ASTRO 1050 - Fall 2012
LAB #7: The Electromagnetic Spectrum

ABSTRACT

Astronomers rely on light to convey almost all of the information we have on distant astronomical objects. In addition to measuring the brightness of a given object we can also measure its brightness as a function of wavelength, that is, its *spectrum*. A rainbow is simply a reflection of light through water droplets in our atmosphere, resulting in a spectrum of the sun. In particular, it is found that a hotter object will generally emit more of its light at shorter wavelengths and a cooler object will emit more of its light at longer wavelengths. This continuous spectrum has a broad peak that can be used to infer the temperature of the object. Now this “thermal spectrum” or “black-body spectrum” is usually produced by a solid object or a dense gas. Spectra that show certain behavior are the result of specific phenomena, collectively known as *Kirchhoff's Laws*:

- A hot solid, liquid or gas, under high pressure (compact object), gives off a continuous spectrum.
- A hot gas under low pressure (diffuse gas) produces a bright-line or emission line spectrum.
- A dark line or absorption line spectrum is seen when a source of a continuous spectrum is viewed behind a cooler gas under low pressure.
- The wavelength of the emission or absorption lines depends on what atoms or molecules are found in the object under study.

Refer to Figure 1.

Materials

Part I: Four different discharge tubes (four different gases), diffraction grating
Part II: Incandescent light bulb, meter stick, diffraction grating
Part III: Incandescent light bulb attached to dimming control

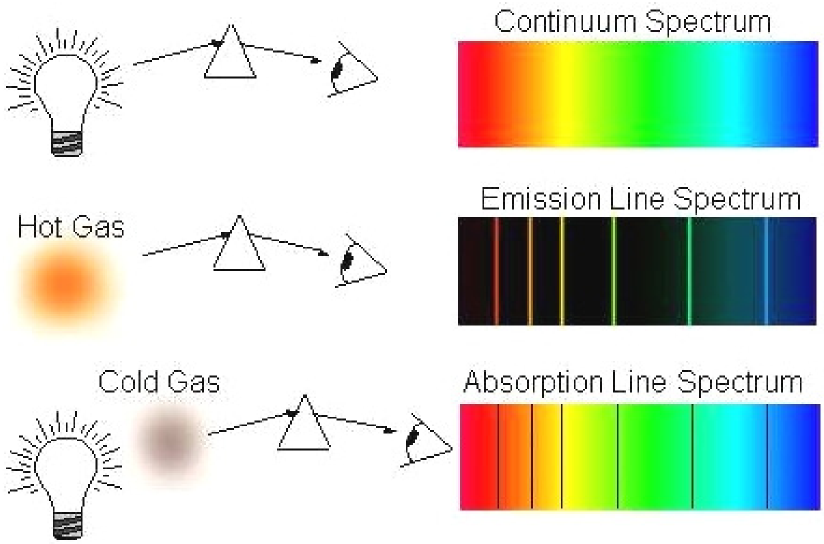


Fig. 1.— Exhibiting Kirchoff's Laws.

1. Introduction

As stated above the wavelength of the emission or absorption lines depends on what atoms or molecules are found in the object under study. The atoms or molecules that exist depend on:

- temperature
- chemical composition

Each atom or molecule exhibits a different pattern of lines (rather like a fingerprint or DNA signature).

The Bohr Atom:

The origin of discrete wavelengths of emission and/or absorption by gasses of a given composition was a mystery until Niels Bohr developed a new model of the atom. This later became known as the Bohr model of the atom. In this model the atom can be symbolized as a planetary system with the nucleus forming the center and the electrons orbiting around it. Bohr proposed that the electrons are only found in very specific orbits.

When a given atom is illuminated with a thermal spectrum it will absorb only the wavelengths that correspond to the differences in energies of these orbits. This allows the electron to "jump" to a higher level. The inverse is also true, meaning electrons in a high energy orbit can emit a particular wavelength of light and lose energy to "jump" to a lower orbit. The spectrum emitted and/or absorbed is then related to energy of the atomic orbits.

The result is that each atom will have a unique spectral signature. Thus astronomers can determine the chemical composition of a distant star or galaxy by comparing its spectrum to known gases measured in the laboratory.

