Spectroscopy

In the Lab, and Out

SP3176

The Universe

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General cautions and safety

In this series of experiments, the phenomenon that is being investigated is electromagnetic and radiative in nature. Please take caution, especially when dealing with the sources. **In both experiments, the steps or procedures for the experiment will not be provided. Only details and procedures of select equipment will be given and it is up to your group to figure out what to do to achieve the objectives and provide the deliverables**. We provide a list of non-exhaustive precautions; please be sure to follow them when performing the experiments.

General precautions

- Do not look directly into the radiative sources for prolonged periods. Extended exposure to intense sources of light may cause long-term retina damage.

- The first experiment is to be carried out in the dark. Take regular breaks to prevent excessive strain on your eyes.

- In the second experiment, do **not** look into the Sun with the naked eye for **any** amount of time. The source is extremely bright and has an intense emission profile, especially in the infra-red region. If necessary, use protective eyewear. Minimize time looking through your instrument at the light source; use cameras or other optical sensors instead.

Equipment precautions

- The electrical terminals of the emission lamps are held at extremely high voltages; do not touch them.

- The discharge tubes of the emission lamps are extremely fragile and can easily break.

- The discharge tubes of the emission lamps can attain very high temperatures when in operation. Do not touch them.

- The spectrophotometer assembly contains optical components, do not scratch or touch the optics with your bare hands.

- Always start the experiment with the lowest gain setting on the light sensor and increase as needed. Oversaturation of signal via gain will damage both your experimental results and the sensor itself.

Experiment 1: Atomic Spectra

1. Tasks and Objectives

In this experiment, you will use a diffraction grating based spectrophotometer to measure the atomic emission spectra of two dilute elements in discharge tubes. The experiment is done in groups and will be conducted in a laboratory setting. **Prior to the experiment, a demonstration of the setup <u>must be conducted by a mentor or instructor</u>. Subsequent sessions do not require the supervision of a mentor.**

The primary objectives of the experiment are:

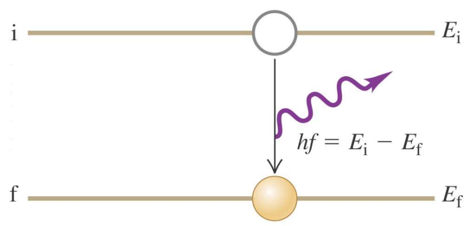
- ☐ Identify, understand and explain the roles of the components in the spectrophotometer
- ☐ Optimize and explain the choice of the best possible setup to observe light spectra
- ☐ Compare your results of the experiment for Hydrogen with literature
- ☐ Identify the unknown element, using the results from Hydrogen for calibration

The secondary objectives of the experiment are:

- ☐ Understanding and working with unfamiliar instruments
- ☐ Fault-finding and troubleshooting
- ☐ Communication and general group work etiquette

2. Theory

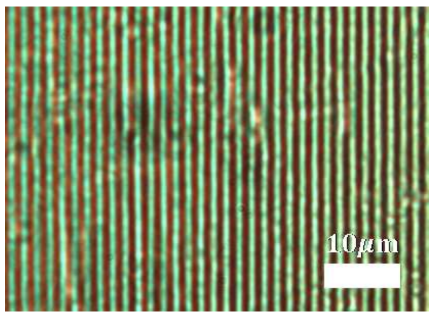
Remember from Chapter 3 that an excited electron in a higher energy orbital will release energy in the form of light when it eventually relaxes to a lower energy orbital. The wavelength of the light emitted is



$$\lambda = \frac{hc}{E_f - E_i}$$

The energy orbitals that are allowed in an atom are unique for each element. As such, the spectrum can serve as an *atomic fingerprint*. This experiment aims to demonstrate the use of this fingerprint to identify atoms.

