KUNGL TEKNISKA HÖGSKOLAN

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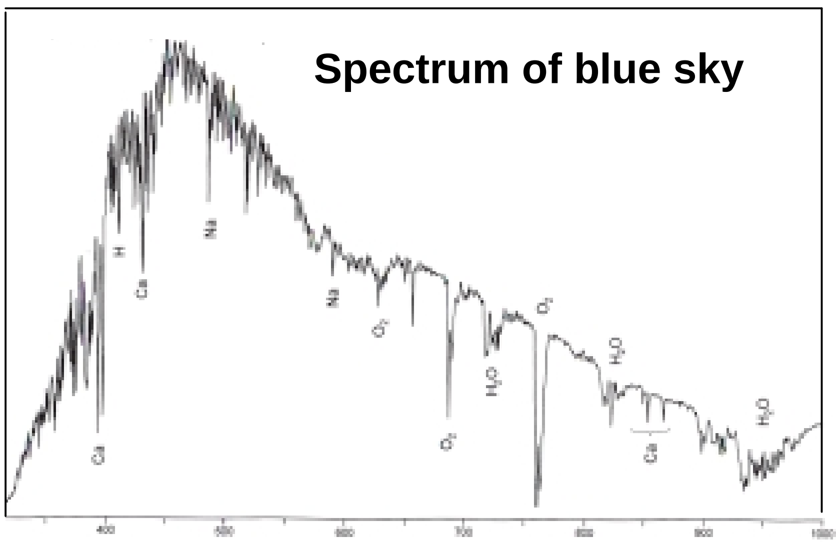
Laboration O-12
Environmental Spectroscopy



Goals

There are several goals with this laboration. The main goal is to study environmental spectroscopy and look for pollutants and abundant molecules and atoms in the atmosphere. One specifically important goal is to try to measure the depth of the atmospheric ozone layer. A second goal is to study the Planck curve and measure the temperature of the surface of the sun. A third goal to do this is to use modern spectroscopic equipment, i.e. CCD cameras connected to a monochromator and a computer. Finally a fourth goal is to perform computer operations and data handling. There are still more goals, i.e. the use of sensitive electronic devices will show the necessity of performing experiments that will not effect the sensors, why precautions have to be made in order to protect the detector.

The laboration will be performed in three steps. Firstly, calibration of the monochromator has to be done by using standard calibration lamps and the mercury lamps in the experimental hall. Secondly, a registration of a thermal spectrum will be recorded from a glowing object to study the thermal intensity distribution as a function of wavelength, and thirdly the registration of the radiation from blue sky light (or in bad weather, the absorption of light in the laboratory, when white light passes, say 10 m of air.)

1. Introduction.

Light from the sun reaching the earth is essential for life. The intensity and colors of the solar spectrum as it reaches the atmosphere is transmitted and arrives finally at the surface of the earth. The detailed balance between inflow and outflow of solar energy establishes the temperature of the earth's surface. It is well known that the abundance of ozone (O_3) in the atmosphere protects the earth from too intense UV radiation. Ozone absorbs radiation at wavelengths < 295 nm. Another important molecule in the atmosphere is CO_2 that is vital in regulating the energy balance of absorbed and emitted light of the earth. In this laboration we will study the abundance of molecules and atoms in the atmosphere by recording the radiation from blue sky. We will also measure the blackbody radiation of the sun seen by studying the sky and try to determine the Temperature of the surface of the sun.

2. Thermal Radiation

2.1 Introduction

Electromagnetic radiation in the UV, visible and IR wavelength regions can be observed by using grating monochromators and detectors such as photomultiplier tubes, photodiodes and CCD-cameras. The silicon detectors can detect radiation between 285 nm and 1.23 µm.

2.2 Detection of Electromagnetic (E-M) Radiation

The most commonly used device, when detecting E-M radiation in the UV, visible and near IR wavelength regions, is the grating monochromator (Fig.1)

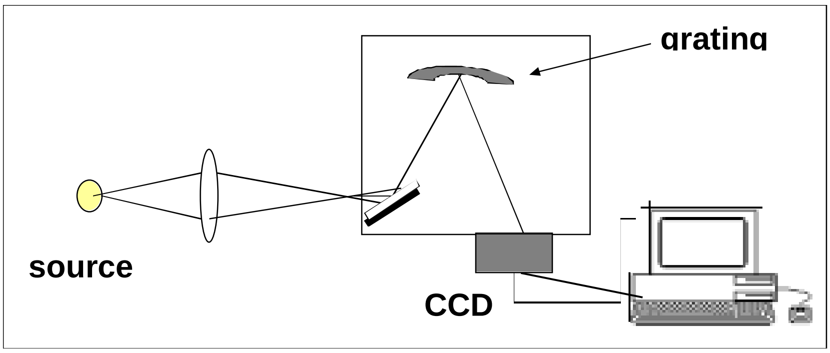


Fig.1 The experimental setup with the grating monochromator

Grating equation. The grating equation for light of wavelength λ incident perpendicular on the grating is

$$n\lambda = d \sin \theta \qquad (1)$$

where n is the order number, d is the distance between the grooves of the grating and θ is the diffraction angle.

Overlapping orders. When one looks at the spectrum at a certain angle θ, one can in some cases, observe different wavelengths λ_1 and λ_2 in the same position of the spectrum, i.e. we have $n_1 \lambda_1 = n_2 \lambda_2 = d \sin\theta$. If we have $n_1 = 1$ and $n_2 = 2$ and $\lambda_1 =$ 500 nm we get $\lambda_2 = 250$ nm. Thus, one has to be very careful, when studying grating spectra due to the problem with overlapping orders. However, in this laboration, the grating is "blazed" why this is a minor problem. In this laboration we will study atomic spectral lines of different light source. We will use known spectral lines to calibrate the spectrometer.

