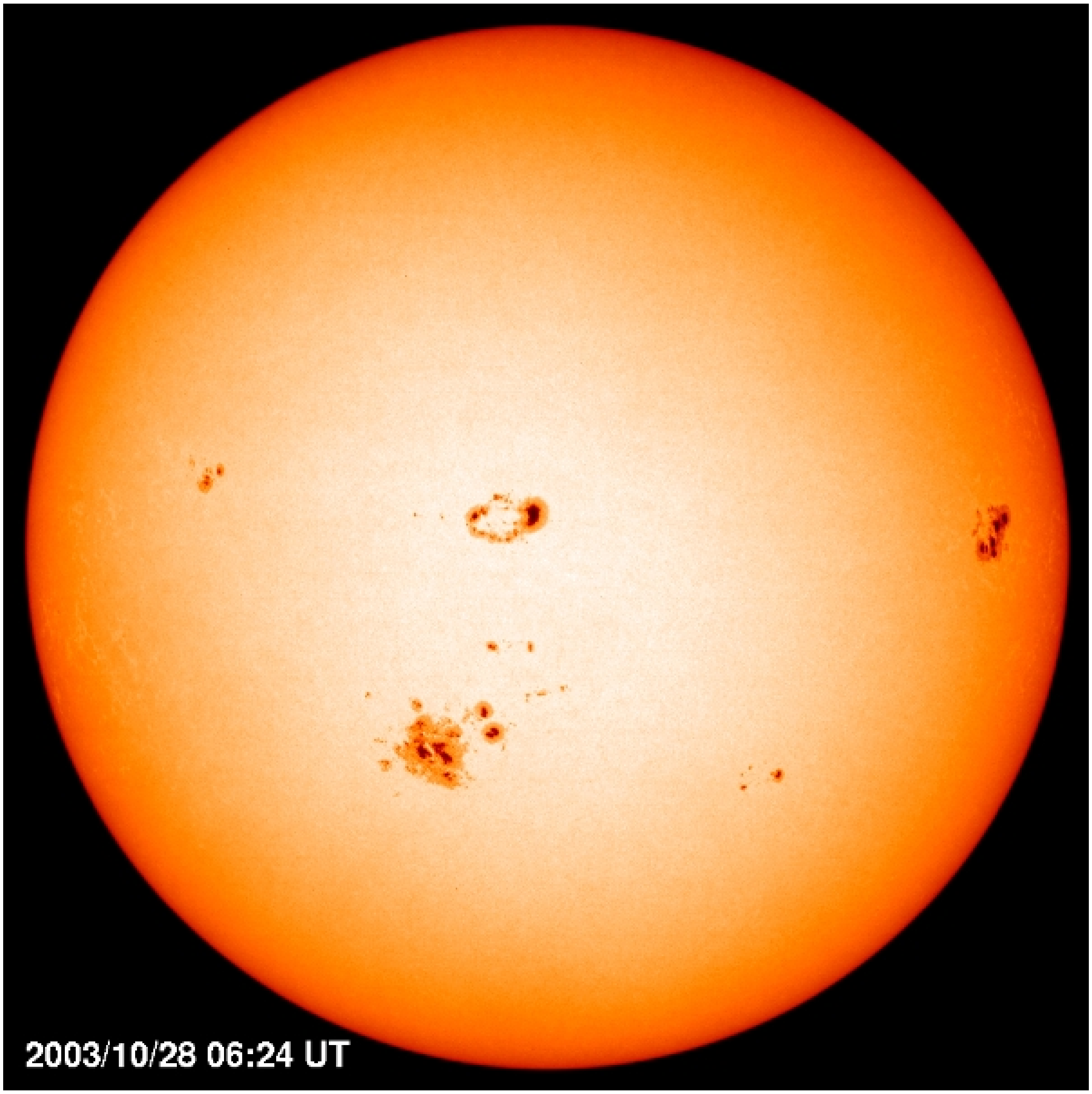
AS 102 – Lab
The Luminosity of the Sun



SOHO Image of the Sun

The Problem

The **luminosity** of a light source – whether it is a star or the Sun or a light bulb – is a measure of the actual light output of the source. Its **apparent brightness** depends on the distance of the source as well as its luminosity. If we understand how apparent brightness changes with distance, we can calculate the luminosity of a star. Or if we know the luminosity and the apparent brightness, we can calculate the distance. The goal of this exercise is to test the inverse square law of brightness, and use this relation to estimate the distance to the Sun.

