MEASURING AND GRAPHING LIGHT (TEACHER'S COPY)

ENGAGE

1. On a sticky note, write your answer to this question: What planet or moon in the Solar System (excluding Earth) should our country target for building a human colony?

Slide 5. Answers will vary. Mars, Venus, Earth's Moon, and Jupiter Moons will be popular.

2. As directed by your teacher, form pairs and compare answers. Explain to your partner why you think your location would be a good place. Then, form groups of four and repeat the process. Finally, post your suggestion where the entire class can see it. Fill out T-Chart below as you watch the video "Can We Colonize Mars?" (https://youtu.be/9yI3U_yCfj8)

   Record the benefits and challenges of targeting Mars for a colony (Slide 6):

Reasons to Target Mars	Challenges of Building on Mars
• Water on surface	• Produces food
• Oxygen in soil	• Less heat and energy from sun
• Gets "enough" sun	• Dangerous bacteria
• Earth-like day length	• Radiation
• Etc.	• Time delay
	• No ozone layer (no atmosphere)
	• Etc.

3. One challenge of colonizing Mars is collecting solar energy for warmth and energy. List strategies the video suggests for collecting this beneficial solar radiation.

Slide 7. The video implicitly mentions several strategies for gathering beneficial radiation: (a) placing colonies near the equator; (b) using satellites to redirect light; (c) darkening the soil (to increase light absorption); and (d) adding atmosphere to increase heat retention (IR radiation from the Mars surface). Discuss to help students realize the implicit connection to solar radiation gathering.

4. Managing hazardous radiation is another challenge. What types of electromagnetic radiation from the Sun are hazardous? (See the figure below.)

Types of Electromagnetic Radiation Made by the Sun

Slide 7. UV is a well-known form of damaging radiation and causes skin cancer. X-ray and gamma radiation are also harmful. IR is not considered harmful. Solar wind is comprised of ionized particles, not EM radiation, but is another harmful emission from the Sun.

5. Mars is farther from the Sun than the Earth. Does that make the intensity of incoming solar radiation relatively higher on Mars or on Earth? Explain.

Slide 8. See the note for the below question for more information.

6. In general, does the amount of radiation increase, decrease, or stay the same as the distance from a source is increased? Is there a mathematical equation for this relationship?

Accept varied answers as hypotheses preceding the lab activity. Moving further from the Sun reduces incoming radiation, and many students will have this basic intuition. Possibly, a few students will know about the inverse square mathematical relationship. Emphasize that these questions will be answered by completing the Explore phase.

EXPLORE

Measurements:

1. Form groups as directed. Each group needs one flashlight and 1–2 metersticks.
2. In a dark room, hold the flashlight at a distance shown in Column 1 of the data table away from a flat surface (it can be a wall, the floor, or a table).
3. For each distance from the surface (Column 1), measure the RADIUS of the OUTERMOST circle of light in centimeters (cm). Record this radius in Column 2 of the data table on page 4. Measure all of the Column 2 radii before calculating Columns 3–5.

Calculations:

1. Calculate Column 3 by dividing the number in Column 2 by 100 (100 centimeters = 1 m).
2. Using ***COLUMN 3*** radii, calculate the light circle AREA using the area equation for a circle: AREA = πr^2. Report results in Column 4.
3. Brightness (or intensity) of light depends on the area the light occupies. So, you can calculate the brightness of light by dividing the number "1" by the area in Column 4. (A shortcut is to use the "1/x" button with the Column 4 result). Write the result of this calculation in Column 5.
4. Have your teacher check your calculations before continuing. Numbers in Column 5 should decrease as you go down the table and near or greater than "1" in value.

Graphing: Use the graph paper on the page 4 to make two scatter graphs.

GRAPH A. Plot CIRCLE RADIUS (Column 2; y-axis) vs. distance from surface (Column 1; x-axis)

GRAPH B. Plot BRIGHTNESS (Column 5; y-axis) vs. distance from surface (Column 1; x-axis).

Label the axes of graphs. Numerically spread data along axes. (Do not evenly space numbers if they are not evenly spaced).

Checking student data and graphs:

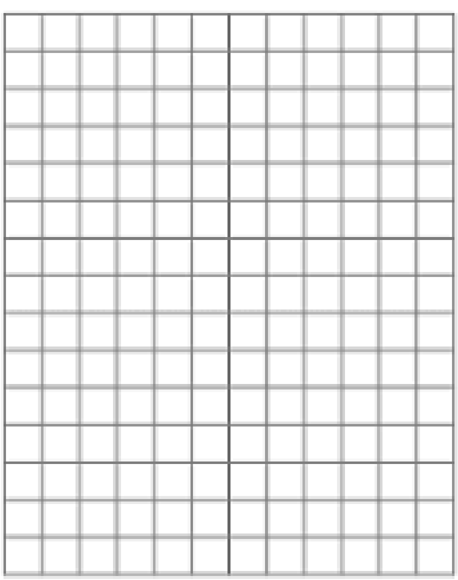
Column 2 should be linearly increasing. Column 3 should be 100 times smaller than Column 2. Column 4 should be geometrically increasing (area ~ radius squared) and relatively small numbers (Column 3 data). Column 5 should be geometrically decreasing (inverse of area)

Graph A should be linear with positive slope. Graph B should look like Graph C.

