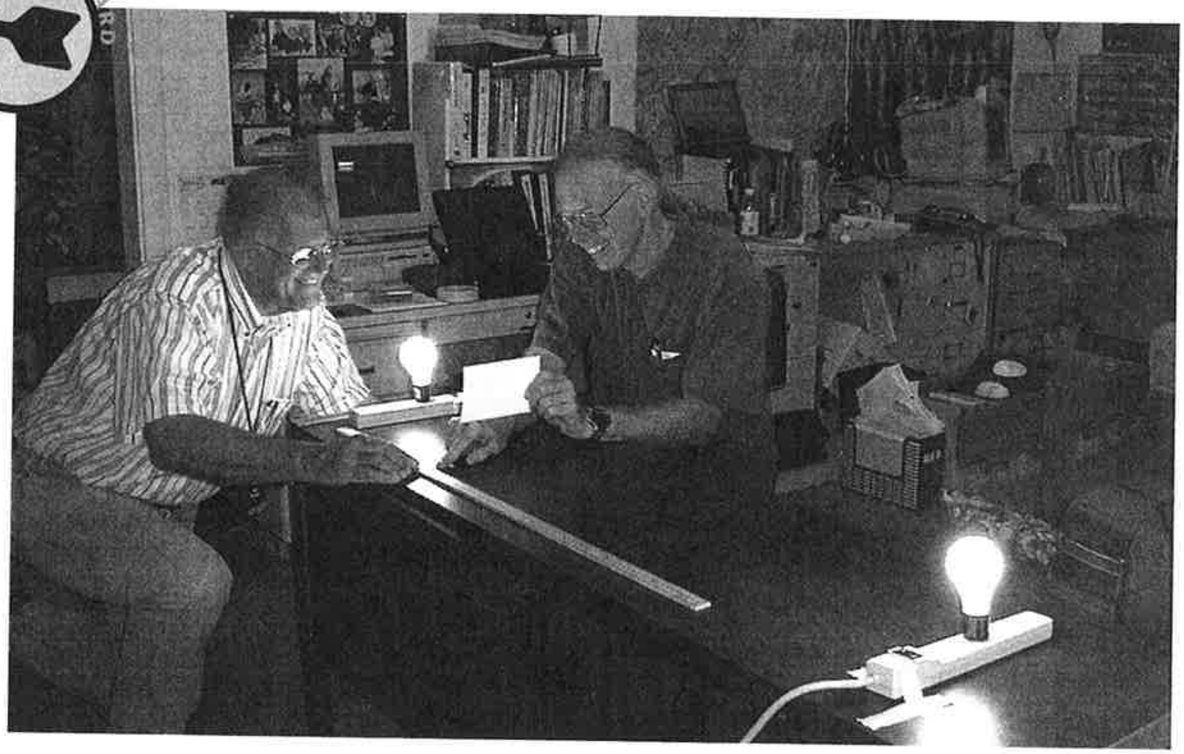
# Oil-Spot Photometer

## Greased lighting.

**A** drop of grease or oil on white card stock is easily visible because it changes the way that light interacts with the card. In this snack, you take advantage of this effect to make a kind of light meter. When an oil spot on a card is illuminated equally from both sides, it mysteriously disappears. This allows you to compare the brightness of the light sources on either side of the card.

# Materials

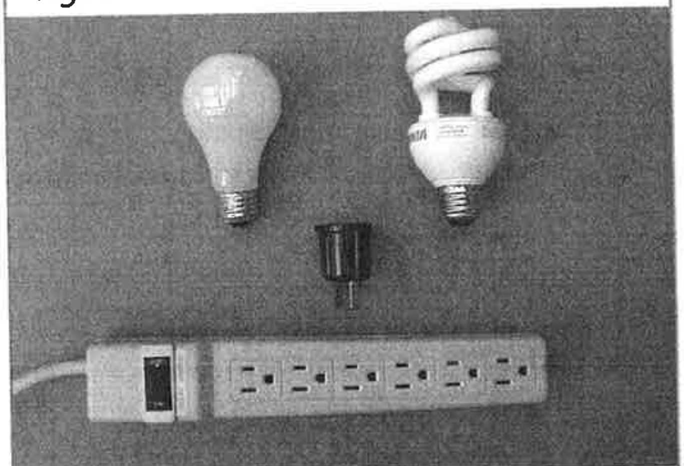
- 1 drop of cooking oil
- white card (e.g., 4 in × 6 in or 3 in × 5 in)
- paper towel or tissue
- 2 new 60-watt frosted incandescent light bulbs (bulbs should be as identical as possible, e.g., same brand, both standard or both "soft white")
- 2 power strips
- 2 plug-in lamp sockets (see figure 1)
- extension cord(s) as necessary to allow both lights to be placed on a table and moved about 3 ft (1 m) apart
- 1 40-watt frosted incandescent light bulb (other characteristics the same as the 60-watt bulbs if possible)
- 1 75-watt frosted incandescent light bulb (other characteristics the same as the 60-watt bulbs if possible)
- pot holder or towel for handling hot bulbs
- 1 compact fluorescent light bulb that fits a standard socket and is intended to replace a 60-watt incandescent bulb
- packaging that the light bulbs came in, containing information about power (watts) and illumination (lumens)

