SOLAR ENERGY, SEASONS, and the ATMOSPHERE
THE UNIVERSE
THE UNIVERSE

• Contains all the matter and energy that we know about

  ≈92 billion light years wide
  ≈80,000,000,000,000,000,000,000,000 stars

• Originated with the Big Bang, ≈14 bya
  — All matter and energy compressed to a point under its own gravity, exploded
  — Universe is still expanding and cooling
Our Place in the Universe
THE SOLAR SYSTEM
The SOLAR SYSTEM

• Formed ≈4.6 bya from gas and dust
  – Nebular clouds began to cool, compress, and rotate

• Planetesimal Hypothesis
  – Idea that stars and planets formed from cooling and compressing nebular clouds

• Accretion
  – Growth of planetesimals through collisions with other planetesimals
Formation of the Sun and Planets

- Gas pressure attempting to expand the cloud
- Gravitational force attempting to collapse the cloud

The cloud spins more rapidly as it collapses because of conservation of angular momentum
Formation of the Sun and Planets
The SUN

• Dominates the solar system
  – Accounts for ≈99.8% of the total mass
  – 875,000 miles wide (1.4 million km)
  – Rotates every ≈25 days

• Converts Hydrogen to Helium
  – Nuclear fusion
  – Burns at ≈10,000˚F
How Big is the SUN?

Our Sun has a diameter of 1.4 million km and Earth a diameter of almost 13,000 km

If the Sun were the size of an official league basketball, Earth would be a little dot no more than 2.2 millimeters

See how our Solar System’s planets would look like in the same scale:

- Pluto
- Neptune
- Uranus
- Saturn
- Jupiter
- Mars
- Earth
- Venus
- Mercury

Orbital distances are not depicted proportionally.
Conversion of H to He
RADIATION and SOLAR WIND

• Radiation
  – Radiant electromagnetic energy of different wavelengths

• Solar Wind
  – Ionized particles (electrons and protons)
  – Earth’s magnetosphere deflects solar wind
  – Can cause radio interference, etc.
  – Might cause increased lightning strikes
Radiation and Solar Wind
AURORA BOREALIS/AUSTRALIS

• Northern Lights and Southern Lights
• Interaction of solar wind with upper atmosphere
  – Ions excite gases until they glow
  – Magnetosphere shields us from solar wind, but it doesn’t exist above the north and south poles
Aurora Borealis and Australis
THE PLANETS

• Revolve around the sun in counterclockwise, concentric orbits
  – The closer a planet is to the sun
    • The less time it takes to revolve
    • The shorter its year is

• Eight planets, classified as
  – Inner/Terrestrial
  – Outer/Gas Giants
The Planets
EARTH
EARTH

• Formed ≈4.56 bya
  – Unique in its water and distance from sun
  – Evidence of life as far back as 3.7 bya

• Revolves counter clockwise
  – When viewed from “above”

• One moon
  – An object, perhaps as big as Mars, struck Earth shortly after it formed
The crew of Apollo 8 were the first humans to witness Earthrise, on December 24, 1968.
THE MOON ILLUSION

• The moon appears larger at the horizon
  – It is closer at certain times of year (eccentric orbit)
• Exaggerated size at horizon is an optical illusion
  – Earth features (buildings, trees, etc.) provide a scale of reference
  – Moon in space is lost in the cosmos
The moon seems larger in angular size when it is near the horizon than when it is high in the sky.
EARTH-SUN RELATIONSHIPS
REVOLUTION and ROTATION

• Revolution
  — Orbiting of Earth around the sun
  — Counterclockwise from above
  — Orbit is a state of equilibrium between gravity and centrifugal force

• 365 ¼ days to complete one revolution
  — Leap Year every four years (2016)

• Orbit is slightly elliptical and eccentric
PERIHELION and APHELION

• Perihelion
  – Earth is closest to sun
  – January 3

• Aphelion
  – Earth is furthest from sun
  – July 4

• Difference of \( \approx 3 \) million miles

• Not the cause of the seasons
Perihelion and Aphelion

Earth Aphelion: July 3, 2009, 9pm CDT (02z 7/4)
Earth Perihelion: January 4, 2009, 9am CST (15z)
ROTATION