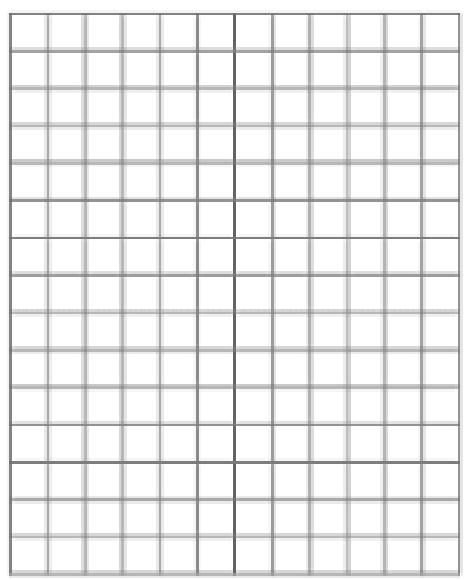
DATA TABLE

Column 1 Light distance from surface (cm)	Column 2 Light circle radius (cm)	Column 3 Light circle radius (m) = Column 2 / 100	Column 4 Light circle AREA $=\pi$(radius)(radius) $= \pi r^2 = \pi$ (column 3)^2	Column 5 Light circle BRIGHTNESS = 1/AREA = 1/Column 4
7				
14				
21				
28				

GRAPH A: Radius vs. Light Distance

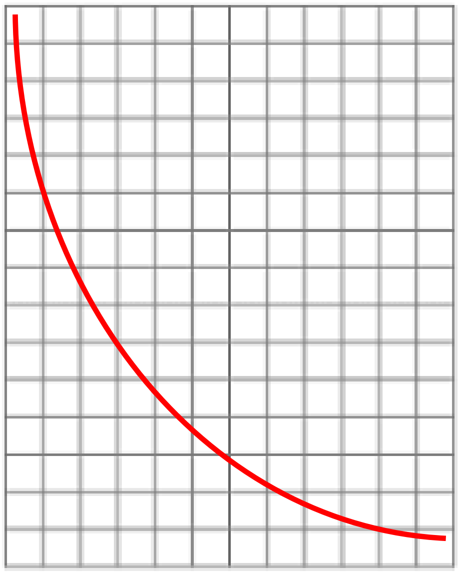


GRAPH B: Brightness vs. Light Distance



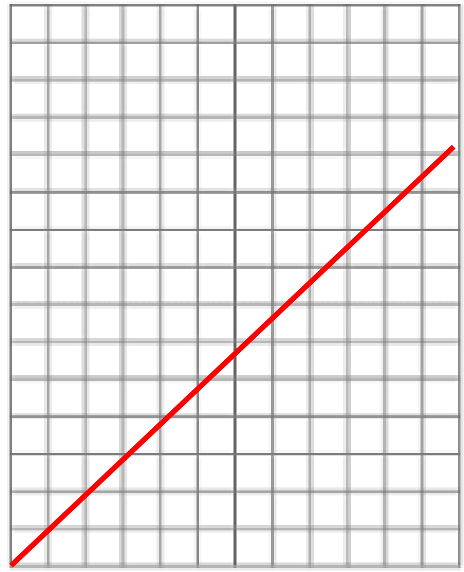
GRAPH C: An INVERSE Relationship

y ~ 1/x ; y decreases as x increases



GRAPH D: A DIRECT Relationship

y ~ x ; y increases as x increases



EXPLAIN

1. Look at Graph A. As the distance between a flashlight and a surface increases, does the light circle RADIUS increase or decrease?

Slides 11 and 12. Graph A should show that as the distance between a flashlight and a surface increases the light circle RADIUS increases

2. Does Graph A look more like Graph C or Graph D?

Slide 11. Graph A should look more like Graph D.

3. Based on your previous answers, does Graph A show a DIRECT or INVERSE relationship?

Slide 11 and 12. Graph A shows a DIRECT relationship, like Graph D does.

4. As the distance between the flashlight and the surface increases, does the AREA of a light circle increase or decrease? Is that a DIRECT or an INVERSE relationship with light distance?

