Lecture 5

- More on neutrino observations
- Center to limb variation
- Maxwell equations
- Index notation
- Opacity
- LASP visit 8:30-9:45

Summary of previous lecture

- Nuclear burning
- Helium production
- Comment on faint Sun paradox
- # of neutrinos

Neutrino detection

- ^{37}Cl and ^{71}Ga have large cross-section
  - Homestake mine (S Dakota) and Gran Sasso
- $\nu + {}^{71}Ga \rightarrow {}^{71}Ge + e^-$
  - Germanium chemically extracted
  - its decay (11.4 days half time) was measured with counters
- Super Kamiokande and Ice Cube work with Cherenkov radiation of leptons moving faster than light in water

$[{}^3He + {}^3He \rightarrow {}^4He + 2{}^1H + \gamma]$ where energy out = γ= 12.86 MeV (4)

ltimately six protons and two electrons interact, producing one helium nucleus, two electron-neutrinos, two protons, and 6.7 MeV of energy. Line (5) summarizes the reaction.

$$[6{}^1H + 2e^- \rightarrow {}^4He + 2\nu_e + 2{}^1H + 26.7\ MeV] \quad (5)$$

Theories developed in the 1930s by Hans Bethe and others proposed at every fusion reaction should produce a chargeless reaction by-oduct called a *neutrino*. Neutrinos and photons exit the Sun, but on stly different time scales. Unlike photons that require millions of years escape the solar interior, neutrinos leave the Sun within seconds of ir creation. If we could sense every solar neutrino, the sheer number of m would blind us. Billions of neutrinos pass through an area the size a fingernail every second. However, these ghostly particles ignore ter and most pass through the entire Earth without an interaction. y the highest energy neutrinos are observable with current nology. Scientists expect to observe hundreds per day, but the best ure facilities observe only about 10 neutrinos per day. Investigations inue. For now, we have the results shown in Fig. 2-10: a fuzzy view e tiniest particles associated with solar nuclear reactions.

o gain information about the deep solar interior, scientists study rinos, the extremely low-mass particles generated by fusion ions. These particles are key figures in verifying our understanding clear physics and are our primary means of peering into the Sun's . However, even demonstrating that these stealthy particles have was a major undertaking that yielded a definitive answer only in [Fukuda et al., 1998]. After the Super-Kamiokande experiment in provided data showing that some types of neutrinos do have mass, r experiments conducted at the Sudbury Neutrino Observatory in o, Canada, showed that neutrinos change appearance as they through space [Ahmad et al., 2002]. (They have a natural ng" capability). These discoveries help explain the dearth of ations, but even these experiments capture fewer neutrinos than scientists think they should. Besides having no and only the tiniest mass, which makes them notoriously difficult to detect, these particles seem to disappear nally. The best hope of capturing any of them comes in focusing on a rare side branch of the proton-proton chain has <1% occurrence frequency) that should produce a particularly energetic neutrino. If we measure the neutrino n this reaction, then we can make progress in verifying the reaction rates of all of the chains.

Fig. 2-10. A Neutrino Image of the Sun. This view of the Sun is from the Super-Kamiokande (Super-K) experiment in Japan. Brighter colors represent a larger flux of neutrinos. Three hundred days of data were collected to produce this neutrino image of the Sun. The picture covers a significant fraction of the sky; however most of the neutrinos are coming from the vicinity of the solar core. *(Courtesy of NASA and Robert Svoboda at Louisiana State University)*

- Define entropy
- Relate the Second Law of Thermodynamics to the mechanical work

The First Law of Thermodynamics states that en destroyed. Energy that enters a system must be balar system and energy exiting the system as shown in I many energy conservation problems is defining the s examples and describe conservation of mechanical e earlier in the chapter. Next, we give a thought exa including non-conservative forces resulting in dissip

$$E_{total\ initial} = E_{total\ final} = co$$

Yet, often we hear of "energy loss." Can ener usually refers to energy lost from the system to the the energy transferring to the environment solves t

Suppose a meteor collides with a satellite. The an external force on the satellite, doing work on move faster (if hit from behind) and into a higher the satellite to "give" (deform) (Fig. 2-11). Th internal energy—for example, its temperature c sound waves. The sum of the newly acquired mo the large- and micro-scale, and the energy components resulting from the collision, equals t to the satellite by the meteor.