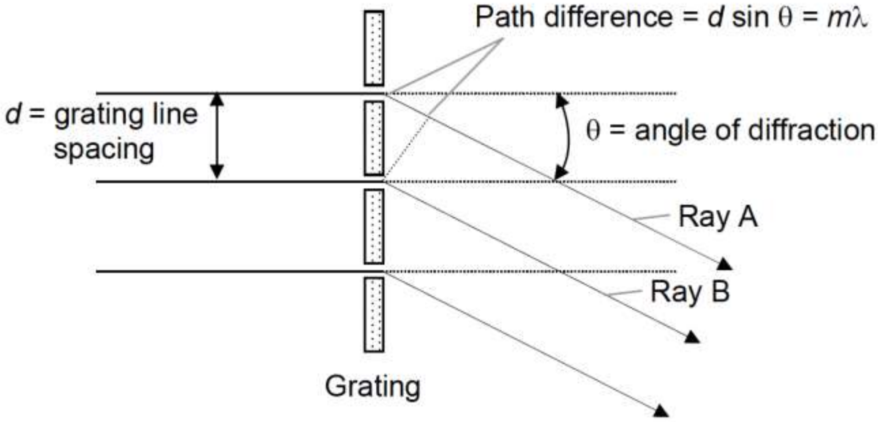
The diffraction grating that is used in this spectrophotometer is a transparent diffraction grating. When light from the discharge tube passes through the grating, it will split and deviate from the original light path. When the diffracted rays eventually coincide at a distance, they will <u>interfere with each other.</u> To be able to observe the bright lines, the rays must travel a path difference such that



Optical microscope image of the diffraction grating.

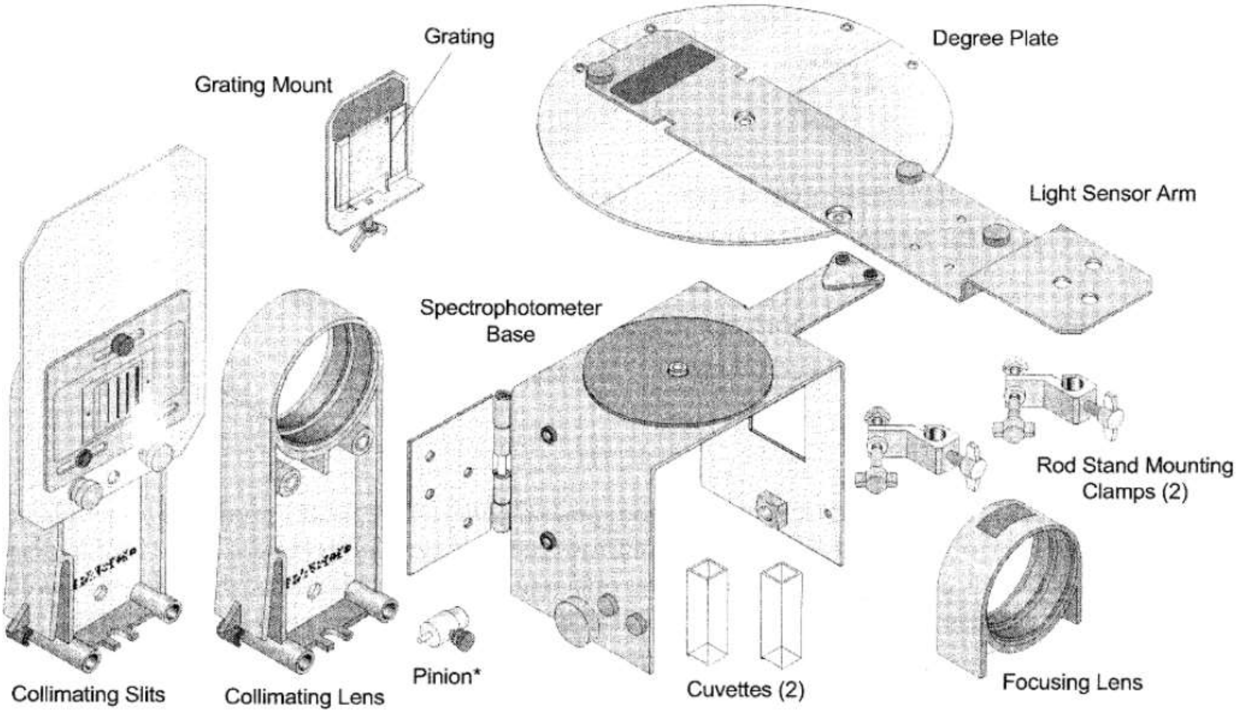
they will constructively interfere with each other. The condition for constructive interference is:

