McAuliffe-Shepard Discovery Center

Solar Intensity

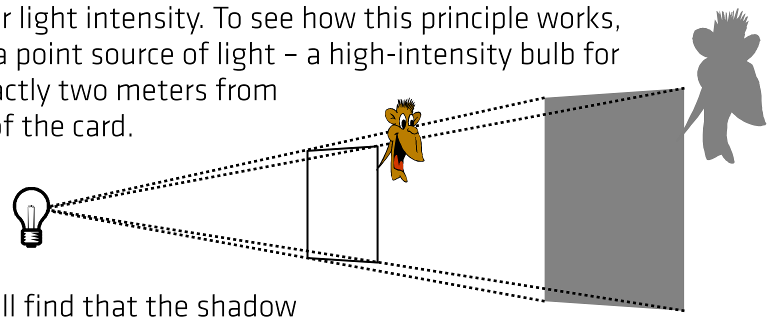
Because their distances from the Sun vary, the planets do not all receive the same intensity levels of solar energy. If you could stand on Mercury and peer at the Sun (wow, that's blinding!), it would look almost three times as big as it does from Earth; and the intensity of solar radiation would be almost seven times that on Earth. At the farther reaches of the solar system, say on Pluto, the effect would be quite different. There the Sun would appear as a very bright star, and the light level would resemble being in a dimly lit room.

In terms of the physics involved, we know precisely how much sunlight falls on a planetary body at any distance from the sun. There is an unchanging mathematical relationship: The intensity of solar energy at any point in the solar system is inversely proportional to the square of its distance from the Sun, or, expressed in symbols,

$$I \propto 1/d^2$$

where I is solar intensity and d is distance from the Sun.

This principle is known as the inverse square law for light intensity. To see how this principle works, imagine a rectangular card placed one meter from a point source of light – a high-intensity bulb for instance. Now imagine a moveable wall located exactly two meters from the light source on which is projected the shadow of the card. The shadow's dimensions will be twice the dimensions of the card, and the area of the shadow will be four times the area of the card.



Move the wall back an additional meter, and you will find that the shadow has grown to three times the dimensions and nine times the area of the card.

If you take away the card, the light that illuminates the area that used to be in shadow is the same light that fell on the card before it was removed. What's different is not the amount of light reaching the card or the wall, but its intensity (brightness). Double the distance and the light intensity is reduced to one-fourth the amount. Triple the distance and it is reduced to one-ninth, and so on. In general terms, the amount of light stays the same, but it is spread over an increasingly larger area as you move away from the light source, so the intensity is less.

When considering the intensity of solar radiation on the nine planets of the solar system, it is sometimes useful to think of relative intensity, a ratio comparing the solar intensity to that on Earth. For the reasons explained above, if a hypothetical planet were twice the distance from the Sun as Earth, the solar intensity would be one-fourth the solar intensity on Earth. For any planet, this ratio, derived from the inverse square law, may be written as follows:

$$\text{Relative solar intensity} = \frac{I_{planet}}{I_{Earth}} = \frac{d^2_{Earth}}{d^2_{planet}}$$

At this point it is helpful to introduce the concept of the astronomical unit (abbreviated AU), as its use in the above equation simplifies the math. One astronomical unit is defined as the mean Earth-Sun distance, which is 149,597,870.66 kilometers (rounded to 150 million km), or 92,955,807.25 miles (rounded to 93 million miles). For reasons that are probably obvious, interplanetary distances are often written in AUs.

The table below lists the eight planets plus dwarf-planet Pluto and their distances from the Sun. Complete the column for relative solar intensity by applying the given equation. The calculation for Mars is provided as an example.

$$\frac{I_{Mars}}{I_{Earth}} = \frac{d^2_{Earth}}{d^2_{Mars}} = \frac{1^2}{1.524^2} = 0.431$$

The calculation shows that Mars, at a little more than 1.5 times Earth's distance from the Sun, receives solar radiation that is about 43 percent of the intensity on Earth. Can you tell, without using a calculator, which planet has only 1/900th, or 0.00111 times, the solar intensity on Earth?

