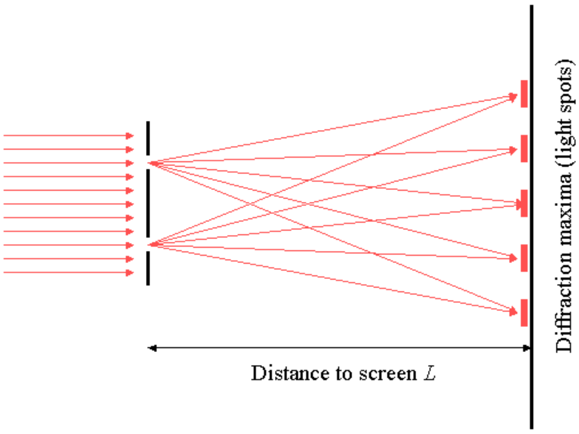
Experiment Nr. 43

Diffraction Grating - Determination of the Light Source Wavelength

Theory

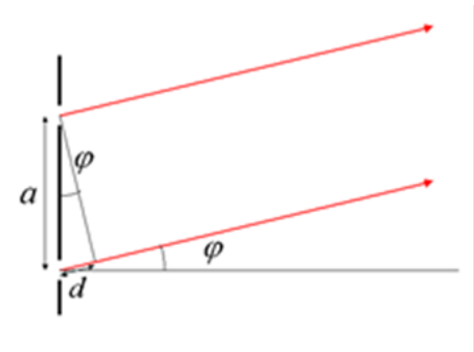
The principle of operation of a diffraction grating is based on the phenomena diffraction and interference of light. Often diffraction gratings are used to split a beam of white light into its spectral components - beams of monochromatic light, i.e., with some given wavelength λ (or colour). As we shall see, the angle at which the different monochromatic beams appear behind the grating depends on its wavelength λ and can be used to determine the latter.

Diffraction gratings are made of transparent material with numerous parallel thin lines, etched into their surface. To understand how a diffraction grating works, consider first a flat monochromatic light beam falling on a screen with two slits, see the following figure:



Each slit turns into a linear source of light waves. These waves interfere with one another and the places of constructive and destructive interference appear on a screen behind as an "interference pattern", consisting of light spots (maxima) separated by dark regions (minima). Take a point on the screen behind. If the distance from it to the two slits differs by a whole number of wavelengths, then whenever a crest (resp. a trough) of the wave coming from one slit reaches that point, also a crest (resp. a trough) of the wave from the second slit will reach it. (We say that the two waves are in phase.) The resultant wave at this point will have maximal amplitude. The point will be illuminated. This is a point of constructive interference. For points where the above condition does not hold waves from the two different slits arrive in different phases and the resultant wave will have practically zero amplitude.

The diffraction grating is based on the same principle except that instead of two slits we have a large number of parallel slits. There is one important simplification - the distance between two neighbouring slits is very small (1-2 μm typically), while the distance to the screen is of the order of 1-2 m. Let us look at two slits and the beams coming from them and converging to a point on the very distant screen:



The two beams are practically parallel. The difference in length of the two beams is d. Constructive interference occurs when $d = n\lambda$, where n is an integer. From the right triangle (see the figure above) one sees that $d = a\sin\varphi$, where a is the distance between two neighbouring slits. It is called the constant of the grating and is usually specified by the manufacturer. Thus we have the following condition for the appearance of diffraction maxima:

$$n\lambda = a\sin\varphi$$

It can be seen easily that this same condition holds for any two slits and therefore for the whole grating. In the formula above φ is the angle at which diffraction maxima occur, measured from the perpendicular to the grating and $n = 0, \pm1, \pm2, ...$ Obviously for any λ there exists the central maximum ($\varphi = 0$) corresponding to $n = 0$. The angles at which the other maxima, corresponding to $n = \pm1, \pm2, ...$ appear, depend on λ. Many gratings are especially manufactured, so that only the central maximum and the first maxima to the left and to the right appear.

Measurement objectives

1. Determine the number of slits in the diffraction grating using a light source with well-known wavelength (laser light). Compare the obtained value to the manufacturer data.

2. Determine the wavelength of selected lines of the mercury discharge lamp. Use the number of slits calculated in the objective Nr. 1. Compare the results to the tabular data.

3. Determine the wavelength of selected colours of the white light. Use the number of slits calculated in the objective Nr. 1. Compare the results to the tabular data.

Comments

Ad 1. Try to adjust the optical system so you can see more than one maximum of the diffraction scattering. Calculate the number of slits from the first and second laser diffraction maximum and determine the average value of the results. Notify that the diffraction angles are relatively high so the tangent of the angle should be used for the diffraction angle calculation.

Ad 2. The mercury discharge lamp principle is based on the gaseous state excitation. When the atoms of some gas are excited in some way (say by bombarding them with electrons) they may go into higher energy states (i.e. excited states). After some time the atoms undergo a spontaneous transition to lower energy states emitting light photons with strictly defined energy (and frequency / wavelength). Each chemical element is characterized by its own discrete set of energy levels and therefore the light that it emits contains specific frequencies of light. When this is passed through a diffraction grating, it is spectrally decomposed and we observe the characteristic spectral lines for that element. We can then determine the wavelengths of the light forming the spectral lines knowing the constant of the diffraction grating.