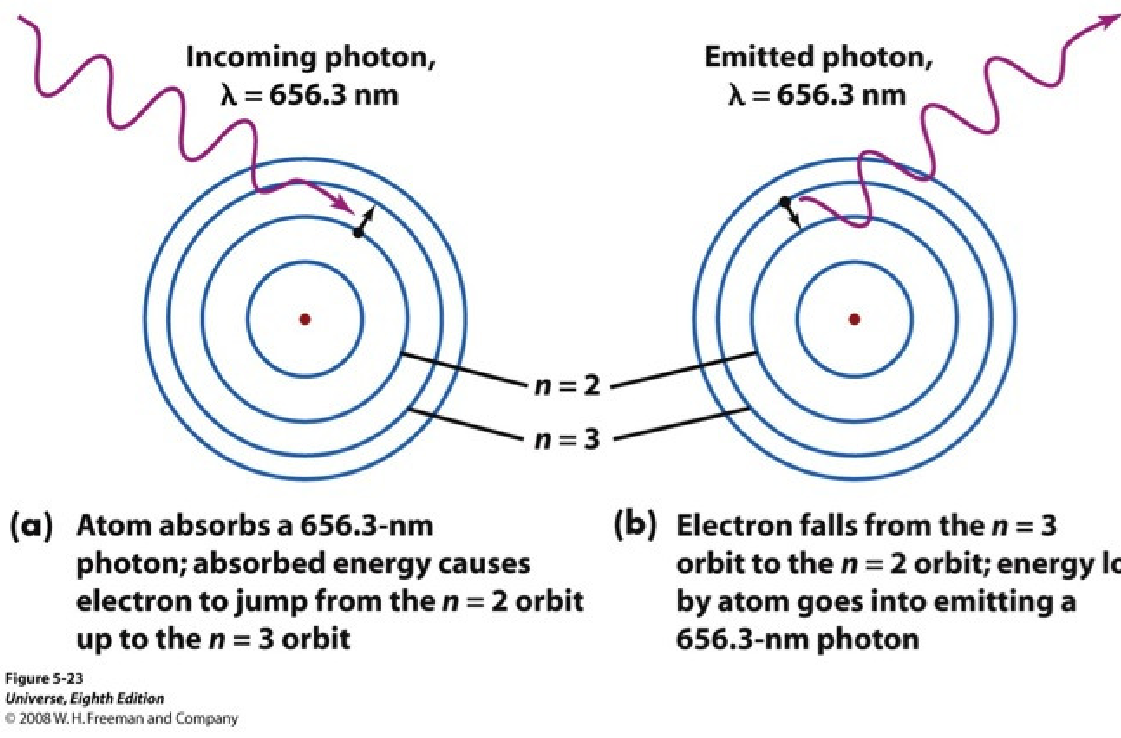


Fig. 2.— (a) Excitation versus, (b) De-excitation. Remember $E = hc/\lambda$.

2. Exercises

Part I: Identifying Gas Composition from the Emitted Spectrum

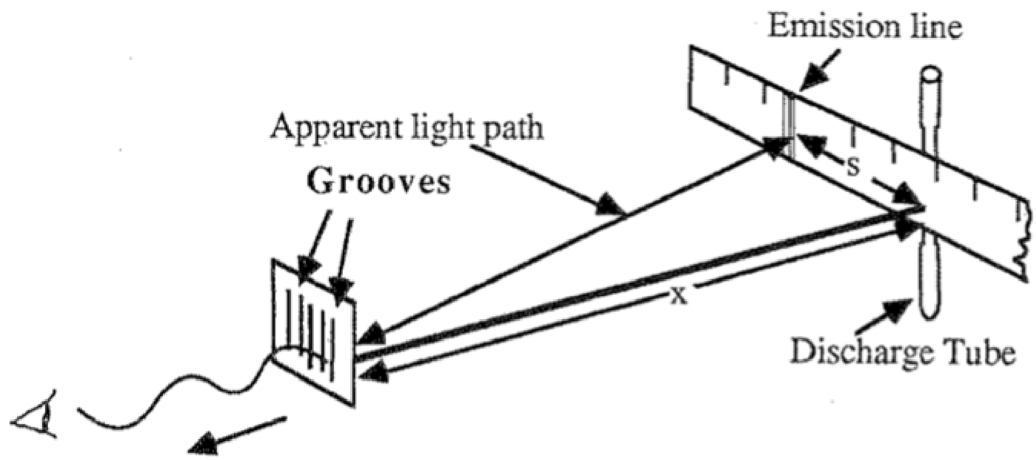
Around the lab room are four different discharge tubes consisting of four unknown gases. Your goal is to determine which gas is in which discharge tube. First, state the general color of the gas in the tube as seen without a spectroscope, or diffraction grating. Next, using the spectroscope, examine the spectra of each gas and draw the spectrum as best you can. Put red wavelengths on the right and blue on the left (use the colored pencils or crayons). Also, pay careful attention to the intensities of the lines as well as the relative spacing between the lines in the spectra. Use the spectrum charts located at the back of the lab room to identify your gases according to their signature spectrum lines.

