Estimate the Sun's temperature without leaving the school

Optional introductory activity: The inverse square law for light intensity

It is common sense that starlight, or another source of light, looks dimmer as it is farther away from us, for example, stars brighter and bigger than the Sun seem to emit fainter light than the Sun's light, but this actually follows a quantifiable pattern: the intensity of light from a point source is inversely proportional to the square of the distance from the source. This is known as the inverse square law.

In this activity, in a darkened room, students measure the distance between a light bulb and a smartphone sensor. Subsequently, they construct a graphical representation of these measurements and derive a corresponding mathematical equation for the inverse square law. Students are then invited to consider what this means for planets and the distance to their nearest star.

This activity takes around 30 minutes.

Materials

Per group:

- Introductory activity worksheet
- A smartphone with a light sensor and phyphox software.
- A 7 W light bulb
- A ruler
- A piece of paper

Procedure

1. Before the lesson: place a suitable light bulb on the school laboratory bench for each group of students.
2. Divide students into groups of four. Each group should have access to a smartphone with the phyphox software installed. This can be downloaded for free at https://phyphox.org/.
3. Instruct students to use the ruler to mark positions on a piece of paper placed on the bench at distances of 20 cm, 40 cm, 60 cm, and 80 cm away from the source.

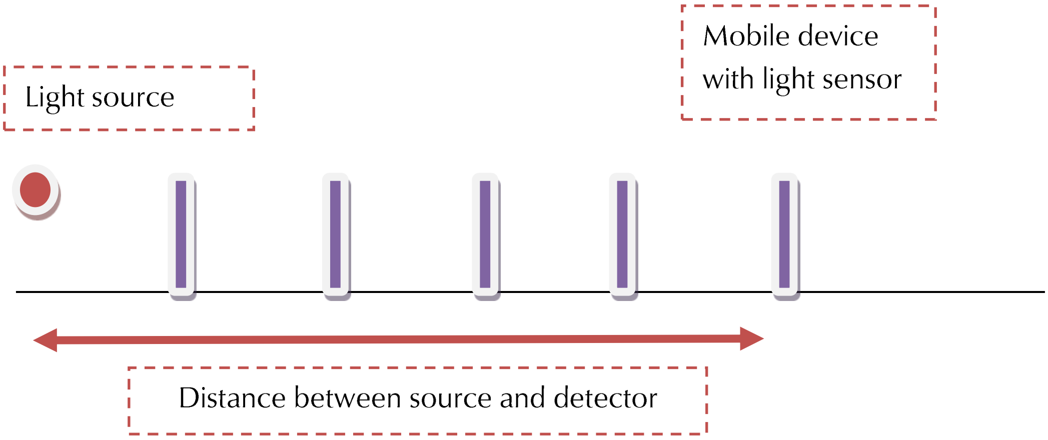


Image courtesy of the author

4. Ask students to predict what will happen to the light intensity if it's measured at distances of 20 cm and 40 cm (double the distance). Answer: intensity will decrease to one fourth as it spreads over four times the area. If students only know it decreases but aren't sure how, that is ok, since they will next investigate this experimentally.
5. Turn off the lights and close the curtains of the classroom. Then, ask students to turn on the light bulb and activate the phyphox software, which they have installed on their smartphones.

