Agenda for Ast 309N, Sep. 11

- Feedback on 9/6 card and advice on how to answering short essay questions. See card file.
- Solar magnetic field and the solar cycle
- Begin reviewing light: wave-particle duality
- **Quiz 1** is this Thurs., Sep. 13, starting at the **beginning** of class (don't be late!). No need for blue books (you'll answer on sheet provided). Topic: what we have learned about the Sun.

A few Last Words on Neutrinos

Neutrinos have three properties:

(1) Type: electron, muon, tau neutrinos – the Sun produces electron neutrinos
(2) Energy: *not* the same thing as type!
A neutrino can have any energy, but those from specific reactions have certain energies
(3) Neutrinos or anti-neutrinos – Note: the differences are not yet fully understood.

Neutrinos Made by Fusion in the Sun

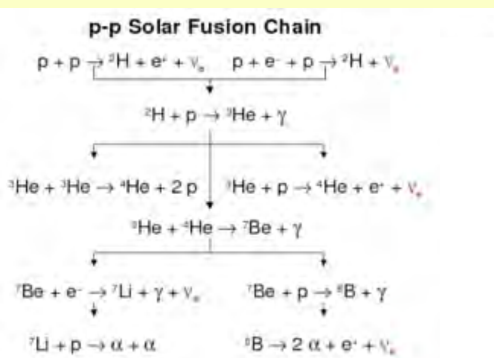
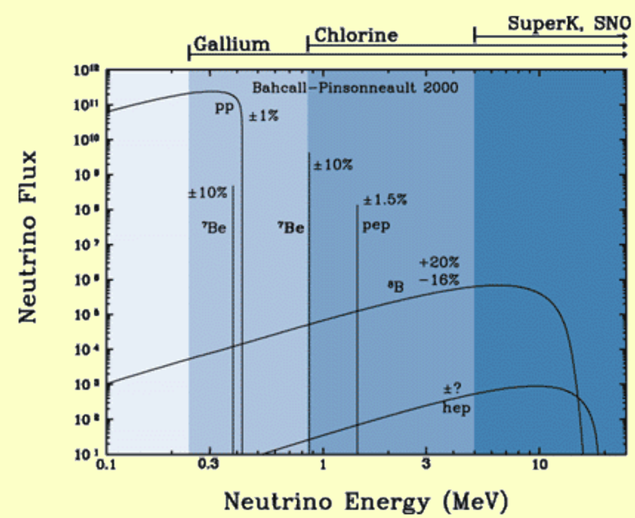


Table 10.1: The Principal Reactions of the *pp* Chain

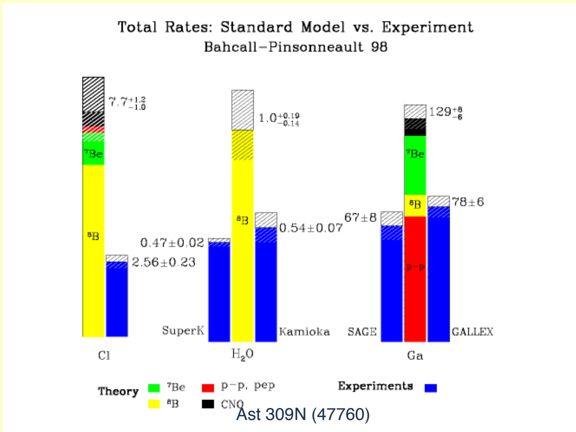
Reaction	Neutrino Energy (MeV)
$p + p \rightarrow {}^2H + e^+ + \nu_e$	0.0 to 0.4
$p + e^- + p \rightarrow {}^2H + \nu_e$	1.4
${}^2H + p \rightarrow {}^3He + \gamma$	
${}^3He + {}^3He \rightarrow {}^4He + 2p$	
or	
${}^3He + {}^4He \rightarrow {}^7Be + \gamma$	
then	
$e^- + {}^7Be \rightarrow {}^7Li + \nu_e$	0.86, 0.38
${}^7Li + p \rightarrow {}^4He + {}^4He$	
or	
$p + {}^7Be \rightarrow {}^8B + \gamma$	
${}^8B \rightarrow {}^8Be + e^+ + \nu_e$	0 to 15

