7.2: Review- Photons

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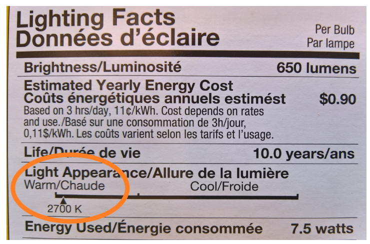
Review: Photons

D1.3 Blackbody Radiation

Have you noticed that some LED light bulbs are a different color from others? Some are "warm" and others are "cool" (see Figure 6). Candlelight is "warmer" (yellower) than fluorescent lights: the latter have a blue cast that can make people's faces look sickly. These observations are related to **blackbody radiation**—the continuous spectrum of light emitted by matter as the matter is heated to higher temperatures.



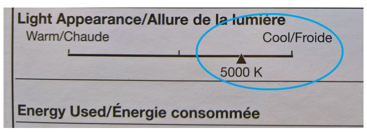


Figure 6. *Labels from LED light bulb boxes. Notice that the "warm" bulb is labeled 2700 K while the "cool" bulb is labeled 5000 K.*

Figure 7 shows the **spectra**, graphs of intensity versus wavelength, for blackbody radiation emitted by matter at several different temperatures.

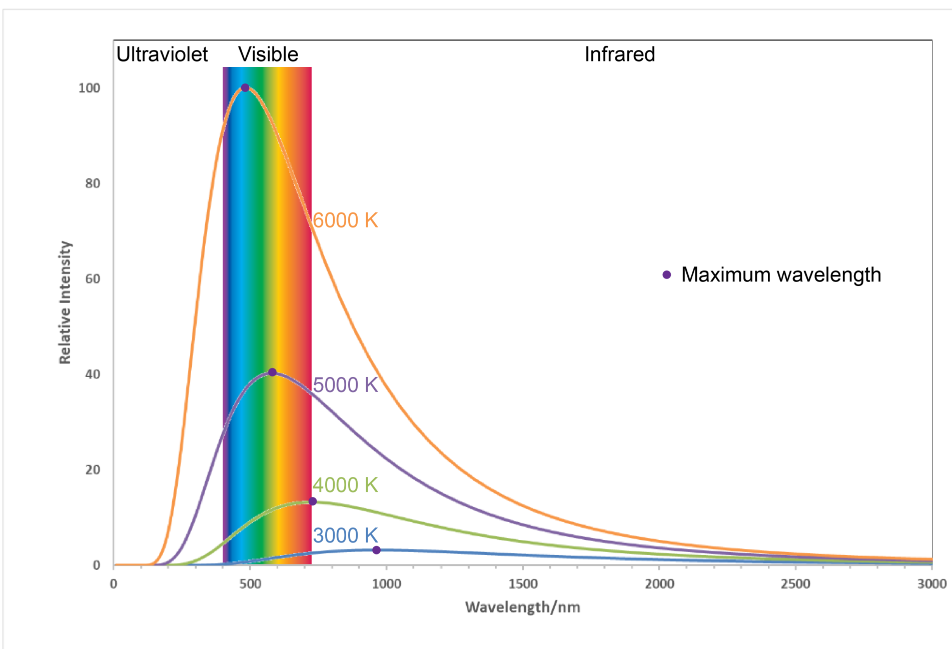


Figure 7. *Blackbody spectral distribution curves and their maxima are shown for four temperatures.*

Here, each spectrum depends only on temperature. The wavelength of the maximum in each curve,

$$\lambda_{max}$$

shifts to shorter wavelengths as the temperature increases. This corresponds to a heated metal first becoming red hot, then brighter and white hot as the temperature increases.

Additional Practice 1

Additional Practice 2

D1.4 Planck's Quantum Theory

In the late 1800s, physicists derived mathematical expressions for the blackbody curves using well-accepted concepts of mechanics and electromagnetism. They assumed that as the temperature increased the energies of atoms in a metal object would increase as the atoms vibrated more vigorously; these vibrations were assumed to create electromagnetic waves—the blackbody radiation. But no theory based on these ideas was able to predict the shapes of the curves shown in Figure 7. Even worse, the theory predicted that the intensity would become infinitely large for very short wavelengths, an absurd result.