The energy loss for the meteor is energy gain for all of it by defining the system to consist of th suspect that something has been lost in this pro quality energy that efficiently does work, and th return to the meteor or the meteor-plus-satell applications the fact that the energy is no longe is available as heat is called energy loss or energ in such degradations of energy are called *non-c*

In most human endeavors (water heaters, c energy or energy stored in random forms is don't have easy ways to extract work from it remain a part of the overall energy budget. T even as energy is conserved, is the basis for e

Entropy (S) is a measure of disorder i *Thermodynamics* says that nature tends to available for useful work decreases as entrop Second Law, as illustrated in Fig. 2-12. A

Why is hydrogen burning best?

A. Most abundant
B. Energy gain per nucleon is largest
C. Repulsive electric force smallest
D. Both A and C
E. All: A, B, C

Approximate solution

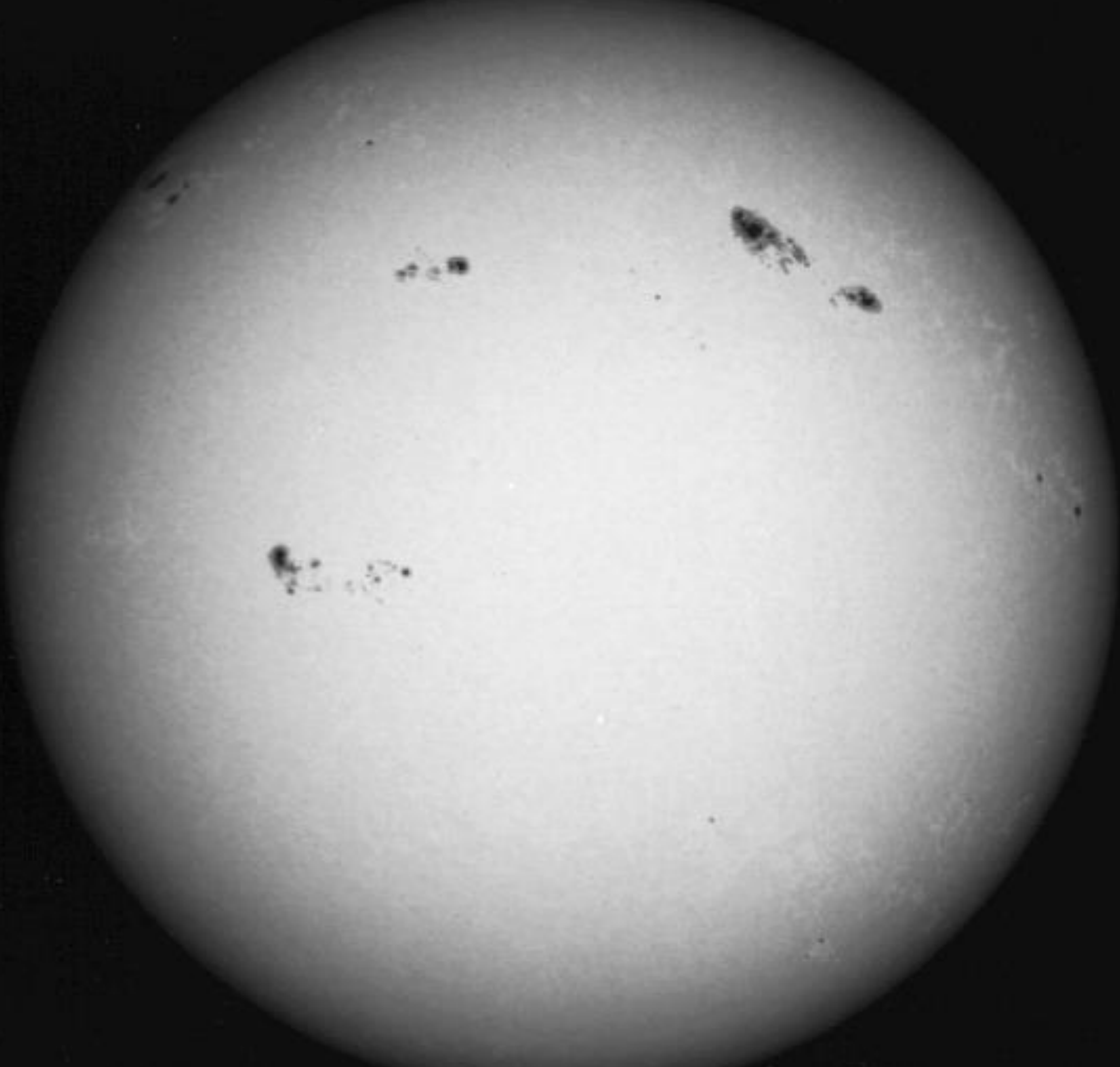
Leading order $$I_\nu = B_\nu$$

Insert

$$\cos\theta \frac{dB_\nu}{dr} = -\rho\kappa_\nu \left(I_\nu - B_\nu \right)$$

so

$$I_\nu = B_\nu - \frac{\cos\theta}{\rho\kappa_\nu} \frac{dB_\nu}{dr}$$

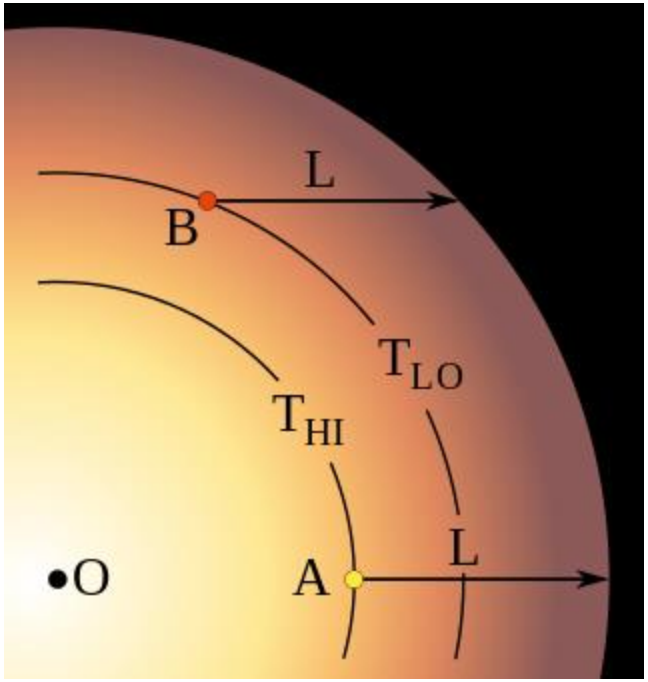


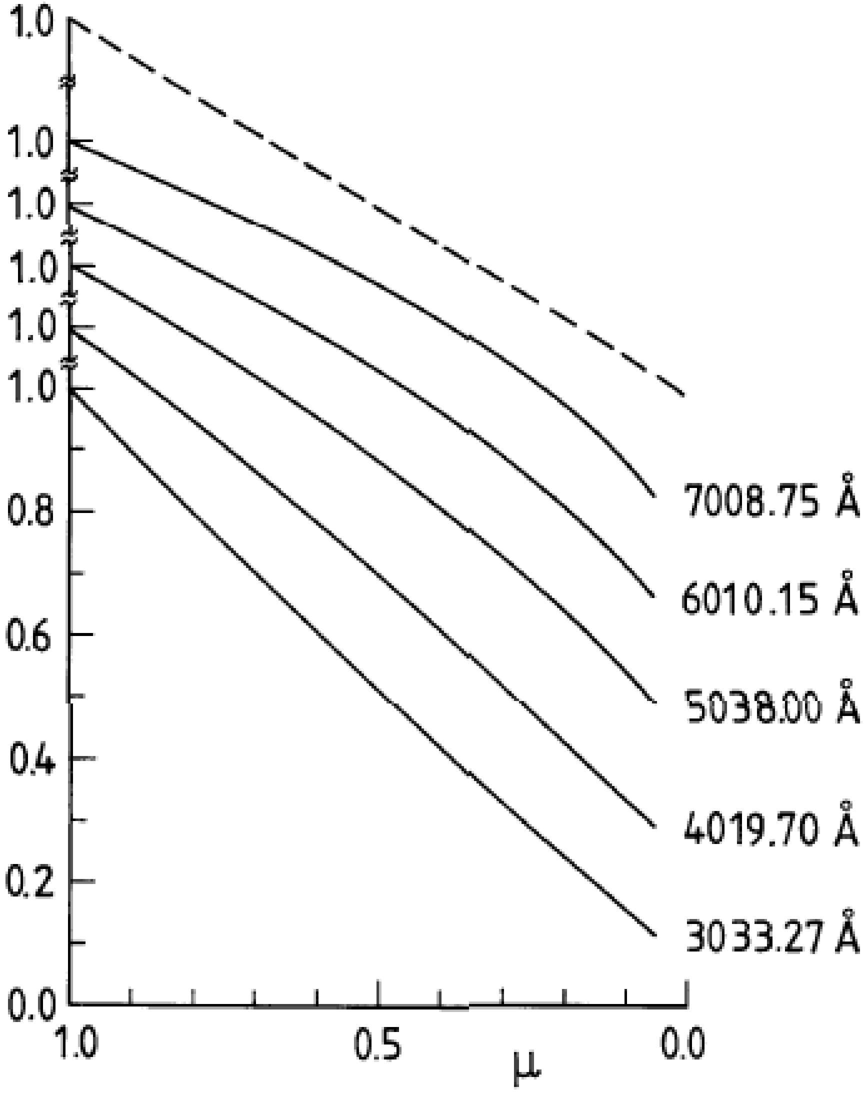
Why dimmer toward limb

A. Refraction, less bright in red
B. Emission maximum normal to surface
C. Temperature increases with depths
D. Edge is further away from us

