Chapter 2

Energy: Warming the Earth and the Atmosphere

Energy (pp. 28-29 + extra not in book)

- Energy: capacity to do work
  - Concept dates from mid-1800's
  - Can be converted between various forms
    - Kinetic (energy of motion)
    - Gravitational potential (e.g., lifting weights)
    - Radiant (e.g., from sunlight)
    - Heat (random molecular motion)
  - Energy is often conserved
  - Einstein showed energy is not always conserved: $E=mc^2$, meaning that energy can be converted to mass and vice versa. The sun's energy comes from fusion, which fuses hydrogen into helium. Helium has slightly less mass than the hydrogen used to make it. The difference goes into energy.

Recognizing Heat as Energy

- Late 1700's, American Benjamin Thompson, who had become Bavarian Count Rumford, discovered heat was not a separate substance previously called caloric (Latin root "calor") measured in calories
- He supervised boring canon, which became so hot that water used for cooling would boil.
  - Old theory: "heat" stored in metal when it was cast would be released as metal is drilled out as shavings
  - Rumford observed heat being released even when drill was dull & metal not ground up. (The exception probes the rule.)
  - He realized energy of drilling was converted to heat.
  - Similar to making fire by rubbing two sticks together, which had been known for thousands of years.

Temperature (pp. 29-30)

- Temperature measures average random energy of motion (kinetic energy)
- Gas: term coined by van Helmont, early 1600's, from Greek word chaos. Excellent name because we now know that a gas consists of molecules in random motion
- Temperature scales (freezing, boiling)
  - Fahrenheit in US (32, 212 deg F)
  - Celsius everywhere else (0, 100 deg C)
- Absolute zero: -459 deg F = -273 deg C
  - Lowest approachable temp
  - Minimum motion

Fahrenheit and Celsius
$F = (9/5)C + 32$, $C = (5/9)(F-32)$

deg F		deg C
-40	=	-40 (same with both temp scales)
32	=	0 (cold)
50	=	10 (cool)
61	=	16 (digits reversed)
68	=	20 (warm)
86	=	30 (68 and 86 are reversed) (hot)
104	=	40 (04 is 40 reversed)
212	=	100 (boiling)

(Similar to fig. 2.2, p. 30)

calorie is a unit of energy

- calorie = energy needed to warm 1 gram of liquid water by 1 deg C
- Food Calorie (usually capitalized) = 1000 calories

Energy addition & temperature change (First column of p. 30: Specific heat)

Table 2.1, p. 30: calories needed to warm 1 g of substance by 1 deg C

Water	1.0
Wet mud	0.6
Sandy clay	0.33
Dry air	0.24

Much energy needed to warm water, medium amount to warm ground. Little energy is needed to warm air.

Consequently, marine & coastal areas don't have extreme seasons. In summer, sunlight warms water. In winter, warm water gives off energy that heats surroundings. Example: Western Europe and Alaska have relatively mild climates because of nearby ocean. Ocean currents (Gulf Stream in Atlantic & Kuroshio in Pacific) not so important for mild climate in midlatitiudes but do warm polar areas.

Latent heat (pp. 30-31)

- Latent means hidden (e.g., latent talent)
- Latent heat is energy that evaporates water. Evaporation cools you when you get out of a swimming pool.
- In general, evaporation cools environment; condensation warms environment.
- 600 calories evaporates 1 g of liquid water. (Recall: It takes 1 calorie to warm 1 g of water 1°C.)
- Energy is needed to melt ice (80 calories/gram); energy is released when ice freezes.
- It takes 80+600=680 calories to evaporate ("sublimate") 1 g of ice.
- During boiling, temp stays at 100°C (212°F). Energy added goes to evaporate water.
- During freezing, temperature stays at 0°C (32°F). Energy taken away makes ice.

Latent heat (cont.)