Tube #	General Color	Spectrum	Gas Identification
______	______________	,	____________________
______	______________	,	____________________
______	______________	,	____________________
______	______________	,	____________________

Part II: Measuring the Wavelengths of the Hydrogen Atom

In this section hydrogen atoms will be excited by adding energy to the electrons via a small electric current. The electrons will jump back and forth between higher and lower orbits. Each time an electron falls from a higher to lower orbit, it emits a photon. If the wavelength of this photon is within the visible range we will see an emission spectrum of visible light.

Ensure your lab set-up looks as follows:



Now you will measure the wavelengths of three of the emission lines of hydrogen, in Angstroms. Better results are given with greater distances between the diffraction grating and the emission tube (100 cm or so). Make sure the emission tube is as close to the center of the meter stick as possible. The emission lines can be seen projected against the meter stick. One spectrum is to the right of the center of the meter stick; an identical spectrum is projected to the left.

From the meter stick read the positions of each line on both the right and left sides of the discharge tube. Even a slight misalignment of the grating can shift the spectrum to the left or right on the meter stick. To correct for this you must average the distance s of a line in the left spectrum from the center of the meter stick with the corresponding distance in the right spectrum. The easiest way to do this is to find the distance between the two lines and divide by two. This gives you s (in cm). Record your values for s in the first table.

Line Color	Left Position	Right Position	(Left - Right) / 2 (+ cm)
Red	________	________	________
Blue-Green	________	________	________
Violet	________	________	________

Note that the distance between lines on the diffraction grating can be found on the grating itself. It will give you a certain number of lines per inch. Do a little algebra to convert the number of lines per cm and record it here:

Given the distance from the center to each spectral line, s, the distance from the diffraction grating to the meter stick, d, and the number of grooves per centimeter, g, we may calculate the wavelength for each line (in cm). It can be calculated from the following relation:

$$\lambda = \frac{s}{g\sqrt{x^2 + s^2}}. \tag{1}$$

Please see me if you would like to see how this relation was derived. Calculate the wavelength of each line in centimeters and record it in the following table. Convert this wavelength to angstroms.

The visible red, blue-green, and violet emission lines are created from electron jumps between r_n and r_2 as follows:

blue: $r_3 \Rightarrow r_2$
blue-green: $r_4 \Rightarrow r_2$
violet: $r_5 \Rightarrow r_2$

