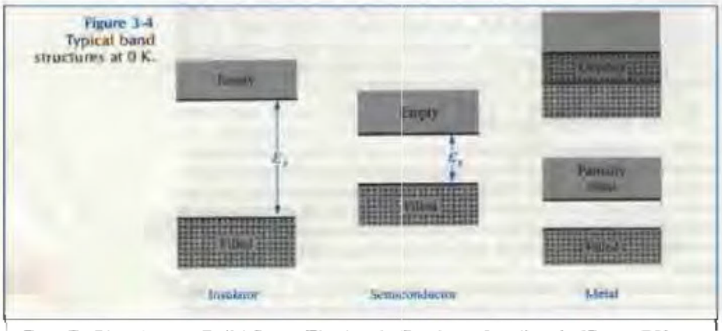
# Investigating Properties of Light Dependent Resistors

## Aim:

The aim of the experiment was to first determine the relationship between illuminance and resistance of the LDR. Illuminance was changed by altering the distance between the light and the resistor. The impact of surface area of the LDR sensor exposed was also investigated by changing the radius of the hole of disks covering the sensor.

## Introduction:

Electric current is generated by a flow of charged particles (electrons) and defined as the rate of flow of charge ($\frac{\Delta q}{\Delta t}$)[1]. Resistance, the mathematical ratio of voltage to current, can be seen as a restriction of current, what obstructs the flow of charge[2]. Resistors are materials which cause resistance thus restricting current flow. Light dependent resistors (LDRs) are variable resistors made of semiconductors. Atoms have different energy levels and as the distance between atoms decreases energy levels combine and then split into different bands which don't have discrete energy but a certain range[3]. The two highest energy levels are the conduction band and the valence band. The highest energy level where electrons are found at absolute zero and too tightly bound to conduct electricity is the valence band. The band with higher energy level is the conduction band, where if present, electrons can conduct electricity.[4] In conductors these two bands can overlap or be separated but have a partially filled conduction band. The valence and conduction bands of semiconductors are separated by a small gap. Thus semi-conductors require energy such as heat or light for electrons to jump from valence to conduction band. LDRs absorb photons from incident light providing energy to excite electrons to detach from valence shell and jump to the conduction band so more free electrons able to conduct electricity.[5]




Ben G. Streetman, *Solid State Electronic Devices*, fourth ed., [Page 56]

When light intensity, power over area,[6] increases it means more photons are present (with energy $hf$, $h$: Planck's constant, $f$: their frequency)[7] contributing to a higher total energy and power. More electrons can thus absorb them to jump to conduction band making the LDR more conductive, less resistive. Illuminance, measured in lux, can be used as a measure of intensity since they are proportional to each to other[8]. If intensity/illuminance remains constant, a greater LDR sensor area means more of the energy/photons propagated can be absorbed thus also reducing resistance. Numerous other factors impact resistance for example the longer the wire or the smaller cross-sectional area the more resistance. Resistance also depends on resistivity; intrinsic property of materials. In

[1] "Electric Current," HyperPhysics, accessed December 7, 2015, http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elecur.html
[2] "Resistance," the Physics Classroom, accessed September 3, 2015, http://www.physicsclassroom.com/class/circuits/Lesson-3/Resistance.
[3] "Principles of Semiconductor Devices," Electrical, Computer & Energy Engineering, accessed December 8, 2015, http://ecee.colorado.edu/~bart/book/book/chapter2/ch2_3.htm.
[4] Ben G. Streetman, *Solid State Electronic Devices*, fourth ed., 55
[5] "Light Dependent Resistor, LDR," ERT, accessed September 3, 2015, http://www.electronics-radio.com/articles/electronic_components/resistors/light-dependent-resistor-ldr.php.
[6] "Light Basics," Multiverse, accessed December 10, 2015, http://cse.ssl.berkeley.edu/segwayed/lessons/light/measure3.html.
[7] "Testing the wave-particle duality of light.," The Electronic Universe, accessed December 10, 2015, http://zebu.uoregon.edu/2000/ph101/lec06.html.
[8] "Lighting calculations," Physics, Electronics and IT, accessed December 10, 2015, https://smsbarbados.files.wordpress.com/2015/04/light-calculations.pdf.

metals a temperature increase causes more protons to vibrate increasing difficulty of electrons to move[9]. However this is different for semiconductors because heat excites electrons, more energy is available. More electrons are excited and have enough energy to jump to conduction band. LDRs are often connected in series with a resistor to limit current going through to prevent the LDR from breaking.

