ATOMIC SPECTRA EXPERIMENT - KSCIASE

ATOMIC SPECTRA EXPERIMENT

1. Key Concepts

- Atomic structure
- Quantum nature of light
- Diffraction
- Spectrometer
- Emission spectra

2. Introduction

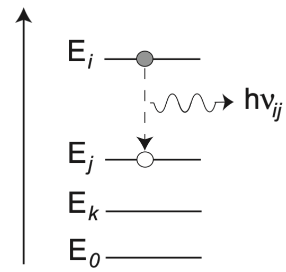
The source of Electromagnetic radiation is atoms. When the atoms of an element are in an excited state, they return to a lower energy state by emitting electromagnetic (EM) radiation. The transition of the electrons in the atom from higher energy level to a lower energy level is the reason for the emission of EM radiation. Atoms of different elements have unique energy levels for the occupation of electrons, due to this the EM spectrum emitted is a unique signature of an element or a substance. The study of the characteristics of EM radiation emitted by atoms is called atomic emission spectroscopy (AES). Owing to fact that the atoms belonging to elements have unique set off energy levels for the occupancy of electrons, the absorption of electromagnetic radiation by the electrons in an atom is also unique. The study of the characteristics of EM radiation absorbed by atoms is called atomic absorption spectroscopy (AAS). By studying the EM radiation in particular (light) emitted/absorbed by atoms, we can gain knowledge about the atomic structure of the atom. Spectroscopy has vast number of applications ranging from astrophysics to elemental analysis in chemistry. Spectroscopy is the field that deals with the study of interaction between EM radiation and matter.

3. Objective

- To observe atomic emission spectra of various elements.
- To examine the visible spectrum of hydrogen, helium and mercury.
- To measure and analyze the spectral lines emitted by various elements.

4. Theory

The simplest atom is the Hydrogen atom, as it contains one proton and one electron. Because of the quantization of the energy levels in the atom, the electrons can occupy only the energy levels provided by the quantization rule. Generally, the electrons in an atom are normally in the ground state (E_0: lowest possible energy state). If the atom is now imparted with energy in the form of light (other forms of energy like: collision by electron, electric field etc. can also be used), the absorption of a photon by the electron can cause the electron to make a transition to a higher energy level (say E_1). An electron



can only stay for a short duration of time (lifetime of the energy level) in the higher energy level. The excited electron then relaxes to the ground state in the process emitting a photon of energy that isthe difference between the ground state and the excited state,

$\Delta E = E_1 - E_0$. The wavelength of the emitted radiations can be obtained with the following equation:

$$\lambda = \frac{hc}{\Delta E} \quad \text{——————————————} \quad (1)$$

where is the wavelength of the emitted radiation, is the Plank's constant (= $6.62607004 \times 10^{-34}$ m^2 kg / s), is the velocity of EM in vacuum and E is the energy difference between the two transition levels.

In the current experiment, a high value of applied voltage creates free electrons and ionsin the gas to establish a current, the moving charged particles collide with the neutral atom's electrons and excite them to different energy levels. The light emitted from the excited atoms (when they transit to the ground state) can be separated into a spectrum ofits individual wavelengths with the help of diffraction grating. A diffracting grating is a flat glass piece on which there are parallel grooves etched regularly. Diffraction grating acts like an interference device having a large number of slits. A transmission diffraction grating is used in this case. Condition for constructive interference is as follows:

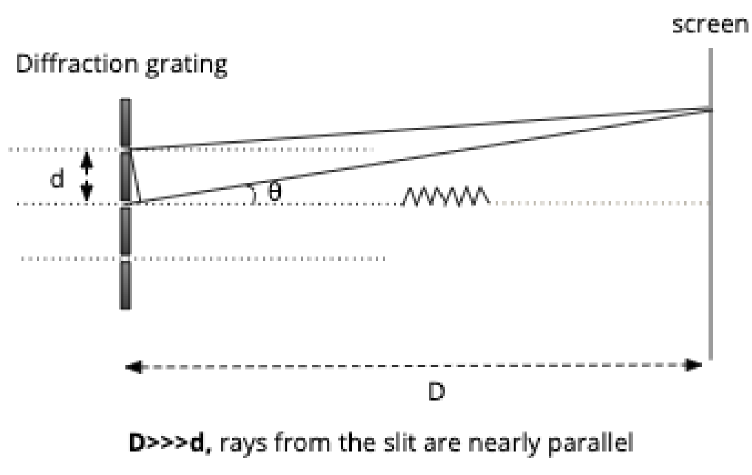
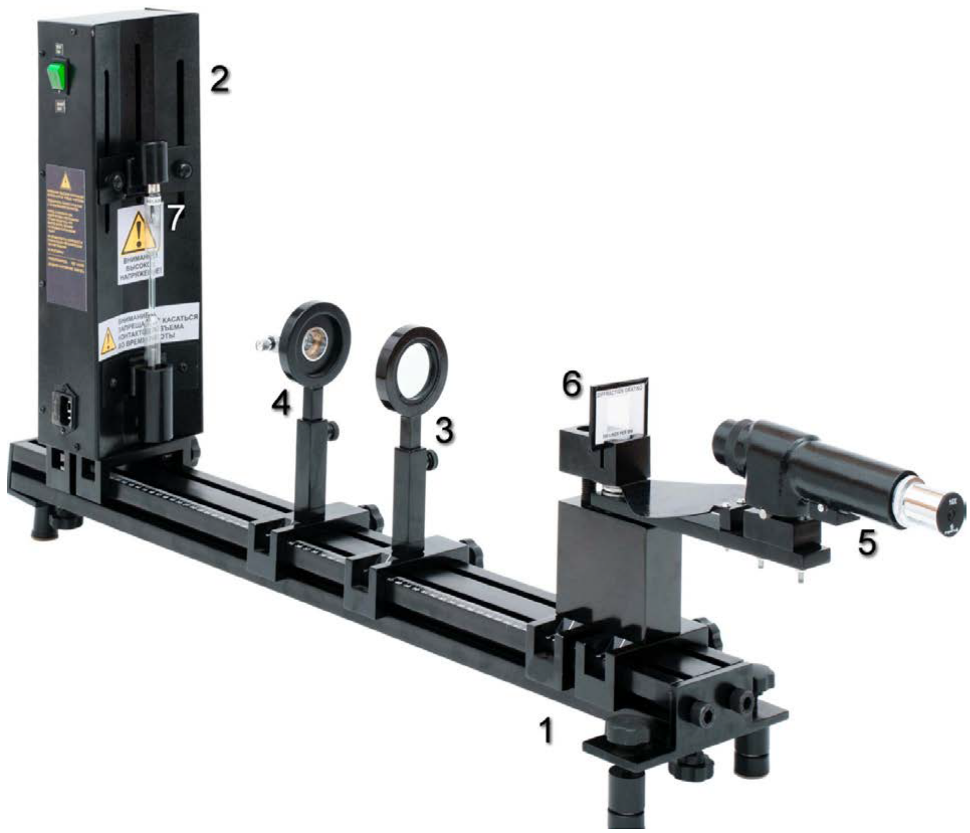


Fig 1: Light from diffraction grating forming constructive interference

$$m\lambda \quad d\sin\vartheta \quad \text{—————————————} \quad (2)$$

where m is the order of diffraction, d is the grating constant (distance between the gratinglines). The grating constant is calculated using the formula $d = 1/N$ Where, N is the number of lines in the diffraction grating and θ is the angle between the incident wavedirection and the diffracted wave direction.

5. Equipment



S.No	Equipment	Item Code	Quantity
1	Optical Bench Set 0.8m	KSCIOB1	1
2	Spectrum Tube Power Supply Assembly	KSCIUP040	1
3	Converging Lens Holder	KSCIHA010	1
4	Adjustable Collimating Slit Holder	KSCIHA012	1
5	Telescope Assembly	KSCIUP035	1
6	Diffraction Grating 500lines/mm		1
7	Spectrum Tube, Hydrogen	KSCIAC021	1
8	Spectrum Tube, Helium	KSCIAC022	1
9	Spectrum Tube, Mercury	KSCIAC023	1
10	Spectrum Tube, Krypton	KSCIAC024	1
11	Spectrum Tube, Argon	KSCIAC025	1

6. Safety Instruction

- Components like horizontal bench, telescope mount base, power supply areheavy.
- Take adequate safety measures while handling them.
- The power supply for the discharge tubes is a high voltage supply.
- Do not useany non-insulated wires to establish connections.
- Do not touch any electricalterminals
- Always switch off the power supply to discharge tubes before changing them. Do not touch the discharge tubes with bare hands.
- Use thermal protective glove.
- The discharge tubes are fragile. Handle them with care