Introduction

As a distance of a light source from the observer, increases, it appears to get fainter. That is such a simple, common-sense concept that most of us never think about it. But astronomers have learned to use this relationship to derive the distance to stars and galaxies. From simple geometrical considerations one can show that the apparent brightness of an object should **decrease** as the square of its distance **increases**. This **inverse square law** of luminosity is a fundamental relation used by astronomers to compare the luminosities of astronomical objects. It states simply that if the distance to an object is doubled, the apparent brightness decreases by a factor of 4. If the distance increases by a factor of 3, the brightness decreases by a factor of 9, and so on.

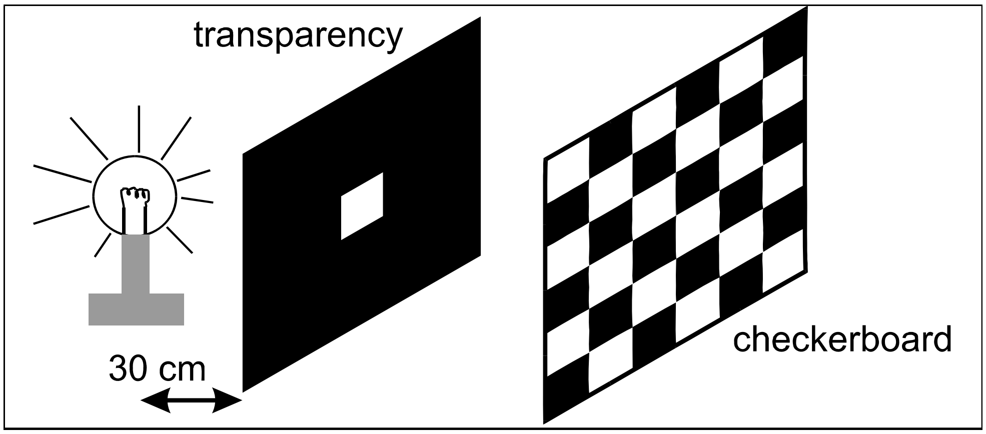


Figure 1: Layout showing illuminating light bulb (and filament), transparency mask, and checkerboard screen.

The goals of this project are first to verify the inverse square law of apparent brightness, and second, to use the law to calculate the actual luminosity of the Sun. The inverse square law can be probed in two ways. The first is by direct projection of a light source through an aperture onto a checkerboard grid (see figure 1). The second is to compare the apparent brightness of two light bulbs of different wattages at different distances. The luminosity of the Sun can be calculated by comparing its apparent brightness with that of a 100 watt light bulb.

The key to these measurements is a very simple device called a **null photometer** or **differential photometer**. A photometer is just a device for measuring the brightness of a light source. With a null photometer, it is possible to compare the brightness of two sources, and to judge when they have the *same* brightness. It is possible to make an extremely simple, but surprisingly precise, null photometer with two blocks of paraffin wax and some aluminum foil. If the aluminum foil is sandwiched between the two blocks and viewed from the edge (see figure 2), the light that strikes the faces of the blocks will diffuse through to the edge.

If the amount of light striking the two faces of the wax blocks is the same, the amount of light escaping through the edge will be the same as well. Conversely, if one of the sources is brighter than the other by even a small amount, the difference will be noticeable because the eye is very good at discriminating small brightness differences. This provides the basis for using the null photometer the help to verify the inverse square law. This can be done by comparing a light source (L1 in figure 2) at some distance, d1, with another source (L2 in the figure) at distance d2. Typically, the distance to one of the light sources is adjusted until the null is reached and the edges appear identical in brightness. Then the distances can be measured and the luminosity law can be easily verified.