• Movement of Earth around its axis
  – Counterclockwise from above

• Solar Day
  – 24 hours
  – The time it takes to complete one rotation in relation to the sun

• Equator spins at around 1,000 mph
  – Speeds decrease to zero at the poles
Rotation
ROTATION

• Is responsible for
  – The diurnal cycle (day and night)
  – Equatorial bulge and flattening at poles
  – The Coriolis Effect
    • Deflection, or curving, of large-scale moving objects
  – Tides, in conjunction with gravitational pull of the moon and sun
SOLAR RADIATION
SOLAR RADIATION

• Electromagnetic Radiation (EMR)
  – Energy from the sun, but not Solar Wind
  – Electrical and magnetic components
• The sun converts Hydrogen to Helium in the process of nuclear fusion
  – Massive amounts of energy are released
  – Earth receives a minute fraction of this energy
Electromagnetic Radiation (EMR)
SOLAR RADIATION

• All objects on Earth emit EMR, even Earth itself
  – But almost all originated from the sun

• All EMR is the same type of energy
  – Hotter objects radiate shorter wavelengths
  – Cooler objects radiate longer wavelengths
ELECTROMAGNETIC SPECTRUM

• Categorizes EMR by wavelength
  – Gamma, X, UV
  – Visible
    • A very narrow range
    • The sun radiates more in this range
  – Infrared
    • Below red
  – Microwave, Radio
The Electromagnetic Spectrum

- Gamma rays
- X-rays
- Ultra-violet
- Visible
- Near infrared
- Shortwave infrared
- Middle infrared
- Thermal infrared
- Microwave
- Radio waves

Energy discharges from atomic nuclei
- Medical applications (hard X-ray)
- Medical applications (soft X-ray)

Visible light
- Heat lamp
- Microwave radar
- Television
- FM radio
- AM radio

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Sun emits primarily shortwave radiation (UV-SIR)
Earth emits primarily longwave radiation (TIR)
INSOLATION and NET RADIATION
INSOLATION

• Incoming Solar Radiation
  – Primarily shortwave

• The Solar Constant
  – Average amount of insolation intercepted at the top of the atmosphere
    \(\approx 1,400 \text{ watts/m}^2 \text{ of insolation}\)
INSOLATION

• Amount intercepted depends on
  – Circle of illumination
    • Lighted hemisphere receives insolation
  – Length of day
    • Determined by latitude and season
  – Latitude
    • Insolation is more concentrated near the equator
Insolation, Controlled by Circle of Illumination and Length of Day
Insolation, Controlled by Latitude

- More diffuse, larger area covered
  - More concentrated, smaller area covered

- Oblique
- Direct
- Sun’s rays arrive parallel to Earth

Annually 2.5 times more energy than poles
NET RADIATION

• Insolation minus outgoing radiation
  – How much radiation retained in an area
  – Positive in some places, negative in others

• Surplus
  – During the day, during summer, below $\approx 40^\circ$

• Deficit
  – At night, during winter, above $\approx 40^\circ$
Net Radiation
NET RADIATION

• Uneven net radiation leads to
  – Large-scale atmospheric and oceanic circulation patterns

• Poleward Heat Transfer
  – Atmosphere and oceans act as giant “heat engines” in an attempt to equalize uneven temperatures on Earth
THE SEASONS
CAUSES of the SEASONS

• Earth’s axis is tilted
  \[ \approx 66\frac{1}{2}^\circ \text{ from the plane of the ecliptic} \]
  \[ \approx 23\frac{1}{2}^\circ \text{ from vertical} \]

• Plane of the ecliptic
  – Imaginary plane that passes through the sun and Earth

• Earth’s axis retains its orientation
  – It always points to the North Star, Polaris
Earth’s Tilting Axis

Perpendicular to plane of ecliptic

23.5°

66.5°

North Pole

Equator

Plane of ecliptic
CAUSES of the SEASONS

• Earth’s orientation with the sun changes constantly throughout the year
  – A location on Earth is either tilted toward the sun, away from the sun, or neither, depending on the time of year

• Seasons are defined by the position of Earth in relation to the sun
  – The sun’s path in the sky changes with the seasons (solar noon is 28° to 75° in Sac.)
The Seasons