7. Experimental Setup

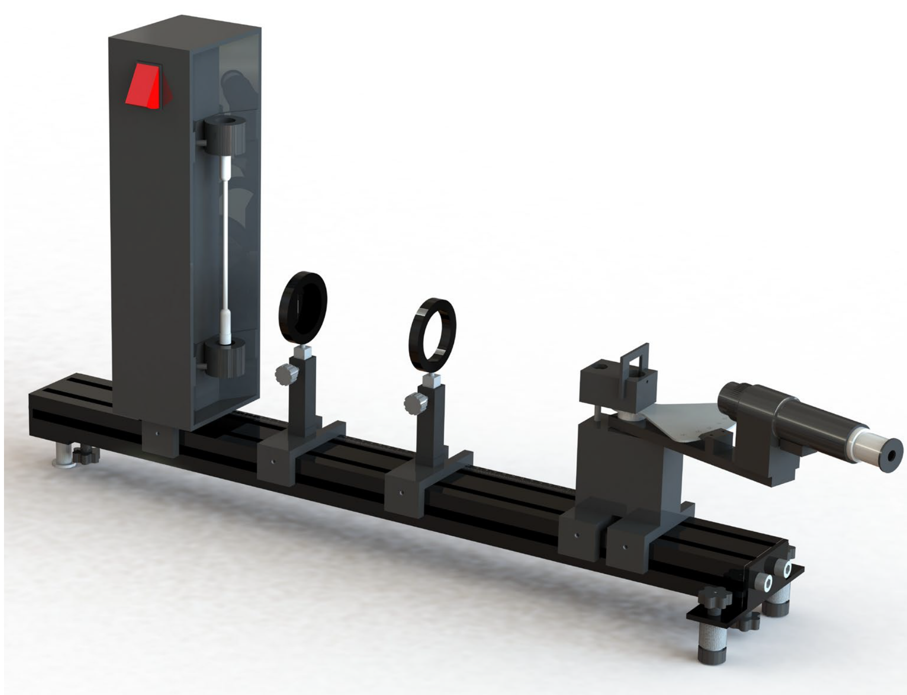


Fig 3: Diagram showing set up to study atomic emission spectra

- Place the bench on a stable horizontal surface such as a sturdy table top and makesure the bench is parallel to the horizontal surface.
- Mount the discharge tube holder on the optical bench and fasten the lock. Ensure the availability of an AC power socket in the vicinity for operating the light source.

- Place the discharge tubes between the terminals of the tube holder during calibration and experiment. Use the L-hook given in the discharge tubes for easy placement and removal.

  CAUTION:

  The discharge tube will be hot after a few minutes of use. Wear safety glovesbefore removing the tubes from the holder.

  Ensure that the tubes are stored safely as they are fragile items.

- Mount the uprights and accessories for the adjustable slit and the collimating lens adjacent to each other and calibrate as explained further. Fasten the lock for both.
- Carefully place the spectrometer rotating table with telescope on the optical bench andfasten the lock of both the slider locks.
- Place the grating in the grating holder and fasten the screw. Ensure the grating isparallel to the slit and collimating lens (by eyesight). *This is important!*

• Calibration

7.1 Calibrating the telescope

- Remove the grating (if placed). View through the telescope and focus on any far off object. This is because, light rays coming from a relatively far off object are assumed to be parallel. Since the light from the source (during the experiment) is collimated, the pre focused telescope enables larger view of spectral lines.
- Use the course adjustment screw and focus the telescope to get a sharp image of theobject under view.
- This particular position is appropriate for viewing for the person who calibrates. Thesame position may or may not be appropriate for another person.

7.2 Calibrating collimator

- After placing the adjustable slit and collimating lens on the optical bench, ensure that the distance between the center of the slit and the center of the lens is equal to the focal length of the lens.
- Adjust the height of the slit and the lens so that they are in line with light source, gratingand the telescope.
- Turn on the light source. Remove the grating (if placed). View through the focusedtelescope to get a sharp image of the slit.
- Adjust the slit width get a thin sharp image of the slit.

• Experiment

1. Keeping the power supply OFF, place the hydrogen discharge tube in the tube holder. Now, remove your hand from the discharge tube and turn the power supply ON.

2. The diffraction grating given with this equipment has 500 lines/mm. That means the distance between two slits/grooves in the grating is 0.002 mm.

