Examining optic emission spectra

Exercise goals:
- identifying elements based on their spectrum
- examining spectra of selected sources of white light

Introduction
Spectrum is a very broad term in science and technology. In broad meaning it's a dependence of signal intensity from its frequency. Spectrum may concern electromagnetic waves (microwaves, light, x-rays), acoustic waves (infrasound, sound, ultrasound) and other signals. Branch of science concerned with examining spectra is spectroscopy. Spectroscopy gives us a lot of information about different phenomena and properties of matter. Because spectroscopy is a very broad branch of science in this exercise we will focus on small segment of examining optic spectra. *Optic spectrum* is a dependence of illuminance from wavelength.

Methods of obtaining optic spectra.

Light commonly describes electromagnetic waves visible to human eye (wavelengths between 380 and 780 nm). In engineering light is a broader term: it describes electromagnetic waves which behave according to laws of optical geometry. Besides visible light it also applies to close infrared and close ultraviolet.

To observe and register spectra in visible range we use spectrometers equipped with elements that splits light (prisms or diffraction gratings). In modern spectrometers split light falls on light sensitive charge-coupled device, and then is registered on a computer. Figure 1 shows schematic spectrometers equipped with prism and reflective diffraction grating. In reality spectrometers are more complicated, and more advanced devices are equipped with several elements that split light.

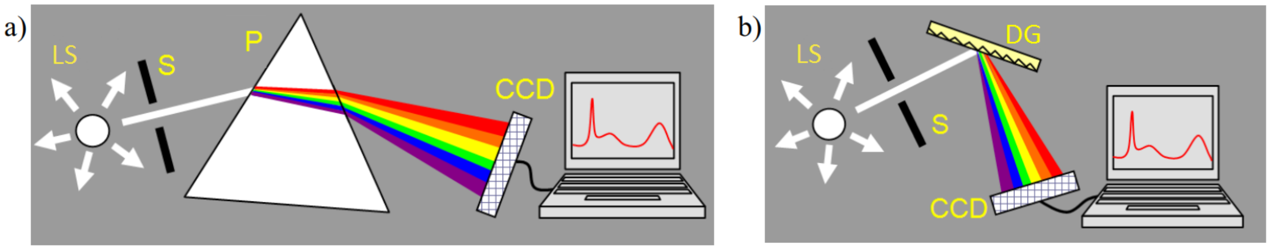

Figure 1: Schematic model of optical spectrometer a) equipped with prism b) equipped with reflective diffraction grating. Markings: LS - light source, S - slit, P - prism, CCD - charge-coupled device, DG - reflective diffraction grating

Types of optic spectra

There are a lot of methods of classifying spectra. Two basic ones are shown here.

1. Based on mechanism of generation spectra can be divided to:

a) emission spectra – received as a result of medium radiating light (Figure 2a)

b) absorption spectra – received after white light travels through examined medium (Figure 2b)

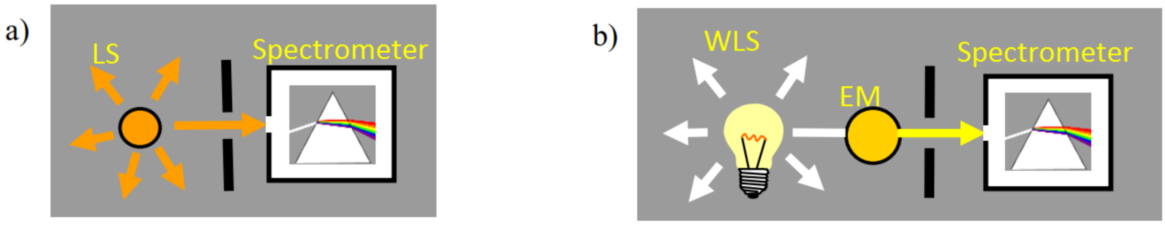

Figure 2: Methods of generating a a) emission, b) absorption spectra. Markings: LS - light source, WLS - white light source, EM - examined medium

