## THE INVERSE SQUARE LAW

As distance from the source doubles, light falls off by two stops.


## Learning Outcomes

## No CONTENT

Inverse square law

| I $=\frac{P}{A} \quad I_{1} d_{1}^{2}=I_{2} d_{2}^{2} \quad I=\frac{k}{d^{2}}$ |
| :--- |
| I know that irradiance is the power per unit area incident on a surface. |
| I can use the equation $I=\frac{P}{A}$ to solve problems involving irradiance, the power of |
| radiation incident on a surface and the area of the surface. |
| I know that irradiance is inversely proportional to the square of the distance from a |
| point source. |
| I can describe an experiment to verify the inverse square law for a point source of |
| light |
| I can use and $I_{1} d_{1}^{2}=I_{2} d_{2}^{2}$ to solve problems involving irradiance and distance from a <br> point source of light. |

## Irradiance

- Irradiance, I at a surface on which radiation is incident is the power per unit area.
- Irradiance, I is measured in watts per square metre.
- The equation for irradiance comes from the equation, $I=\frac{E}{A t}$
- Reducing to

$$
\begin{aligned}
& I=\frac{P}{A} \\
& \text { watts per square metre }=\frac{\text { watts }}{\text { square metres }}
\end{aligned}
$$

Irradiance, I is inversely proportionat to the square of the distance, $d$, from a point source.

Imagine a balloon with a light bulb shining inside (for these models we will ignore the Health and Safety problems with such an experiment). If the source is radiating 100 W , then 100 W of light is landing on the inside of the balloon skin. This is true, regardless of the size df the battoon skin. As the balloon is blown up the amount of light (irradiancenlanding on each part of the balloon skin reduces.

$$
I=\frac{100 \mathrm{~W}}{\text { surface area }\left(\mathrm{m}^{2}\right)}
$$

- Suppose we arranged for the balloon to have radii of $1 \mathrm{~m}, 2 \mathrm{~m}, 3 \mathrm{~m}$ etc. one after the other, then I for each surface (assuming the balloon was spherical) would be
- Therefore:


## Results show

$$
I \propto \frac{1}{r^{2}}
$$

- Which gives the equation:

$$
I_{1} d_{1}^{2}=I_{1} d_{1}^{2}
$$

Where $d=$ radius of the sphere

| distance | distance | d 2 | $1 / \mathrm{d} 2$ | $1 / \mathrm{d}$ | irradiance $($ Wm-2) |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $(\mathrm{cm})$ | $(\mathrm{m})$ | $\left(\mathrm{m}^{2}\right)$ | $\left(\mathrm{m}^{-2}\right)$ | $\left(\mathrm{m}^{-1}\right)$ | 1 | 2 | 3 | av |
| 50 | 0.50 | 0.25 | 4.0 | 2.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| 45 | 0.45 | 0.20 | 4.9 | 2.2 | 5.0 | 5.0 | 5.0 | 5.0 |
| 39 | 0.39 | 0.15 | 6.6 | 2.6 | 7.0 | 7.0 | 7.0 | 7.0 |
| 36 | 0.36 | 0.13 | 7.7 | 2.8 | 8.0 | 8.0 | 8.0 | 8.0 |
| 32 | 0.32 | 0.10 | 9.8 | 3.1 | 10.0 | 10.0 | 10.0 | 10.0 |
| 27 | 0.27 | 0.07 | 13.7 | 3.7 | 14.0 | 14.0 | 14.0 | 14.0 |
| 25 | 0.25 | 0.06 | 16.0 | 4.0 | 16.8 | 16.0 | 16.5 | 16.4 |
| 22 | 0.22 | 0.05 | 20.7 | 4.5 | 20.0 | 20.5 | 20.5 | 20.3 |
| 20 | 0.20 | 0.04 | 25.0 | 5.0 | 24.0 | 24.8 | 24.8 | 24.5 |
| 19 | 0.19 | 0.04 | 27.7 | 5.3 | 26.0 | 27.5 | 27.5 | 27.0 |
| 18 | 0.18 | 0.03 | 30.9 | 5.6 | 30.0 | 30.3 | 30.3 | 30.2 |
| 17 | 0.17 | 0.03 | 34.6 | 5.9 | 33.3 | 34.0 | 34.0 | 33.8 |
| 15 | 0.15 | 0.02 | 44.4 | 6.7 | 41.0 | 42.0 | 43.2 | 42.1 |
| 14 | 0.14 | 0.02 | 51.0 | 7.1 | 48.0 | 49.0 | 49.0 | 48.7 |
| 13.5 | 0.14 | 0.02 | 54.9 | 7.4 | 52.5 | 53.5 | 53.5 | 53.2 |
| 13 | 0.13 | 0.02 | 59.2 | 7.7 | 57.5 | 58.0 | 58.0 | 57.8 |
| 12 | 0.12 | 0.01 | 69.4 | 8.3 | 67.0 | 68.0 | 67.0 | 67.3 |
| 11 | 0.11 | 0.01 | 82.6 | 9.1 | 78.0 | 80.4 | 80.4 | 79.6 |
| 10 | 0.10 | 0.01 | 100 | 10 | 94.0 | 95.5 | 96.5 | 95.3 |

