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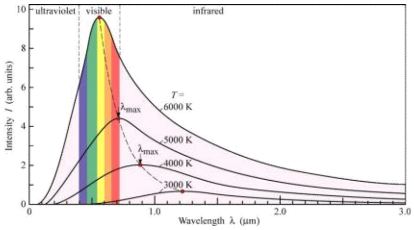


Spectroscopy Part I

Purpose

- Investigate Kirchhoff's Laws for continuous, emission and absorption spectra
- Analyze the solar spectrum and identify "unknown" lines

Equipment

- Colour print out of the solar spectrum
- Emission tubes
- Variac – variable power supply
- Colour filters
- Diffraction grating film
- 150-300W incandescent light bulb

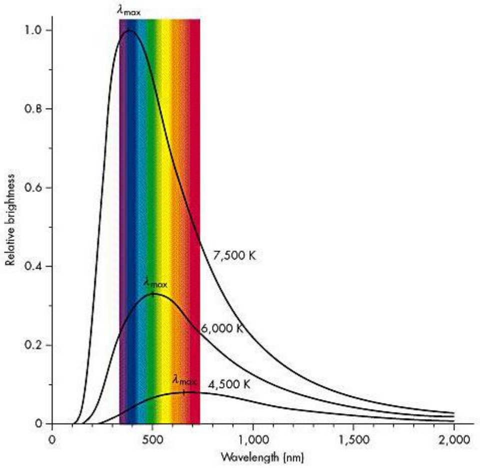
Introduction and Theory: In this lab, we will first look at different sources of light and study their individual spectra. Questions 1, 2 and 3 can be done in any order. Instead of a prism, you can use a diffraction grating: it also splits up light into individual wavelengths so you can see its spectrum.

Spectroscopy: The photosphere of the Sun is the layer where all the photons we see originate. The transparent region above the photosphere is called the atmosphere of the Sun. By collecting photons that travelled through the atmosphere of the Sun, astronomers can gain information about the **temperature**, **density**, and **chemical composition** of the Sun. This is done by studying the Sun's spectrum, i.e. the number of photons received at each wavelength (colour).

Blackbody radiation: All objects at a temperature above absolute zero (-273°C) emit radiation. For example,

- Objects at around room temperature emit mainly infrared radiation, which is invisible.
- The sun emits most of its radiation at visible wavelengths (the colours of a rainbow), particularly green (500 nm).

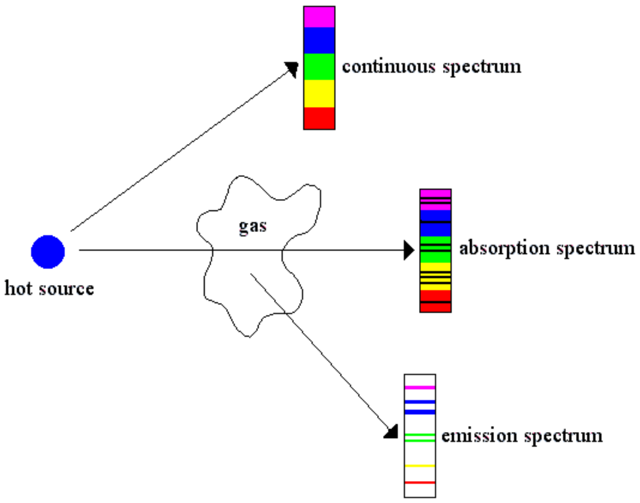
A simple example of a black body is a furnace with a small hole in the door to look at the colour of the burning material. The furnace first glows dark red, but as it gets hotter, the radiation shift toward bluer colours (orange, then yellow, then white, then light blue). As the furnace becomes hotter, the intensity of the radiation increases and looks brighter.



At a particular temperature, a blackbody would emit the maximum amount of energy possible for that temperature. It would emit at every wavelength of light (colour) with a maximum emission at a given wavelength. Standard black body radiation curves can be drawn for each temperature, showing the energy radiated at each wavelength. The larger the temperature of the body, the more the peak wavelength shifts toward bluer wavelengths.

Stars are approximate black bodies. The black body radiation curve shows that the black body emits at a peak wavelength, at which most of the radiant energy is emitted. At 5800K (i.e. the Sun) the peak wavelength is about 500 nm, which is in the yellow section. Hotter stars are bluer.

Kirchhoff's Laws: If you analyze the light coming from a star with a prism, you obtain the spectrum of the star. For example, a rainbow is a spectrum of the light coming from the Sun.



I. A hot, dense plasma or solid (e.g. a light bulb filament) will emit a continuous spectrum (continuous rainbow), with the brightness and typical colour described by the blackbody model.