2. Based on character (representation) of spectrum (Figure 3)
- linear – consisting of series of thin lines corresponding to specific wavelengths; monoatomic gases and metal vapours are sources of this spectra
- band – consists of large number of lines close to each other, creating quite wide bands as a result: diatomic gases or particles are sources
- continuous – consists of waves of all lengths: solids and liquids are sources

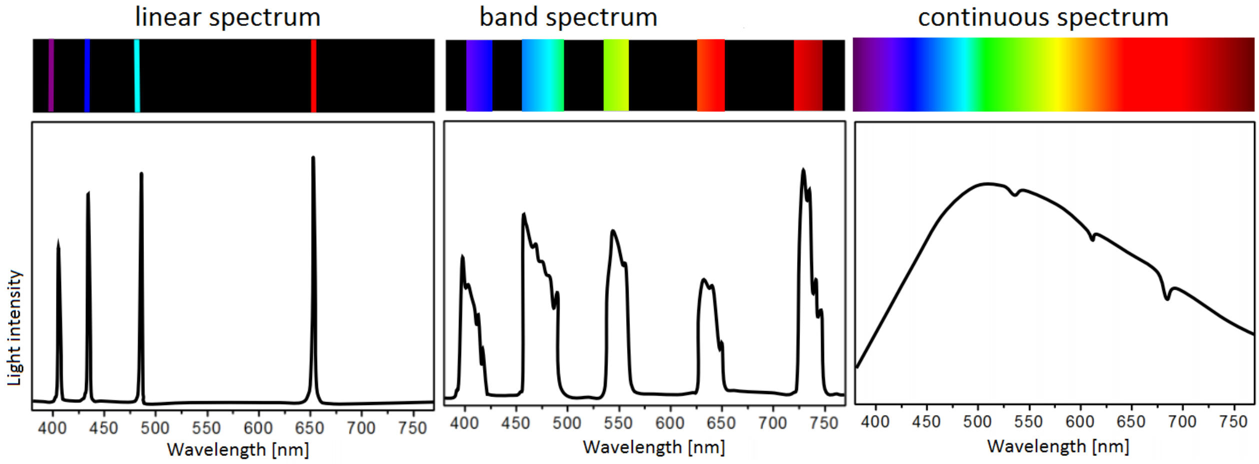

Figure 3: Examples of emission spectra: linear, band, continuous. Top images shows separated rays of light, bottom registered spectra

Why does matter shine?

To answer this question we must examine structure of atom. Atom consists of small, heavy, positively charged nucleus and orbiting around it negatively charged, small electrons. Movement of those electrons takes place on so called stationary orbits, and the energy of electron on each orbital is specified. In other words: energy of electron in atom is quantified. When electron moves from higher energy orbital (orbital further from nucleus) to lower energy orbital electron emits quantum of energy equals to:

$$E = h\nu E_n - E_m \qquad (1)$$

where h - Planck constant, ν – frequency of emitted electromagnetic wave, E_n and E_m – energies of electron on nth and mth orbital. Using dependence between frequency and wavelength $\nu = c/\lambda$ we can transform formula (1) to:

$$\lambda = \frac{hc}{E_n - E_m} \qquad (2)$$

where λ – length of emitted electromagnetic wave, c – speed of light in vacuum.

This formula shows that if energies of electrons in atom can have only certain values, it can only emit waves of certain wavelengths. Based on analysis of spectrum we can learn a lot about structure of an atom, or on the other hand identify type of element that emits waves. Waves emitted by atom in a way described above fall in range of infrared, visible, ultraviolet of X-rays. If waves are in range of visible light we say that object shines.