# ASSEMBLY

**1** Dip your finger into a drop of cooking oil, and then press the end of your finger on the middle of the white card, forming an oil spot about a half inch to 1 inch (1 or 2 cm) in diameter. Make sure the spot is visible on both sides of the card. Use a paper towel or tissue to blot excess oil from the spot, but do not smear oil anywhere else on the card.

**2** Put the two 60-watt bulbs in the sockets and plug one socket into each power strip. Then place the power strips so that the centers of the bulbs are about 6 feet (2 m) apart and turn the bulbs on. If you're short of space the bulbs can be as close as 3 feet (1 m) apart, but 6 feet is better.

***Figure 1***



***A power strip, plug-in socket, incandescent bulb, and a compact fluorescent bulb. A light bulb can be screwed into the socket, which can then be plugged into the power strip.***

## To Do and Notice

Hold the card upright between the lights, so that each side of the card directly faces one of the lights.

Move the card back and forth between the lights so that it is first closer to one light and then the other. As you do this, stand so you can keep your eye on one side of the card. What happens to the darkness and lightness of the oil spot (compared to the rest of the card) as you move the card back and forth? When is the spot darker than the rest of the card? When is it lighter?

Notice that there is a location between the lights where the grease spot comes close to disappearing. Move the card to this location, and take note of where it is relative to the two lights.

Replace the two 60-watt light bulbs with the 40-watt and 75-watt bulbs (use the pot holder or towel if the lights are hot). As before, find the position between the lights where the oil spot disappears, and notice the approximate location of the card relative to the two lights.

Replace the 40-watt and 75-watt bulbs with a 60-watt incandescent bulb and the compact fluorescent bulb that is designed to serve as a replacement for a 60-watt incandescent bulb. (**Note:** You may have to let the fluorescent bulb warm up for a short time to achieve full brightness.) Again, locate the position between the lights where the oil spot disappears, and notice the approximate location of the card relative to the two lights.

Hold your hand above each of the bulbs. You should easily be able to feel that the incandescent bulb is much hotter than the fluorescent bulb. Now take a look at the boxes these two bulbs came in, and notice the power (watts), illumination (lumens), and price for each bulb. (If the prices aren't printed on the boxes, see if you can find out what they are.)

## What's Going On?

Compared to the normal white surface of the card, the oil spot reflects less light and transmits (lets pass through) more light. When the side of the card you are looking at is illuminated more than the other side, more light is reflecting from the rest of the card than from the oil spot, and the amount passing through the spot toward you from the dimmer side isn't enough to make up the difference. As a result, the oil spot appears darker than the rest of the card.

When the side of the card you are looking at is illuminated less than the other side of the card, there is still more light reflecting from the rest of the card than from the oil spot, but the amount passing through the spot toward you from the brighter side is more than enough to make up the difference. As a result, the oil spot appears lighter than the rest of the card.

The oil spot disappears when it is equally illuminated from both sides. In this case, the combination of the light reflected from the oil spot plus the light transmitted through it from the other side is equal to the light reflected from the card. For the two 60-watt bulbs, this point should be about halfway between the two bulbs, since they should be providing approximately equal illumination. For the 40- and 75-watt bulbs, however, the location where the spot disappears should be noticeably closer to the 40-watt bulb. The dimmer the light source, the closer you have to be to it to receive a given amount of illumination.

For the 60-watt incandescent bulb and the fluorescent "60-watt replacement" bulb, the card should again be approximately halfway between the two bulbs when the oil spot disappears, showing that the two lights are of approximately equal brightness. Fluorescent bulbs are more efficient than incandescent bulbs, converting a greater percentage of electrical energy into light rather than heat. According to the ratings on the boxes, the fluorescent bulb we experimented with uses 16 watts of electricity to give a light output of 800 lumens, whereas the incandescent bulb uses 60 watts of electricity to give a light output of 855 lumens. The fluorescent bulb gives about 90 percent of the light output of the incandescent bulb, but uses only about 25 percent as much energy to do it.

