Chapter 1

CCD Camera Operation

1.1 The HeNe and Fourier Lab CCD Camera

For several experiments in this course you will use the CCD cameras to capture images or movies. Make sure to copy all files to your own directories or transfer them to a usb stick as the files will be periodically deleted.

1.1.1 Capturing Image and Video Files

On the computer, select 'Run Command' from the start menu, type **xawtv** and press 'Enter' (alternatively select *Applications* → *RunCommand* and type 'xawtv').

Right click on the image window to open the options menu

Ensure the "TV norm" is set to "NTSC"

Adjust the brightness and contrast by clicking in the respective scroll bars

- Left clicking will increase the brightness/contrast
- Right clicking will decrease the brightness/contrast

Select "Grab Image (JPEG)" to save an image. The image will be named *snap_unknown_timestamp_nr*.jpg To change the base name (from *snap* to something else), initialize the program by typing **xawtv -o** followed by the new base.

For example, initializing with the string **xawtv -o HeNeModes** will cause images to be saved as $HeNeModes_timestamp_nr$.jpg

Recording a movie requires that "Capture" is set to "grabdisplay"

- Select "Record Movie (avi)"
- Set the movie driver to "Microsoft AVI (RIFF) format"
- Set the "movie/images filename" to *base*.avi
- Set the audio format to "No Sound"
- Set the sample rate to "44100"

- Set the video format to “MJPEG (AVI)”
- Set the frames per second to “12.0 fps”

Make sure to copy all files to your own directories or transfer them to a USB stick as the files will be deleted periodically from the machines.

Chapter 2

Extended Fourier Analysis

Use the following example of Fourier spectra to compare the observed Fourier spectrum of the mesh to theory.

2.1 Plane Wave

A plane wave that is propagating along the $z-$axis has the following Fourier transform:

$$E(x,y) = A_0 e^{ik_z z - wt} \equiv E_0[f(z,t)] \tag{2.1}$$

Now we will drop f(z,t)

$$F[E(x,y)] = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E_0 e^{-2\pi i(k_x x + k_y y)}\mathrm{d}x\mathrm{d}y = E_0\delta(k_x)\delta(k_y) \tag{2.2}$$

You can verify that the Fourier transform of a constant is a delta function by taking the inverse Fourier transform of a delta function:

$$F^{-1}[\delta(k_x)] = \int_{-\infty}^{\infty}\delta(k_x)e^{2\pi i k_x x}\mathrm{d}x \tag{2.3}$$

and since the delta function has the fundamental property that

$$\int_{-\infty}^{\infty} f(x)\delta(x-a)\mathrm{d}x = f(a) \tag{2.4}$$

it follows that

$$F^{-1}[\delta(k_x)] = e^{2\pi i(0)x} = 1 \tag{2.5}$$

therefore

$$F[1] = F\big[F^{-1}[\delta(k_x)]\big] = \delta(k_x) \tag{2.6}$$

Thus the transverse Fourier tansform of a plane wave is a point on the focal plane at $(k_x, k_y) = (0,0)$.

2.2 slit

A plane wave passing through a slit in one dimension of width w can be described by a rectangular function:

$$E(x,y) = E_0 \text{rect}(\frac{x}{w}) = \begin{cases} E_0 & |x| < w/2 \\ 0 & \text{else} \end{cases} \tag{2.7}$$

Thus in the Fourier transform plane the spectrum should be:

$$F[E(x,y)] = E_0 \int_{-\infty}^{\infty} \int_{-w/2}^{w/2} e^{-2\pi i(k_x x - k_y y)} \mathrm{d}x\mathrm{d}y \tag{2.8}$$

$$= E_0 \delta(k_y) \int_{-w/2}^{w/2} e^{-2\pi i k_x x} \mathrm{d}x \tag{2.9}$$

$$= E_0 \delta(k_y) \frac{1}{-2\pi i k_x} e^{-2\pi i k_x x} \Big|_{-w/2}^{w/s} \tag{2.10}$$

After some manipulation, this can be shown to be

$$= E_0 \delta(k_y) \frac{\sin(\pi k_x w)}{\pi k_x} \tag{2.11}$$

Using the definition $\text{sinc}(x) = \frac{\sin(\pi x)}{\pi x}$, the above equation further reduces to

$$F[E(x,y)] = E_0 w \delta(k_y) \text{sinc}(w k_x) \tag{2.12}$$

2.3 Grid

A grid is a periodic sequence of N slit functions with width w and separation s in the $x-$direction. Thus;

$$E(x,y) = E_0 \sum_{n=1}^{N} \text{rect}(\frac{x}{w} - \frac{n \cdot s}{w}) \tag{2.13}$$