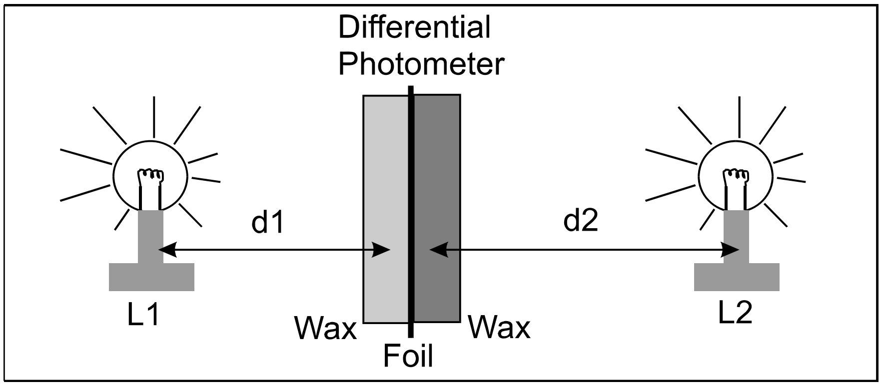


Figure 2: Differential Photometer, consisting of two wax blocks and a piece of aluminum foil between, viewed from the side with two light bulbs. Each bulb illuminates only one wax block.

It is an easy matter to replace one of the light bulbs in figure 2 with the Sun. If the distance to the Sun and the distance and wattage of the bulb are known, then the null photometer measurement will make it possible to learn the luminosity of the Sun.

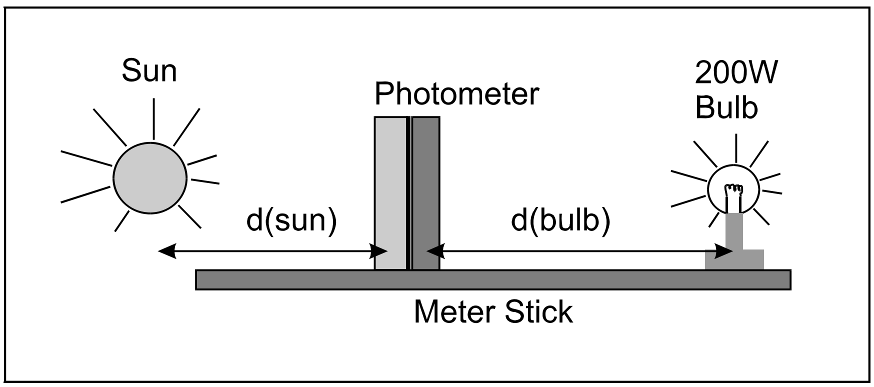


Figure 3: Setup for measuring the luminosity of the Sun.

In principle, this experiment will work with any two light sources. But what happens if the two sources are different in temperature? In particular, a light source such as an ordinary incandescent light bulb is not very hot, and radiates most of its energy in the infrared part of the spectrum. The Sun is much hotter and radiates much of its energy in the visible part of the spectrum. A higher wattage bulb will in general be hotter than a low wattage bulb, and so in the visible part of the spectrum, the lower wattage bulb will appear less efficient. For purposes of this exercise, we can assume that a typical 100 watt light bulb radiates in the visible spectrum with an efficiency of perhaps 10%, or even less

Available Equipment

1. Paraffin-block null photometer.
2. Light bulbs of various wattages.
3. Meter sticks.
4. Mask with an almost-square hole.
5. Checkerboard with a grid pattern with matching rectangles.
6. Colored filters

Suggested Experimental Procedure

Part I. Verification of the inverse square law.

Two experiments can be done to illustrate the nature of the inverse square law:

A. Checkerboard Test

A standard picture in textbooks shows light expanding outward from a source onto a checkerboard – as the distance between the source and the checkerboard increases, the number of illuminated rectangles increases. This idea can be put into an experiment in the lab.

