



## 28.2 Calculating Luminosity

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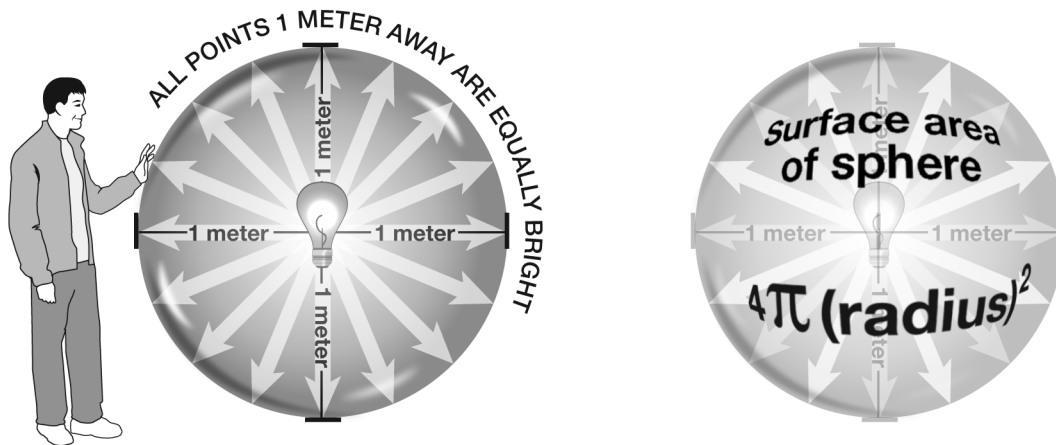


You have learned that in order to understand stars, astronomers want to know their luminosity. *Luminosity* describes how much light is coming from the star each second. Luminosity can be measured in watts (W).

Measuring the luminosity of something as far away as a star is difficult to do. However, we can measure its brightness. *Brightness* describes the amount of the star's light that reaches a square meter of Earth each second. Brightness is measured in watts/square meter ( $\text{W}/\text{m}^2$ ).

The brightness of a star depends on its luminosity and its distance from Earth. A star, like a light bulb, radiates light in all directions. Imagine that you are standing one meter away from an ordinary 100-watt incandescent light bulb. These light bulbs are about ten percent efficient. That means only ten percent of the 100 watts of electrical power is used to produce light. The rest is wasted as heat. So the luminosity of the bulb is about ten percent of 100 watts, or around 10 watts.

The brightness of this bulb is the same at all points one meter away from the bulb. All those points together form a sphere with a radius of one meter, surrounding the bulb.



If you want to find the brightness of that bulb, you take the luminosity (10 watts) and divide it by the amount of surface area it has to cover—the surface area of the sphere. So, the formula for brightness is:

$$\text{brightness} = \frac{\text{luminosity}}{\text{surface area of sphere}} = \frac{\text{luminosity}}{4\pi(\text{radius})^2}$$

The brightness of the bulb at a distance of one meter is:

$$\frac{10 \text{ watts}}{4\pi(1 \text{ meter})^2} = \frac{10 \text{ watts}}{12.6 \text{ meter}^2} = 0.79 \text{ W}/\text{m}^2$$

Notice that the radius in the equation is the same as the distance from the bulb to the point at which we're measuring brightness. If you were standing 10 meters away from the bulb, you would use 10 for the radius in the equation. The surface area of your sphere would be  $4\pi(100)$  or 1,256 square meters! The same 10 watts of light energy is now spread over a much larger surface. Each square meter receives just 0.008 watts of light energy. Can you see why distance has such a huge impact on brightness?



If we know the brightness and the distance, we can calculate luminosity by rearranging the equation:

$$\text{luminosity} = \text{brightness} \times \text{surface area of sphere} = \text{brightness} \times 4\pi(\text{distance})^2$$

This is the same formula that astronomers use to calculate the luminosity of stars.

### EXAMPLE

You are standing 5 meters away from another incandescent light bulb. Using a light-meter, you measure its brightness at that distance to be  $0.019 \text{ watts/meter}^2$ . Calculate the luminosity of the bulb. Assuming this bulb is also about ten percent efficient, estimate how much electric power it uses (this is the wattage printed on the bulb).

**Step 1:** Plug the known values into the formula:

$$\text{luminosity} = \frac{0.019 \text{ watts}}{\text{meter}^2} \times \frac{4\pi(5 \text{ meters})^2}{1}$$

**Step 2:** Solve for luminosity:

$$\text{luminosity} = 0.019 \times 100\pi \text{ watts} = 6 \text{ watts}$$

**Step 3:** If the bulb is only about ten percent efficient, the electric power used must be about ten times the luminosity. The bulb must use about  $10 \times 6 \text{ watts}$ , or 60 watts, of electric power.

### PRACTICE

1. Ten meters away from a flood lamp, you measure its brightness to be  $0.024 \text{ W/m}^2$ . What is the luminosity of the flood lamp? What is the electrical power rating listed on the bulb, assuming it is ten percent efficient?
2. You hold your light-meter a distance of one meter from the light bulb in your refrigerator. You measure the brightness to be  $0.079 \text{ W/m}^2$ . What is the luminosity of this light bulb? What is its power rating, assuming it is ten percent efficient?
3. **Challenge:** Finding the luminosity of the sun.

You can use the same formula to calculate the luminosity of the sun.

Astronomers have measured the average brightness of the sun at the top of Earth's atmosphere to be  $1,370 \text{ W/m}^2$ . This quantity is known as the *solar constant*.

We also know that the distance from Earth to the sun is 150 billion meters (or  $1.5 \times 10^{11}$  meters).

What is the luminosity of the sun?

Hints:

1. You may wish to rewrite the solar constant as  $1.370 \times 10^3 \text{ W/m}^2$ .
2.  $(10^{11})^2$  is the same as  $10^{11} \times 10^{11}$ . To find the product, add the exponents.
3. Don't forget to find the square of 1.5!