In 1900, Max **Planck** introduced a revolutionary idea, from which he was able to derive a theoretical expression for blackbody spectra that fit the experimental observations within experimental error. Instead of assuming that the vibrating atoms could have a continuous set of energy values, Planck restricted the vibrational energies to discrete values—that is, he assumed that there must be some minimum quantity of energy that could be transferred between vibrating atoms. That quantity of energy is proportional to the frequency of vibration and is called a **quantum**.

$$\mathrm{E_{quantum}} = h\nu; \qquad \text{because } c = \lambda\nu,\ \nu = \frac{c}{\lambda},\ \mathrm{E_{quantum}} = \frac{hc}{\lambda}$$

The proportionality constant "*h*" is now known as **Planck's constant**. Its value is very small, 6.626×10^{-34} J·s (joule-seconds). According to Planck's theory, electromagnetic radiation occurs in small, indivisible quantities (quanta), just as matter consists of small, chemically indivisible quantities (atoms).

Additional Practice

Although Planck had developed a theory of blackbody radiation that worked, he was not satisfied with the assumption of quantized energies for the vibrating atoms. But not for long—a few years later Albert **Einstein** used the idea of quantization of electromagnetic radiation to explain another puzzling phenomenon: the photoelectric effect, which is a topic for the next section.

D2.1 The Photoelectric Effect

Activity 1: Preparation—Photoelectric Effect

In your course notebook, make a heading for Photoelectric Effect. After the heading write down what you recall about the photoelectric effect from courses you have already taken. If you remember having a question about the photoelectric effect or if there is anything you remember being puzzled about, write that down as well. We will ask you to refer back to what you have written when you complete this section.

Planck's quantum theory was able to predict accurately the distribution of wavelengths emitted by a blackbody at various temperatures. However, Planck found it difficult to justify his assumption that vibration energies had to be multiples of a minimum energy—a quantum. When Albert **Einstein** used Planck's quantum hypothesis to explain a different phenomenon, the photoelectric effect, the validity of quantum theory became clearer.

Exercise 1: Quanta and Laser Light (Review)

Before doing any calculation or looking at the hint, <u>write in your class notebook</u> an explanation of how you plan to work out the problem. <u>Do all the steps in the calculation in your notebook</u>. Once you have arrived at an answer, then submit your results below and click the "Check" button to see if it is correct. If one or more parts of your answer is incorrect, go over your work in your notebook carefully and check for errors. "Retry" with your new answer. Look at the hint (click on it to expand for view) only after you have attempted to answer the question at least twice.

When electromagnetic radiation shines on a metal, such as sodium, electrons can be emitted and an electric current (a flow of electrons) can occur. This is called the **photoelectric effect**. The effect is complicated: for some wavelengths no electrons are emitted, but at other wavelengths electrons are emitted.

Exercise 2: Photoelectric Effect Simulation

Watch this photoelectric effect animation, where sodium is already selected, to answer the questions below. *Write down your observations as you watch the animation, and then answer the questions in your course notebook.*

1. **For which colors of visible light are electrons emitted by sodium? Determine the maximum wavelength at which electrons are emitted.**
2. **At a wavelength where electrons are emitted, describe the shape of a graph of number of electrons emitted vs. light intensity.**
3. **Determine the shape of a graph of electron energy vs. light frequency. How does this graph differ from the electrons vs. intensity graph?**
4. **Based on your observations, draw a rough graph with labeled axes to show how the number of electrons emitted varies with wavelength of light. How would the graph change if the intensity of light increased?**

If you would like to experiment with the simulation further, download and save the simulation program, go to the location where you saved it, and double-click on the file name (photoelectric_en.jar) to install and run it. You need to have Java installed for this to work.

Additional Practice

Activity 2: Summary of Photoelectric Effect Results

In your course notebook, write a brief summary of the results you obtained from experimenting with the photoelectric effect simulation. Also write a summary of how your experimental results can be interpreted based on the idea that light consists of quanta. Compare what you wrote with the summary below [also available at this link] and, if necessary, revise what you wrote.

Additional Practice

Activity 3: Wrap-up—Photoelectric Effect

Refer to what you wrote (including things that puzzled you) when you made the heading Photoelectric Effect in your class notebook. Revise what you wrote based on what you have just learned. Write a summary so that it will be a good study aid when you review for an exam. If you still have questions, ask them on Piazza.