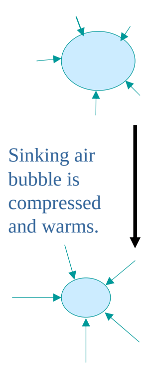
- Water evaporating from Earth's surface takes energy from surface. When that water condenses as rain, the latent heat is released into the atmosphere.
- Latent heat released during a thunderstorm exceeds the energy of small nuclear bomb.
- A similar kind of energy transfer occurs in an air conditioner. Warm air inside a car or house is blown past an "evaporator" (looks like car radiator), in which coolant evaporates (changes from liquid to gas) using the heat inside the car or house. The gaseous coolant is piped to the condenser (another radiator) outside the car or house, where the coolant condenses and gives up its heat to the outside air. The liquid coolant is then pumped back to the evaporator, and the process repeats.

p. 34: Rising air cools, sinking air warms

- Recall: Pressure is due to weight of overlying air, so pressure always decreases with increasing height.
- When a bubble of air rises, it moves into lower pressure and expands to equalize its internal pressure with the surrounding pressure. The same expansion happens to a weather balloon as it rises.
- Because an expanded bubble of air occupies more volume, it has to push other air out of the way.
- Pushing back the surrounding air means that the expanding air bubble is doing work.
- The energy for this work comes from the air's "internal energy," i.e., random kinetic energy of its molecules, so its temperature drops.

p. 34: Rising air cools, sinking air warms

- The opposite occurs when air sinks and moves into higher pressure.
- In greater pressure, the air bubble is compressed, meaning that the surrounding air is doing work on it.
- This increases the internal energy of the sinking air bubble, warming it.
- Analogies from daily life:
  - If you pump a bicycle pump, you are doing work to compress air, heating it.
  - A can of pressurized air gets cold when it is sprayed as air from the can expands into the surrounding air.



Energy transport (pp. 32-35)

- **Conduction** of solar energy from ground to air
- **Convection** of energy as warm or cold air moves around. In meteorology, horizontal convection in atmosphere is called "advection," vertical transport is called convection." (Example: thunderstorms are called convection.)
- **Radiation** (radiative energy, such as from sun)
- **Advection of** water vapor (**latent heat**)
- Heat also convects and advects in ocean.

Conduction (pp. 31-32)

- Warm molecules bump cooler molecules, giving them energy.
- Newly warmed molecules bump other molecules, giving them energy.
- Energy diffuses through an object.
- Heat conducts between the atmosphere and the underlying land or water surface as air molecules collide with molecules on the surface.

Convection (pp. 33-35)

- Warm wind (or ocean current) carries energy horizontally (called "advection" in meteorology)
- Examples: Southerly winds & Gulf Stream in Atlantic Ocean bring ("advect") warmth to polar areas. Winds and ocean currents from north (such as by California) bring cold.
- Heat rises from Earth's surface in bubbles of warm air (called convection in meteorology)
- Examples of convection
  - Thunderstorms
  - Air rising over asphalt on hot summer day. You can see the shimmery appearance caused by rising hot air.

Radiation = Radiant energy (pp. 35-38)

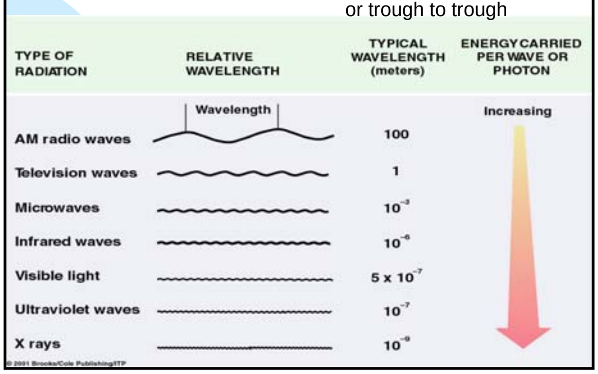
- Examples of radiant energy: light (ultraviolet, visible, infrared), microwaves, TV, radio
- Anything with temperature above absolute zero emits radiation.
- White hot: incandescent light bulb or sun's surface

- Red hot: electric stove
- Infrared hot: you, chair, building, ground, trees, etc.