Limb darkening

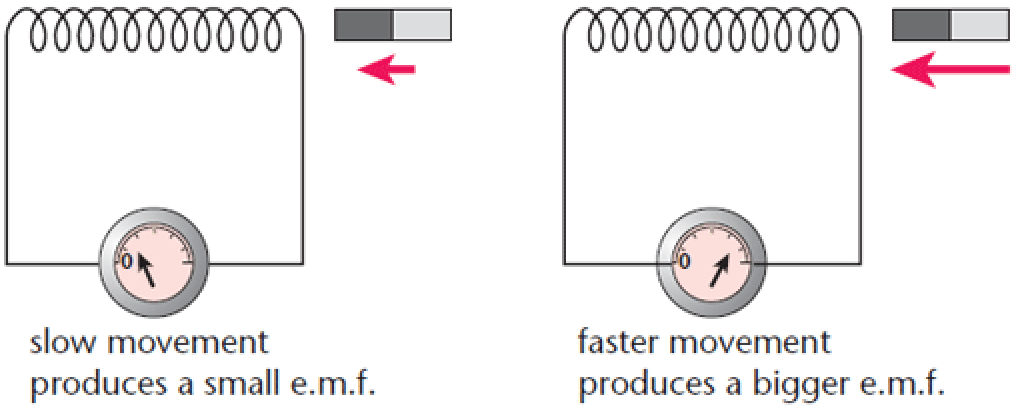
- Stix Sect. 4.3.1
- See deeper



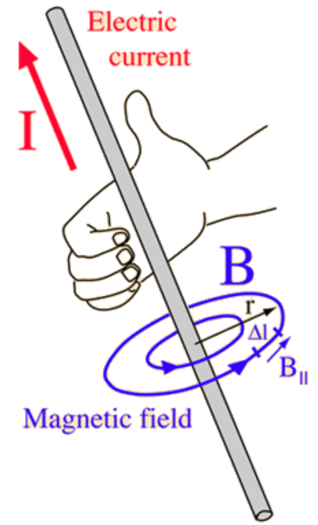


Maxwell equations

Q1: Faraday's law



Q2: Ampere's law



A. $$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}$$

B. $$\nabla \cdot \mathbf{B} = 0$$

C. $$\mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} = +\nabla \times \mathbf{B} - \mu_0 \mathbf{J}$$

D. $$\nabla \cdot \mathbf{E} = \rho_c / \varepsilon_0$$

Index notation (1st exposure)

divergence

$$\nabla \cdot \mathbf{F} = \sum_{i=1}^{3} \frac{\partial}{\partial x_i} F_i \equiv \frac{\partial}{\partial x_i} F_i \equiv \partial_i F_i$$

Einstein's summation convention

Subscript means spatial coordinate direction

curl

$$\left(\nabla \times \mathbf{F}\right)_i = \varepsilon_{ijk} \partial_j F_k$$

$$\left(\mathbf{G} \times \mathbf{F}\right)_i = \varepsilon_{ijk} G_j F_k$$

$$\varepsilon_{123} = \varepsilon_{231} = \varepsilon_{312} = 1$$

$$\varepsilon_{321} = \varepsilon_{213} = \varepsilon_{132} = -1$$

$$\varepsilon_{ijk} = 0 \ \text{otherwise}$$

Application (useful for homework!)

Divergence and cross product combined: use product rule

$$\nabla \cdot (\mathbf{E} \times \mathbf{B}) = \varepsilon_{ijk} \partial_i (E_j B_k)$$
$$= \varepsilon_{ijk} (\partial_i E_j) B_k + \varepsilon_{ijk} E_j (\partial_i B_k)$$

Re-express in terms of vector notation

$$\nabla \cdot (\mathbf{E} \times \mathbf{B}) = (\varepsilon_{kij} \partial_i E_j) B_k + E_j (\varepsilon_{jki} \partial_i B_k)$$
$$= (\varepsilon_{kij} \partial_i E_j) B_k - E_j (\varepsilon_{jik} \partial_i B_k)$$
$$= (\nabla \times \mathbf{E}) \cdot \mathbf{B} - \mathbf{E} \cdot (\nabla \times \mathbf{B})$$

LASP visit on Wednesday 8:30-9:45