***differentiation***
  - Differentiation will occur in a mixture of heavy and light materials if these materials are liquid for a long enough time in a gravitational field
  - Consequently, the Earth must have been almost entirely liquid in the past
- The Earth's inner core is solid because it is under such high pressure (from overlying materials) that the temperature there is not high enough to liquefy it – this is not the case for the outer liquid core

Differentiation



Temperature Inside the Earth

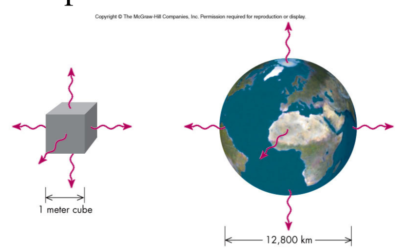
- Heating the Earth's Core
  - The estimated temperature of the Earth's core is 6500 K
  - This high temperature is probably due to at least the following two causes:
    - Heat generation from the impact of small bodies that eventually formed the Earth by their mutual gravitation



B

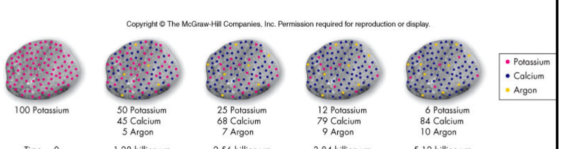
- The ***radioactive decay*** of ***radioactive elements*** that occur naturally in the mix of materials that made up the Earth

Temperature Inside the Earth



- In either case, the thermal energy generated is trapped inside the Earth's interior due to the long time it takes to move to the surface and escape

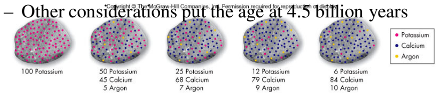
Age of the Earth



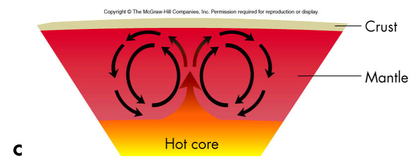
- Radioactive decay used to determine the Earth's age
  - Radioactive atoms decay into ***daughter atoms***
  - The more daughter atoms there are relative to the original radioactive atoms, the older the rock is

Age of the Earth

- Radioactive potassium has a half-life of 1.28 billion years and decays into argon, which is a gas that is trapped in the rock unless it melts
  - Assume rock has no argon when originally formed
  - Measuring the ratio of argon atoms to potassium atoms gives the age of the rock
  - This method gives a minimum age of the Earth as 4 billion years
  - Other considerations put the age at 4.5 billion years

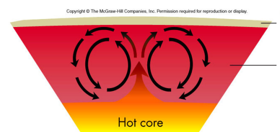


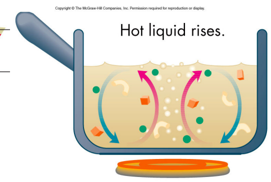
Motion in the Earth's Interior



- Heat generated by radioactive decay in the Earth creates movement of rock
- This movement of material is called ***convection***
- Convection occurs because hotter material will be less dense than its cooler surroundings and consequently will rise while cooler material sinks

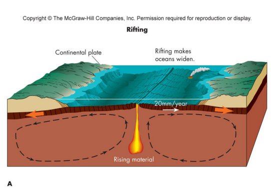
Convection





- Convection in the Earth's interior
  - The crust and mantle are solid rock, although when heated, rock may develop convective motions
  - These convective motions are slow, but are the cause of: earthquakes, volcanoes, the Earth's magnetic field, and perhaps the atmosphere itself

Plate Tectonics



- Rifting
  - Hot, molten material rises from deep in the Earth's interior in great, slow plumes that work their way to the surface
  - Near the surface, these plumes spread and drag the surface layers from below
  - The crust stretches, spreads, and breaks the surface in a phenomenon called ***rifting***

Subduction

- Subduction
  - Where cool material sinks, it may drag crustal pieces together buckling them upward into mountains
  - If one piece of crust slips under the other, the process is called ***subduction***

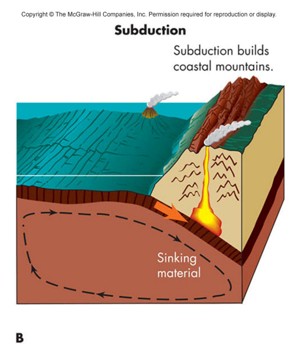
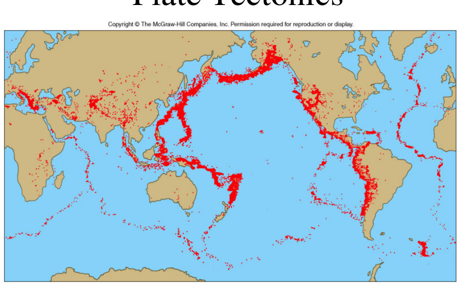