I was fascinated when learning light could impact resistance and became even more interested after realizing its usefulness in everyday applications. LDRs can allow lights to turn on only if natural lighting goes below a certain value, only when artificial light is necessary, some street lights use this system[10]. This prevents electricity to be consumed uselessly. Sustainability is very important to me and I am interested in conserving energy, another reason why LDRs appealed to me.

I conducted research however couldn't find much information or experiments about properties of LDR and the different relationships with its resistance. The only source found regarding the area of the sensor and its resistance was a datasheet sent by the company Lascells (producer of model used) via mail which states the relationship between area of sensor and intensity is inversely proportional. The relationship between intensity/illuminance and resistance was only found on one website, which isn't guaranteed to be trustworthy, that claimed "Resistance is inversely proportional to the intensity of light"[11]. The limited sources and information awoke my curiosity and increased my interest to investigate LDRs myself.

## Variables:

### Independent variables:

*Part 1:* Illuminance what was changed: distance between lamp and LDR

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Distance (m) | 0.020 | 0.060 | 0.100 | 0.140 | 0.180 | 0.220 | 0.260 | 0.300 |
| Illuminance (lux) | 32380 | 16340 | 9191 | 5225 | 3230 | 2243 | 1579 | 1182 |

*Part 2:* Area of the hole of LDR disk what was changed: diameter of hole of LDR disk

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Diameter hole (m) | 0.001 | 0.002 | 0.003 | 0.004 | 0.005 | 0.006 | 0.007 | 0.008 |
| Area of hole ($10^{-7}$ $m^2$) | 7.85 | 31.4 | 70.7 | 126 | 196 | 283 | 385 | 503 |

**Dependent Variable:** (Part 1 & 2) Resistance of LDR unit: Ohms (found by reading the voltage and current)

### Control variables:

*Part 1:*
Surface area of the LDR sensor: no disks with different aperture sizes were ever added over the sensor
Light in the room: The blinds and door of the room were shut to limit the impact of fluctuating natural light.

*Part 2:*
Same intensity/illuminance of light: kept constant throughout every level by shutting the blinds in the room and not altering the height of the lamp in between trials.

---

9 "Resistance in a Conductor," Regents Exam Prep Center, accessed September 3, 2015, http://www.regentsprep.org/Regents/physics/phys03/bresist/default.htm.
10 . "Automatic Street Light Control System," Electrical Technology, accessed December 10, 2015, http://www.electricaltechnology.org/2013/04/automatic-street-light-control.html.
11 "Photodetectors," Studytronics, accessed August 23, 2015, http://studytronics.weebly.com/photodetector-ldr.html.

*Part 1 and 2:*
Supply voltage: 10 volts
Light Dependent Resistor: The same LDR was used throughout the whole experiment to ensure that if it had any error it would impact all trials the same way.
Lamp and light bulb: The lamp and light bulb were the same ones used throughout the whole investigation
Resistor: the same 180 ohm resistor was used in the circuit
Circuit: Same wires voltmeter, ammeters were used as well as the format of the circuit
Constant temperature: the experiment was carried out in the same room under approximately same temperature; no changes were made to thermostat and the data was collected all at once during a specific time of the day.

## Apparatus:

- 6 wires
- 2 crocodile clips
- Ammeter
- Multimeter
- Voltmeter add-on
- LDR from Lascelts model S200-060
- 5 wooden blocks
- Light sensor
- GoPro link
- Tablet with LoggerPro program
- Clip 60 watt lamp
- Stand
- Low voltage unit
- 180 ohm resistor
- 2 plugs
- 8 LDR disks (diameter: 8,7,6,5,4,3,2,1 mm)