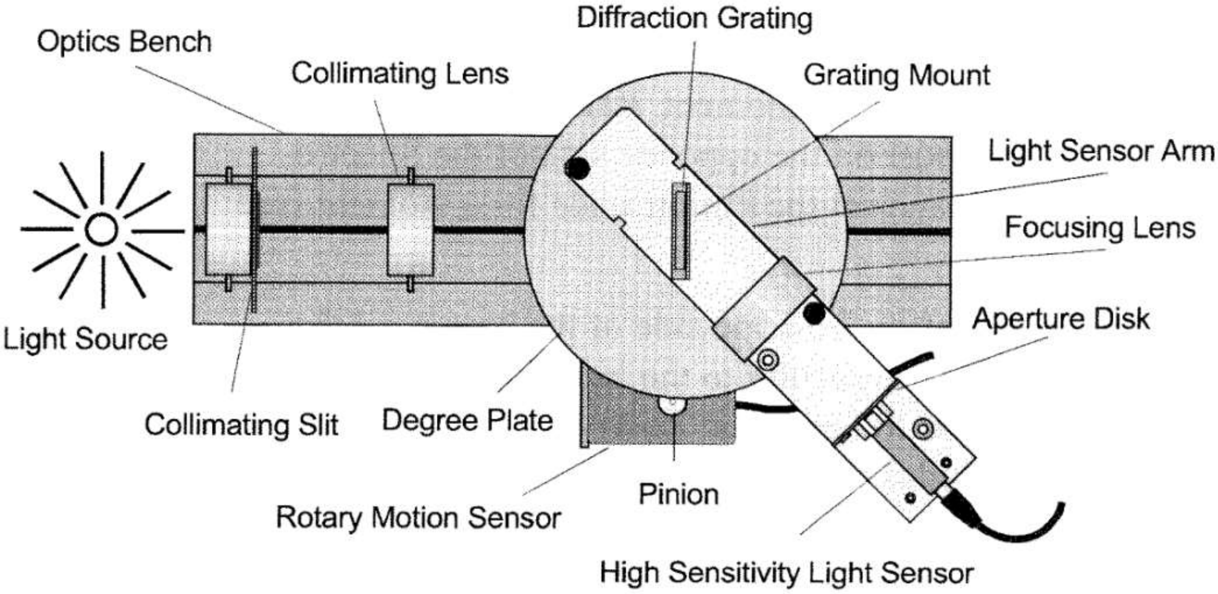
$$m\lambda = d \sin \theta$$



3. Equipment details

Spectrophotometer schematics





The spectrophotometer consists of a set of optics, a mechanical setup, sensors and a digital interface. It is also an optical aligning tool, keeping your equipment and setup in a perfectly straight line for optical purposes. Summarily, the system does the following:

1. Light is selected from the source and made parallel to the optical axis of the system
2. The light impinges the diffraction grating, diffracting the light in accordance with their wavelengths
3. The light sensor, mounted on the rotary base, measures the distribution of light intensity across various angles
4. The angle of the rotary base and the light sensor output are recorded on a computer

Rotary sensor

The rotary sensor is the sensor by which the system is able to read the current angle of your rotary base. Here are some details on the rotary sensor:

1. The sensor's resolution is 1440. That is to say, the sensor is accurate up to 1/1440 of a rotation of the pinion.
2. The rotary plate is geared to the pinion; when one rotates, so must the other. Its larger radius means that one rotation of the plate will result in multiple rotations of the pinion. The gearing ratio is 1:60, i.e. 1 rotation of the pinion is 1/60 rotation of the degree plate. Thus

$$1\ \mathrm{sensor\ division} = \frac{1}{1440}\frac{1}{60}360^{\circ} = \left(\frac{1}{240}\right)^{\circ} \text{ of the degree plate}$$

Digital Interface

To generate digital signals for the computer to interpret from mechanical actions, the experiment makes use of a digital interface. The Science Workshop 500 Interface is a device that takes in mechanical readings and converts them to an output signal suitable for computers. The rotary motion sensor connects to digital channels 1 and 2, while the Light sensor connects to the analog channel (Use channel A as it is preconfigured).

Software

On the computer, start *DataStudio*. Ensure that the signal interface is also connected to the computer.

1. Select 'Setup'
2. Select:
   - Light sensor to Analog Channel A by double-clicking on the icon.
   - Rotary sensor to Digital channels 1 and 2 by double-clicking on the icon.

3. Setup the sensors

   Angular sensor
   - Get the program to read the angular sensor at 20Hz (sample rate: 20 Hz)
   - Ensure that it measures angular positions on both channels ('Measurements tab')
   - Records at the appropriate maximum resolution ('Rotary motion sensors' tab)

   Light sensor
   - Measure the light intensity, Ch A (% max). Uncheck 'Voltage, Ch A, (V)'.

4. At this stage, the angular sensor measures the rotation of the pinion. To obtain the rotation of the plate, we need to use the gearing ratio. We can do this by telling the program's experiment calculator to recalculate the angular position of the plate.
   - Under definition, input 'Actual Angular position = *x*/60'
   - Under variables, define '*x* = Angular position, Ch 1 & 2(rad)' via 'Measurement data'

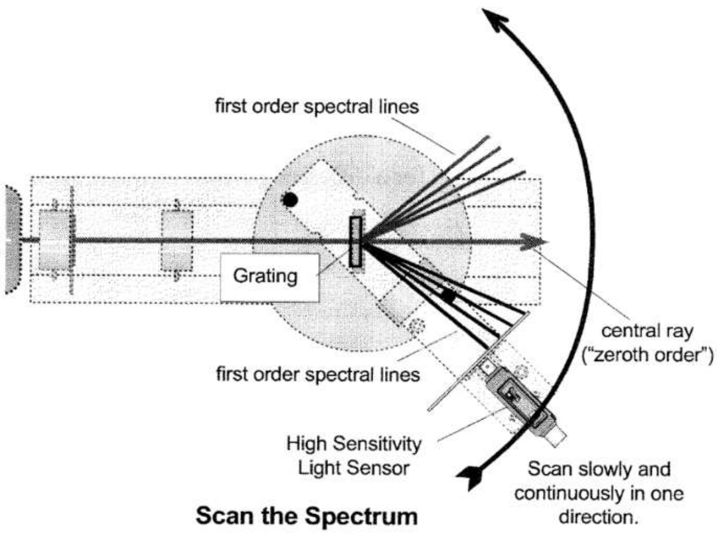
5. With the variables set up, we can now select a graph display that is set to plot light intensity against actual angular position.

General advice

1. When you are ready to collect data, proper techniques should be used to obtain the spectrum. From the discussion of diffraction, the spectrum pattern *will repeat past a certain angle*. The smallest range of angles at which a full spectrum is observed is known as the first order. The beam that passes directly through is known as the zeroth order. To scan the spectrum,

- Ensure that the lamp has been switched on for at least 5 minutes to reach equilibria.
- Move the light sensor arm using the post <u>such that it starts beyond the end of the first order, but before the start of the second order</u>.
- Adjust the gain on the light sensor as necessary.
- In the *DataStudio* program, click on the start icon to begin recording data.
- Scan the spectrum slowly but continuously by pushing the sensor arm along.
- Ensure that you measure past the zeroth order, to the other side of the starting position.

