Atomic Spectroscopy

Experiment objectives: identify the chemical composition of some mystery discharge lamps by analyzing their visible spectra.

History

The observation of discrete lines in the emission spectra of atomic gases played fundamental role in developing of the quantum mechanics and gave an important insight into the quantum nature of atoms. Only quantum mechanics was able to explain the existence of the discrete lines, whose energies (or wavelengths) are given by characteristic values for specific atoms. These emission lines are so fundamental that they are used to identify atomic elements in objects, such as in identifying the constituents of stars in our universe or the chemical decomposition of the car exhaust.

Available equipment

A discharge lamp has been a work horse of spectroscopy for many decades. Its operational principle is rather simple: they generate light by sending an electrical discharge through an ionized gas. Free electrons, accelerated by the electrical field in the tube, collide with gas atoms or molecules, and excite their internal electrons to the higher energy states. When the excited atom falls back to a lower energy state, it emits photons of characteristic energies. By analyzing the emitted light frequencies, it is possible to reconstruct the energy level structure of an atom or molecule.

To measure and characterize the emitted spectra of various gasses you will have available several spectrometers. The first one is the diffraction glasses, which are essentially just a pair of the diffraction gratings, that send light at somewhat different angles depending on its wavelength. The glasses is more for fun, but it also provides an easy way to visualize the spectral lines of various lamps. The optical spectrometer is based on the same principle - light travels through the diffraction grating, but this time it is calibrated, so one can read the actual wavelength of each spectral line. It also is equipped with a vertical collimator slit of variable width that can help control the width of the recorded lines (and thus the precision of the measurements) at the expense of the brightness. Finally, there is an automated spectrometer, in which human eyes are replaced with the calibrated camera, so the intensity as a function of wavelength can be recorded. This method is most modern (and the digital output spectra for all lamps are available for your analysis).

Goals of this project

In this project you will have to study visible spectra of several "mystery" discharge lamps and identify what gasses are in each of them. The lamps are numbered II to IX (lamp I has left us prematurely, unfortunately), please use these numbers to identify each lamp. You will work with NIST database of spectroscopic data https://physics.nist.gov/PhysRefData/Handbook/element_name.htm to obtain information about allowed transitions in various atoms.

Specifically, you will have to accomplish the following three goals:

- One of the mystery lamps is Hydrogen. Using its spectrum, measure the value of Rydberg constant. Make sure to evaluate the uncertainty and explain how you arrive to these values.

- One of the mystery lamps is Helium. Identify the electron energy levels involved in observed strong optical transition. The NIST Atomic Spectra Database Lines Form can be useful to visualize the transitions: https://physics.nist.gov/PhysRefData/ASD/lines_form.html . Choose "He I" (i.e. he atom with both electrons attached), and click "Grotrian Daigram" to see the energy level structure and possible transitions. Clicking on each line will give you details of this particular transition/level.

- Using characteristic strong lines, identify the remaining mystery elements. Below are some pointer to make your search a little less daunting:

  - Two of the lamps are krypton (Kr) and mercury (Hg).
  - Two of the lamps contain molecular gasses H_2O and CO_2. Think about energy levels of simple atoms and molecules - can you distinguish the molecular spectra just by looking on their general structure? There are no good references for wavelengths of the molecular lines - and yet you should be able to figure out which one is which.
  - Finally there are two truly "mystery" lamps. However, they are fairly common gasses used in the discharge lamps.

You have to design your own experimental procedure for measuring the spectral lines and matching them with the known transitions. There are several ways to approach it, so it is likely that different people can choose different paths, and this is perfectly normal. However, make sure you describe your procedure in details in your lab report (probably in more details than in previous labs). For each lamp you will have to present a clear justification of why you think it contains the particular gas. Discuss the experimental uncertainties and any problems or discrepancies you may have encountered.