II. A low-density gas along the line of sight to a hotter continuous radiation source will absorb photons of specific energies, leaving an absorption spectrum, i.e. a rainbow with dark lines for missing colours.

III. A low-density gas viewed alone or in front of a cool background will produce an emission spectrum, i.e. a few bright lines against a dark background.

Question 1: Continuous spectrum (light bulb).

a) What kind of light-source are you looking at: thin gas, opaque gas, solid or liquid?

b) According to Kirchhoff's laws, what type of spectrum should this produce?

c) Observe the first order spectrum (first set of ROYGBIV) with the diffraction grating. What kind of spectrum is it: continuous, line emission or absorption? Why did you identify it as this type of spectrum?

d) How many higher order spectra can you see?

By changing the voltage going to the light bulb, you can change the temperature of the filament. Watch the spectrum as you turn up the voltage, especially the relative strengths of the colours. The brightest colour is the peak colour and is generally the colour of the filament. However, our eyes and brains adjust quickly to the light, dimming the brightest colours and reacting poorly if the light is bright (so the filament will never look blue-green). Because of this, you must take your first impression from the spectrum. The best thing to get the peak colour is to close your eyes for a few seconds then take your first impression from the spectrum.

Change the voltage a couple times and observe the light spectra, then answer the questions below.

e) Was the bulb hotter at a low voltage or a high voltage?

f) At what voltage was the bulb brightest: high or low?

g) List the colours you could see at high voltage? Low voltage?

h) Which colour appeared to be the brightest at high and at low voltage?

i) As you increase the voltage, how do the colours change (overall and the peak colour)?

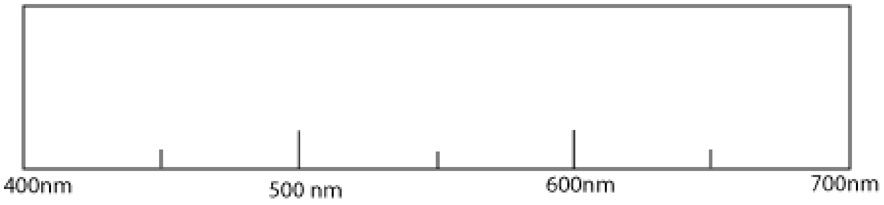
Question 2: Emission Spectrum (discharge tubes). These tubes are each filled with a low-density gas made of a single kind of atom. The process is similar to the process that occurs in the low-density, incredibly hot outer-most regions of stars called the corona and in low-density, gas clouds in space called emission nebulae.

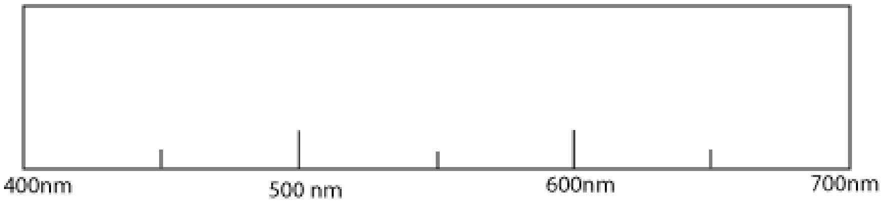
a) What kind of light-source are you looking at: thin gas, opaque gas, solid, or liquid?

b) According to Kirchhoff's laws, what type of spectrum should this produce?

c) What kind of spectrum is it: continuous, line emission or absorption? Explain why you identified it as this type of spectrum.

d) Sketch the spectra seen in 3 different tubes and label each spectrum with the element name. Place lines at the correct wavelengths. (Use pencil crayons to show the colours.)





Question 3: Absorption spectrum (filters). It is difficult to replicate a cold thin gas with sufficient density for visible absorption lines in the lab. 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 Kirchhoff's law.

There are several filters for you to use. 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 and then place the filter between the grating and your eye.

a) What kind of material is the light source: transparent gas, opaque gas, solid or liquid?

b) What kind of spectrum will it produce?

c) Look at the light source through one of the coloured filters. What kind of spectrum do you see? Explain why you decided it must be this type.

d) For each filter, give its colour and the colours it blocks. Write your answers in a table.

e) Observe the emission tubes from question 2 and then place the filter between you and the diffraction grating. Why would this filter be useful to astronomers? (Hint: where does the filter get its name?)

Question 4: Spectrum of the Sun. Joseph von Fraunhofer first measured and cataloged over 600 absorption lines of the Sun spectrum. These lines are now known collectively as the "Fraunhofer lines." He did not know that these lines were chemical in origin. Thus, the letters he used to identify the lines have no relation to chemical symbols.

Now we know that each element has a distinct pattern of absorption lines. In this section, we will work with the solar spectrum between approximately 390 and 660 nm (3900 - 6600 Angstroms) and identify some of the strongest Fraunhofer lines. The designations in the table below correspond to the labeling on your solar spectrum.

“Known" Lines		
Designation	**Wavelength (nm)**	**Origin**
A	759.4	terrestrial oxygen
B	686.7	terrestrial oxygen
C	656.3	hydrogen (Hα)
D_1	589.6	neutral sodium (Na I)
D_2	589.0	neutral sodium (Na I)
E	527.0	neutral iron (Fe I)
F	486.1	hydrogen (Hβ)
H	396.8	ionized calcium (Ca II)
K	393.4	ionized calcium (Ca II)

a) On the solar spectrum, measure the distance between two widely spaced, "known" lines. Fill in the table below. Average the results of the four measurements to get the scaling factor. This scaling factor is like a scale on a map; it tells you what one cm on your spectrum card represents in actual wavelength (nm) spacing.

Lines	**Distance between lines (cm)**	**Distance between lines (nm) (use above table)**	**Scale Factor (nm/cm)**
K, F		**92.7**	
H, E			
F, C			
K, D_2			

Average: ________ nm/cm

b) With the information from part (a), you will now identify “unknown” lines in the solar spectrum. Pick the **K** line of **Ca II** at **393.4**nm to serve as your reference and use the following steps to complete the table below.

i. Measure the distance in cm from the reference **K** line to each of the unknown lines.
ii. Use the scaling factor and convert the distances from cm to nm.
iii. Add the distances in nm to the wavelength of your reference line to get the wavelength of the “unknown” lines.
iv. Compare these wavelengths to the list of lines in the table at the bottom of the page and identify the "unknown" lines. Your values may not exactly match those given.

Note: If you find that some of your calculated wavelengths do not seem to match any of those in the table, find the closest match and the corresponding element.

Line #	**Distance from ref. line in cm**	**Distance (nm)**	**Wavelength (nm)**	**Element Name**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Reference table:

A. Wavelength (nm)
B. Line Width (nm)
C. Element

A	B	C	A	B	C	A	B	C	A	B	C
393.3682	2.0253	Ca II	420.2040	0.0326	Fe I	440.4761	0.0898	Fe I	525.0216	0.0062	Fe I
394.4016	0.0488	Al I	422.6740	0.1476	Ca I	441.5135	0.0417	Fe I	526.9550	0.0478	Fe I
396.1535	0.0621	Al I	423.5949	0.0385	Fe I	452.8627	0.0275	Fe I	532.8051	0.0375	Fe I
396.8492	1.5467	Ca II	425.0130	0.0342	Fe I	455.4036	0.0159	Ba II	552.8418	0.0293	Mg I
404.5825	0.1174	Fe I	425.0797	0.0400	Fe I	470.3003	0.0326	Mg I	588.9973	0.0752	Na I (D_2)
406.3605	0.0787	Fe I	425.4346	0.0393	Cr I	486.1342	0.3680	**H**	589.5940	0.0564	Na I (D_1)
407.1749	0.0723	Fe I	426.0486	0.0595	Fe I	489.1502	0.0312	Fe I	610.2727	0.0135	Ca I
407.7724	0.0428	Sr II	427.1774	0.0756	Fe I	492.0514	0.0471	Fe I	612.2226	0.0222	Ca I
410.1748	0.3133	**H**	432.5775	0.0793	Fe I	495.7613	0.0696	Fe I	616.2180	0.0222	Ca O
413.2067	0.0404	Fe I	434.0475	0.2855	**H**	516.7327	0.0935	Mg I	630.2499	0.0083	Fe I
414.3878	0.0466	Fe I	438.3557	0.1008	Fe I	517.2698	0.1259	Mg I	656.2808	0.1020	**H**
416.7277	0.0200	Mg I				518.3619	0.1584	Mg I			

Question 5: Thought questions.

a) Stars are made up of approximately 90% Hydrogen, 9% Helium, and 1% heavier elements. Based on this, is the strength of the lines you've observed correspond to that distribution of elements?

b) Two of the known lines ('A' and 'B') are actually caused by terrestrial oxygen, from our own atmosphere on Earth. If you were in charge of the telescope during these observations, what simple extra observation could you make to verify this is true?

c) (ASTR3311) Did you have discrepancies between your calculated wavelengths and those given in the table of wavelengths? Describe and comment.

c) (ASTR1102) Estimate the uncertainty in your measurements and your calculated wavelength. If you do not know how to do this, ask your instructors. Do your calculated wavelengths agree with those given in the table of wavelengths?