2. Of the following photons, which has the lowest energy? a. infrared, b. gamma ray, c. visible light, d. ultraviolet, e. X ray
   a. infrared

4. What is a blackbody? What does it mean to say that a star appears almost like a blackbody? If stars appear to be like blackbodies, why are they not black?

   A blackbody is an object that absorbs all of the energy that falls on it. According to the laws of physics it therefore re-radiates thermal radiation with the blackbody spectrum with 100% efficiency. Stars radiate with an efficiency around 85%, so behave as blackbodies. The nature of a blackbody is that it radiates electromagnetic radiation. This radiation is in the visible range for a temperature of several thousand kelvin.

6. What is the Stephan-Boltzmann Law? How do astronomers use it?

   The Stephan-Boltzmann Law states that the total radiated energy of an object (or every square meter thereof) increases proportional to the fourth power of the absolute (Kelvin) temperature. Astronomers use this to determine immediately the power per square meter the star emits. This gives a relation between the size of the star and its luminosity. We will see in chapter 11 that this is used to determine the size of the star.

8. What color will an interstellar gas cloud composed of hydrogen glow, and why?

   A cloud of gas will glow pink or red (personal perception) if it is illuminated by a hot star that emits a lot of ultraviolet. The color is dominated by the $n = 3$ to $n = 2$ transition in hydrogen, which emits red light ($\text{H}_{\alpha}$, $\lambda = 656$ nm), but with a significant amount of $n = 4$ to $n = 2$, which emits blue ($\text{H}_{\beta}$, $\lambda = 486$ nm). (Dozens of other transitions are also present.) The ultraviolet illumination is necessary to excite the hydrogen above the $n = 1$ level in the first place. See the Fig 12-16 on page 387 (9th edition). A cloud containing dust (a reflection nebula) will glow blue if illuminated by white light. This is because the dust scatters blue light more than red, so the scattered light that reaches Earth is dominantly blue. The same thing happens in Earth’s atmosphere to make the sky blue.

11. Explain how the spectrum of hydrogen is related to the structure of the hydrogen atom.

   The structure of the hydrogen atom is
   a. that the electron can orbit only in certain orbits ($n = 1, 2, 3, 4, ...$);
   b. that each orbit has a characteristic energy;
   c. that the hydrogen spectrum consists of photons whose energies are the differences in energy between allowed transitions; and
   d. that the energy of a photon automatically determines its wavelength (a universal characteristic of light, not specific to hydrogen).

13. Explain why the Doppler shift tells us only about the motion directly along the line of sight between a light source and an observer, but not about motion across the celestial sphere.

   The Doppler shift tells us about motion along the line of sight because motion along the line of sight stretches or compresses the waves. Motion across the line
of sight does not stretch or compress the waves, so it cannot be detected, except by waiting for the object to move far enough to measure.

17. The bright star Procyon in the constellation Canis Minor (the Little Dog) emits the greatest intensity of radiation at a wavelength $\lambda_{\text{max}} = 445$ nm. Approximately what is the surface temperature of the star in Kelvins?

This is a job for Wien’s Law. Use the formula from the textbook in *An Astronomers’ Toolbox 4-1* (p 107):

$$\lambda_{\text{max}} = \frac{2.93 \times 10^{-3}}{T}.$$  

Solve for $T$ to get:

$$T = \frac{2.93 \times 10^{-3}}{\lambda_{\text{max}}}.$$  

Plug numbers, converting 445 nm to meters:

$$T = \frac{2.93 \times 10^{-3}}{445 \times 10^{-7}} = 6580 \text{ K}.$$  

I gave the same formula in class, but with the constant being $2.93 \times 10^6$, and remarking that the wavelength must be in nm. Doing it this way:

$$T = \frac{(2.93 \times 10^6)}{\lambda_{\text{max}}} = \frac{2.93 \times 10^6}{445} = 6580 \text{ K}.$$  

The same final answer, of course.

19. In the spectrum of the bright star Rigel, H$_\alpha$ is observed to have a wavelength of 656.331 nm. Is the star coming toward us or moving away from us? How fast? [In the laboratory, H$_\alpha$ has a wavelength of 656.281 nm.]

Since the wavelength from Rigel is longer than in the lab, the star is moving away from us. The Doppler formula in *An Astronomer’s Toolbox 4-3* gives

$$\frac{\Delta \lambda}{\lambda_0} = \frac{v}{c}.$$  

Note that $\Delta \lambda = \lambda - \lambda_0 = 656.331 - 656.281 = 0.050 \text{ nm}.$

$$v = c \frac{\Delta \lambda}{\lambda_0} = \frac{(300,000 \text{ km/s})(0.050/656.281)}{656.281} = 23 \text{ km/s}.$$  

This is rocket-ship speed, which shows that a small Doppler shift corresponds to a fast (for us Earthlings) velocity. This is a typical magnitude of the Doppler shift, and a typical velocity for a star in our galaxy relative to us. The fact that shifts are so small means that there is normally no trouble in identifying lines.

24. What if: The Sun were twice its actual diameter but still had the same surface temperature? At what wavelength would that new Sun emit its radiation most intensely? How many times brighter would the new Sun be than the present Sun? How might things on Earth be different under the bigger Sun?

Since the surface temperature is the same, the peak wavelength would not be changed from its current value. The Sun would have 4 times the surface area, which scales as $R^2$, so would emit 4 times the radiation. Earth would be hotter than Venus.