3. With the naked eye, observe and locate the spectral lines of the first order.

4. Bring the telescope in line with the optical axis. Align the cross wires present in field ofview of the telescope with the slit.

5. Using the focus screw, adjust the focus of the telescope until a clear image of the slitis seen. Note down the angle indicated on the vernier scale (MSR, CVD). Let this reading be represented as ϑ_0.

6. Move the telescope to the region where you had located the first order spectrum. Align the vertical cross wire and measure the angle of all the spectral lines. (The angleis indicated by the reading indicated by the vernier scale)

7. Denote the angle readings corresponding to each coloured line as θ_1

8. Calculate the angle of diffraction $\theta = |\,\theta_0 - \theta_1|$ for each spectral line.

9. Tabulate the readings and calculate for each reading using the equation (2). Compare the obtained values with the expected values.

10. Turn OFF the power supply.

CAUTION:

Do not keep the power supply on for long time.

Do not turn on the supply without placing the discharge tubes.

11. For examining other spectral tubes, carefully replace the hydrogen tube with the required tube and repeat step 1 to step 9.

Table 1: Tabulation of angles and wavelength of spectral lines

Color of the spectral line	θ_0 (deg)	θ_1 (deg)	$\theta = \vert \theta_0 - \theta_1 \vert$ (deg)	Wavelength (nm)	Expected wavelength (nm)

Compare the obtained wavelength values with the expected ones. Calculate the percentage difference to check if it lies within 3%. If not, repeat the experiment the takethe readings again for the relevant cases.

10. Applications

10.1 Inductively coupled plasma atomic emission spectroscopy (ICP-AES)

It is a technique used in analytic chemistry for detection of elements and its concentrationin a given sample. The sample to be analyzed is atomized and thermally energized by the plasma that is driven by a Radio frequency generator. The temperatures can reach up to (7000-8000K). This is done to avoid any molecular contributions to the optical spectrum. The EM radiation (mostly in visible spectrum) is passed through a monochromator/ diffraction grating and separated into the constituent wavelengths.

10.2 Astrophysics

The elemental analysis of the stars can be done by the analyzing the light they emit. The light emitted from the stars is passed through a monochromator to split the light to its constituent wavelengths.

Large amount of information can be obtained by analyzing the spectrum of the stellar objects. Namely, the composition of the object, the velocities of the gas in the object, ionization state of the gas and the plasma, redshift of the objects etc..

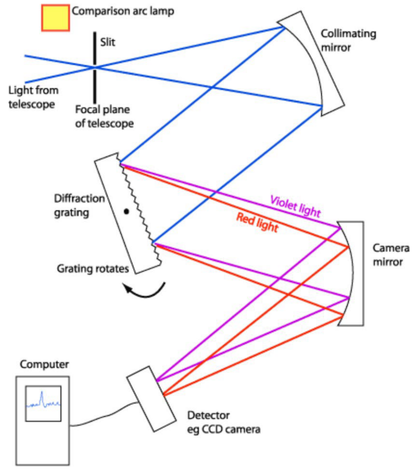


Figure 4 : A slit spectrograph (*source*: *Australian National Telescope Facility)*

11. References

1. Physics of atoms and molecules, Prof . K. Heyne, University of Berlin (link)
2. Bohr model of hydrogen atom, university of Oxford, (link)
3. Atomic emission and absorption spectroscopy (link)
4. Spectrographs and spectroscopy, Caltech, (link)
5. Spectroscopy in astronomy, national central university, Taiwan (link)
6. Optics, Eugene Hecht, 5th edition, Pearson.
7. Basic atomic spectroscopic data, (link)
8. Atomic Spectra, (link)

12. Appendix

Sample readings:

Mercury Spectra

Colour	ϑ_0(deg)	ϑ_1 (deg)	$\vartheta = \lvert \vartheta_0 - \vartheta_1 \rvert$ (deg)	Wavelength (nm)	Expected wavelength (nm)
Blue	27.3	53.2	25.9	436.59	435.8
Blue-green	27.3	60.1	32.8	541.46	546.1
Yellow -1	27.3	62.4	35.1	574.75	577
Yellow-2	27.3	62.7	35.4	579.02	579
Orange	27.3	64.5	37.2	604.33	615.2

**A pair of yellow lines will be present very close to each other within a wavelength range of 577 nm to 579 nm. However,it can be measured only in dark room with a vernier scale of least count 0.01 degree.*