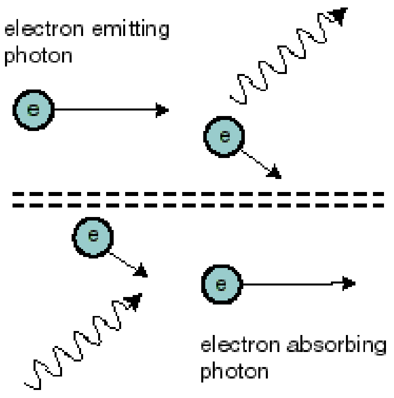
Principles of Spectroscopy

Introduction



A **photon** is a small bit of electromagnetic energy sent across space. Photons can be emitted or absorbed by electric charges – usually an **electron**.

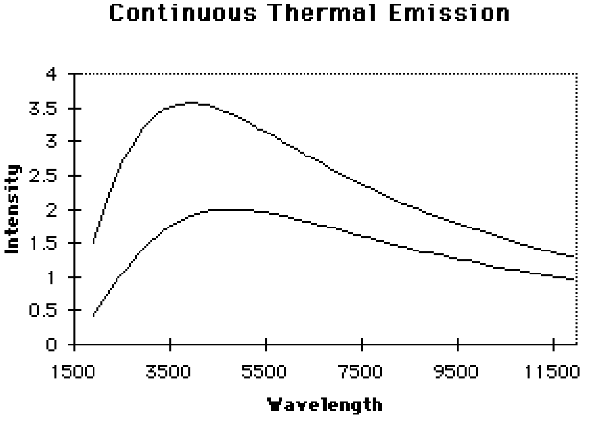
A hot, dense object contains many "loose" electrons which can emit photons of any energy. The light produced is called **continuous emission** because it contains photons of all energies, i.e. light of all colors, or wavelengths. Hotter objects contain more energetic electrons, which in turn tend can emit more energy overall. This is described by the **Stephan-Boltzmann Law:**

$$f = \sigma \, T^4,$$

where f is the **flux** of light energy emitted per unit area, or brightness, T is the temperature, and σ is the Stefan-Boltzmann constant, 5.67×10^{-8}J m^{-2} K^{-4}. If two objects are the same size, but one is twice as hot as the other, the hotter one will be sixteen times brighter.

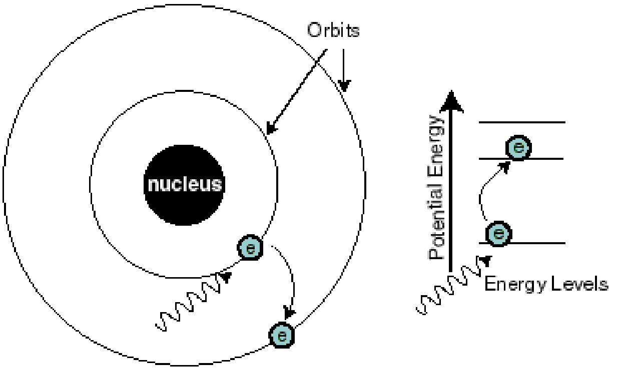
As an object heats up, the energy of the typical photon emitted increases, and the continuous emission shifts toward shorter wavelengths (higher energies) and therefore looks bluer. This is described by Wien's Law:

$$\lambda_{\text{peak}} \cdot T = 0.29 \text{ cm K}.$$



Any hot, opaque object will produce continuous emission, with the total energy and dominant color described by these two laws. This is called **blackbody radiation** or **thermal radiation**. Remember that Wien's law and the Stefan-Boltzmann Law apply only to continuous thermal emission.

We've described "loose" electrons in a hot medium. However, if electrons are part of an atom, they can only possess certain energies. As a result, these electrons emit photons that only possess certain energies, and produce emission and absorption spectra.



Continuous Emission

Get a dispersion grating from your instructor. A dispersion grating does the same thing as a prism: it splits up the light into individual wavelengths so that you can see the spectrum. Use the grating to observe the spectrum of the incandescent bulb.

1. What kind of light-source are you looking at: thin gas, opaque gas, solid, or liquid? What type of spectrum should this produce?
2. Observe the first order spectrum with the diffraction grating. What kind of spectrum is it: continuous, line emission or absorption? How did you identify it as this type of spectrum?
3. How does the brightness change with voltage?
4. How does the peak color change with voltage?
5. Explain using both Wien's and the Stephan-Boltzmann Laws: if two stars are the same size, which is *brighter*, a red star or a blue star?

Line Emission

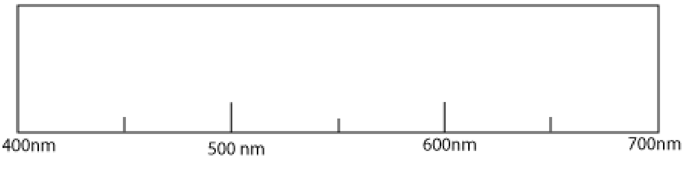
Now we will look at "discharge tubes," which are each filled with a low-density gas made of a single kind of atom. Running an electric current through the discharge tube kicks the electrons up to a high energy level. The electrons quickly fall back to their original energy level, emitting a photon with a wavelength determined by the difference in energy between the levels.

6. What kind of light-source are you looking at: thin gas, opaque gas, solid, or liquid? What type of spectrum should this produce?

There should be a spectroscope set up to observe the spectrum. A slit is aligned with the light source that allows light to travel down to the diffraction grating at the eyepiece. The spectrum is projected onto a scale to the left of the light source. Observe the spectrum through the spectroscope.

7. What kind of spectrum is it: continuous, line emission or absorption? How did you identify it as this type of spectrum?
8. Observe the spectrum of at least four of the discharge tubes, including hydrogen and the sodium lamp. Roughly sketch what you see, labeling the element's name and the colors of the brightest lines. Compare these to the chart of emission lines in the classroom. PLEASE TURN OFF THE DISCHARGE TUBES WHEN NOT IN USE (but leave the sodium lamp on)

   Example:



9. The hydrogen atom has only one electron, but when you look through the spectroscope, you see several emission lines. Explain how this is possible.
10. How are emission lines useful to an observer?

Line Absorption

It is difficult to replicate a cold thin gas with sufficient density for visible absorption lines in the lab, so we will use solid filters to observe an absorption spectrum. Since these are solids, they produce very broad absorption lines, not quite the same as the absorption patterns from Kirchoffs law.

To use the filters, hold a filter in one hand and the diffraction grating in the other. Look through the diffraction grating at the spectrum, then place the filter between the grating and your eye.

11. What kind of material is the light source: transparent gas, opaque gas, solid or liquid ? What kind of spectrum will it produce?

12. You are looking at it through air, which is a thin transparent gas. What kind of spectrum should you see? Why dont you see it?

13. Look at the light source through one of the colored filters. What kind of spectrum do you see? Explain how you determined it must be this type.

14. Observe the spectrum with at least 5 different filters, including the Hα. Make a table with the color of the filter (the plastic ones are primaries, the ones in the slide holders have their names printed on them) and what color(s) it blocked.

Filter Color	Color(s) Blocked

15. Look through the Hα filter at the discharge tubes and sodium lamp. Which light is NOT significantly blocked by the filter?

16. Why would this filter be useful to astronomers?

Thinking Questions

17. Describe two ways astronomers could determine the composition of a planets atmosphere without leaving Earth (Remember that emission and absorption lines are not restricted to the visible spectrum.)

18. Notice that the discharge tubes have different colors to our eyes. Can we use Wien's Law to tell the relative temperatures of the gas within the tubes? Explain.