So far we talked about generating linear spectra. Why are spectra of complex gases, liquids and solids different from spectra of singular atoms shining? It's because system consisting of multiple atoms increases the number of possible energy levels. For example: hydrogen molecule H_2 consists of two electrons and two protons, but it's spectrum is much more complex than spectrum of singular hydrogen atom. Internal energy of molecule additionally consists of energy of molecular vibrations and rotations. As a result H_2 molecule has numerous spectral lines compared to only four in visible range for singular atom H. The more complex molecule and atoms building it are, the more complex its spectrum is. For liquids and solids number of lines is so large that we observe continuous spectrum.

Examples of applying optical spectroscopy:

1) To control the quality of plates in rolling mill, electric arc is crated, which makes shining atoms to evaporate from material. by examining linear spectrum of this vapour, we can determine composition of material (using characteristic lengths of lines) and proportions of atoms (based on ratio of intensity of lines of specific elements0

2) Based on spectrum emitted by a star astronomers can determine its composition and velocity at which it's moving relative to Earth. Using subtle changes in star spectra it was concluded that the universe is expanding.

What is white light?

White light is commonly defined as combination of all colours (all waves in visible range). If we observe white sunlight spliting in raindrops we see multicolour rainbow. However for human eye we can create impression of white light in multiple ways. It's a result of the fact that photoreceptor cells (cones) in human eye are sensitive to three basic colours: red, green and blue. Mixing them in different proportions we can create impression of white light or create new colours. Sometime white light from different sources falling on white piece of paper looks almost identical, but have significantly different spectra. Also colourful painting will look different when it's lit by, for example, light bulb, compact fluorescent bulb, or LED lamp, despite the fact that theoretically all of the emit white light. It's caused by different methods of creating light in those sources and therefore different spectra.

Let's examine ways in which we can create white light. As it was mentioned in order to make an atom shine its electron must obtain energy necessary to "jump" to higher orbital to later lose this energy by emitting electromagnetic wave. This energy can be delivered in different ways. Easiest way is heating up to high temperatures. For example surface of the Sun, heated to 5800 K emits intense white-blue light. Phenomena of light being created as a result of high temperatures is used in classic light bulbs. Its tungsten filament is heated to 2700 K and shines white-yellow light. However this method is inefficient. Only about 3-5% of light is in visible range, rest is invisible to human eye infrared radiation. Compact fluorescent bulb is a more efficient source of white light. In this bulb vapours of mercury are stimulated to shine by electric discharges. Light emitted by mercury falls on phosphor which shines thanks to fluorescence. Spectrum of this lamp is considerably different than sunlight and because of that colours of for example a painting looks different than in sunlight. Other source of white light is LED lamp. Usually it's a collection of light-emitting diodes covered in phosphor and placed in a casing intended for light bulbs. Diodes, thanks to effect of electroluminescence emit blue light which causes phosphor to shine. Yellow-green-red light emitted by phosphor is mixed with blue light of diode which gives white light. If spectrum of white light contains a lot of blue light it's called cool white light, if there isn't much blue light we call it warm white light.

Measuring system

Measuring system (Figure 4) consists of spectrometer (range between 300 – 1000 nm) connected to computer. Using optic fibre spectrometer can receive light from seven different sources marked A, B, C and 1, 2, 3, 4. Spectrometer is operated using *Overture* program, which should be launched after turning the computer on. Symbols of selected functions are on station.

Exercise consists of two stages. First stage is identifying elements in spectral tubes. Lamps on station contain: A – mixture of monoatomic gas and metal vapour; B – monoatomic gas; C- simple diatomic gas. During identification small resolution of spectrometer has to be taken into account. Because of that if distance between lines is smaller than 3 nm, they can blend together. Second stage is observing white light coming from different sources: 1- compact fluorescent bulb, 2 – LED lamp, 3 – LED RGB lamp, 4 – light bulb.