Planck radiation. When observing the IR wavelength region, the spectrum is most often due to black body or thermal radiation that can be described by the Planck radiation law. The power distribution function of the Planck radiation law is given by the following expression:

$$F(\lambda) = \frac{const}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1} \qquad (2)$$

Where h is Planck's constant, k is the Boltzmann's constant, c is the speed of light and T is the absolute temperature. The function is shown in Fig.2 below.

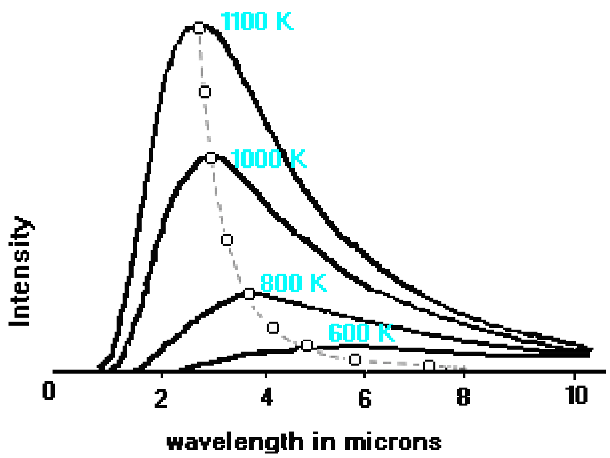


Fig.2 Planck radiation law. Power distribution function F(λ,T). The intensity of the source as a function of wavelength at different temperatures.

This function agrees well with experiments and it also contains the Wien's displacement law where the value of λ_m is given as a function of the absolute temperature T:

$$\lambda = hc/(4.965kT) \qquad (3)$$

This equation can be used to determine the temperature T, of a black body or a lamp, if the spectrum is recorded and the wavelength λ_m, where we have the maximum intensity is deduced. Here the monochromator equipped with the CCD-detector can be used. It consists of a linear array of 2048 silicon detectors of a total length of 25mm.

2.3 Temperature of the sun

The recording of blue sky enables us to determine the temperature of the sun by measuring the wavelength where the intensity of the spectrum is at its maximum and to use Wien's law to deduce the temperature.

3. Atmospheric spectra

3.1 Introduction

Looking at the blue sky spectrum on the cover, we can observe several absorption bands belonging to both molecular and atomic species. The ozone molecule is responsible for many of the absorption bands. One sees a broad, but not deep dip in the intensity between 550 nm to 610 nm (The diffuse B-X Chappuis bands). However, the main absorbing region of light by the ozone molecule lies in the 220 nm – 300 nm wavelength region (The diffuse D-X Hartley bands). Other diffuse bands can be found in the IR region around 10 μm. The maximum concentration of ozone appears between 20 km to 26 km above the ground in the atmosphere. If one would collect all the ozone molecules in a layer at atmospheric pressure, the thickness of the layer would only be 0.3 – 0.4 cm!

At several other wavelengths than mentioned above, we se strong absorption due to water and of course also that is due to oxygen.

3.2 Absorption of radiation

If radiation is being absorbed by an absorbing gas one can deduce the so-called Lambert-Beer's law:

$$I(z) = I(0)\, e^{-Kz} \qquad (4)$$

where K is the absorption coefficient and z is the distance of absorption. The coefficient K depends on several parameters, the number of molecules in the volume the light has passed, the refractive index, the Einstein coefficient for absorption and the light frequency. For ozone, the coefficient K has been measured to be of the order of 10^{-5} m^{-1}. This coefficient varies with altitude, why this value can be regarded as a rough mean value. Due to the fact that we use the sun as a light source for the experiment, and that the angle between the sun, the ozone layer and the observer, changes during the day, we have to use a constant that varies with the time of day according to the table below:

Time of day	constant
9,00	0.040 exp(-4)
10,00	0.062 exp(-4)
11,00	0.068 exp(-4)
12,00	0.074 exp(-4)
13,00	0.080.exp(-4)
14,00	0.093.exp(-4)
15,00	0.101 exp(-4)
16,00	0.140 exp(-4)

Tasks during the laboration.

- Study the mercury spectrum and calibrate the spectrometer.
- Use a white lamp and record its spectrum with the grating monochromator. Find the wavelength that gives the maximum intensity. Determine its color temperature using Wien's law.
- Register the spectrum of blue sky and determine the temperature of the solar spectrum by applying Wien's law.
- Study the solar spectrum and identify the absorption bands of ozone, O_3, O_2 H_2O and the abundant atoms. Make a table of these bands and their corresponding wavelength and compare with standard wavelength tables.
- Try to calculate the ozone depth in the atmosphere by measuring the intensity variations of the he diffuse B-X Chappuis bands in the visible region.

Appendix

CP200 Imaging spectrograph computer key words

In order to start the computer program after switch on:
Go to directory LAMDA
Then start the program by running: LS2000

C:<enter>
CD \LAMDA <enter>
LS2000 <enter>

Then the program starts and the readout on the last page in this paper is shown.

Exposure times can be varied from 0.005 s to 8 s.
Always start with short exposures, say 0.05 s for strong light sources.

A single scan will be obtained if the **ONE** mode has been chosen.

If you want to make a scan, just press **RUN**

If you already have made a recording and wants to clear the picture, then press **CLEAR**.

If you want to find the wavelength of a peak, just press **PEAK** and point at the peak and you will get the wavelength and intensity.

If you want to change **the intensity scale or the wavelength** scale, just click the number on the axes, i.e. 9999 on the intensity and a window will appear where you can choose the wanted intensity.

More details can be found in the manual. You will easily be making exposures after a couple of minutes.