This can be expressed as a convolution of a series of delta functions with the rectangular function:

$$E(x,y) = E_0 \Big[\sum_{n=1}^{N} \delta(x - n \cdot s) \Big] * \text{rect} \frac{x}{w} \tag{2.14}$$

where the $*$ represents a convolution. The Fourier transform of a convolution product [1] is

$$F\big[(E_1 * E_2)\big] = F[E_1] \cdot F[E_2] \tag{2.15}$$

Therefore in the Fourier transform plane the spectrum should be

[1] See the Appendix in Fundamentals of Physics

$$F[E(x,y)] = F\Big[\ \sum_{n=1}^{N} \delta(x - n \cdot s)\ \Big] \cdot F\Big[E_0 rect(\frac{x}{w})\Big] \tag{2.16}$$

The second Fourier transform is the same as the slit from the last example. For the first term, the summation can be moved outside of the Fourier transform:

$$= \sum_{n=1}^{N} F[\delta(x - n \cdot s)] \cdot \big(E_0 w \delta(k_y)\mathrm{sinc}(wk_x)\big) \tag{2.17}$$

Using equation 2.4

$$= \sum_{n=1}^{N} e^{-2\pi i n s k_x} E_0 w \delta(k_y)\mathrm{sinc}(wk_x) \tag{2.18}$$

The infinite series of exponentials can be rewritten:

$$\sum_{n=1}^{N} e^{-2\pi i n s k_x} = e^{-\pi i s k_x (N+1)} \frac{\sin(\pi N s k_x)}{\sin(\pi s k_x)} \tag{2.19}$$

so;

$$F[E(x,y)] = E_0 \delta(k_y) w \mathrm{sinc}(wk_x) \cdot e^{-\pi i s k_x (N+1)} \frac{\sin(\pi N s k_x)}{\sin(\pi s k_x)} \tag{2.20}$$

Thus the intensity is

$$I(k_x, k_y) = |E_0^2| \delta(k_y) w^2 \mathrm{sinc}^2(wk_x) \frac{\sin^2(\pi N s k_x)}{\sin^2(\pi s k_x)} \tag{2.21}$$

Chapter 3

The Monochromator and Photomultiplier: description and usage

3.1 Introduction

A monochromator is a device used to isolate a small wavelength interval of a spectrum. It consists of an entrance slit, a dispersive element (*e.g.* a grating), and an exit slit which allows only a selected portion of the spectrum to pass to a detector. The photon detector in this lab is a photomultiplier tube. The instrument can be used to study the wavelengths and intensities of spectral lines emitted by a source.

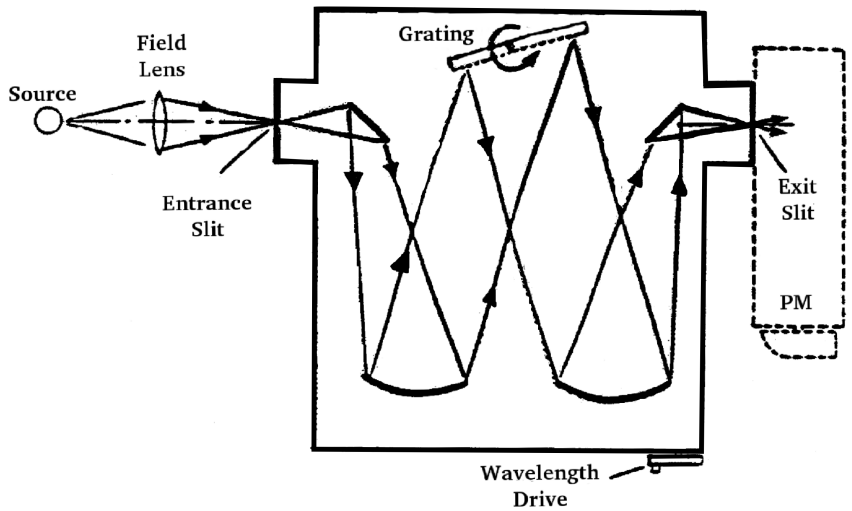


Figure 3.1: The Czerny-Turner Monochromator (the field lens is optional).

3.2 The Czerny-Turner Monochromator

Although the particular model of monochromator used here is small, the design and operation is identical to that of larger models. This particular arrangement of mirrors, slits, and grating is referred to as the Czerny-Turner arrangement. The dispersive element is a diffraction grating.