Spring
Summer Solstice

Vernal Equinox

Winter Solstice
Winter

Summer
Autumnal Equinox
Autumn
SOLSTICE

• Day when Earth’s axis points “toward” or “away” from the sun
  – Summer Solstice
    • ≈June 21, first day of summer
    • Longest day of year, sun at maximum angle
  – Winter Solstice
    • ≈December 21, first day of winter
    • Shortest day of year, sun at minimum angle
EQUINOX

• Day when Earth’s axis is neither pointing “toward,” nor a “away” from the sun
  – Length of night is the same everywhere on Earth, and day is the same length as night
  – Vernal Equinox
    • ≈March 20, first day of spring
  – Autumnal Equinox
    • ≈September 22, first day of fall
Solstices and Equinoxes

- **Equinox**: March 21-22, Sun vertical at equator
- **Equinox**: September 22-23, Sun vertical at equator
- **Solstice**: June 21-22, Sun vertical at Latitude 23° N
- **Solstice**: December 21-22, Sun vertical at Latitude 23° S

**Important Locations**:
- **Arctic Circle**
- **Tropic of Cancer**
- **Equator**
- **Tropic of Capricorn**
OTHER “SEASONS”

• Solar Summer
  – The quarter of the year with the greatest insolation (centers on summer solstice)

• Meteorological Summer
  – The quarter of the year with the warmest average temperature
TROPICS and CIRCLES
TROPICS

• Tropic of Cancer: 23½° North
  – Parallel upon which the sun’s rays fall from directly above on the first day of summer in the northern hemisphere

• Tropic of Capricorn: 23½° South
  – Parallel upon which the sun’s rays fall from directly above on the first day of summer in the southern hemisphere
CIRCLES

• Arctic Circle: 66½° North
  – Parallel that defines the maximum reach of the sun’s rays on the first day of summer in the northern hemisphere

• Antarctic Circle: 66½° South
  – Parallel that defines the maximum reach of the sun’s rays on the first day of summer in the southern hemisphere
Areas above the Arctic and Antarctic Circles receive from 24 hours of day/night to 6 months of day/night.
ATMOSPHERIC COMPOSITION
ATMOSPHERIC COMPOSITION

• The lower ≈60 miles (100 km) of the atmosphere
  ‒ Contains gases that are somewhat uniform in their distribution
  ‒ Turbulence constantly mixes gases
  ‒ Above ≈60 miles gases are not well mixed
# Components of the Lower Atmosphere

**TABLE 2.3** Stable Components of the Modern Homosphere

<table>
<thead>
<tr>
<th>Gas (Symbol)</th>
<th>Percentage by Volume</th>
<th>Parts per Million (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen ($N_2$)</td>
<td>78.084</td>
<td>780,840</td>
</tr>
<tr>
<td>Oxygen ($O_2$)</td>
<td>20.946</td>
<td>209,460</td>
</tr>
<tr>
<td>Argon (Ar)</td>
<td>0.934</td>
<td>9,340</td>
</tr>
<tr>
<td>Carbon dioxide ($CO_2$)*</td>
<td>0.0394</td>
<td>394</td>
</tr>
<tr>
<td>Neon (Ne)</td>
<td>0.001818</td>
<td>18</td>
</tr>
<tr>
<td>Helium (He)</td>
<td>0.000525</td>
<td>5</td>
</tr>
<tr>
<td>Methane (CH$_4$)</td>
<td>0.00014</td>
<td>1.4</td>
</tr>
<tr>
<td>Krypton (Kr)</td>
<td>0.00010</td>
<td>1.0</td>
</tr>
<tr>
<td>Ozone ($O_3$)</td>
<td>Variable</td>
<td></td>
</tr>
<tr>
<td>Nitrous oxide ($N_2O$)</td>
<td>Trace</td>
<td></td>
</tr>
<tr>
<td>Hydrogen (H)</td>
<td>Trace</td>
<td></td>
</tr>
</tbody>
</table>
COMMON GASES

• Nitrogen: 78%
  – Plants need it, but humans don’t absorb it
  – Good thing it isn’t poisonous to us

• Oxygen: 21%
  – Essential to human life – respiration process uses oxygen to burn food

• Argon: <1%
  – Inert – Used in “neon” lights
GREENHOUSE GASES

- Contribute to the greenhouse effect
  - Process by which thermal radiation from Earth is trapped by atmospheric gases