Infrared radiation from tress can melt snow. (What is evidence that "craters" not caused by wind?)

Radiation consists of waves (Fig. 2.7, p. 35)

Wavelength = distance from crest to crest or trough to trough



Stefan-Boltzmann Law of Radiation (p.36)

- Stefan-Boltzmann law: $E = \sigma T^4$, where E = power emitted per unit area of surface (watts/sq meter), $\sigma = 5.67 \times 10^{-8}$, and T = temperature in kelvins (degrees above absolute zero)
- Multiply by surface area to get total power emitted.
- Increase in temperature means BIG increase in energy radiated.
- Example 1: Your skin temperature is about 300 kelvins, & your surface area is about 1 sq meter. You emit $(5.67 \times 10^{-8})(300^4)(1\ m^2) = 450$ watts

Stefan-Boltzmann Law of Radiation (p.36)

- Example 2: Surface of Earth is about 300 kelvins. Like you, it emits about 450 W/m^2.
- Example 3: Surface of Sun is 6000 kelvins, 20 times hotter than Earth. So each square meter of Sun's surface emits 20^4 = 160,000 times as much energy as a square meter of Earth, or about 73 megawatts per sq meter. (Coal-fired power plant produces about 1000 MW, equiv to emission from 14 m^2 of sun's surface.)
- Surface area of Sun is about 12,000 times greater than Earth's surface area, so solar energy emitted is (160,000) x (12,000) = 1.9 billion times that emitted by Earth

Wien's Law of Radiation (p. 36)

- Wien's law: λ_{max} = constant / T
- Wavelength of max radiation decreases with increase in temperature; i.e., color of glow depends on temperature
  - Judge temperature of pottery kiln by color inside. (Color of gas flame and aurora due to other factors.)
  - Light setting on TV camera (indoor vs outdoor)
  - Given Sun's temperature, its max output is in visible.

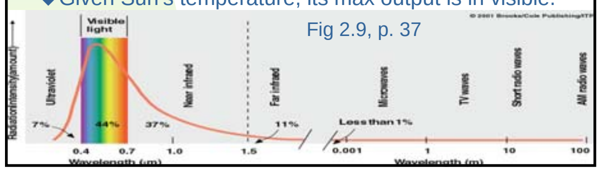
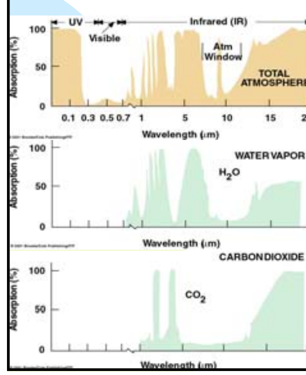


Fig 2.9, p. 37

Kirchoff's Law of Radiation (p. 40)

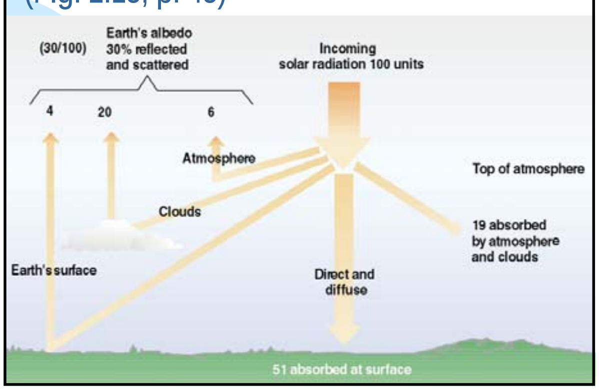
- Kirchoff's law: At any particular wavelength, a good absorber is also a good emitter, and a poor absorber is a poor emitter.
- In the infrared, most things except shiny metals are good absorbers and hence also good emitters.
- Something can be a good absorber/emitter at one wavelength and a poor absorber/emitter at another.
- Example: Snow is a poor absorber of visible light but a good absorber and emitter of infrared, so it absorbs little sunlight but radiates well in the infrared. Therefore, it stays cold.