1. Begin by experimenting with the proper set-up procedure. Decide on a suitable arrangement of the light source, mask and checkerboard. You might find that putting a colored filter in from of the light will help you to visualize the situation. Start by setting up a light bulb some distance away from the mask (perhaps 30 cm). Place the checkerboard at various distances from the mask. Can you find a way to illuminate just one box on the checkerboard? Take note of what you find and describe any difficulties or surprises you found.

2. Now make some quantitative measurements. Adjust the position of the checkerboard so that the projection of the mask hole fills one square. Record the distance between the light and the checkerboard. Next double the distance between the mask and the checkerboard. Count the number of rectangles covered by the light through the mask. Repeat the process with the distance between the mask and the checkerboard set at 3 and 4 times the original distance. These data can be used to test the inverse square relation (see the analysis section below).

B. Null Photometer measurements

For the second experiment, use the paraffin-block null photometer to compare the apparent brightness of light bulbs with one another. Set light bulbs up, two at a time approximately 2 meters apart. Take the time to shield your lights from the other groups and to shield your null photometer from any stray light the other groups may create. Move the null photometer along the meter sticks until there is a balance. Record the wattages of the lights, the distances from the photometer to the two bulbs, and other relevant information. You should try this experiment with several pairs of light bulbs of various wattages. Can you reconcile the wattages and the relative distances of the lights?

Part II. The Luminosity of the Sun

Choose one light bulb as a reference source for comparing to the luminosity of the Sun. Start with the bulb at a convenient distance from the null photometer (for example, one meter away). Move the photometer along the meter stick until there is a balance between the light coming from the two sides (with the Sun on one side and the light source on the other). Record the distance between the reference source and the null photometer.

Analysis and discussion

From part I you should have the count of the number of rectangles illuminated at each distance setting. The test is to see what the relationship is between the separation of the mask and the checkerboard and the size of the illuminated area on the mask. The inverse square law predicts that the illuminated area should equal the square of the distances – so try plotting the distance squared vs rectangles illuminated.

In the second experiment of part I, you will need to assume that the luminosity of each bulb is proportional to the wattage of the bulb. The null photometer has already told us that the apparent brightnesses of the two bulbs are equal. So the ratio of the bulb wattages should equal the ratio of the distances squared. Here a table showing the distance and luminosity ratios you get with the various combinations should test the hypothesis.

For part II, you know the luminosity of the bulb (you will have to trust the manufacturer for this), and you have measured the distance from the bulb to the null photometer. The distance to the Sun is known to be 1.49×10^8 km. So it is a simple matter to calculate the luminosity of the Sun from this information. Be sure to keep your units straight.

For your error analysis, there are only a few possible sources of error: there is your uncertainty in deciding when you have a null, there is the uncertainty of your distance measurements and there is the uncertainty in the wattages of the bulbs. You can evaluate how accurately you can estimate the null reading on your photometer from your data in the second experiment of part I. You may also be able to estimate how accurate the claimed bulb wattages are.

There is one final source of uncertainty that may be the most important one. The Sun has a temperature of almost 6000K, whereas the light bulbs have temperatures less than 1500K. So the bulbs have a very different spectrum from the Sun, which means that to some degree, the comparison is not valid.

Records and Data

You must attach your **origina**l data pages and lab notes to your report. These should include notes on the details of your experimental procedure, all your actual measurements, and any other materials that you generate while you are doing the lab. Your report should be consistent with these data pages.

AS 102 – Lab 3 Preparation

The Luminosity of the Sun

Name________________________

Answer the questions directly on this page and hand the form in at the beginning of the lab.

1. If one star appears 16 times brighter than another, can you tell how much closer the bright one is? If the two stars have the same color (or temperature) what would be a reasonable guess as to their relative distances?

2. As you move the checkerboard closer or further from the light source (see figure 1), what do you expect to happen to the brightness of the light in each square?

3. Strictly speaking, the comparison between the light bulb and the Sun is not valid. What is the problem that we will be ignoring?

4. What are some of the things that you do not understand about this exercise?