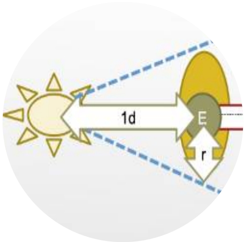

Radiation and the Inverse Square Law

Electromagnetic Radiation, Astronomy, and the Inverse Square Law

Lindsey Link, Matthew Peck
Published by *K20 Center*

Grade Level	8th – 12th Grade	**Time Frame**	1-2 class period(s)
Subject	Mathematics, Science	**Duration**	100 minutes
Course	Chemistry, Earth Science, Geometry, Physical Science, Physics		

Essential Question

How does the intensity of radiation change as the distance from the radiating object changes? How does this relationship help us find planets for human colonization?

Summary

Students will establish the relationship between radiation intensity and the distance of a radiating source using a simple flashlight model. Students will learn to apply the inverse square relationship to consider the effects of a planet's distance from the Sun on its ability to be colonized and adapt the inverse square law to charge-charge and gravitational attraction forces and other situations.

Snapshot

Engage

Students select and share their ideas for a planet or moon in a solar system that humans could colonize. Next, students take T-Chart notes while watching a video on Mars colonization. Follow-up questions engage consideration of solar EM radiation in colonization.

Explore

Students use flashlights as a radiation model to measure the relationship between the distance from a surface and the brightness of a light circle. Students measure light circle radii, use geometry to calculate the light circle areas and brightness, and make two graphs to visualize data.

Explain

Students explain how the light circle radius, area, and brightness depend on the distance of a light source from a surface. They analyze graphs to describe relationships as "direct" and "inverse." They explore the equations and geometry behind brightness' "inverse square law" relationship.

Extend

Students apply flashlight logic and the inverse square law to radiation in the solar system. The inverse square law is extended to charge-charge attraction, gravity, and other situations.

Evaluate

Students watch a second video, which considers colonization of Venus. Students use evidence from the lesson (including the two videos) to write a letter to the President advocating for colonization of Mars, Venus, or an alternative solar system body.

Standards

Oklahoma Academic Standards (Physics)

PH.PS4.1 : Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
PH.PS4.1.DCI.1: The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.

Attachments

- Lesson Slides—Radiation and the Inverse Square Law.pptx
- Measuring and Graphing Light (Teacher's Copy)—Radiation and the Inverse Square Law.docx
- Measuring and Graphing Light (Teacher's Copy)—Radiation and the Inverse Square Law.pdf
- Measuring and Graphing Light—Radiation and the Inverse Square Law - Spanish.docx
- Measuring and Graphing Light—Radiation and the Inverse Square Law - Spanish.pdf
- Measuring and Graphing Light—Radiation and the Inverse Square Law.docx
- Measuring and Graphing Light—Radiation and the Inverse Square Law.pdf

Materials

- Measuring and Graphing Light (attached; 1 per student)
- Measuring and Graphing Light (Teacher's Copy) (attached)
- Lesson Slides (attached)
- Flashlights (1 per group of 2–4 students)
- Meter sticks (1–2 per group of 2–4 students; rulers could be substituted)
- Calculator or phone with calculator app (1 per group of 2–4 students)
- Lab notebook (optional)
- Pencil or pen
- Sticky notes (1 per student)

20 minutes

Engage

Before you begin, pass out a copy of the attached **Measuring and Graphing Light** handout to each student. Use the attached **Lesson Slides** and **Measuring and Graphing Light (Teacher's Copy)** handout to guide students through the lesson. Briefly review **slides 2–4**, introducing the lesson title, Essential Questions, and Lesson Objectives.

Teacher's Note: Main Goals of the Lesson and Leveling Information

The main goals of this lesson are for students to use a flashlight to measure and graph changes in light circle radius, area, and brightness as a function of light distance from a surface. These observations will be used to introduce the inverse square law, which has some application to solar radiation in the solar system, charge-charge interactions, gravitational attractions, and other situations.

Bookending the lesson, two videos will be shown to inform students about challenges of human colonization of solar system planets, including challenges caused by solar radiation. This lesson involves the use of a two-variable y = 1/x2 equation and circle and triangle geometry. It is suitable for physical science (to work on general quantitative skills), chemistry (to introduce Coulomb's Law), and physics (to introduce Newton's Law of Gravitation or light optics). Use in a math class to show applications of similar triangles and inverse square algebra.

Direct students to the Engage section of the Measuring and Graphing Light handout. As you go through the next few slides (with instructions below), have students record their answers either in their lab notebook or on the handout, depending on your preference.

Display **slide 5**. Hand each student a sticky note (or have them use paper or an electronic submission form) and have them write a response to the question on the slide: "What planet or moon in the Solar System (excluding Earth) would be the best place to build a human colony?" As prompted by slide 5, direct students into pairs to share their answers and rationale. Using the instructional strategy Affinity Process, ask them to combine two groups to form a larger group and repeat the process. Finally, have them post their answers to enable all classmates to view the variety of answers. Many students are likely to suggest Mars, which segues into the video shown next.