## Method:

*Part 1:*

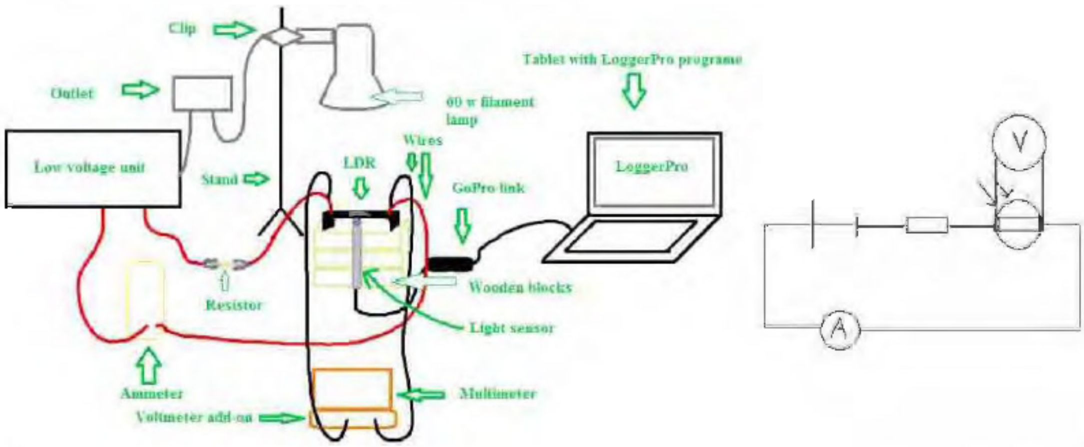
1. Connect a voltmeter across the low voltage unit and alter the settings so that the voltmeter reads approximately 10 volts
2. Place a crocodile clip on two respective wires and clip the two extremities of the 180 ohm resistor
3. Plug the other end of one wire into the low voltage unit and plug the end of the other wire into the LDR
4. Use two additional wires to create a series circuit connecting the resistor LDR and ammeter, set the ammeter to 200m
5. Connect voltmeter add-on to multimeter, use two wires to connect it across the LDR
6. Use the clip of the 60 watt lamp to clip it to a metal stand so that it is directly above the LDR
7. Plug in the low voltage unit and lamp into an electric source
8. Use a ruler to measure 0.30 m between lamp and LDR
9. Turn on the voltage unit and lamp
10. Take readings of the fluctuation in ammeter and voltmeter (minimum and maximum values)
11. Turn off the voltmeter change the terminals, turn it back on and repeat the readings
12. Plug in a light sensor into a tablet and place it so that the sensor is right next to the LDR, same level
13. Select an appropriate setting so that the illuminance fits within the range (0-600, 0-6000 or 0-150,000) and record illuminance for 10 seconds

14. Lower the lamp without changing angle facing LDR for the different independent variables (26,22,18,14,10,6,2) and repeat steps 8 -12

*Part 2:*

1. Use the same set-up as part 1 describes in steps 1 through 7
2. Place an 8 mm diameter disk onto the LDR
3. Repeat steps 8 through 12
4. Replace the 8mm disks by a different one for every independent variable (1,2,3,4,5,6,7 mm)
5. For each independent variable repeat steps 8 through 12

## Set-up:

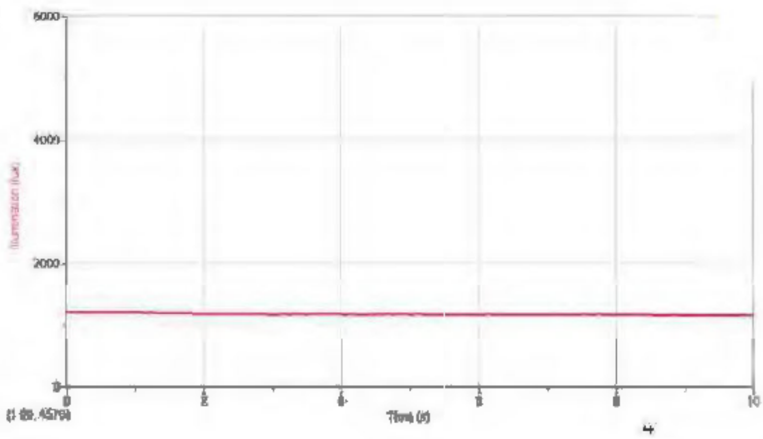



**Risk Assessment:** Handle equipment with care to avoid getting electrocuted. Never touch the metal ends of the wires, turn off the power source when manipulating the circuit. Make sure your hands are dry and never touch the light bulb.