Planet	*Mean Distance from Sun (AU)*	*Relative Solar Intensity*
Mercury	0.387	
Venus	0.723	
Earth	1.000	
Mars	1.524	0.431
Jupiter	5.203	
Saturn	9.539	
Uranus	19.189	
Neptune	30.060	
Pluto	39.439	

Take a moment to consider the possibility of a future colony on Mars or beyond, where the level of solar intensity would be less – possibly many times less – than it is on Earth. Think about ways in which the weaker sunlight might affect life in the colony and how technology might be employed to deal with this situation. Jot down your impressions and ideas in a few sentences.

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You might be thinking that reduced sunlight would be a major consideration in planning for a remote colony in space. Because of its proximity and physical characteristics, Mars presents itself as the most likely candidate for such a mission. In the opinion of many experts, the technological demands of establishing a temporary outpost on Mars, although daunting, could be met within a few decades from now.

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Solar intensity

Teachers' Notes

Objectives: Students will learn that solar intensity follows the inverse square law and will perform calculations to compare solar intensity among the nine planets of our solar system.

Grade Level: High

NSES: A5, A6, B6, B11, C7, C13, D6, E6, E7, F10, F13

NHSCF: 1a, 2c, 4a, 5c, 5g

Key Concepts

The intensity of solar energy varies inversely with the square of the distance from the Sun. Because of this mathematical relationship, sunlight intensity diminishes rapidly beyond Earth's orbit. Solar intensity on Mars is less than half that on Earth; while on dwarf-planet, Pluto, solar intensity is reduced to less than one-tenth of one percent that on Earth.

Consideration of relative intensity is not limited to comparisons with Earth. For example, we can observe that Mars, being twice the distance from the sun as Venus, experiences only one-fourth the solar intensity of Venus. And Neptune, being 20 times farther from the sun than Mars, receives about $^1/_{400}$th the sunlight intensity of the closer planet. Having astronomical distances presented as they are in the student activity sheet makes these sorts of comparisons easy, for it is necessary only to square the ratios of the distances.

The extreme range in solar radiation levels provides a ready explanation for differences in surface temperatures between the innermost planets and the more distant objects in the solar system. However, solar intensity is only one factor affecting surface temperature, even if it is the most important. The presence of an atmosphere, geologic activity, and albedo are significant other factors in determining how warm or cold a planet is. Such considerations may be brought out in class discussion to help give context to the solar intensity values that students are asked to calculate and compare.

The writing component is intended to elicit students' thoughts about the possible obstacles to space colonization that derive from reduced solar intensity levels. Some students may recognize solar energy as a significant potential source of power in the inner regions of the solar system, but of greatly diminished value in the outer regions. Consideration of energy supply may lead to discussion of alternatives to solar power. Other students may express concern over the psychological effects of reduced natural daylight levels – a sort of "cabin fever" brought on by unrelenting dusk and darkness in an otherworldly setting.

Technical note: *Flux* is the term often used for radiation intensity. Solar flux at the top of Earth's atmosphere is approximately 1,370 watts of power per square meter of area (abbreviated W/m^2). Although it is an average, this quantity is referred to as one solar *constant*. The actual value varies slightly because of the elliptical nature of Earth's orbit and because of fluctuations in sunspot activity affecting solar output. This last point is of considerable interest, as cyclical periods in sunspot activity lasting hundreds or thousands of years have been linked to episodes of global warming and cooling in Earth's recent past. However, when viewed over very long periods of time, solar intensity has remained sufficiently stable that life on Earth has been able to adapt and flourish.

Extension Activity: Have students research and present their findings on the relationship between global temperatures and the Maunder Minimum in recorded sunspot activity. A good place to learn about this topic is the following website:

http://solarscience.msfc.nasa.gov/SunspotCycle.shtml

For general information on solar intensity and the inverse square law, visit these websites:

http://csep10.phys.utk.edu/astr162/lect/light/intensity.html
http://www.atmos.washington.edu/~davidc/ATMS211/Lecture12-handout-PDF.pdf

ANSWER KEY

Planet	*Mean Distance from Sun (AU)*	*Relative Solar Intensity*
Mercury	0.387	*6.68*
Venus	0.723	*1.913*
Earth	1.000	*1.000*
Mars	1.524	*0.431*
Jupiter	5.203	*0.0369*
Saturn	9.539	*0.0110*
Uranus	19.189	*0.00272*
Neptune	30.060	*0.00111*
Pluto	39.439	*0.00064*