The light path through the instrument is shown in Fig. 3.1. The light from the source falls on the entrance slit. If necessary the light intensity can be increased with a field lens. A spherical mirror then collimates the beam of light and illuminates the grating. The grating disperses different wavelengths at different angles and one of these wavelengths is focussed onto the exit slit by the other spherical mirror. Since the slits are very narrow (typically 0.1mm or less), only a small range of wavelengths emerges from the exit slit. The instrument width of this monochromator is approximately 1nm, but for more expensive instruments a width of 10^{-2}nm is easily achievable.

3.3 The RCA 931A Photomultiplier Tube

The photomultiplier tube is a vacuum tube device used in industry to measure light signals, especially those from transient light sources. (A transient light source is one which only emits for a short period of time, such as a spark). The active element of a PM is the photo-cathode, which liberates electrons when struck by light. These electrons form a current pulse, which is amplified by a series of dynodes. Because the photon energy depends on the colour of the light, the energy (and number) of liberated electrons will also. This changes the dynode avalanche amplification which results in a current pulse amplitude dependent on the colour of the light. The last dynode is called the anode and is connected by an anode resistor to ground (see Fig. 3.2). A voltage is therefore developed across the anode resistor which, in the ideal case, is proportional to the intensity of the incident light. The schematic construction and operation of the photomultiplier tube is shown in Fig. 3.2.

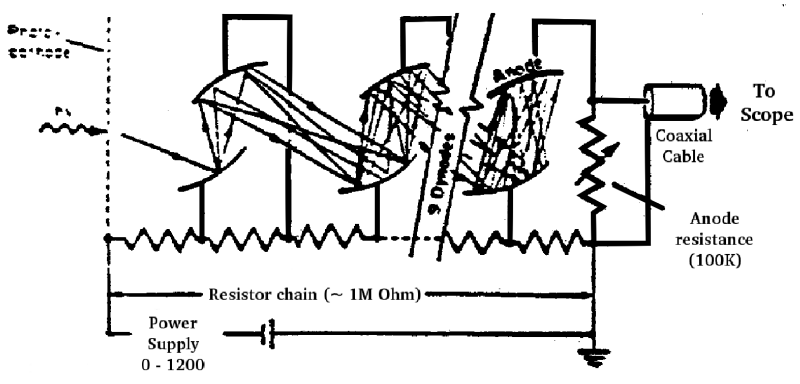


Figure 3.2: Schematic of the RCA 931 Photomultiplier Tube.

The linearity of the PM response must be established before accurate in-

tensity measurements can be made. This is done by plotting the amplitude of the PM signal as a function of the intensity of the incident light. Ideally the graph should be linear, but at large signals a deviation from linearity is usually observed.

3.4 Monochromator alignment

The transmission through the monochromator is highly dependent on the angle of the light with respect to the monochromator. To line up the monochromator, first make sure the gain and the supply voltage on the PMT are set to ZERO and remove it from the monochromator. Set the monochromator to 500 nm and then take the slits out the front and back and look in through the back of the monochromator (i.e. put your eye where the PMT would normally be). Move the light source around until you can see light through the monochromator and then put in the first slit and optimize the position of the lamp with this first slit in place. Put in the second slit and repeat the above step. When you are done, put the PMT back in place and turn the supply on and adjust the gain setting until you get a measurable signal (about 1V). The supply voltage to the PMT can be increased if more gain is needed, but do not exceed 1.2 kV. While you can use the voltmeter to measure the voltage output of the PMT, in most cases where the PMT output noise is high and you want a reliable measurement, you will need to use a fan to chop the light going to the monochromator, and you will use the oscilloscope to measure the PMT response to the dark and light periods.

3.5 Spectral Response of the PM-Monochromator Combination

It was pointed out in Section 3.3 that the photomultiplier does not respond equally to light of different wavelengths; neither does the monochromator. The combination of the two is very wavelength sensitive. For many experiments involving comparison of intensity measurements at various portions of the spectrum, it is necessary to know the spectral response of the entire system.

To measure this response, light from a known continuum source is passed through the system and the PMT signal, $S(\lambda)$, is measured at many wavelengths over the complete spectrum. If the intensity of the source, $I_w(\lambda, T)$ at a temperature of T, is known as a function of wavelength, λ, then the response of the system as a function of wavelength is given by,

$$R(\lambda) = \frac{S(\lambda)}{I_w(\lambda, T)} \tag{3.1}$$

Once the response function is known, the intensity of any other source at wavelength λ may be determined by measuring $S_2(\lambda)$ and dividing by $R(\lambda)$.