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# Practical Laboratory #2: Emission Spectra

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## 2.1 Objectives

- measure the emission spectrum of a heated gas using the digital spectrometer.
- record a number of the bright lines in the spectrum.
- compare the measured spectrum with the known spectra for specific gases
- identify the unknown gas.

## 2.2 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. 2.1, 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

## 2. EMISSION SPECTRA

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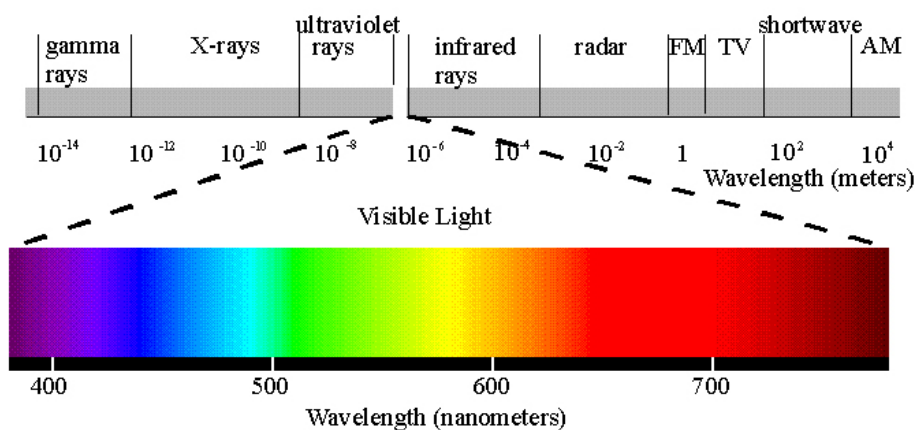


Figure 2.1: The electromagnetic spectrum with the visible light region blown up.

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

### 2.3 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

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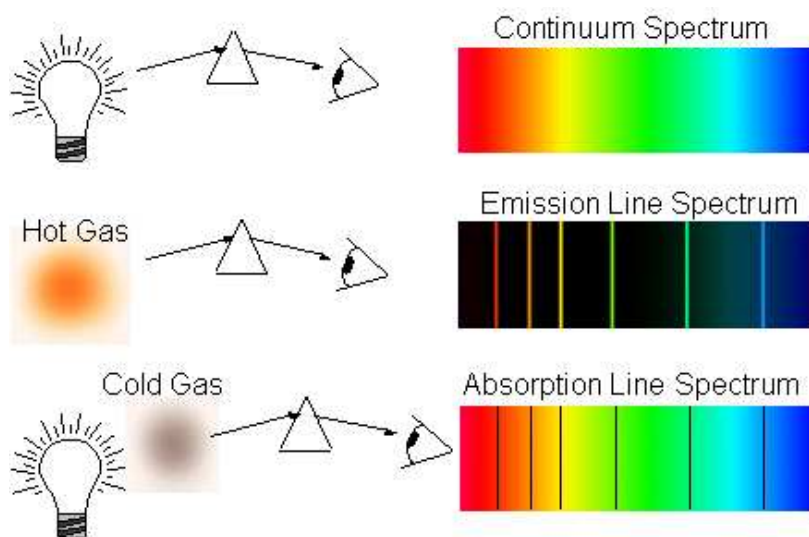


Figure 2.2: Examples of a continuous, an emission and an absorption spectrum with diagrams illustrating how the spectra were obtained.