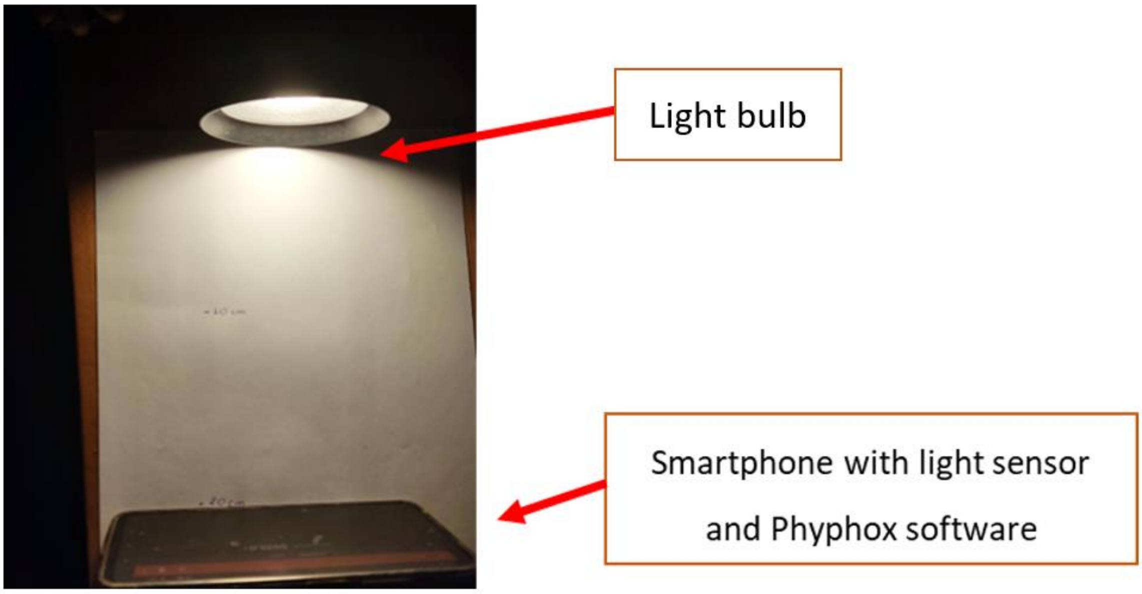


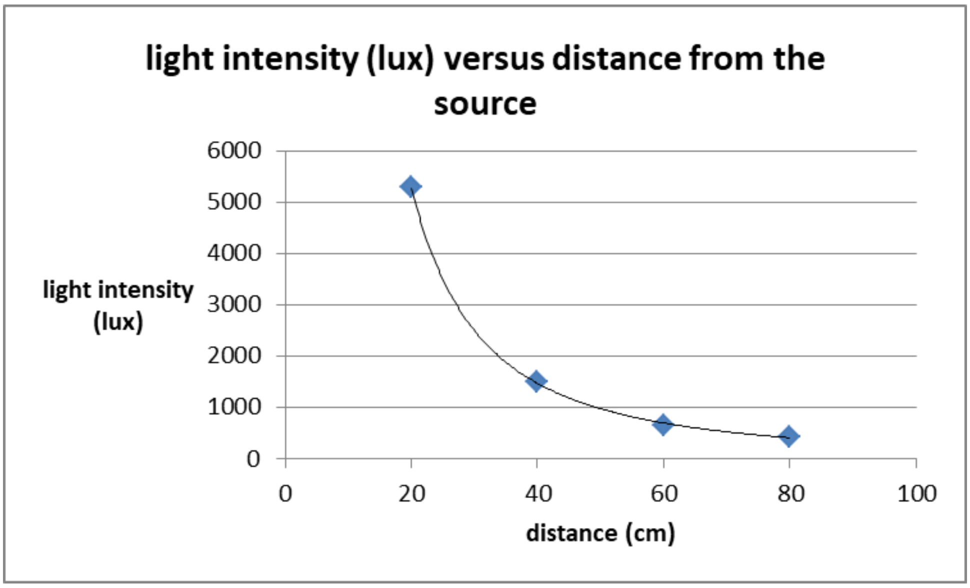
Image courtesy of the author

6. They should then place their smartphones at the marked distances and measure the intensity and record it in the table on worksheet 1.

Distance, *D* (cm)	**Intensity of light (lux)**
20	5300
40	1500
60	650
80	430

A table showing some sample measurements.

7. Once they have completed the table on worksheet 1, students plot the graph of light intensity as a function of distance from the light source.



An example of a graph of light versus distance, showing how intensity is proportional to the inverse square of the distance

Image courtesy of the author

8. Ask students what kind of relationship this demonstrates. They might not know the exact answer but should see that it's a nonlinear inverse relationship.
9. The teacher can guide the discussion to help students figure out the key to the relationship themselves, or provide the inverse square law and guide a discussion to understand it. It is important to note that energy disperses uniformly across a spherical surface with radius r and area $4\pi r^2$. A good hint is to ask students to envision what shape describes the light a set distance from the source. Answer: a sphere with a diameter equal to that distance! How does the area of a sphere increase as the diameter is doubled?

10. Having established the inverse square relationship, students answer the questions at the bottom of worksheet 1. The key question is the last one about the electromagnetic energy of the Sun.
    The Sun emits electromagnetic energy with a power of 3.9×10^{26} W. What is the intensity on Earth (which is approximately 150 million km from the Sun)?

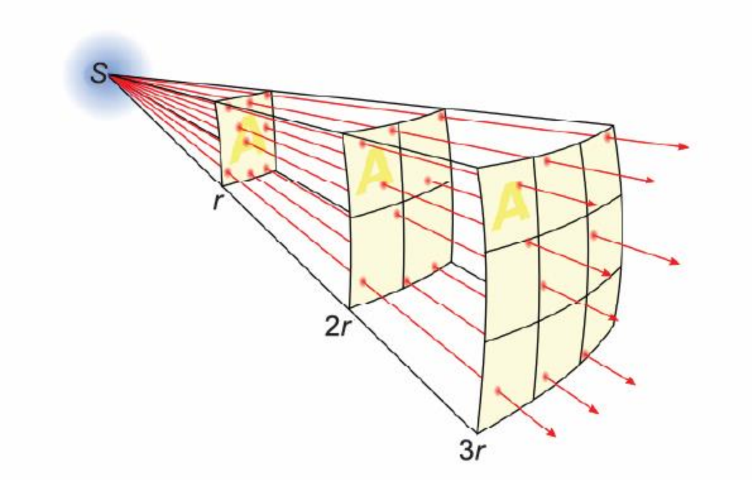
Results and discussion

The students' data should show an inverse square law for intensity with distance. Formally: $I = P/A$, where I stands for light intensity, P stands for the emitted power (in this case of the Sun), and A stands for the area of a sphere with a radius given by the distance from the source.

Using this formula for the final question:
$A = 4\pi r^2 = 2.83 \times 10^{23}\ m^2 = 28.3 \times 10^{22}\ m^2$
$I = P/A = 1.37 \times 10^3\ W\ m^{-2} = 1.4 \times 10^3\ W\ m^{-2}$

Upon completion of the activity, students should engage in a discussion of their findings.

Students should understand the underlying reasons for the inverse square law and investigate the historical development of this law. Energy disperses uniformly across a spherical surface with radius r and area $4\pi r^2$. So, the intensity is inversely proportional to the square of the distance from the source.



The inverse square law. S represents an ideal source of electromagnetic radiation, A represents an arbitrary segment of the surface of a sphere of radius r around the source, and the lines represent the flux emanating from the source.
Image: Borb/Wikipedia, CC BY-SA 3.0

Optionally, start with an investigation into the history of the inverse square law.

- Firstly, ask the students whether any additional physical phenomena adhere to the inverse square law. Examples include the rest of the electromagnetic spectrum (not just light), electrostatic force, and the force of gravity.
- Next encourage students to reflect on the practical consequences of the inverse square law. Consider posing the following question: why do planets positioned at greater distances from the Sun, within larger orbital paths, exhibit lower temperatures? Note: in general, the surface temperatures of planets decrease with increasing distance from the Sun. Venus is an exception because its dense atmosphere acts like a greenhouse.