# So What?

The fluorescent bulb costs more than the incandescent bulb. But, according to the manufacturer, the fluorescent will last up to ten times longer and will consume far less energy in the process. Overall, there is a significant savings in both cost and energy consumption. Replacing some household incandescent bulbs with fluorescent bulbs is an easy way for people to conserve energy.

# Did You Know?

### *Orange Hot*

Both the sun and most of the light bulbs we use are incandescent producers of light. That is, they emit light because they're hot. When an electric current passes through the tungsten filament of an incandescent bulb, it heats up to about 2900 Kelvin (4700°F). That's about half the temperature of the sun. The glowing filament looks orange because it's cooler than the sun, and so it gives off proportionately more long-wavelength radiation, which we see as reddish-orange light. If it could get hotter, it would look more white.

### *Blue + Red = White*

When electricity passes through a fluorescent bulb, the moving electrons excite the mercury vapor that fills the bulb. In response, the mercury vapor emits mostly high-frequency blue light (which we can see) and ultraviolet light (which we can't see). A phosphorescent material that coats the inside of the bulb absorbs this ultraviolet light and emits lower-frequency visible light.

Try waving a white-barreled pen over a piece of black paper in a room lit by normal fluorescent lights. You should be able to see bluish and reddish bands as the pen waves back and forth. Why? Fluorescent lights flash on and off 120 times a second. During the moment the light is on, you see bluish light emitted by the mercury vapor. Then, a fraction of a second later when the light is off, you see reddish light emitted by the glowing phosphors. Together, the bluish light and reddish light look white.

### *A Bunsen What?*

A slightly more sophisticated form of the oil spot photometer you make in this snack is officially known as a Bunsen photometer.

# Going Further

### *Double Bright*

If you hold the oil-spot card between a single 60-watt bulb on one side and two adjacent 60-watt bulbs on the other, where will the "equal point" be? Try predicting the location of the equal point using this hint: Brightness varies inversely with the square of the distance from the light source. Then set up the bulbs this way and test your prediction. (See Box o' Math for an explanation.)

### *A Bright Idea*

How much brighter is the 75-watt bulb than the 40-watt bulb? Use your photometer and the inverse square relationship cited above to figure this out.

### *How Much Dimmer?*

Use your photometer to test the relative light output of bulbs that have the same wattage but differ in some other way (e.g., a new bulb and a bulb that's been used for awhile, or two different brands or shapes of bulb, or a standard bulb and a "soft white" bulb).

### *Light and Power*

On the bulb packages, light output is given in lumens. In incandescent bulbs, are lumens and watts proportional? Would twice the wattage give twice the light output? How are lumens and watts related? Look up lumen and the related units candela and lux.

## Box o' Math

### *Inverse Square Law*

The intensity of a light ($I$), which the human eye sees as brightness, is the light power ($P$) per unit area ($A$):

$$I = \frac{P}{A}$$

As light moves outward from a bulb, the power spreads over a spherical area of radius ($r$) that increases as the square of the distance from the bulb. The area ($A$) of a sphere with radius $r$ is

$$A = 4\pi r^2$$

So for a bulb of constant power ($P$), the intensity is

$$I = \frac{P}{A} = \frac{P}{4\pi r^2}$$

Because $r^2$ is in the denominator of the fraction, it's verbally described as an *inverse square.*

When the oil-spot card held between two light sources reaches the point of equal brightness, the intensities of the two lights are the same. Therefore, $I_1 = I_2$ since the power of one light is $P_1$ and the power of the other is $P_2$, while the distance from the center of one light to the card is $r_1$ and from the other light is $r_2$:

$$\frac{P_1}{4\pi r_1^2} = \frac{P_2}{4\pi r_2^2}$$

and

$$\frac{P_1}{P_2} = \frac{r_1^2}{r_2^2}$$

The above equations let us calculate the distances at which two lights of different powers will balance. For example, if the second light is twice the power of the first, $P_2 = 2P_1$, then

$$\frac{P_1}{P_2} = \frac{1}{2} = \frac{r_1^2}{r_2^2}$$

and

$$\frac{r_1}{r_2} = \frac{\sqrt{1}}{\sqrt{2}} = \frac{1}{1.4}$$

The distance to the brighter light is 1.4 times the distance to the dimmer light.

Light is one of many phenomena that vary inversely with the square of the distance from the source. Other phenomena that follow an inverse square law include sound, magnetism, and gravity.

## Credits

This snack is related to the Exploratorium exhibit Light Edge Photometer.