## Irradiance v distance

A graph of Irradiance against 1/d for a light source


## I v $1 / \mathrm{d}^{2}$

a straight line through the origin shows the quantities (I and $1 / \mathrm{d}^{2}$ ) are directly proportional


## Examples

A satellite is orbiting the Earth where the irradiance of the Sun's radiation is $1.4 \mathrm{~kW} \mathrm{~m}^{-2}$. Calculate the power received by the satellite's solar panels if they have an area of $15 \mathrm{~m}^{2}$.

A pupil measures the light irradiance of a 100 W light bulb as $0.2 \mathrm{~W} \mathrm{~m}^{-2}$ at a distance of 2 m . Calculate the irradiance that would be measured at a distance of:

- 1 m from the light bulb
- 4 m from the light bulb.

1. 21 kW

$$
\begin{gathered}
I=\frac{P}{A} \\
1.4 k=\frac{P}{15} \\
P=21 \mathrm{~kW} \\
I_{1}\left(d_{1}^{2}\right)=I_{2}\left(d_{2}^{2}\right)
\end{gathered}
$$

2. 

(a) $0.8 \mathrm{~W} \mathrm{~m}^{-2}$

$$
\begin{gathered}
0.2\left(2^{2}\right)=I_{2}\left(1^{2}\right) \\
I_{2}=0.8 W^{-2}
\end{gathered}
$$

(b) $0.05 \mathrm{~W} \mathrm{~m}^{-2}$

$$
\begin{aligned}
& 0.2\left(2^{2}\right)=I_{2}\left(4^{2}\right) \\
& I_{2}=0.05 \mathrm{Wm}^{-2}
\end{aligned}
$$

## Proving the Inverse Square Law


metre stick

- Darken the room. Place the light detector a distance from the lamp.
- Measure the distance from the light detector to the lamp and the irradiance of the light at this distance.
- Repeat these measurements for different distances between detector and lamp.
- Plot a graph of light irradiance against 1 /distance ${ }^{2}$ from the lamp.


## Other set ups!

 tube


## Exam Question



- A student carries out an experiment to investigate how irradiance on a surface varies with distance from a small lamp.
Irradiance is measured with a light meter.
The distance between the small lamp and the light meter is measured with a metre stick.
The apparatus is set up as shown in a darkened laboratory.
The following results are obtained.

| Distance from source/m | 0.20 | 0.30 | 0.40 | 0.50 |
| :--- | :---: | :---: | :---: | :---: |
| Irradiance/units | 675 | 302 | 170 | 108 |

(a) What is meant by the term irradiance?
(b) Use all the data to find the relationship between irradiance I and the distance $d$ from the source.
(c) What is the purpose of the black cloth on top of the bench.

$$
\begin{aligned}
& \therefore I d^{2}=k \\
& \text { where } k \\
& =27
\end{aligned}
$$

| Distance from <br> source/m | 0.20 | 0.30 | 0.40 | 0.50 |
| :--- | :---: | :---: | :---: | :---: |
| Irradiance/units | 675 | 302 | 170 | 108 |
| Distance ${ }^{2} / \mathrm{m}^{2}$ | 0.04 | 0.09 | 0.16 | 0.25 |
| Irradiance $\mathrm{d}^{2} /$ <br> $\mathbf{W m}^{-2}$ | 27 | 27 | 27 | 27 |

## Light Irradiance

Irradiance is the product of the number of photons per second per square metre and the energy carried by each photon.

$$
I=N E \Leftrightarrow I=N h f
$$



