EXPERIMENT 1

Inverse Square Law

1. Energy flow

The power radiated by a source of light is described by the flow of light away from it, into a particular direction, and through a defined surface. The intensity I is the energy emitted per unit time, per unit area of the source, per unit frequency interval, per unit solid angle into a chosen direction. The flux F is the energy flowing per unit time onto a detector, through a unit area of its surface, per unit frequency interval. So if a point source emits energy at a rate P joule/sec uniformly into all directions and summed over all frequencies, then the flux through a sphere around it of radius r is simply

$$F = \frac{P}{4\,\pi\,r^2} \qquad (1)$$

This is the inverse square law describing the decline of flux with increasing distance from the source. The energy of light is carried by quanta, each with energy $h\nu$. Since these quanta travel at the speed of light c, those in a shell of thickness dr will pass through the outer surface of the shell in the time dr/c. Since the area of the shell is $4\,\pi\,r^2$, if there are n photons per unit volume in the shell, the number passing through the surface per second will be

$$\frac{n\,4\,\pi\,r^2 dr}{dr/c} = 4\,\pi\,r^2\,n\,c \qquad (2)$$

each with energy $h\nu$. With this quantum view, the flux must be this number times the energy per photon, divided by the surface area, or

$$F = \frac{h\nu\, 4\,\pi\, r^2\, n\, c}{4\,\pi\, r^2} \tag{3}$$

$$F = h\nu\, n\, c \tag{4}$$

The equations for flux must measure the same thing. It follows that the density of photons depends on distance from the source too according to

$$h\,\nu\, n\, c = \frac{P}{4\,\pi\, r^2} \tag{5}$$

$$n = \frac{P}{4\,\pi\, r^2\, h\,\nu\, c} \tag{6}$$

The photon density also decreases as the 2nd power of r. Either a detector counting photons or one measuring energy will show an inverse square law with distance from the source.

2. The experiment

Light source and detector

For this experiment we use a zirconium arc lamp, a bright source only about 0.1 mm in diameter. An electrical discharge occurs between a small metal rod and a disk with a matching hole. The hole is the "point" source. To turn on the lamp, flip the switch and if necessary press the red start button. The source should be located at one end of the optical bench. A schematic illustration of the experiment is shown in Figure 1.1.

The flux is measured with a *p-n* junction photodiode. This device is sensitive to wavelengths from the infrared (1000 nm) to the near ultraviolet (380 nm). It has a small area less than 1 mm^2 so that the photoelectron current is proportional to the flux at the detector. The current flows through the input impedance of a voltmeter to produce signals of a few millivolts.

The photodiode is located on an optical bench with a precision millimeter scale. You will measure the photocurrent for several positions of the diode to see how the signal depends on separation of detector and source.

How to begin

Select a scale of 200 millivolts on the voltmeter. Turn on the light source. Set the detector at about the 30 cm mark and record the signal. It should be of the order of 100 mV.

What to measure

Record the position of the light source carrier, and take readings with the photodiode carrier at every 5 cm out to 100 cm. All the other lights in the booth should be off to avoid an inaccurate measurement. Be careful if you are standing forward of the detector because you can scatter stray light back toward it.