Atmospheric Absorption at Various Wavelengths (Part of Fig 2.11, p.41)



- Air is transparent to visible light, so sunlight comes in.
- Opaque at places in infrared (IR): energy escape blocked.
- Most important absorbers & emitters in IR are water vapor and carbon dioxide
- Called "greenhouse effect," but "atmospheric effect" better name because greenhouse works by keeping out cold air.

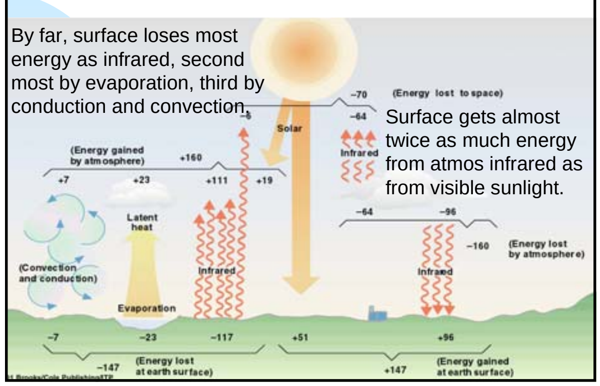
What happens to sunlight? (Fig. 2.15, p. 45)



Earth's Energy Budget (fig. 2.16, p. 47)

By far, surface loses most energy as infrared, second most by evaporation, third by conduction and convection.

Surface gets almost twice as much energy from atmos infrared as from visible sunlight.



Aurora borealis/australis: Northern/Southern Lights (p. 49)

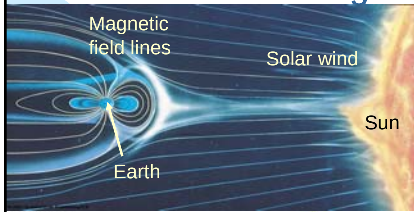


Fig. 2.19, p. 49: Solar wind (hot particles from Sun) is guided by Earth's magnetic field. Particles enter atmos near magnetic North and South Poles

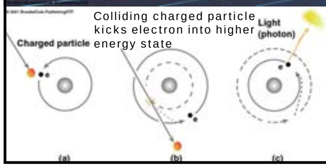
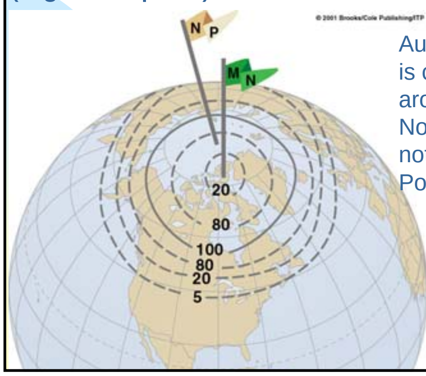


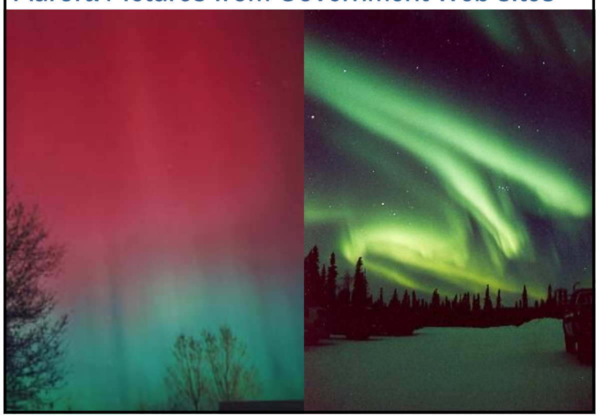
Fig. 2.20, p. 50: Charged particles from solar wind hit molecules in atmosphere and kick electron to higher energy level. Electron later gives up energy as light, i.e., aurora.

Avg no. of days per year with aurora (Fig. 2.22, p. 50)



Aurora activity is centered around magnetic North Pole ("MN"), not regular North Pole ("NP")

Aurora Pictures from Government Web sites



Aurora Pictures from Government Web sites

Aurora with Perseid Meteor Streaks