Plate Tectonics

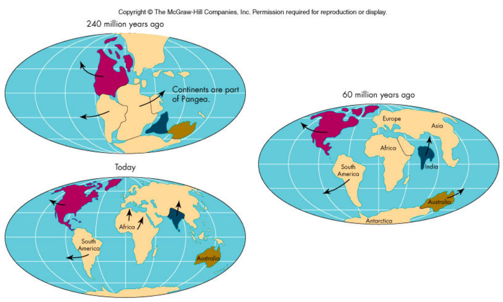


- Rifting and subduction are the dominant forces that sculpt the landscape – they may also trigger earthquakes and volcanoes

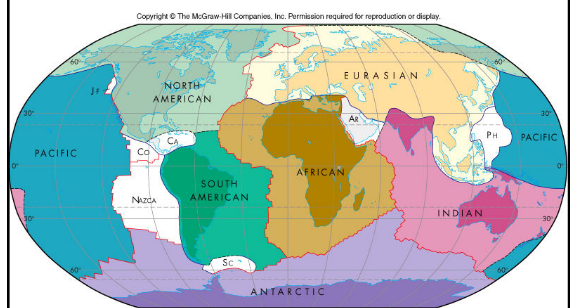
Plate Tectonics

- The shifting of large blocks of the Earth's surface is called ***plate tectonics***
  - Early researchers noted that South America and Africa appeared to fit together and that the two continents shared similar fossils
  - It was later proposed (1912) that all of the continents were once a single supercontinent called Pangea
  - The Earth's surface is continually building up and breaking down over time scales of millions of years

Continental Drift



Continental Plates



The Earth's Atmosphere

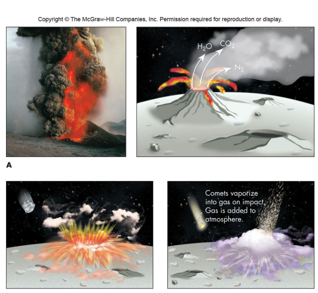
- Veil of gases around Earth constitutes its atmosphere
- Relative to other planetary atmospheres, the Earth's atmosphere is unique
- However, studying the Earth's atmosphere can tell us about atmospheres in general

Composition of the Earth's Atmosphere

- The Earth's atmosphere is primarily nitrogen (78.08% by number) and oxygen (20.95% by number)
- The remaining gases in the atmosphere (about 1%) include: carbon dioxide, ozone, water, and argon, the first three of which are important for life
- This composition is unique relative to the carbon dioxide atmospheres of Mars and Venus and the hydrogen atmospheres of the outer large planets

Origin of the Earth's Atmosphere

- Several theories to explain origin of Earth's atmosphere
  - Release of gas (originally trapped when the Earth formed) by volcanism or asteroid impacts
  - From materials brought to Earth by comet impacts



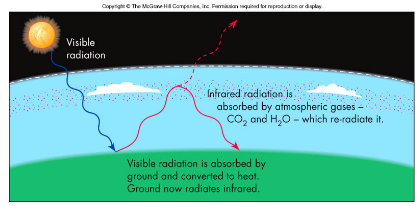
The Early Atmosphere

- Early atmosphere different than today
  - Contained much more methane (CH_4) and ammonia (NH_3)
  - Solar UV was intense enough to break out H from CH_4, NH_3 , and H_2O leaving carbon, nitrogen, and oxygen behind while the H escaped into space
  - Ancient plants further increased the levels of atmospheric oxygen through photosynthesis

The Ozone Layer

- Oxygen in the atmosphere provides a shield against solar UV radiation
- O_2 provides some shielding, but O_3, or **ozone,** provides most of it
- Most ozone is located in the ozone layer at an altitude of 25 km
- Shielding is provided by the absorption of UV photons by oxygen molecules (both O_2 and O_3) and their resultant dissociation
- Single O atoms combine with O and O_2 to replenish the lost O_2 and O_3
- It is doubtful that life could exist on the Earth's surface without the ozone layer

The Greenhouse Effect



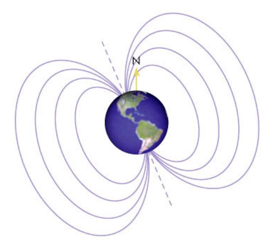
- Visible light reaches the Earth's surface and is converted to heat
- As a result, the surface radiates infrared energy, which is trapped by the atmosphere at infrared wavelengths
- This reduces the rate of heat loss and makes the surface hotter than it would be otherwise