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. 2.2 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. 2.3. (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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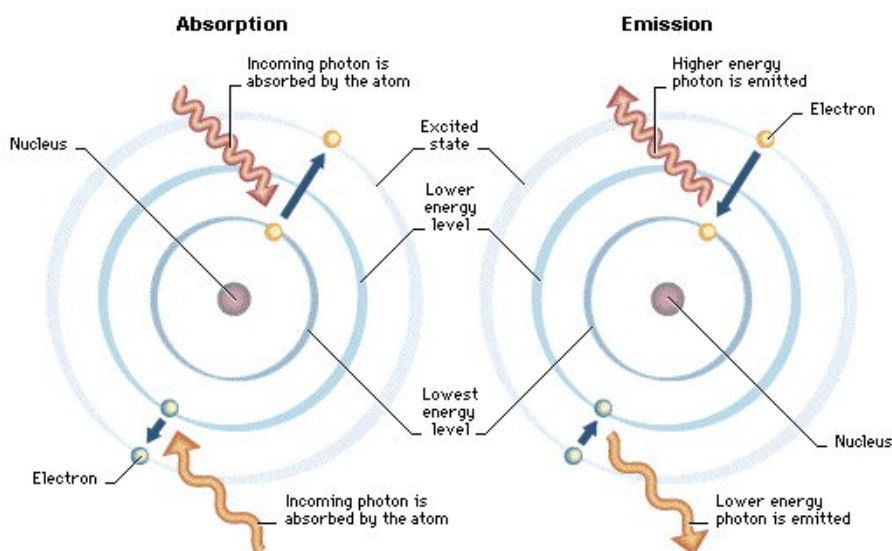


Figure 2.3: Model of an atom showing absorption and emission of photons.

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. The spectrum of various gases and phosphors are shown in Fig. 2.4.

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:

$$E = \frac{hc}{\lambda} \quad (2.1)$$

where  $\lambda$  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

## 2.4. Equipment

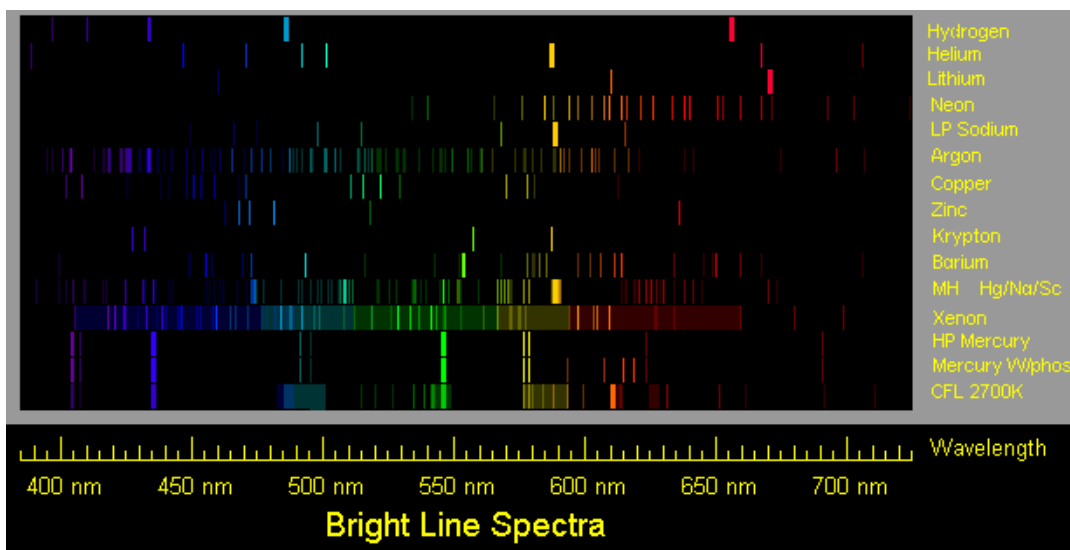


Figure 9.4: Emission spectra for various elements and phosphors

is convenient to convert the quantity  $hc$  into units of electron volts (eV)<sup>2</sup> and nm. Equation 2.1 can now be written as:

$$E = \frac{hc}{\lambda} = \frac{1240 \text{ eV nm}}{\lambda} \quad (2.2)$$

where  $\lambda$  is the wavelength in nm and the energy of the photon is in eV.

## 2.4 Equipment

- Digital spectrometer with optical fiber (Ocean Optics USB650 Red Tide) (see Fig. 2.8)
- Logger Pro software
- Gas discharge tube (see Fig. 2.5a) in a box labeled with a letter from A to E.

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<sup>2</sup>An 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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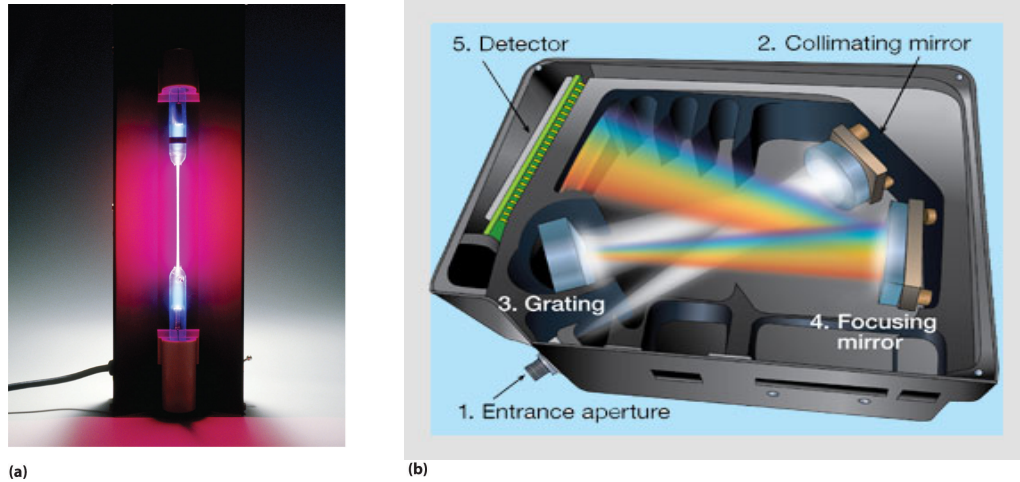


Figure 9.5: (a) A discharge tube containing hydrogen gas. (b) Schematic showing the components of a digital spectrometer, with a diffraction grating.<sup>3</sup>

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<sup>3</sup>Remember the discussion in the lab on diffraction and interference of light, a diffraction grating is like a double-slit but with thousands of slits.

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Figure 2.8: The digital spectrometer with a white USB cable and blue optical fiber plugged in.

## 2.5 Procedure

### Setup

1. Connect the SpectroVis Plus spectrometer to the USB port of a computer. The white cable in Fig. 2.8 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. 2.8) 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.

### Observing the gas discharge tube light source

You will investigate the spectrum of ONE unknown light source, in the gas discharge tube box labeled with a letter from A to E.

**Gas discharge tube** — 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. **Do not leave the tube on after making your measurements.**

### Safety Tip

- Gas discharge tubes get **very hot**. Do not touch them unless cooled



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### Data Collection and Analysis

Do the following steps for the **unknown** light source after you've set it up:

1. **Start data collection** on the Logger Pro software. An emission spectrum will be graphed.
2. **When you achieve a satisfactory graph, stop data collection.** 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  $\leq 1$ . If this doesn't help, stop data collection and increase or decrease the **Sample Time** as described in Step 4 of the **Setup** section.
3. **Print out the graph** containing a full spectrum 350 - 800 nm
4. **Write down your observations** of the emission spectrum in the data table at the beginning of the Questions.

**Find the wavelength and intensity of at least the 4 highest peaks for your gas discharge tube.** The highest peak corresponds to the most intense light. Label your graph (by hand) with the peak's wavelength and relative intensity. 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.

5. Estimate **the uncertainty in the wavelength.** Use half the width of the peak,  $\frac{\lambda_{\max} - \lambda_{\min}}{2}$ , at half the maximum intensity.

$$\delta\lambda = \frac{\lambda_{\max} - \lambda_{\min}}{2} \quad (2.3)$$