Slide 11 and 12. As the distance between the flashlight and the surface increases, the AREA of a light circle increases. That is a DIRECT relationship (like radius).

5. Now switch to Graph B. As the distance between the flashlight and the surface increases, does the BRIGHTNESS of the light circle increase or decrease?

Slide 11 and 12. As shown in Graph B, when the distance between the flashlight and the surface increases, the BRIGHTNESS of the light circle decreases.

6. Compare your BRIGHTNESS graph (Graph B) to Graphs C and D. Does the brightness of a light circle have a DIRECT or INVERSE relationship with the distance of a flashlight from the surface?

Slide 11. Graph B looks like Graph C, so the brightness of a light circle has an INVERSE relationship with the distance of a flashlight from the surface. This should match what students saw qualitatively as they collected data.

7. Explain (or guess) why the above equations are described as "inverse" and "square" laws.

Graph B and Graph C can be fit to the following algebra equation:
$Brightness = \frac{1}{Distance^2}$ OR $y = \frac{1}{x^2}$
These equations are "inverse square laws,", and other science equations are too.

Slide 13. "Inverse" means brightness gets smaller as distance gets bigger. Distance is in the denominator, so dividing 1 by a larger number would make brightness smaller.

"Square" is from distance being squared in the equation. Y (brightness) responds to the square change in x (distance).

8. From a geometry point of view, why does the radius of the circle increase proportionally with the flashlight distance? A drawing may help.

Slide 13. Use the animation in slide 13 to show similar right triangles that visualize how a 3-fold longer distance leg causes a 3-fold longer radius leg.

9. From a geometry point of view, why does area and brightness change with the "square" of the distance from the surface? (HINT: Review the steps used to calculate the data in the table.)

Slide 13. The area equation for circles says that area changes with the square of radius. So, if the flashlight distance triples and the radius triples (see Q8), the light circle area changes by a factor of nine (three squared). That is the "square" part of the inverse square law. Brightness, being inversely related to the light circle area also has a "squared" relationship with distance, though its relationship is "inverse square". Use slide 13 to show that distance triples, area increases 9-fold (3 squared), and a 9-fold larger circle area spreads out light photons over a 9-fold larger area causing brightness to decrease to 1/9th of its previous intensity.

EXTEND

A flashlight is a model for the Sun and radiation projected by the Sun onto planets.

1. Which planet encounters the brightest, most intense sunlight: Venus, Earth, or Mars? Why?

Slide 14. As shown in lab, the brightness is in order of closest to farthest from Sun: Venus > Earth > Mars

2. Average surface temperatures of Venus, Earth, and Mars are 471°C, 16°C, and -28°C respectively. Do the temperature differences correlate with incoming sunlight? Explain.

Slide 14. Yes, the average surface temperatures of Venus, Earth, and Mars correlate with differences in incoming sunlight. HOWEVER, a general rule of science is that correlation does not necessarily mean causation. In this case, there are other factors that are very important. If distance was the only factor, the Earth and Moon would be a similar temperature. They are not.

3. Though distance from the Sun correlates, it is not the most important factor affecting solar system temperatures (e.g., the Earth is warmer than the Moon). What other factors affect the temperatures of Venus, Earth, and Mars? (Do research or brainstorm for discussion.)

Slide 14. Other factors besides the incoming radiation that affect planet temperatures include (a) absorption by the surface of a planet (white snow absorbs less than dark soil) and (b) absorption of incoming visible light and outgoing IR light (greenhouse effect) by gases in the atmosphere. Venus and Earth have richer atmospheres that absorb more energy and led to significantly higher temperatures than are found on the Earth's Moon or Mars.

4. The Earth's orbit is elliptical, but northern hemisphere seasons are inversely correlated with distance from the Sun (we are closest in December). Get a flashlight and compare the light when you direct it straight down and at an angle. How does angling the light change the area and brightness of the light? How does this relate to seasons on Earth?

Slide 14. Angled light makes an ellipse with a larger area and reduced brightness. In the winter, light hits the Norther hemisphere at an angle, thus light is not as bright, and there is less radiant energy to convert to heat, causing winter temperatures.

5. The “Goldilocks theory” says that a distant star is more likely to have a habitable planet within a range of distances that are neither too close nor too far from the star. Do you think the location of the “habitable zone” around a star depends on the brightness of a star? Explain using the inverse square law.

Slide 14. Brightness is important for setting the zone. The radiation intensity has to be enough to warm the planet, but not so high that the planet overheats or damaging radiation inhibits the evolution of life. If the outgoing light from a star is brighter the zone moves further away to allow the intensity to diminish enough to be best for supporting life.