Structure of the Earth's Atmosphere

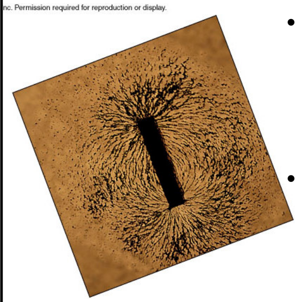
- Atmosphere extends to hundreds of kilometers becoming very tenuous at high altitudes
- The atmosphere becomes less dense with increasing altitude
- Half the mass of the atmosphere is within the first 4 kilometers
- The atmosphere eventually merges with the vacuum of interplanetary space

The Earth's Magnetic Field

- Magnetic forces are communicated by a ***magnetic field*** – direct physical contact is not necessary to transmit magnetic forces
- Magnetic fields are depicted in diagrams by ***magnetic lines of force***
  - Each line represents the direction a compass would point
  - Density of lines indicate strength of field



The Earth's Magnetic Field

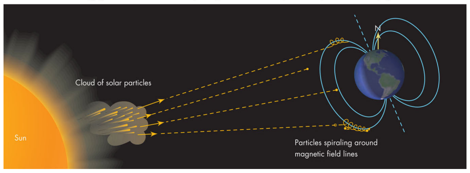


- Magnetic fields also have ***polarity*** – a direction from a north magnetic pole to a south magnetic pole
- Magnetic fields are generated either by large-scale currents or currents on an atomic scale

Origin of the Earth's Magnetic Field

- The magnetic field of the Earth is generated by currents flowing in its molten iron core
- The currents are believed to be caused by rotational motion and convection (magnetic dynamo)
- The Earth's geographic poles and magnetic poles do not coincide
- Both the position and strength of the poles change slightly from year to year, even reversing their polarity every 10,000 years or so

Magnetic Effects in the Upper Atmosphere

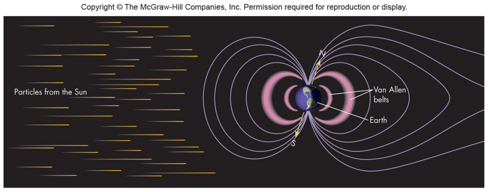


- Earth's magnetic field screens the planet from charged particles emitted from the Sun
- The Earth's magnetic field deflects the charged particles into spiral trajectories and slows them down

Aurora

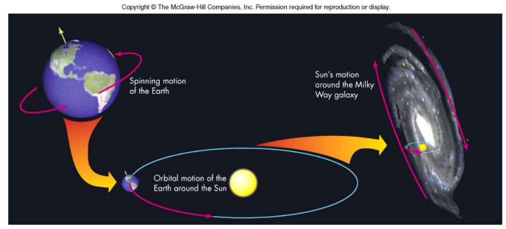
- As the charged solar particles stream past Earth, they generate electrical currents in the upper atmosphere
- These currents collide with and excite molecules
- As the molecules de-excite, light photons are given off resulting in ***aurora***

The Magnetosphere



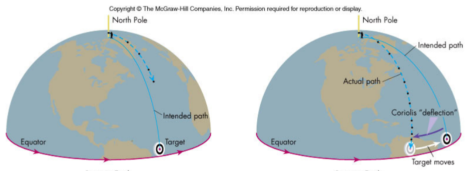
- Region of the Earth's environment where the Earth's magnetic field affects particle motion is called the ***magnetosphere***
- Within the magnetosphere charged particles are trapped in two doughnut shaped rings that encircle the Earth and are called the ***Van Allen radiation belts***

Motions of the Earth



- Rotational and orbital motions define the day and year and cause the seasons
- But our planet's motions have other effects

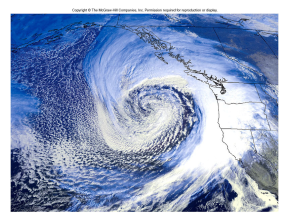
Air and Ocean Circulation



- In the absence of any force an object will move in a curved path over a rotating object
- This apparent curved motion is referred to as the ***Coriolis effect***

The Coriolis Effect

- Responsible for:
  - The spiral pattern of large storms as well as their direction of rotation
  - The trade winds that move from east to west in two bands, one north and one south of the equator



- The direction of the ***jet streams,*** narrow bands of rapid, high-altitude winds
- The deflection of ocean currents creating flows such as the Gulf Stream

The Coriolis Effect

- Also…
  - The atmospheric band structure of the rapidly rotating Jupiter, Saturn, and Neptune

Precession

- As the Earth moves around the Sun over long periods of time, the direction in which its rotation axis points changes slowly
- This changing in direction of the spin axis is called ***precession***
- Precession is caused by the Earth not being a perfect sphere – its equatorial bulge allows the Sun and Moon to exert unbalanced gravitational forces that twist the Earth's spin axis
- The Earth's spin axis precesses around once every 26,000 years
- Currently the spin axis points at Polaris – in A.D. 14,000 it will point nearly at the star Vega
- Precession may cause climate changes

Precession