The Solar Neutrino "Spectrum"



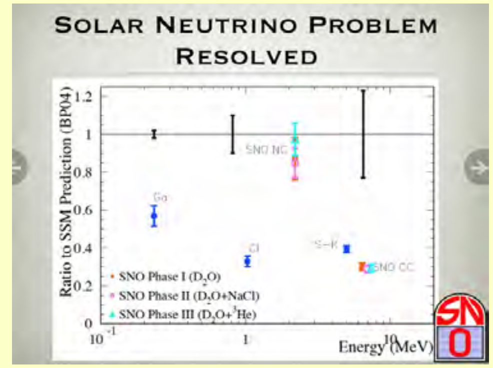
The Solar Neutrino Problem

TOO FEW SOLAR NEUTRINOS DETECTED, COMPARED TO PREDICTIONS FROM MODELS



Sudbury Neutrino Observatory (SNO)

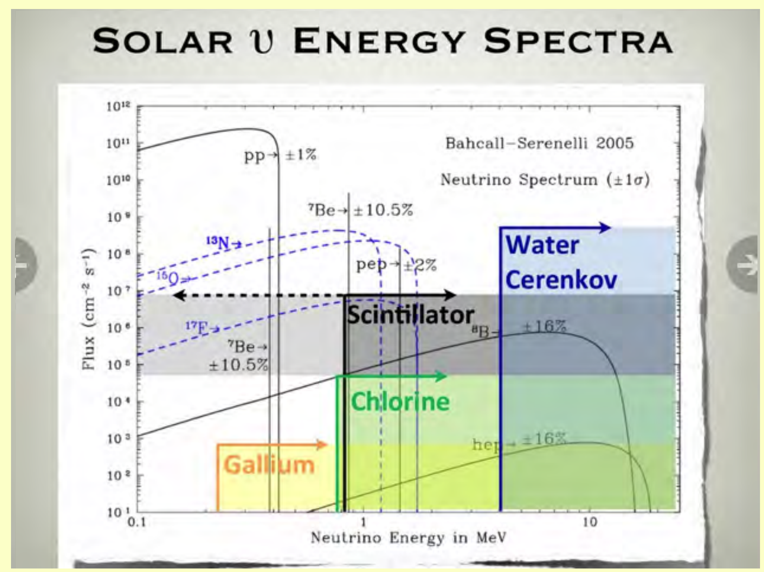
THE NEUTRINOS WERE CHANGING INTO OTHER TYPES ON THEIR WAY FROM THE CORE. THE SNO EXPERIMENT NAILED IT, DETECTING THEM ALL!



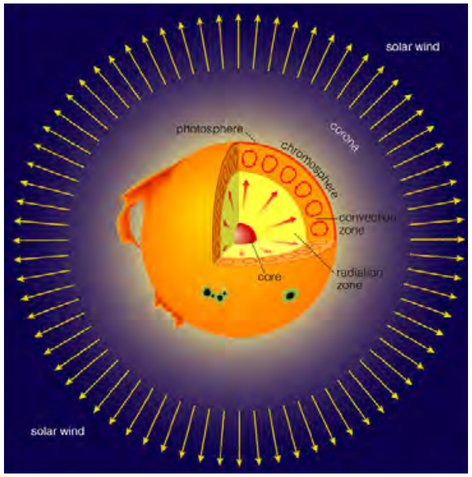
The Solar Neutrino Frontier

Much of the focus is now on the properties of neutrinos. Current and upcoming experiments:

(1) SuperK (in Japan): solar, atmospheric, and accelerator-made (KamLAND) neutrinos
(2) Borexino (in Italy, where the Ga experiments were): sees neutrinos from specific reactions
(3) SNO$^+$ (SNO-plus): Re-uses the SNO site, with new detector (liquid scintillator); will be a bigger, better version of Borexino