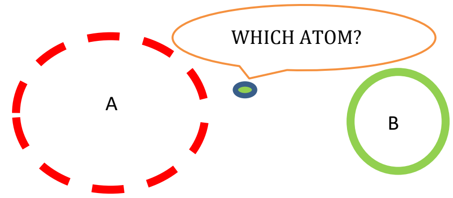
6. Two observations about incoming radiation at Mars and Earth: (a) A larger amount of dangerous solar radiation (such as UV light and solar wind) hits the Earth than Mars, but (b) a smaller amount of dangerous radiation reaches the Earth’s surface than Martian surface. Which observation (a or b) is consistent with the “inverse square law”? What causes the other observation to deviate from the inverse square law (research or guess before discussing)?

Slide 14. Because Earth is closer than Mars to the Sun, solar radiation is more intense (brighter) at this closer distance. This is consistent with flashlight logic and the inverse square law. However, both the atmosphere and the magnetosphere of the Earth block dangerous radiation and solar wind. To have a magnetosphere, a planet needs a liquid core. There is some evidence that, before Mars' core cooled, it used to have a protective magnetosphere that allowed atmosphere and water to build up well above current levels. When the Martian inner core cooled, the magnetosphere was lost and solar wind scrapped away most of the atmosphere and water content of the planet.

7. Jupiter is five times further than the Earth from the Sun. Use the inverse square law to estimate the quantitative difference in the brightness of solar radiation hitting the Earth and Jupiter.

Visualize using slide 15. The 5-fold change in distance leads to a 5-fold change in light circle radius (similar triangles). That turns into a 25-fold change in area (r squared) and a 1/25-fold change in brightness. Thus, radiation is less intense by a factor of 25 at Jupiter.

8. Attractive forces between negatively charged electrons and positively charged nuclei also follow the inverse square law and "flashlight logic." In the diagram shown, assume nucleus A and nucleus B have the same charge. Is the attraction stronger when the electron is on the dotted circle next to nucleus A or when the electron is located on the solid circle next to nucleus B? Explain.



Slide 16. Attractive forces are stronger when the electron occupies the closer distance available at the solid ring around atom B. The general law for charge-charge attraction (Coulomb's Law) is shown on slide 16. It follows the same inverse square dependency as light brightness. Thus, as the distance increases, the intensity of charge-charge attraction decreases with the square of that distance. That means (all other factors being equal) electrons are more attracted to positive nuclei when they are closer to nuclei. This basic rule explains why valence electrons in larger atoms (like alkali metals) have a tendency to leave during a chemical reaction to join smaller atoms (such as halogens) that more strongly attract electrons.

9. Many students find it harder to pay attention when they sit farther away from a teacher in class. Do you think the inverse square law plays any role in this? Why or why not?

Humans are more complicated than electrons, so some of your students will have good arguments against the premise. In contrast, other students (and your own teaching experience) are likely to inform some agreement with the statement. Moving closer to students and asking them if they are suddenly paying better attention is one way to demonstrate this.

10. Apply lesson experience do quick research to improve this MOSTLY TRUE sentence:

> *Mathematical rules for (a) light brightness, (b) gravitational forces between two objects, (c) electrostatic forces between two charges, and (d) magnetic forces between two magnets involve the inverse square law.*

An improved sentence omits or edits clauses about charge-charge and magnetic attractive forces. As slide 16 shows, gravitation and point (or "monopole") charge-charge attractions DO follow the inverse square law. Students may find research that shows that some charge-charge surfaces (non-monopoles) do not follow the law. Students may also find that the inverse square law does NOT apply to real magnets. Theoretical "monopole" magnets follow the inverse square law, but real "dipole" magnets follow an inverse cubed (r3, not r2) relationship with distance.

EVALUATE

1. Fill-out T-Chart notes as you watch the video "Should We Colonize Venus Instead of Mars?" (https://youtu.be/gJ5KV3rzuag) (slide 17).

Reasons to Target Venus	Challenges of Building on Venus
• Closer; less fuel and money needed to move supplies • Good solar power because it's closer to the sun • Atmospheric protection from harmful radiation • Carbon dioxide can be used as a source of oxygen • Can live with 0.9 g of gravity that aids bone health over Mars' 0.4 g	• Impossible to live on the surface due to heat and pressure • Ideal "cloud city" location—which would match the atmospheric pressure of earth—would still be hot (70° C) • "Cloud City" location would still be subject to sulfuric acid in the atmosphere

2. The President of the USA asks you, "Should we colonize Mars or Venus first?"
   - Write a letter to the President to recommend a colony location.
     - You may recommend Mars, Venus, or another location in the solar system.
     - Use evidence to support your recommendation, such as T-Chart notes made while watching the videos. If necessary, rewatch the Mars video.
     - If time allows, do and use additional research.
     - The letter should be at least one page in length.