World of Light - Problem Set #6

Assigned May 13, due at start of class on ***Wed. May 20***.

Reading

Light Science chapters 6.

Topics and equations

This problem set reviews the following topics: polarization, atomic spectra, fluorescence, lasers, and blackbody radiation. It requires the use of the following constants and equations:

speed of light in vacuum = $c = 3\times10^{8}$ m/s
Planck's constant = $h = 6.6\times10^{-34}$ J s
Rydberg constant = $R = 1.097\times10^{7}$ m^{-1}
Stefan-Boltzmann constant = $\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4}

$$v = \lambda f \qquad E = hf$$

$$\frac{1}{\lambda} = R\left(\frac{1}{n^2} - \frac{1}{m^2}\right) \qquad E = \sigma T^4 \qquad \lambda_{max} = \frac{2.898\cdot10^{6}\ \text{nm K}}{T}$$

Problems

Grading scale: basically right = 1 point, basically wrong = 0 points, some right and some wrong = 0.5 points.

1. When light reflects off of a horizontal water surface, its electric field is mostly parallel to the water's surface. (a) To reduce glare, should your polarized sunglasses transmit light with a vertical or horizontal electric field? (b) Would wearing a second pair of polarized sunglasses at the same time reduce the glare even more, have essentially no further effect, or be completely opaque?

2. Consider a sample of hydrogen atoms that are in their ground states (hard to achieve on Earth, but common in interstellar space). (a) Draw an energy level diagram of a hydrogen atom, with the energy levels labeled. (b) Suppose light of 103 nm shines on the hydrogen atoms; what energy level will the hydrogen get excited to (hint: just guess and then compute the wavelength with the Rydberg formula to see if you're correct)? (c) What two wavelengths will the hydrogen atoms emit as they relax back to the ground state?

3. (a) Draw an energy level diagram for fluorescence, with arrows for excitation, non-radiative relaxation, and emission. (b) In which state are most of the atoms? (c) Is fluorescent emission at a longer, shorter, or the same wavelength as the excitation?

4. (a) Draw an energy level diagram for a simple laser showing pumping (excitation), non-radiative relaxation, and stimulated emission. (b) In which state are most of the

atoms? (c) Is laser emission at a longer, shorter, or the same wavelength as the excitation?

5. Consider a piece of pottery in a kiln that is at 1200° C. (a) What is the temperature of the pottery in Kelvin? (b) Write down the equation for the Wien displacement law. (c) What is the wavelength for peak emission by the pottery? (d) What type of light is this? (e) How does the type of light / color change as the kiln is made hotter?

6. Consider the same piece of pottery, and also assume that it has a surface area of 100 cm^2. (a) Write down the equation for the Stefan-Boltzmann law. (b) How much radiant power is emitted by the piece of pottery (units should be in W). (c) Does the emitted radiant power increase or decrease as the kiln is made hotter?

7. Consider a 100 W incandescent light bulb which has color temperature of 2700 K. (a) How much power is radiated per square meter of filament? (b) What is the surface area of the filament in mm^2?

8. (a) Which will get hotter when sitting in the sun: a black car or a white car? (b) Which will get colder when sitting outside on a clear night: a black car or a white car? (c) What color roof will keep a house cooler on a hot summer day, black or white? (d) What color roof will lose less heat on a cold winter night, black or white?

9. When table salt is put in a candle flame, it burns bright yellow because of emission from the sodium atoms. This emission is at 590 nm. (a) What is the natural resonant frequency of the sodium atom that produces this emission (i.e. what is the frequency of this light)? (b) What is the difference in energy between the two levels of the sodium atom that are responsible for this emission (i.e. what is the energy of a photon)?

10. Betelgeuse is a red giant star in the Orion constellation. The peak of its emission spectrum is at about 880 nm. (a) Using this, what is the temperature of the surface of the star?