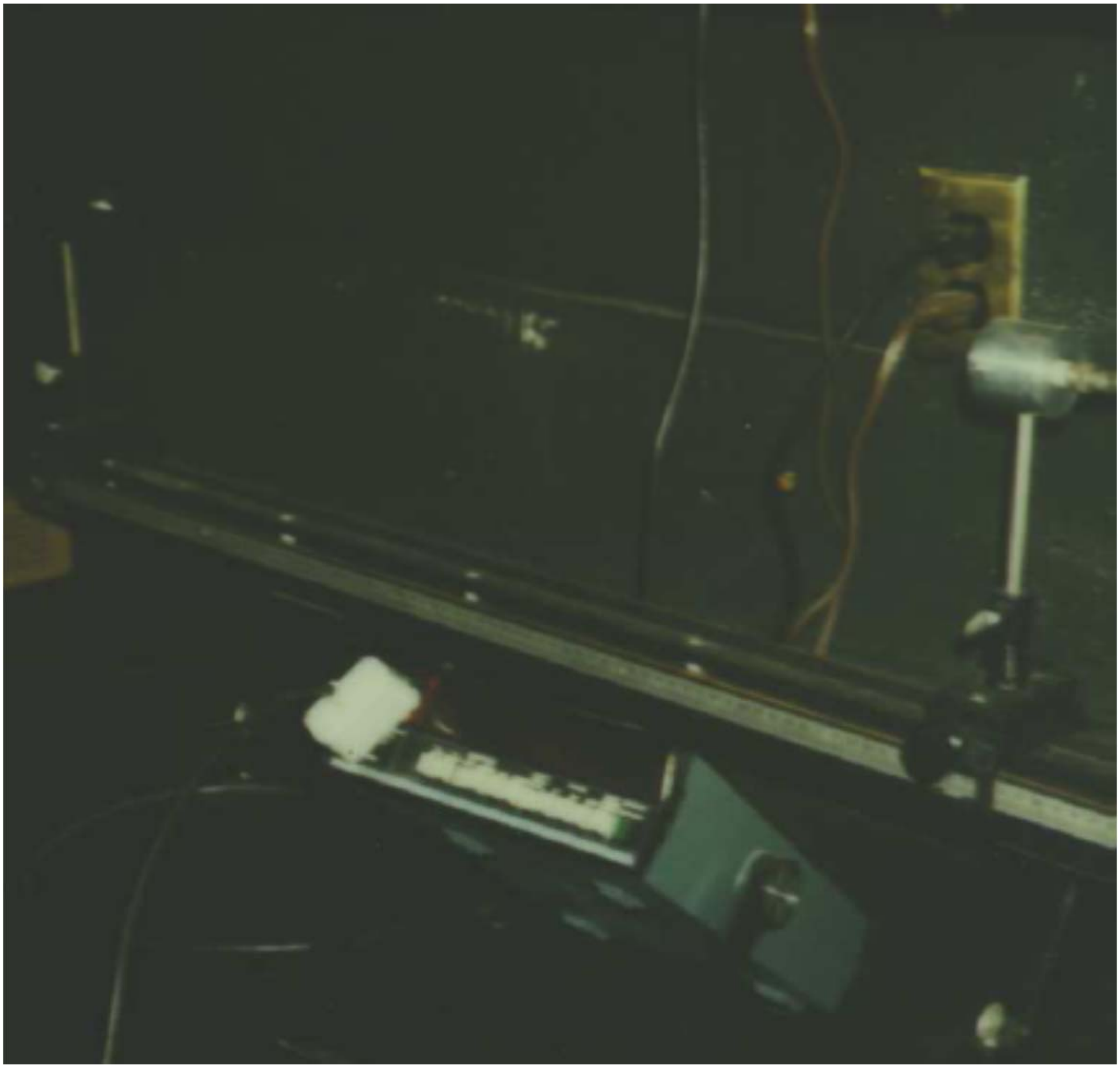

Figure 1.1: In the inverse square law experiment a zirconium arc point light source illuminates a photodiode a distance r away. The photodiode output is measured with a digital millivoltmeter.

Correction for scale zero

Carefully estimate the distance of the point source from the index mark on its carrier using a ruler. A measurement to an accuracy of a few mm should suffice. Similarly, estimate the distance from the photodiode to the index on its carrier. For each measurement of flux calculate the separation of the source and the photodiode.

Observe inverse square behavior

Enter the data into a file on a computer and plot and view the data. Plot graphs of F versus r, and also F versus $1/r^2$. Include printed versions of these graphs with your lab reports. The inverse square law may not seem to hold over the full range of r's. Why? Try to mask the "point source" you have so that it is more like a perfect point source. Also try a very extended source such as a fluorescent tube light. Graph the power flux versus distance for these too. For the extended source, what is the behavior of $F(r)$ at small r, and why?

Check that it really is a power of 2

Create plots of $log_{10}(F)$ versus $log_{10}(r)$. Show that if the inverse square law holds the slope of this graph should be -2. Do a linear least squares fit to the log data, excluding any region you think may suffer from a systematic error. What slope do you find? Include screen dumps of the graphs with your lab report.

A little homework problem ...

For a 100 watt lamp emitting an average wavelength of 550 nm how many photons would there be per cm_3 at a distance of 1 meter from the lamp? How does this compare to the number of molecules per cm^3 in air at atmospheric pressure?