Click on the stop icon to end data recording.



Scan the Spectrum

2. The optical components of the system are to be adjusted to help you obtain the best spectrum. A quick way to check the quality of the spectrum is to place a sheet of paper behind the grating. Repeat and adjust the components as necessary. They are:

1. Light source
2. Collimating slits
3. Collimating lens, focal length approx. 10cm
4. Focusing lens
5. Diffraction grating, spacing $d = 1666nm$.

4. Deliverables

For this experiment, you will be assessed with an in-person oral viva in the laboratory. You will be asked warm-up and in-depth questions by the instructor and mentor(s) conducting the viva. You are expected to show the processed experimental results in the form of figures and tables. The oral viva is **15 min** and is scheduled for **Week 8**. This assessment task carries **15%** of the total assessment for The Universe.

Experiment 2: Spectroscopy-in-the-field

For experiment 2, there will be a **choice between 2 variants of the experiment**. Your group will decide to perform ***one*** of either experiments.

2A: Design and Build your own Solar Spectrometer

In this experiment, you will design and build your own spectrometer from the principles learnt from the previous experiment. The objective of the spectrometer is to be capable of measuring the spectrum of the Sun, following the footsteps of Fraunhofer in the 1800s.

Details

Design ideas and explanations can be found via your own research. Here are some links to start you off:

- CD spectrometer[1]
- Needle Spectrometer[2]
- CD spectrometer: Youtube[3]

Once you have designed and built a spectrometer, test it on known light sources, which may include LED lamps, lasers, incandescent light bulbs, or even the gas discharge tubes from experiment 1. Use a camera as the optical output to obtain your spectra for study.

Deliverables

Analyze the spectra obtained from your spectrometer. Use the spectrometer on the Sun, and analyze the spectrum, attempting to identify the Fraunhofer lines. You are to submit a working prototype of the spectrometer, an image of your best solar spectrum, and a graphical plot of the spectrum. It is advisable to annotate your figures and provide a short caption to tell your story through the figures.
They are **due on Saturday of Week 11** and comprise 10% of your grades.

[1] http://www.cs.cmu.edu/~zhuxj/astro/html/spectrometer.html
[2] http://www.stargazing.net/david/spectroscopy/SimpleNeedleSpectroscope.html
[3] https://www.youtube.com/watch?v=fl42pnUbCCA

2B: Stellar Spectroscopy

In this experiment, you will generate star spectra using a telescope (Celestron Nexstar 6SE) and a specialized diffraction grating as your optics. The objective of this experiment is to obtain and analyze star spectra with the aid of computational programs.

Details

First, visit this link[4] on real-time spectroscopy using telescope optics. Book a date to use and familiarize yourselves with the following equipment:

- Telescope
- Diffraction grating SA100
- ASI camera

Locate a prominent star. While taking photos and videos, fit the diffraction grating, refocus, and obtain a snapshot of a video of the star. In doing so, ensure that both zero order light and first order spectra can be observed, as they are needed for calibration. Proceed to locate at least 2 other prominent stars and repeat.

In the links above, look for tutorials on how to operate the RSpec software. When you are ready, download and install the software (it has a 30-day free trial period) and begin analysis on the stars.

Deliverables

Calibrate and identify the stars from the spectra, with any additional information where available. You are to submit at least two analyzed spectra (of different stars). It is advisable to annotate your figures and provide a short caption to tell your story through the figures.
They are **due on Saturday of Week 11** and comprise 10% of your grades.

[4] https://www.rspec-astro.com/

Additional materials (hyperlinks)

1. Atomic Spectra summary
2. Diffraction Gratings and spectrometry
3. Science Workshop 500 Interface manual
4. Light sensor manual
5. Celestron Nexstar 6SE Technicals
6. SA100 grating
7. RSPEC sample experiment