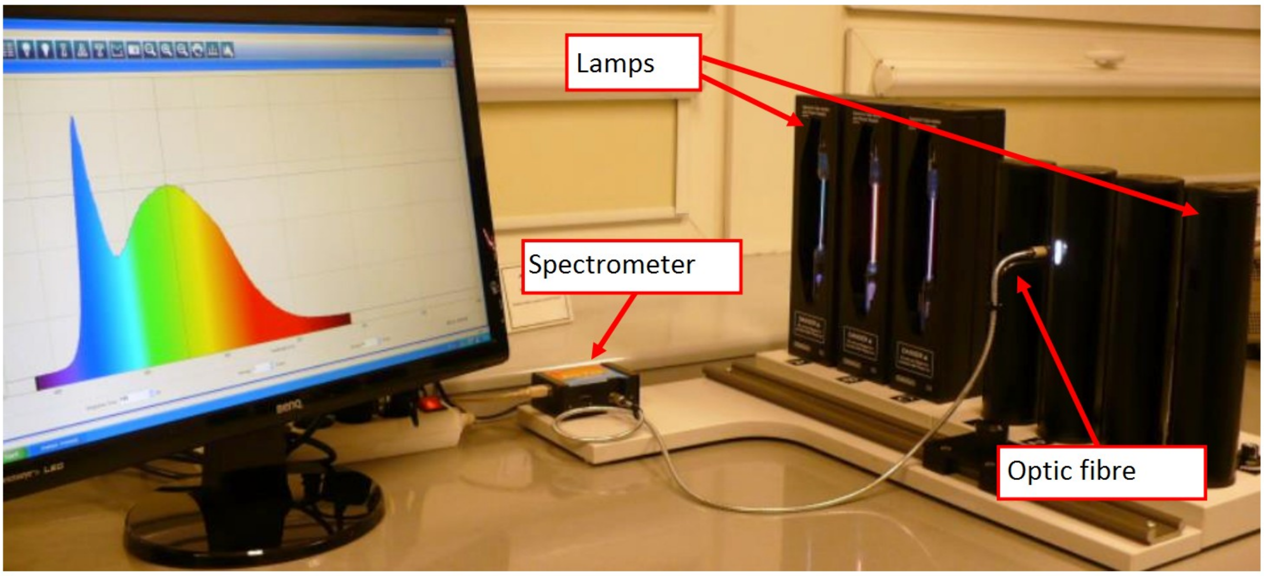

Figure 4: Experimental system used to examine optic emission spectra

Course of exercise

A. *Identifying gases in spectral tubes*

1. Turn on lamp A and move the end of optic fibre in front of it. Regulate position of fibre and "measurement integration time" so spectrum fits on the screen. Click the "colour" icon to show real colours of spectrum.
2. Using computer mouse move the cursor to the maximum of each line. Write down its wavelength and intensity. If a line is wider note that it can be multiple spectral lines close together.
3. Repeat measurements for lamps 2 and 3.
4. Compare obtained spectral lines to spectra in "Spectral tables" added to this exercise or to spectra in *Spektruś* program.
5. Specify elements in lamps A, B and C and note down findings

B. *Observing spectra of selected light sources of white light*

1. Turn on lamp 1 (compact fluorescent bulb) and register spectrum.
2. Write down positions of bands and their intensity and compare them to lines emitted by mercury. Write down findings.
3. Turn on lamp 2 (LED lamp) Write down maximums of spectrum. Write down findings.
4. Turn on lamp 3 (LED RGB lamp) and using pilot set white light (point the pilot to the hole in the back of the cover). Note down wavelengths for which you observe maximum values of spectral bands.
5. Using pilot change colour to for example yellow, purple, orange. Analyze spectra and write down

findings.

6. Turn on lamp 4 (light bulb). Using potentiometer set maximum voltage on bulb, corresponding to maximum temperature of filament. Register spectrum using “shutter’ icon.

7. In the same way register 3-4 more spectra while lowering voltage.

8. Compare obtained spectra for different temperatures of filament. Notice minimal values of wavelengths emitted by bulb for different temperatures of filament. Write down findings.