Absorption and counter radiation increase temperatures to support life as we know it
GREENHOUSE GASES

• Make up far less than 1% of the lower atmosphere
• Carbon Dioxide (CO₂)
  – Essential in photosynthesis, the process that allows plants to grow
  – Produced naturally, and as the result of human activity
GREENHOUSE GASES

• Methane (CH$_4$)
  – Main component of natural gas
  – More efficient than CO$_2$ in trapping heat, but doesn’t last as long in atmosphere
  – Produced mainly by microorganisms in
    • Livestock
    • Landfills
  – Also escapes from leaking gas pipes...
GREENHOUSE GASES

• Water Vapor ($H_2O$)
  – Acts to store and redistribute heat
  – Makes clouds, rain, and snow possible

• Ozone ($O_3$)
  – Found primarily in the “ozone layer” (≈10-30 miles up)
  – Also absorbs Ultraviolet Radiation, which is harmful/fatal to living things
IMPURITIES

• Small particles suspended in the atmosphere
  – Aerosols
  – Dust, smoke, plant spores, bacteria, salt, etc.

• Help produce raindrops
Impurities
IMPURITIES

• Affect the color of the sky
  – Sunlight contains all colors mixed together, or “white” light
  – Blue component is scattered by air impurities and air molecules

• As sunlight passes through a thicker or “dirtier” layer of atmosphere
  – Yellows, reds, and oranges are scattered
Diffuse Radiation (Rayleigh Scattering)

Earth's atmosphere

The sun's rays in space
ATMOSPHERIC LAYERS and TEMPERATURES
TROPOSPHERE

• ≈0-10 miles (≈0-16 km) up
  – Varies between 7-10 miles
  – Thicker near equator due to heat, thinner at poles

• Zone in which we live
  – Densest of all zones
  – All weather occurs here
TROPOSPHERE

• Temperatures decrease with increased altitude

• The Environmental Lapse Rate (ELR)
  – Describes how temperatures change in relation to altitude in stationary air

• The average ELR in the troposphere
  \( \approx 3.5^\circ F/1,000 \text{ ft} \) (\( 6.4^\circ C/1,000 \text{ m} \))
  (the *Normal* Lapse Rate)
CAUSES for the ELR

• Environmental lapse rate results from
  – The atmosphere being heated primarily from below due to longwave radiation from Earth
  – The fact that the atmosphere becomes less dense with altitude
  – Fewer molecules vibrating, and fewer to absorb energy
Atmospheric Density and Altitude
STRATOSPHERE

• ≈10-30 miles (≈16-50 km) up
  – Thin, clear air – good for flying
  – Home to the ozone layer
    • Traps outgoing longwave radiation
    • Traps incoming shortwave radiation (UV)

• Temperature Inversion results
  – Temperatures increase with increased altitude (ozone layer)
MESOSPHERE

• \( \approx 30-50 \) miles (\( \approx 50-80 \) km) up
  - Temperatures decrease with increased altitude, due to thinning of air

• Home of the D Layer
  - Solar radiation creates charged particles (ions) that interfere with communication

• Home of the E Layer
  - Ions reflect radio waves, assisting long-distance communication
OZONE HOLES
OZONE HOLES

• Most prominent hole is over Antarctica
  – Seasonal Himalaya hole, Arctic hole
  – Allow harmful levels of UV radiation to reach Earth

• Caused by natural pollutants
  – Volcanic gases and ash

• Caused by human-produced pollutants
  – Chlorofluorocarbons (CFCs)
OZONE HOLES

• Chlorofluorocarbons (CFCs)
  – Released primarily from refrigerants, fire extinguishers, cleaning solvents, etc.

• During the SH winter, CFCs and ice crystals are exposed to sunlight
  – Chlorine is produced that destroys ozone
  – A single molecule of chlorine can break apart thousands of molecules of ozone
OZONE HOLES: UPDATE

• The Antarctic ozone hole has stopped growing, and will likely begin to shrink
  – Shrinking will take a decade to begin
  – Recovery is entirely due to political determination to phase out the man-made CFC gases that destroy ozone
Ozone Hole Growth
Ozone Hole: *The Movie*

http://youtu.be/AU0eNa4Gr9gU
SOLAR ENERGY,
SEASONS,
and the
ATMOSPHERE