Outer Layers of the Sun



Solar wind: flow of charged particles from Sun's surface

Corona: outer layer, T ~10^6 K; see in X-rays

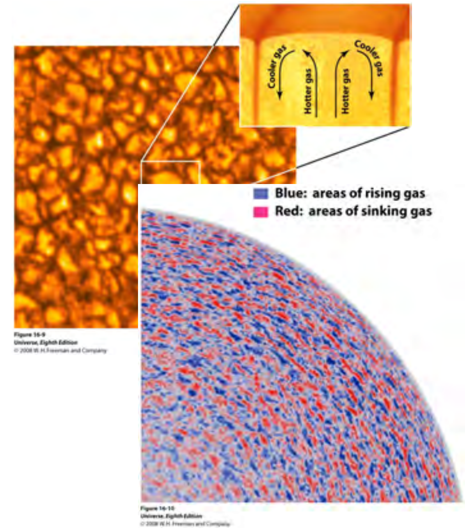
Chromosphere: hotter layer, T ~ 10^4 - 10^5 K

Photosphere: visible surface, T ~ 5800 K

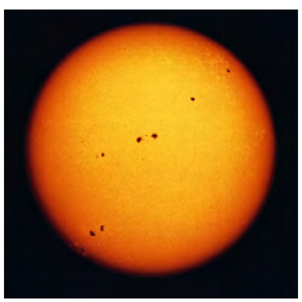
Evidence of Convection: Solar Surface

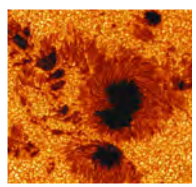
Convection brings energy to the surface in the form of hot gas

The bright blobs ("granules") on the photosphere are the tops of bubbles of hot gas (convection 'cells') breaking through the surface

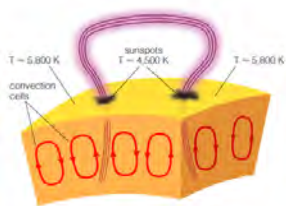


Sunspots





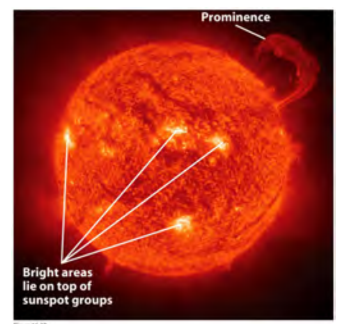
Sunspots appear dark because they are cooler than adjacent parts of the Sun's surface. They are the base of magnetic loops.

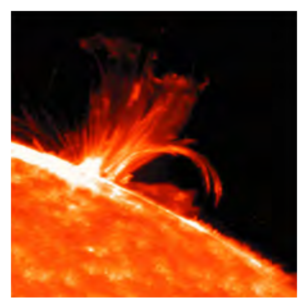


⇐ "side view" of magnetic loop

Solar Prominences and Flares

Solar prominences are giant loops of hot gas trapped by magnetic fields.





Solar flares happen when a magnetic loop snaps, sending a burst of X-rays and charged particles outwards.

The Solar Activity Cycle: P = 11 yrs

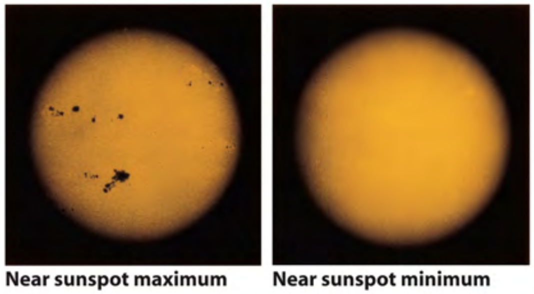


Figure 16-18bc
Universe, Eighth Edition

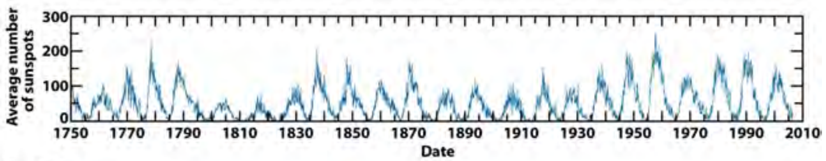
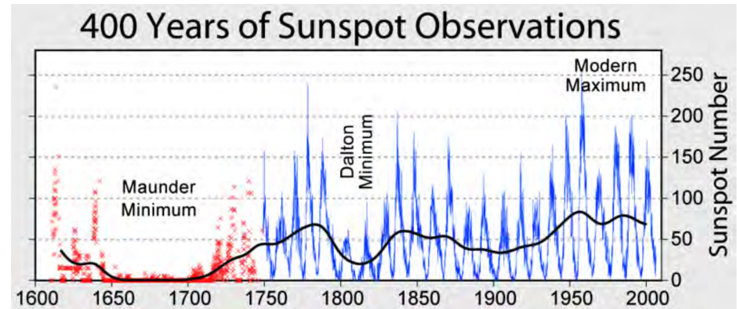