Display **slide 6**. Introduce students to the video "Can We Colonize Mars?" Depending on your preference, have students watch the video as a class or individually. Direct students to use a T-Chart to take notes on the reasons for—and challenges surrounding—the colonization of Mars.

Embedded video

https://www.youtube.com/watch?v=9yI3U_yCfj8

Ask students to spend a few minutes answering Engage questions 3–6. Questions 5 and 6 set up hypotheses for the Explore phase. Ask them to answer questions individually or with an Elbow Partner. Then, display **slides 7 and 8** to discuss answers briefly. Expected answers and clarifications are in the Measuring and Graphing Light (Teacher's Copy) handout.

20 minutes

Explore

Teacher's Note: Materials and Prep before Class

The distances in Column 1 in the data table may need to be adjusted for brightness of available flashlights. During prep for this lesson, take a few minutes to check that the radius of the light circle made when the flashlight is held from the largest distance (28 cm in the provided table) is visible and measurable in a darkened room. If the largest circle is not measurable, reduce the distances (4, 8, 12, and 16 cm is suggested) in Column 1. Ideally, collect sufficient material (1 flashlight and 1–2 meter sticks per group) to allow groups of 2–3 students (one flashlight holder, one light circle measurer, and one data recorder is optimal). Rulers can substitute for meter sticks, particularly for measuring the distance from the flashlight to the surface. Two meter sticks (or rulers) is optimal so a flashlight distance and light circle radius can be measured together, but the activity will work with one meter stick (or ruler) per group.

Direct students to the **Explore** section of the Measuring and Graphing Light handout.

Display **slide 9**. Point out that flashlights are a model of the Sun (and other radiating sources). Demonstrate measurement of the radius of a light circle, pointing out that the outer radius should be measured and recorded in Column 2. Direct students to take all measurements and finish Column 2 before moving onto the calculations of Columns 3–5.

Display **slide 10**, which summarizes the workflow of the **Explore** phase. Use it to orient students to the objectives of the activity before and during the activity.

Put students into groups and ask them to start working. Groups of 2–3 are optimal. Larger groups may inhibit individual student engagement.

Follow these tips to help ensure that the activity runs successfully:

1. **Room Lighting:**
   Darken the room as much as possible so larger, dimmer light circles can be perceived and measured. Encourage students to measure all of the light circle radii first while the room is dark. Then, when all groups have their measurements, turn the room lights back on to catalyze calculation work.
2. **Surfaces may be vertical or horizontal, but must be of sufficient size:**
   The flashlight is held perpendicular to the surface. It does not matter if the light is directed down onto a horizontal surface (desk, floor) or from the side onto a vertical surface (chalkboard, wall). However, the surface needs to be large enough to contain the largest light circle. Thus, lab tables and floors work better than desks.
3. **Measure the outer cone of light:**
   The outermost cone of light from a flashlight usually follows the inverse square law better than inner features. Demonstrate measuring the outermost ring of light (and point out the direction in the handout) to reinforce this tip.
4. **Checking and helping with calculations:**
   Column 3 converts radii measured in cm (Column 2) into meters. This step makes the brightness results in Column 5 larger and thereby easier to understand and graph. Column 4 is calculated using Column 3 (not Column 2) radii using the equation for circle areas (A = pi*r*r). The values in this column should be small numbers (usually <1) that increase as you go down the column. Column 5 is calculated as 1 divided by AREA, and values should decrease moving down the table. Depending on the class's familiarity with quantitative work, you may need to demonstrate a row of calculations to a group or the whole class (use slide 9). Be ready to show students how to use of the "1/x" button on their calculator to turn Column 4 area into Column 5 brightness.
5. **Checking graphs:**
   Graph A (light radius vs. distance from the surface) should be a linear graph that looks like Graph D in the handout. Graph B (light brightness vs. distance from the surface) is an inverse square relationship that looks like Graph C in the handout. Make sure students label their axes and appropriately space numerical values along the axes (less experienced graphers often use even spacing for unevenly distributed values).
6. **Time management:**
   Depending on the time invested in the **Engage,** the length of your period, and the students' comfort with calculations, students may need time at home or at the start of the next class to complete the calculations and graphing steps.

20 minutes

Explain

Direct students to the **Explain** section of the Measuring and Graphing Light handout.

Display **slide 11**. Show students that Graphs C and D are in the Measuring and Graphing Light handout and are used for answering **Explain** questions. Have students answer questions, either individually or in small groups, before discussing answers as a whole class. Questions 1–6 directly relate to the lab data and involve relatively simple comparisons with Graphs C and D. Questions 7–9 address algebraic and geometrical considerations that are more difficult for some students to answer independently.