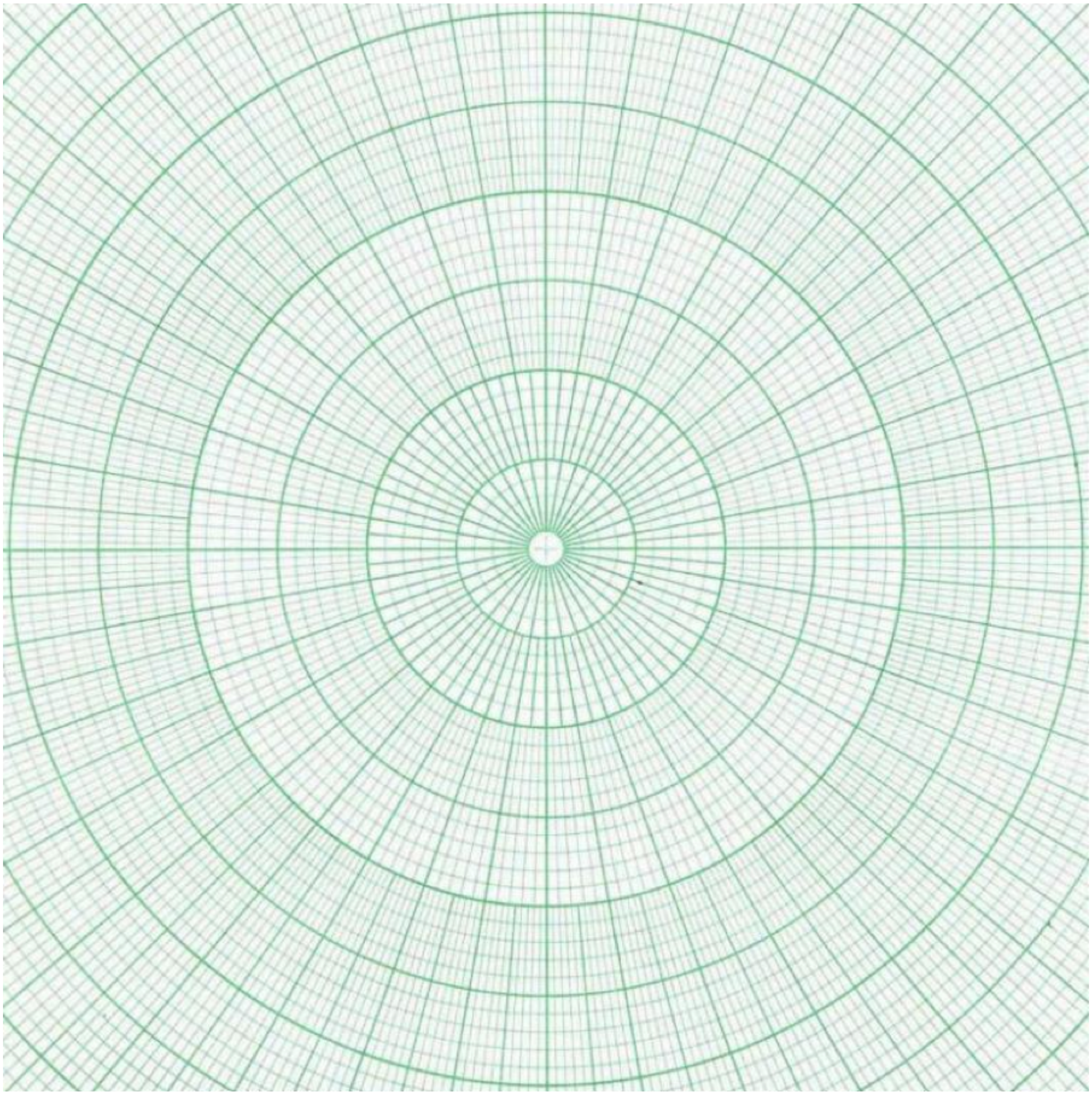
These transitions produce photons with wavelengths in the visible part of the spectrum. This series of lines is called the Balmer series. The other series produce infrared and ultraviolet emission lines. We may also calculate the radius of the nth orbit, r_n using:

$$r_n = \frac{\lambda}{0.473\lambda - 1630}. \tag{2}$$

Now you have the tools necessary to fill out the following table.

n	λ_{cm}	λ_A	r_n
1	-	-	0.53
2	-	-	2.1
3	________	________	________
4	________	________	________
5	________	________	________

Now plot the hydrogen atom by plotting each radius.



Part III: Blackbody Continuous Spectrum and Planck Curves

Use the incandescent light bulb attached to the dimming control at the back of the room. The light bulb represents a blackbody continuous spectrum. The goal for this section is to observe the continuous spectrum of this blackbody at "high temperatures"/bright and at "low temperatures"/dim light. Draw the continuous spectrum with the light very dim and then with the light very bright as seen through your spectroscope.

Continuous Spectrum with DIM light:

Continuous Spectrum with BRIGHT light:

What colors were apparent when the light was bright? Which colors were missing in the dim light? Explain why certain colors were "missing" in the dim light, using your knowledge of the Blackbody Planck curves, temperatures, wavelengths of light and their corresponding colors: