

Experiment 9

Emission Spectra

9.1 Objectives

By the end of this experiment, you will be able to:

- measure the emission spectrum of a source of light using the digital spectrometer.
- find the wavelength of a peak of intensity and its uncertainty.
- compare and contrast the spectra of various light sources.
- understand that a single color can be made of many wavelengths.

9.2 Introduction

We see very differently than we hear. With sound, we are able to pick out many different frequencies, i.e. different pitches. For example, if we listen to music, we can pick out the drums and voice separately, even though they are happening at the same time. We don't have that capability with light. Instead, we end up seeing one individual color, which most likely is made up of many different wavelengths of light.

The electromagnetic spectrum, shown in Fig. 9.1, covers a huge range of wavelengths, from gamma rays at 10^{-14} m to AM radio waves at 10^4 m. In this lab we are going to be concerned with the narrow band of wavelengths, $\sim 400 - 750$ nm (a nm = 10^{-9} m), that make up visible light. In order to

9. EMISSION SPECTRA

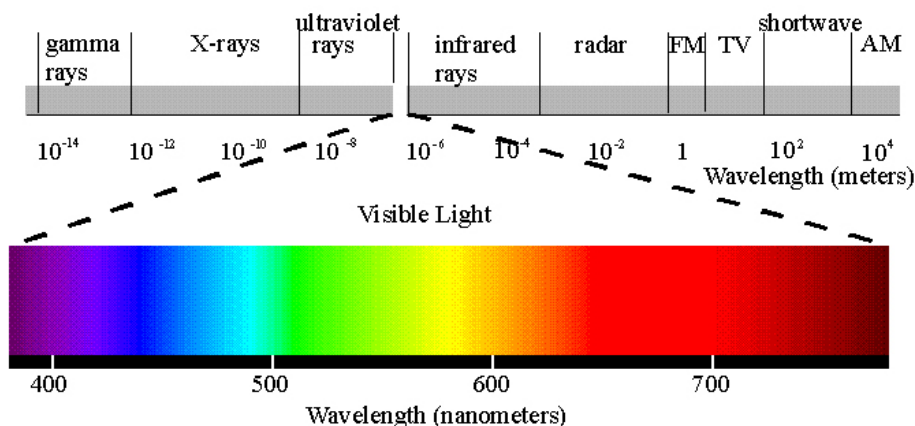


Figure 9.1: The electromagnetic spectrum with the visible light region blown up.

know very accurately what wavelengths are being emitted by a source of light, we will use a digital spectrometer.

9.3 Key Concepts

As always, you can find a summary online at Hyperphysics¹. Look for keywords: “emission, quantum”, electromagnetic spectrum, spectrometer.

9.4 Theory

In last week’s lab you saw evidence of light behaving as a wave. In this lab we will explore light acting as a particle, called a **photon**.

Sunlight and incandescent light (such as from a lightbulb) are sometimes called “white” light as they are made up of many wavelengths of light (all the colors mixed together make white). If you shine white light through a prism it spreads the light out into a rainbow because different wavelengths of light have slightly different indexes of refraction, called **dispersion**. If you heat up a gaseous element, such as hydrogen, until it glows and send that

¹<http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html>

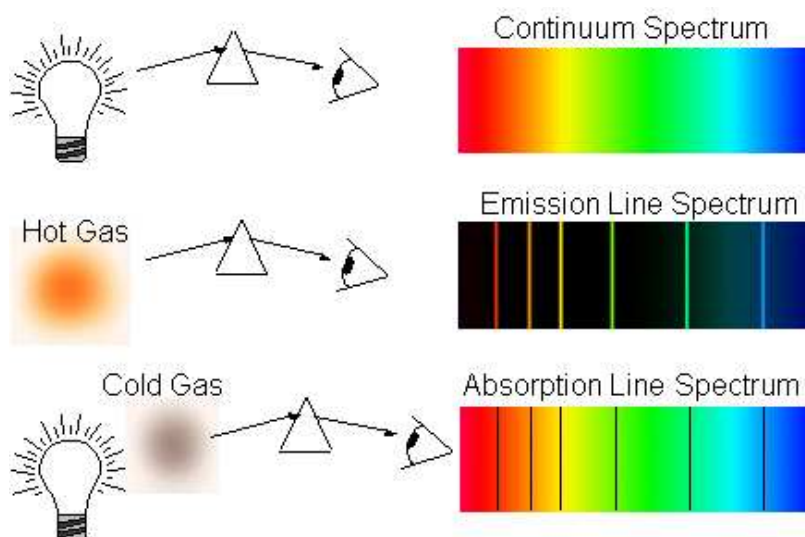


Figure 9.2: Examples of a continuous, an emission and an absorption spectrum with diagrams illustrating how the spectra were obtained.

light through a prism you see discrete lines at specific wavelengths. This is called an emission spectrum because the light is emitted from the element. Alternatively, if you shine white light through a gaseous element and then let the light pass through a prism you see dark lines in the continuous spectrum. This is called an absorption spectrum because the gas is absorbing light at specific wavelengths. Fig. 9.2 shows examples of a continuous, an emission and an absorption spectrum.

Emission Spectra

The discrete bright (dark) lines in the emission (absorption) spectrum can be explained by treating light as a photon that is emitted (absorbed) by an atom, as shown in Fig. 9.3. (For this lab we are going to concentrate on emission spectra.) In the quantum model of the atom, electrons exist only in specific energy states. The photon emitted from an atom when an electron “falls” from an excited energy state to a lower state is limited to the difference between those states, so only specific energies of light are emitted.

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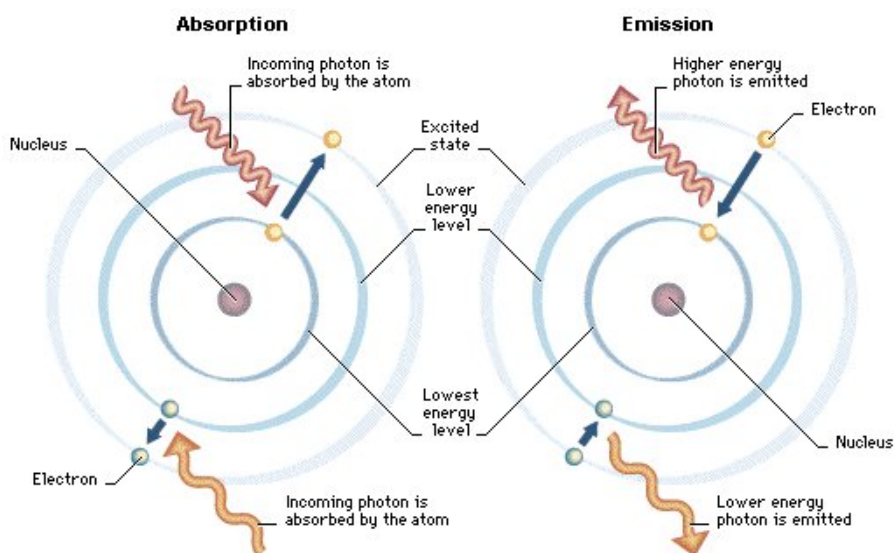


Figure 9.3: Model of an atom showing absorption and emission of photons.

The periodic table of the elements is also explained by the atomic model, where every element is uniquely identified by the number of protons in its nucleus. Quantum mechanics explains the energy states of the electrons in an atom. Every element in the periodic table has a distinct set of electron energy levels, so for a given element only photons of specific energies can be emitted. Therefore, when you are measuring the emission spectrum of an element, only certain wavelengths of light are allowed and the “pattern” that is produced is unique for that substance. Notice the differences in the emission spectra for hydrogen (H), helium (He) and mercury (Hg), that are shown in Fig. 9.4.

The energy of an emitted photon and its wavelength are related. For example, the color of a laser pointer (e.g. red or green) is determined by the energy of the emitted light. The energy of a photon is described by the equation:

$$E = \frac{hc}{\lambda} \quad (9.1)$$

where λ is the wavelength in meters, h is the Planck constant ($h \approx 6.63 \times 10^{-34}$ J s), and c is the speed of light ($c \approx 3.00 \times 10^8$ m/s). When dealing with visible light, wavelengths are usually given in nanometers (nm) so it

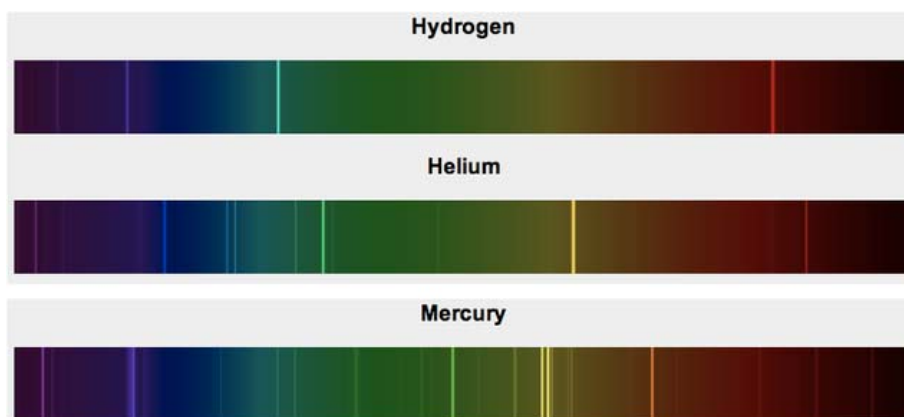


Figure 9.4: Emission spectra for hydrogen, helium and mercury.

is convenient to convert the quantity hc into units of electron volts (eV)² and nm. Equation 9.1 can now be written as:

$$E = \frac{hc}{\lambda} = \frac{1240 \text{ eV nm}}{\lambda} \quad (9.2)$$

where λ is the wavelength in nm and the energy of the photon is in eV.

9.5 In today's lab

Today we'll be investigating the spectrum of light that is emitted from various sources. In the past we used a setup similar to what is shown in Figure 9.5 where you viewed the spectral lines through a prism. Now digital spectrometers (as shown in Fig. 9.8) are readily available. You will use one to make precise measurements of the intensity of the different wavelengths of emitted light for a given source. In order for you to be able see with your eyes what the digital spectrometer “sees” you will first look at each source through a diffraction grating.

²An electron volt (eV) is the amount of energy it takes to move an electron through one volt of potential so $1 \text{ eV} = U = qV = (1.6 \times 10^{-19} \text{ C})(1 \text{ V}) = 1.6 \times 10^{-19} \text{ J}$.

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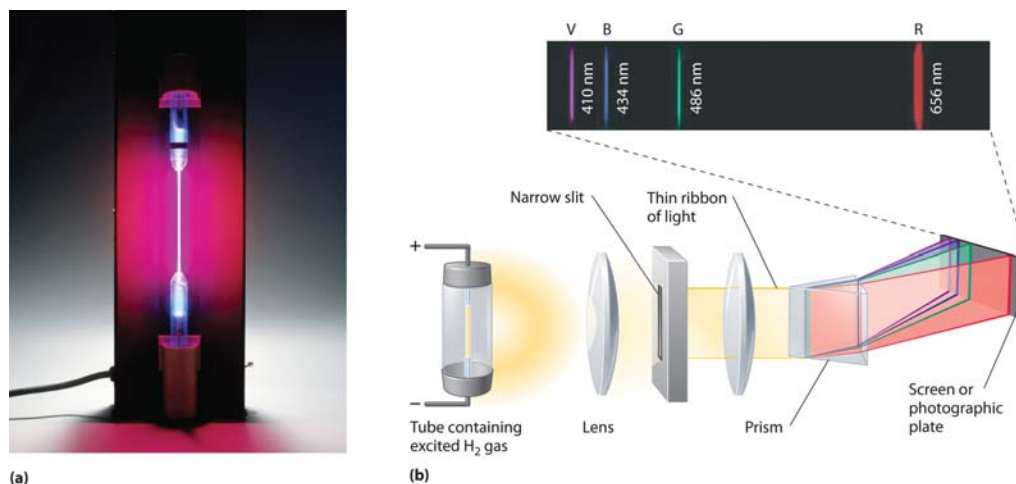


Figure 9.5: (a) A discharge tube containing hydrogen gas. (b) The experimental setup used to obtain an emission spectrum for hydrogen with the wavelengths of the 4 visible emission lines noted.

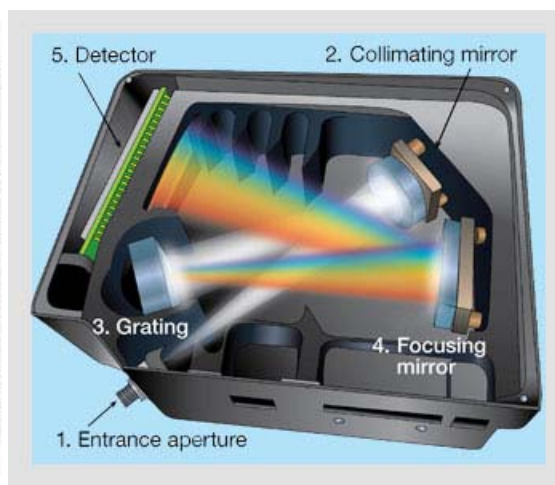
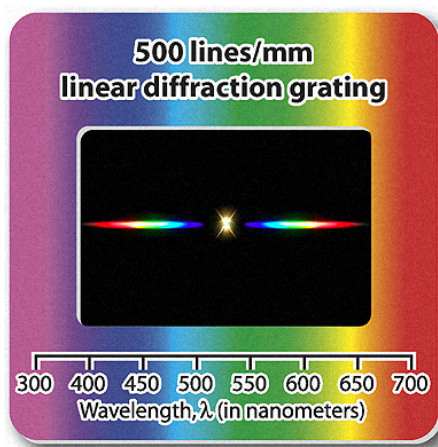


Figure 9.6: The diffraction grating. Figure 9.7: Schematic of how a digital spectrometer works.

Diffraction grating

Like a prism, a **diffraction grating**³ spreads out incoming light into a spectrum. Instead of using dispersion to spread out the light, a diffraction grating bends smaller wavelengths more than it bends larger wavelengths. A picture of the diffraction grating you will be using is shown in Fig. 9.6. The digital spectrometer you will be using also uses a diffraction grating, instead of a prism, to spread out the light. A schematic of how a digital spectrometer works is shown in Fig. 9.7.

9.6 Equipment

- Diffraction grating (see Fig. 9.6)
- Digital spectrometer with optical fiber (Ocean Optics USB650 Red Tide) (see Fig. 9.8)
- Logger Pro software
- Diode laser (see Fig. 9.9)
- Gas discharge tubes (see Fig. 9.5a)

Safety Tips

- Gas discharge tubes get **very hot**. Be very careful to let them cool down before touching them.
- The laser is a device that can produce an intense, narrow beam of light at one wavelength. **NEVER** look directly into the laser beam or its reflection from a mirror, glass, watch surface, jewelry, etc.

³Remember the previous lab on diffraction and interference of light, well a diffraction grating is like a double-slit but with thousands of slits.



Figure 9.8: The digital spectrometer with a white USB cable and blue optical fiber plugged in.

9.7 Procedure

Setup

1. Connect the SpectroVis Plus spectrometer to the USB port of a computer. The white cable in Fig. 9.8 is the USB cable. Start the Logger Pro data collection program, and then choose **New** from the **File** menu.
2. Connect a SpectroVis Optical Fiber (the blue cable being held in Fig. 9.8) to the cuvette holder of the spectrometer (which is located on its bottom).
3. To prepare the spectrometer for measuring light emissions do the following in Logger Pro: Open the **Experiment** menu and select **Change Units** ► **Spectrometer:1** ► **Intensity**.
4. To set an appropriate sampling time for collecting your emission data, in Logger Pro: open the **Experiment** menu and choose **SetUp Sensors** ► **Spectrometer:1**. In the small dialog box that appears, change the **Sample Time** to 60 ms, change the **Wavelength Smoothing** to 0, and change the **Samples to Average** to 1.



(a) Front.

(b) Back.

Figure 9.9: Laser mounted on optical bench.

Observing light sources

You will investigate 5 different light sources: a laser, a helium (He) gas discharge tube, a mercury (Hg) gas discharge tube, the overhead lighting, and an object that is not emitting its own light (just reflecting it).

Notes on specific sources

- **Laser** — The laser light is too intense to measure directly with the spectrometer (i.e. do not point the optical fiber directly at the laser). Instead, point the laser at a sheet of paper and aim the tip of the fiber optic cable at the laser spot on the white paper (see Fig. 9.9).
- **Gas discharge tube** — Your TA will show you how to safely insert tubes into the discharge box. The gas may take some time to heat up and emit its complete spectrum; so after turning it on, wait about 3 minutes before making your observations.
- **Reflected light** — Examples of objects that can be used are: your shirt, the table, a plant, etc., but make sure to pick an object that is not the same color as the overhead lighting.

Data Collection and Analysis

Do the following steps for each light source (5 in total) after you've set it up:

1. **Observe the light source through the diffraction grating.** You may need to hold the grating at an angle to observe the interference pattern. This is the same method that the digital spectrometer uses to separate out the different wavelengths. (For the laser: **Do not look directly into the laser.** Instead, shine the laser on a piece of white paper and observe the spot on the paper.)
2. **Record your observations** in the data table at the beginning of the Questions. Mention how many spectral lines and of what color you can see. Indicate which lines are the brightest and any unique features of the spectrum, especially noting what makes each source's spectrum different from the others.
3. **Start data collection** on the Logger Pro software. An emission spectrum will be graphed.
4. **When you achieve a satisfactory graph, stop data collection.** An example of an emission graph for helium is shown in Fig. 9.10. If the highest peak in the emission spectrum is > 1 , then the sensor is saturated and needs to receive less light. Try moving the optical fiber away from or towards the light source, or point it slightly off-center, until the highest peak is ≤ 1 . If this doesn't help, stop data collection and increase or decrease the **Sample Time** as described in Step 4 of the **Setup** section.
5. **Write down your observations** of the emission spectrum in the data table at the beginning of the Questions. Specifically, identify the 3 tallest peaks (except for the laser where there will only be 1 peak) including their wavelengths (no uncertainty needed here) and describe the range over which the peaks happen. Be sure to emphasize the features of each spectrum that distinguishes it from the other light sources that you tested.
6. **Print out a copy of the graph.** For the laser, zoom in on the peak so the x-axis only covers a range of 40-50 nm centered on the peak

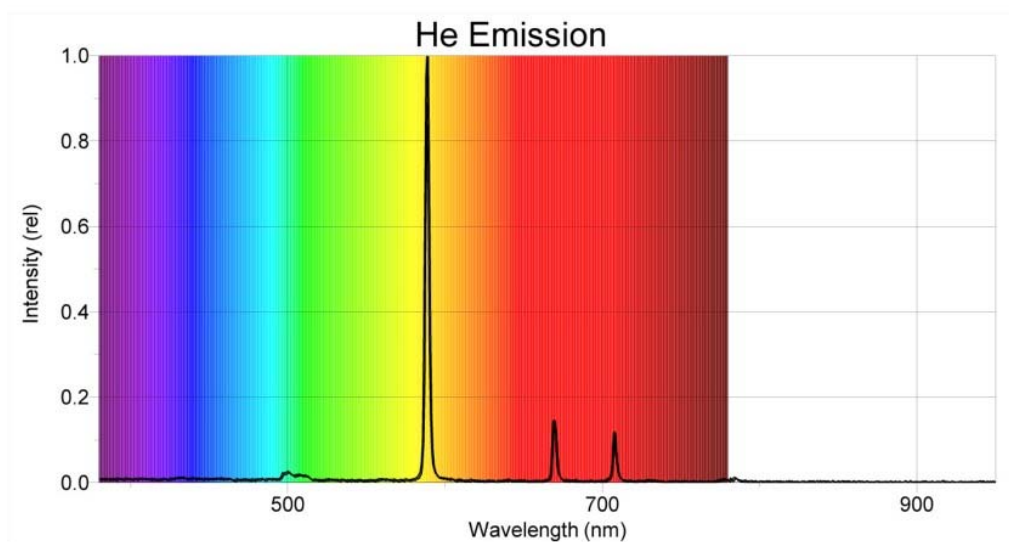


Figure 9.10: An example of an Helium emission spectrum, similar to what you will see on the computer screen.

(see Fig. 9.11). For the other sources, show the full visible spectrum (350–800 nm).

7. **Find the wavelength and intensity of the highest peak for the laser and the 2 gas discharge tubes (helium and mercury).** The highest peak corresponds to the most intense light. Label your graph (by hand) with the peak's wavelength and relative intensity as shown in Fig. 9.11. You can find these values by placing the cursor on the peak and the coordinates will be shown just below the lower left corner of the plotting area or you can use the **Examine** button in the Logger Pro menu.
8. **To find the uncertainty in the wavelength, you will use the “half width at half maximum” (HWHM) of the peak.** To find HWHM, do the following:
 - a) Find the two points on either side of the peak where the intensity is half of the peak intensity and label them with their wavelengths λ and relative intensities, Int (rel), as shown in Fig. 9.11.

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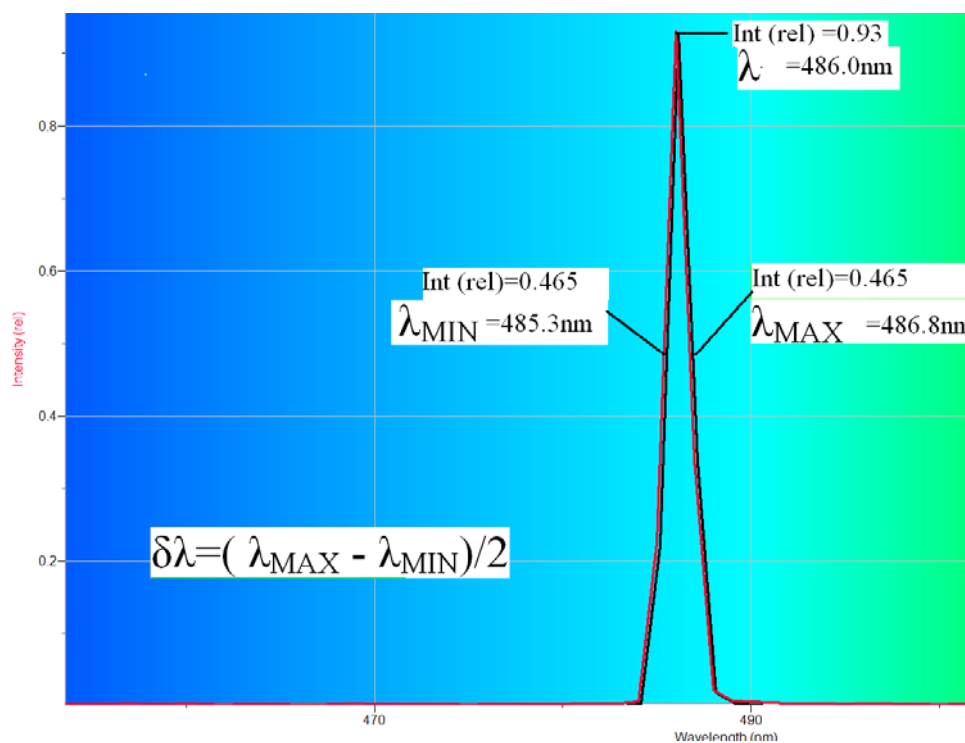


Figure 9.11: Example of how to label the graphs of emission spectra to find the HWHM. This graph shows the zoomed in x-axis used for the laser but your other sources should show the entire visible wavelength range.

For example, in Fig. 9.11 the peak intensity is 0.93 so you want to find the minimum and maximum wavelengths, λ_{\min} and λ_{\max} , that have an intensity of $0.93/2 = 0.465$.

- b) Your uncertainty, the HWHM, on the peak wavelength is found by:

$$\delta\lambda = \frac{\lambda_{\max} - \lambda_{\min}}{2} \quad (9.3)$$

- c) **Record all of this (can be handwritten) on each light source's printed graph. Include a sample calculation of HWHM for just the laser light.**

9.8 Questions

Light Source	Describe peaks or unique features of the spectrum
laser	grating:
	spectrometer:
helium gas	grating:
	spectrometer:
mercury gas	grating:
	spectrometer:
overhead light	grating:
	spectrometer:
reflected light	grating:
	spectrometer:

