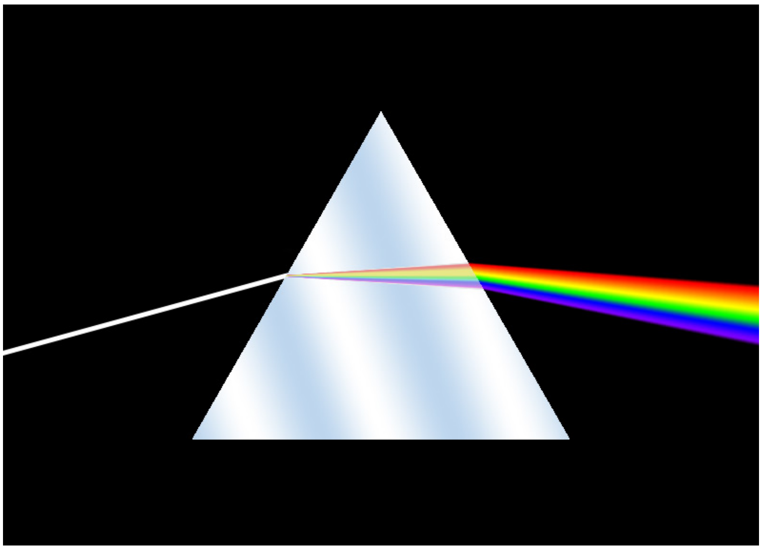
Experiment 2:

Gases and Metal Spectrometry



3rd Year of the Degree in Physics

Experimental Project

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1 Introduction

The main objective of this experiment is to identify unknown elements using the technique of prism spectroscopy. As we will explain in the theoretical section, the basis of this method is analyzing the light emitted by these elements in a plasma state; each one will have its own spectral lines.

In summary, the goals of the experiment are: adjusting the prism spectrometer, calibrating it using a Helium lamp, measuring the spectral lines of each unknown element, and finally identifying them.

The structure of this memory will be: first the explanation of the theoretical principles that rule the experiment. Then, we will describe the procedure of the experiment. Finally, we will analyze the collected data, draw its conclusions, and answer the questions assigned to this task.

2 Theoretical Fundaments

Emission spectrometry is based on the theory of atomic orbitals. This theory describes the atomic structure of electrons and how they behave. It is one of the principal results of Quantum Mechanics.

Atomic orbitals come from solving the Schrödinger equation for a Coulomb potential. This solution primarily describes the structure of the hydrogen atom, but through perturbation theory, it can be generalized for heavier atoms.

$$\left(-\frac{\hbar^2}{2m}\nabla^2 - \frac{ke^2}{r}\right)\psi(r,\theta,\phi) = E\psi(r,\theta,\phi)$$

By solving this equation, we get that atomic orbitals can be described with two types of wave functions, $R_{n,\ell}(r)$ for the radial part and $Y_{\ell,m}(\theta,\phi)$ describing the angular part.

$$R_{n,\ell}(r) = \sqrt{\left(\frac{2Z\alpha\mu c^2}{n\hbar c}\right)^3 \frac{(n-\ell-1)!}{2n(n+\ell)!}} e^{-Zr\alpha\mu c^2/n\hbar c} \left(\frac{2Zr\alpha\mu c^2}{n\hbar c}\right)^\ell L_{n-\ell-1}^{(2\ell+1)}\left(\frac{2Zr\alpha\mu c^2}{n\hbar c}\right)$$

$$Y_{\ell,m}(\theta,\phi) = e^{im\phi}(-1)^m\sqrt{\frac{2\ell+1}{4\pi}\frac{(\ell-m)!}{(\ell+m)!}}P_{\ell,m}(\cos\theta)$$

Where n, m and ℓ are the quantum numbers that determine the geometry of the orbital. Being $P_{\ell,m}$ the Legendre polynomial and $L_{n-\ell-1}^{(2\ell+1)}$ the Laguerre polynomial. This concludes that the orbitals are quantized because they depend on integer numbers.

For each atom, we will find a set of orbitals, each one also has an associated discrete energy. The gap between them follows Planck's law, $E = h\nu$, which means that each electronic transition between orbitals corresponds to a characteristic frequency.

When an electron in a material is excited, such as in the plasma state of elements used in the lamps, it transitions from its ground-state orbital to one of higher energy level. However, since this excited state is unstable, the electron eventually returns to a lower energy level. The excess energy is released in the form of an electromagnetic wave: a photon.

If this phenomenon happens in a material with a large number of atoms, like a gas or a metal vapor, the emitted light is polychromatic. This emission can be analyzed using a spectrometer, which relies on light dispersion via a prism to separate the different wavelengths, allowing the identification of the emitting elements.

3 Experimental Procedure

The materials that make up this practice are a spectral lamp that is full of some element like helium or cadmium, a prism that will deviate the light from the source depending on its wavelenght and a telescope through which we will see the spectral lines. With the help of the experimental set we will also be able to modify the angle in which the light enters the prism.

This setting will allow us to see and measure the different properties of the spectral lines of different elements and how they change depending on the initial conditions of the light and the prism.

4 Experiment Data and Final Results

Now we will show the colors of the spectral lines along with the angles at which these lines are located and its level of uncertainty.

Mercurio (Hg)		
Color	Angulo (º)	Incertidumbre
Morado	7	0,17
Verde	9	0,17
Amarillo	9,66	0,17

Figure 1: Mercury emission lines

Sodio (Na)		
Color	Angulo	Incertidumbre
Naranja	9,66	0,17

Figure 2: Sodium emission lines

Helio (He)		
Color	Angulo (º)	Incertidumbre
Violeta	7	0,17
Verde	9	0,17
Amarillo	9,66	0,17

Figure 3: Helium emission lines

5 Discussion and Evaluation

How do the spectral lines of helium manifest in a spectrogram, and what are their distinctive characteristics?

The spectral lines of helium appear with the main colors of the rainbow: purple, blue, green, yellow, and red. However, unlike other elements, it's the only element with a single yellow line.

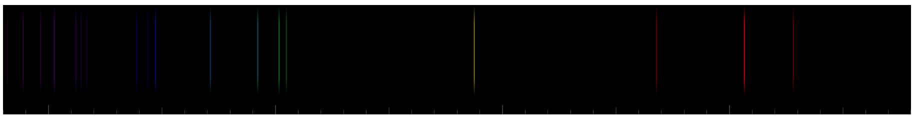

Figure 4: Helium emission spectrum

What is the significance of using cadmium as an element in spectroscopy, and how is it reflected in its spectral lines?

The significance of working with cadmium in spectroscopy is that its spectrum spans the entire visible range, and the positions of its lines are well known. This makes cadmium a useful reference element, acting as a label when studying unknown materials.

How does temperature impact the emission spectrum of helium compared to cadmium?

Since helium is a noble gas, this means that all its atomic orbitals are always fully occupied. As a result, when the temperature is increased, its spectrum will largely remain unchanged because electrons cannot easily access other energy states.

On the other hand, cadmium is a transition metal, so it has more available electronic states than helium. Electrons become excited and transition to higher energy levels; the emission spectrum will be filled with more lines, and also they may shift toward the violet or ultraviolet spectrum.

How can the spectral lines of helium and cadmium be distinguished in a combined spectrum, and what is their relevance in experiments involving gas mixtures?

In a combined spectrum, helium and cadmium lines can be distinguished using a spectrometer, as each element emits light at characteristic wavelengths due to its different atomic structure.

When we are dealing with a gas mixture, the importance relies on finding the concentrations of each component.

What are the common challenges when working with helium and cadmium spectroscopy, and how can they be addressed?

Common challenges include line overlap and weak emission intensity; helium lines may overlap with the ones of other gases, while cadmium can produce faint lines requiring sensitive detectors.

These issues can be addressed using high-resolution spectrometers, proper calibration, and controlling pressure and temperature. Spectral deconvolution can help as well, separating overlapping lines.

What information does the analysis of cadmium spectral lines provide about the composition and properties of the material under study?

Cadmium spectral line analysis reveals the presence and concentration of cadmium in a sample through the intensity and position of its lines. Shifts in the lines may indicate the presence of an electric field or variations in the temperature or pressure in the gas.

How does pressure influence the formation and visualization of helium and cadmium spectral lines in a spectrograph?

Pressure can make spectral lines broad, making them thicker, or shifting. This can cause lines to overlap or be less distinguishable. Standards of measurement usually recommend low pressures to achieve sharper and clearer lines.