Figure 16-18a
Universe, Eighth Edition

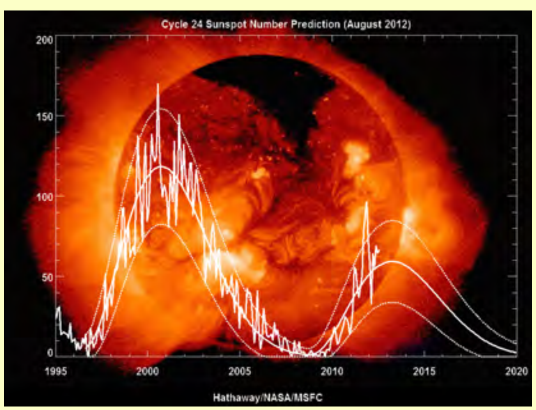
The Solar Activity Cycle, Long-Term

- The Sun is more active during periods called "solar maximum" and less active during "solar minimum."
- The cycle is approximately 11 years long, but the cycles vary in intensity and sometimes in timing.

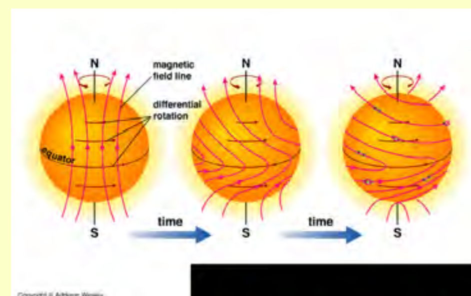


Where are we in the solar cycle?

Approaching solar maximum, but seems to be a wimpy one.



Solar Rotation & Magnetic Field



Since the Sun rotates differentially, the magnetic field "winds up," and loops can eventually break out as flares, prominences, etc.

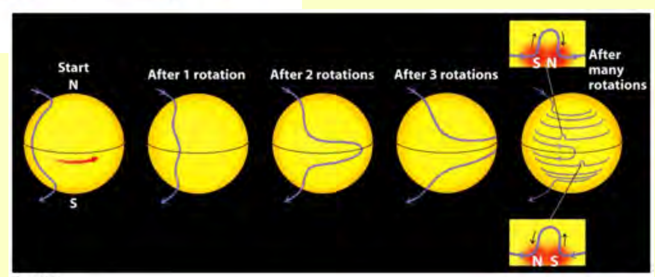


Figure 16-23
Universe, Eighth Edition

Different Kinds of Light: Colors

Figure 5-3
Universe, Eighth Edition
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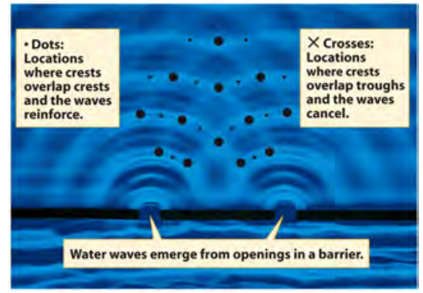
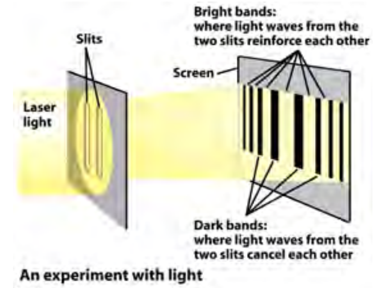
What is "color"? How does red differ from blue light?

In some ways, light acts like a wave

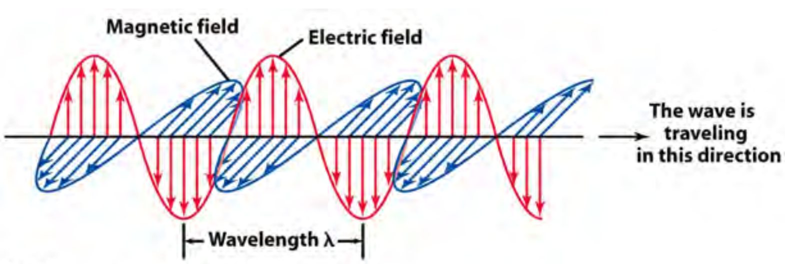


When water waves cross, they interfere with each other; light behaves in a similar way.

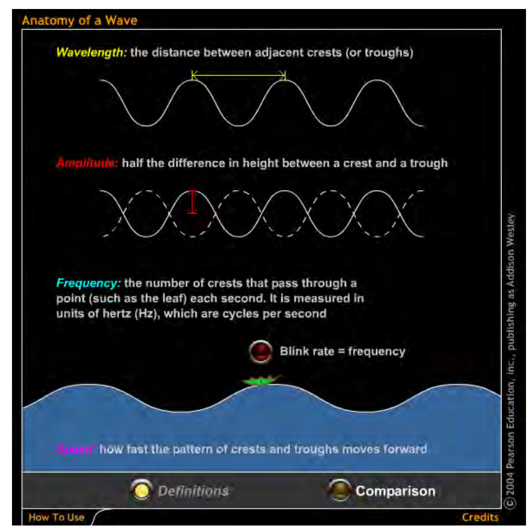


But a wave of … what?

- A light wave is a vibration of electric and magnetic fields (a form of energy)
- Light interacts with charged particles (matter!) through these electric and magnetic fields

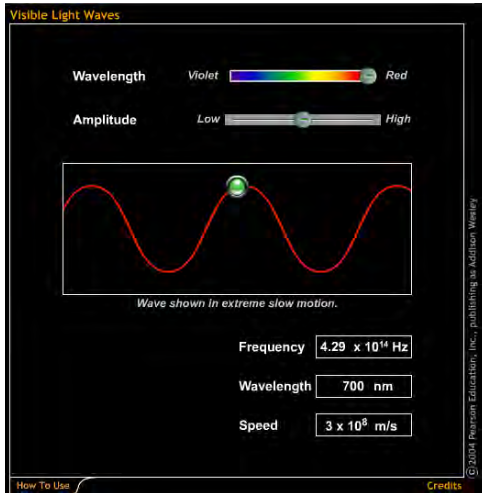


Properties of Waves



Light as a Wave

- The speed of a wave is
  $s = f \times \lambda$
- For all kinds of light, the speed s is constant:
  $c = \nu \times \lambda$
- For higher ν *(frequency)*, you have smaller λ, and vice versa.
- Our eyes interpret light of different λ's as *different colors*.



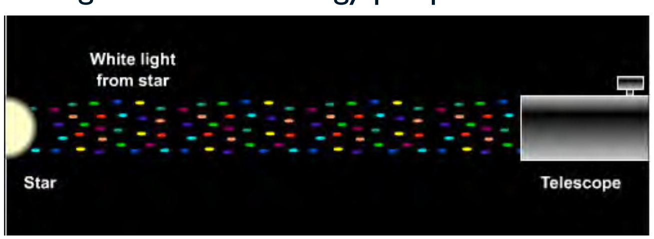
Light Also Acts Like a Particle

- Light energy comes in indivisible packets called photons, which behave like particles
- However, each photon has a specific wavelength and frequency
- The energy of a photon depends on its frequency: $e = h \times \nu$

"wave-particle duality"

Light as a Stream of Particles

- A beam of light can be thought of as a stream of particles (photons) with various wavelengths.
- Since a photon's energy varies with frequency, it also varies with wavelength:
  $E = h \times \nu = (h \times c)/\lambda$ ["h" = Planck's constant]
- Bluer light has more energy per photon.



Wavelength, Frequency, and Energy

$$\lambda \times \nu = c$$

λ = wavelength ν = frequency

$c = 3.00 \times 10^8$ m/s = speed of light

$E = h \times \nu$ = photon energy

$h = 6.626 \times 10^{-34}$ Joule • s = photon energy