

Astronomy 102, Spring 2003  
Solutions to Review Problems from 2003 February 20

1. Chapter 12, Question 16: *The Sun is about 16 trillion ( $1.6 \times 10^{13}$ ) times brighter than the faintest stars visible to the naked eye.*

- (a) *How far away (in AU) would an identical solar type star be if it were just barely visible to the naked eye?*  
 (b) *What would be its distance in light-years?*
- (a) The first point is to note that how bright the star looks is the *flux* of light reaching the earth, so. If  $F_{\min}$  is the minimum flux the eye can see (i.e. the flux of an object barely visible), then:

$$F_{\min} = \frac{F_{\odot}}{1.6 \times 10^{13}}$$

where  $F_{\odot}$  is the flux of the Sun. Another star just like the Sun will have the same luminosity as the Sun ( $L_{\odot}$ ), so we have:

$$F_{\odot} = \frac{L_{\odot}}{4\pi d_{\odot}^2}$$

$$F_{\min} = \frac{L_{\odot}}{4\pi d_{\text{far}}^2}$$

where  $d_{\text{far}}$  is the distance to the far away star just like the sun that we can barely see. Since  $1.6 \times 10^{13} F_{\min} = F_{\odot}$ , we can write:

$$1.6 \times 10^{13} \frac{L_{\odot}}{4\pi d_{\text{far}}^2} = \frac{L_{\odot}}{4\pi d_{\odot}^2}$$

Multiply both sides by  $4\pi$  and divide both sides by  $L_{\odot}$  to get rid of the stuff that is the same:

$$\frac{1.6 \times 10^{13}}{d_{\text{far}}^2} = \frac{1}{d_{\odot}^2}$$

Solve this for  $d_{\text{far}}$ :

$$d_{\text{far}} = \sqrt{1.6 \times 10^{13}} d_{\odot}$$

As  $d_{\odot} = 1$  AU, we can plug in and calculate that the faintest sun-like star we can see is  $4 \times 10^6$  AU away.

- (b) To do this conversion, we just need to look up that there are 63,240 AU in one light-year. Performing the conversion in the usual manner, we find that the dimmest sun-like star we can see is 63 light-years away.

2. Chapter 13, Question 15: *Sunspots appear relatively dark because their surface temperature is typically 1,500 K cooler than the surrounding photosphere (5,780 K). Compare the surface brightness (power radiated per square meter) of a dark sunspot to that of the surrounding photosphere.*

Power radiated per square meter is  $\sigma T^4$ . Thus:

$$\frac{P_{\text{spot}}}{P_{\text{photosphere}}} = \frac{\sigma(4280 \text{ K})^4}{\sigma(5780 \text{ K})^4}$$

We don't even need to look up  $\sigma$ , as that cancels out. We can just take the two numbers to the fourth power and divide them to get:

$$\frac{P_{\text{spot}}}{P_{\text{photosphere}}} = 0.3$$

3. *Suppose that nuclear fusion at the center of the sun were to suddenly stop, but was replaced by some new, non-nuclear way of generating energy (unknown to modern physics). Additionally, suppose that this new energy source generated exactly the same amount of energy as nuclear fusion currently does. Would we be able to tell the difference, and how?*

If the new energy source is generating exactly the same amount of energy— and let’s suppose that it generates light at exactly the same wavelengths— then the layers outside the core of the Sun can’t “know” that there isn’t fusion going on any more. All they get is the light, and if something else is generating the same light, they don’t “care”— it provides the energy and pressure source necessary to maintain the Sun’s structure. Therefore, the surface of the Sun would look exactly the same to us.

How then could we tell if the energy source weren’t fusion? There is one more by-product: the neutrinos. Neutrinos come straight from the core of the Sun to us, not interacting much at all with the outer layers of the Sun. If some other energy source generated all the heat necessary, but did *not* generate the neutrinos, we could tell that it wasn’t fusion. Even though the Sun would stay the same brightness and life on Earth would continue as before, our neutrino detectors would notice that there weren’t any more neutrinos coming from the Sun.

(Although we haven’t talked about it in class, a very important recent experiment in astrophysics measured the number of neutrinos coming from the Sun. For a long time, there was a “Solar neutrino problem,” in that the number of neutrinos we measured from the Sun was *too low* given our understanding of nuclear fusion and the observed brightness of the Sun. The solution to this involved figuring out that neutrinos are really wacky little particles, and that sometimes on their way from the Sun to us they can change from one type of neutrino to another. You will not be tested on any of this Solar neutrino problem stuff, but it is a fascinating topic; you can read more about it in your textbook.)

4. *Why does nuclear fusion take place only at the center of the Sun, and not in the Sun’s outer layers?*

Fusion requires high densities and high temperatures. The full weight of the Sun pressing down on its core provides the high pressures which lead to high density and high temperatures. Outside the core, there is less weight above any given point on the Sun, and thus less weight pushing down on that point. The core is where the pressure is highest, and that’s the only place where the pressure is high enough to induce fusion.

5. Chapter 13, Question 4: *What experiences have you had with energy transmitted by radiation alone? By convection alone? By conduction alone? (You are exposed to all three every day.*

Far be it from me to tell you what experiences you have in a given day.

Some suggestions, though: radiation is feeling the warmth of the sun, or huddling next to an electric heater to absorb its rays when you are cold, or seeing the light from the computer screen projector in A102 lecture. Conduction is burning yourself on the stove burner or curling up with your cat under the bed covers to share its body heat. Convection is the wind blowing past your skin and carrying heat away, or the bubbles of hot water vapor coming to the top of a pan of boiling water.