Display **slide 12** to discuss **Explain** questions 1–6. Sample answers and clarifications are in the Measuring and Graphing Light (Teacher's Copy) handout. Slide 12 is animated to circle the correct relationships. Go back to slide 11 to visually reinforce the similarities between Graphs A and D and between Graphs B and C.

Display **slide 13** to discuss **Explain** questions 7–9. It contains an animation of similar triangles that help students visualize the linear relationship between horizontal distance from a surface and the vertical radius of the light circle.

Teacher's Note: Using Slide 13 to Teach Inverse Square Law Mathematics

Slide 13 shows the geometric relationship between the horizontal distance from a light source and the vertical radius of the projected light cone. The distance and the radius are two perpendicular sides of similar right triangles, so rules of similar triangles in geometry (and measurements in lab) tell us that the radius of the light circle is proportional to the distance from the light source. Use the animation in slide 13 to show that the similar right triangle that is three times longer in the distance leg is three times longer in the radius leg. The area changes as the square of the radius because radius is squared in the area equation for a circle. So, as the distance triples, the radius triples, and the light circle area changes by a factor of nine (three squared). That is the "square" part of the inverse square law.

The "inverse" part of the relationship comes from brightness being inversely related to the area of a light circle. As the circle area increases, the light photons are spread out more broadly and brightness goes down proportionally. Because brightness decreases in the inverse relationship it has with larger areas and the area of the light circles follows a square relationship with distance from the light source, the overall relationship is "inverse square." This geometry applies to several radiating phenomena in science, not just light, as will be shown in the Extend section.

20 minutes

Extend

Direct students to the **Extend** section of the Measuring and Graphing Light handout.

Teacher's Note: Scope and Selection of Extend Questions

Questions 1–6 are core questions connected to the **Engage** and **Evaluate** sections. To save time, you can omit any or all of questions 7–10. Questions 1–6 extend the inverse square law to connect incoming solar radiation to the habitability of planets. These questions are subdivided into a group about temperature (1–5) and dangerous radiation (6). Question 7 reviews the mathematical details of the inverse square relationship using Jupiter. The math is the same difficulty (Algebra 1/Geometry) as in the **Explain** section. Questions 8–10 show that the law can be extended to other radiating phenomena, including charge-charge attraction and gravitational attraction. Questions 8–10 and **slide 16** is the point of focus for a shorter physics or chemistry lesson that is focused on Coulomb's law or Newton's Law of Gravitation instead of solar system colonization.

Direct students to work on the questions on their own (or in small groups). Students will need or want to research details for a complete understanding of questions 3–6.

After students have worked on the **Extend** questions, use a Gallery Walk to have them report out in small groups and/or run a class discussion using **slides 14–16** as visual aids. Sample answers and clarifications are in the Measuring and Graphing Light (Teacher's Copy) handout.

Display **slide 14** to review **Extend** questions 1–6, which apply the flashlight activity logic to the solar system and the search for planets that could support life.

Display **slide 15** to discuss **Extend** question 7. To further demonstrate the inverse square law and the importance of small distance changes making larger brightness changes, move around the room with a flashlight to show students how brightness changes depending on how far the light is from the students.

Display **slide 16** to discuss **Extend** questions 8–10, which apply the inverse square law to situations beyond light.

20 minutes

Evaluate

Direct students to the **Evaluate** section of the Measuring and Graphing Light handout.

Display **slide 17**. Introduce students to the video "Should We Colonize Venus Instead of Mars?" Depending on your preference, have students watch the video as a class or individually. Direct students to use a T-Chart to take notes on the reasons for—and challenges surrounding—the colonization of Venus. The video is about 8 minutes long.

Embedded video

https://www.youtube.com/watch?v=gJ5KV3rzuag

Display **slide 18** and go over instructions for writing a persuasive letter to the US President advocating the colonization of Venus, Mars, or a solar system alternative. Decide how much time students will have to do additional research and write their letters. Depending on your preference, have students work on this task in class or as homework. Having students write letters in groups is not recommended.

Resources

- K20 Center. (n.d.). Affinity Process. Strategies. https://learn.k20center.ou.edu/strategy/87
- K20 Center. (n.d.). Elbow Partners. Strategies. https://learn.k20center.ou.edu/strategy/116
- K20 Center. (n.d.). Gallery Walk. Strategies. https://learn.k20center.ou.edu/strategy/118
- K20 Center. (n.d.). T-Chart. Strategies. https://learn.k20center.ou.edu/strategy/86
- PBS Space Time. (2015, March 4). Should we colonize Venus instead of Mars? [Video]. YouTube. https://www.youtube.com/watch?v=gJ5KV3rzuag
- The Verge. (2014, October 16). Can we colonize Mars? - The big future ep. 2. [Video]. YouTube. https://www.youtube.com/watch?v=9yI3U_yCfj8