## Raw data:

**Illuminance investigation data:**

Sample luminosity graph for 0.300 m:




Uncertainty:

| Range (lux) | Uncertainty (±lux) |
|---|---|
| 0-600 | 0.2 |
| 0-6000 | 2 |
| 0-150000 | 50 |

| | Voltage ($V \pm 0.01V$) | | | | Current ($A \pm 0.0001A$) | | | |
|---|---|---|---|---|---|---|---|---|
| | Trial 1 | | Trial 2 | | Trial 1 | | Trial 2 | |
| Distance($m \pm 0.001m$) | min | max | min | max | min | max | min | max |
| 0.300 | 6.43 | 6.44 | 6.43 | 6.44 | 0.0204 | 0.0205 | 0.0203 | 0.0204 |
| 0.260 | 6.17 | 6.18 | 6.21 | 6.22 | 0.0217 | 0.0218 | 0.0218 | 0.0218 |
| 0.220 | 5.90 | 5.91 | 5.89 | 5.90 | 0.0237 | 0.0238 | 0.0237 | 0.0238 |
| 0.180 | 5.63 | 5.64 | 5.64 | 5.65 | 0.0253 | 0.0254 | 0.0253 | 0.0254 |
| 0.140 | 5.25 | 5.27 | 5.25 | 5.26 | 0.0276 | 0.0277 | 0.0275 | 0.0276 |
| 0.100 | 4.91 | 4.92 | 4.89 | 4.91 | 0.0296 | 0.0297 | 0.0295 | 0.0296 |
| 0.060 | 4.62 | 4.63 | 4.62 | 4.63 | 0.0314 | 0.0315 | 0.0315 | 0.0316 |
| 0.020 | 4.39 | 4.40 | 4.40 | 4.41 | 0.0328 | 0.0329 | 0.0328 | 0.0329 |

**Investigation about LDR sensor surface area:**

| | Voltage (V ±0.01 V) | | | | Current ( A±0.0001 A) | | | |
|---|---|---|---|---|---|---|---|---|
| | Trial 1 | | Trial 2 | | Trial 1 | | Trial 2 | |
| Diameter (m ±0.0001 m)* | min | max | min | max | min | max | min | max |
| 0.0080 | 6.91 | 6.92 | 6.90 | 6.91 | 0.0179 | 0.0180 | 0.0178 | 0.0179 |
| 0.0070 | 7.09 | 7.10 | 7.08 | 7.09 | 0.0167 | 0.0168 | 0.0168 | 0.0169 |
| 0.0060 | 7.33 | 7.35 | 7.35 | 7.36 | 0.0154 | 0.0155 | 0.0154 | 0.0155 |
| 0.0050 | 7.71 | 7.72 | 7.72 | 7.74 | 0.0131 | 0.0132 | 0.0132 | 0.0133 |
| 0.0040 | 8.18 | 8.20 | 8.20 | 8.21 | 0.0105 | 0.0105 | 0.0104 | 0.0105 |
| 0.0030 | 8.81 | 8.82 | 8.80 | 8.82 | 0.0070 | 0.0070 | 0.0069 | 0.0070 |
| 0.0020 | 9.34 | 9.37 | 9.31 | 9.32 | 0.0038 | 0.0038 | 0.0039 | 0.0039 |
| 0.0010 | 9.78 | 9.80 | 9.80 | 9.82 | 0.0011 | 0.0011 | 0.0010 | 0.0011 |

Note: I contacted the company "Lascells", who made the LDR system S200-060 asking them about any of the LDR's characteristics and they gave me the following information: The LDR has a 100 ohm resistor included in the base with a 5% uncertainty and that *the uncertainty of the diameter of the LDR disks is $\pm 0.1\ m$.

## Data processing:

The calculations made throughout the entire data processing were done using an excel spreadsheet, the vales used were therefore the exact one not the rounded values in the tables and formulas. The values were only rounded at the end apart from the % uncertainty.

## Data processing for impact of illuminance:

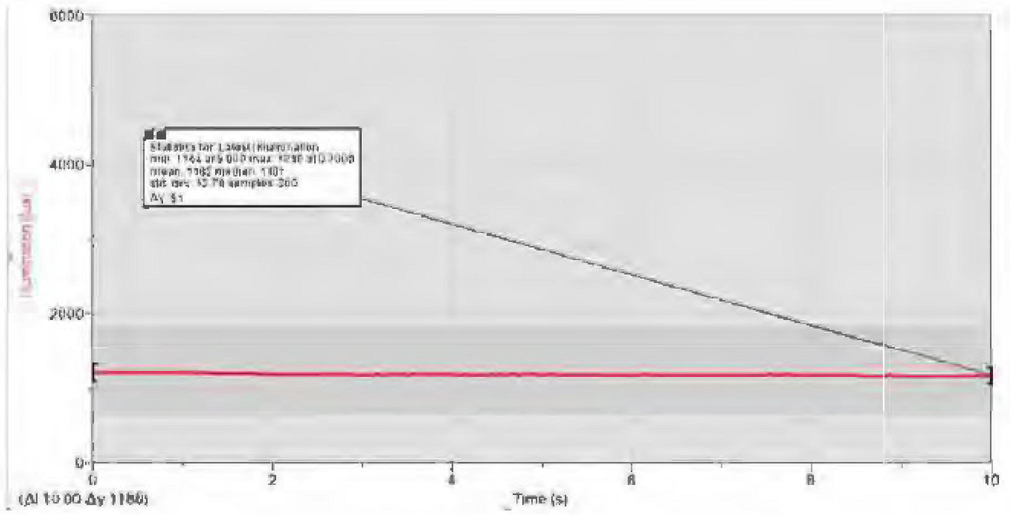
1. **Finding illuminance and its uncertainty**
   Use statistics option of loggerPro to find average:

$Average = 1182\ lux \quad Minimum = 1164\ lux \quad Maximum = 1215\ lux$

Uncertainty :

$Difference\ with\ minimum = 18 \qquad Difference\ with\ maximum = 33$

$Uncertainty\ for\ 0 - 6000 = 2\ lux \qquad \therefore \Delta uncertainty = 33\ lux$




Repeat for all distances:

| Distance (m ± 0.001m) | Illuminance (lux) | Uncertainty (± lux) |
|---|---|---|
| 0.300 | 1182 | 33 |
| 0.260 | 1579 | 18 |
| 0.220 | 2243 | 15 |
| 0.180 | 3230 | 49 |
| 0.140 | 5225 | 110 |
| 0.100 | 9191 | 248 |
| 0.060 | 16340 | 540 |
| 0.020 | 32280 | 1630 |

**1. Finding average current and its uncertainty:**

0.300 m Trial 1:

$current = \frac{Minimum\ value + maximum\ value}{2}$ $\quad current = \frac{0.0204+0.0205}{2} = 0.02045\ A$

$current - minimum = 0.00005$ $\quad \Delta uncertainty\ of\ device = \pm\ 0.0001$

Uncertainty of device greater $\therefore \Delta un = \pm 0.0001\ A$

0.300 m Trial 2:

$current = 0.02035$ $\quad \Delta un = \pm 0.0001\ A$ $\quad Average\ \frac{0.02045+0.02035}{2} = 0.02040$

$Average - 0.02045 = 0.00005$ Uncertainty of measuring device is bigger $\therefore \Delta un = \pm 0.0001\ A$

Repeat method for all measurements:

| Distance (m) | average current (A) | Uncertainty (±A) |
|---|---|---|
| 0.300 | 0.0204 | 0.0001 |
| 0.260 | 0.0218 | 0.0001 |
| 0.220 | 0.0238 | 0.0001 |
| 0.180 | 0.0254 | 0.0001 |
| 0.140 | 0.0276 | 0.0001 |
| 0.100 | 0.0296 | 0.0001 |
| 0.060 | 0.0315 | 0.0001 |
| 0.020 | 0.0329 | 0.0001 |

1. **Finding average voltage and its uncertainty** (Apply same method as current):

| Distance (m) | Average voltage (V) | Uncertainty (±V) |
|---|---|---|
| 0.300 | 6.44 | 0.01 |
| 0.260 | 6.20 | 0.02 |
| 0.220 | 5.90 | 0.01 |
| 0.180 | 5.64 | 0.01 |
| 0.140 | 5.26 | 0.01 |
| 0.100 | 4.91 | 0.01 |
| 0.060 | 4.63 | 0.01 |
| 0.020 | 4.40 | 0.01 |

2. **Finding average resistance and its uncertainty:**

$$R = \frac{V}{I} \qquad R: resistance \qquad V: voltage \qquad I: current$$

0.300 m: $R = \frac{6.44}{0.0204} \approx 315\ \Omega$

$LDR\ resistance = resistance - (built - in\ resistor)$
$built - in\ resistor = 100\ \Omega$ $\qquad resistance\ of\ LDR$ =315-100=215 Ω

Uncertainty: $\%\ uncertainty\ R = \%\ un\ V + \%\ un\ I$

$\%uncertainty = \frac{\Delta uncertainty}{value} \qquad \%un\ V = \frac{0.01}{6.435} \qquad \%un\ I = \frac{0.0001}{0.0204}$

→ $\%un\ R = 0.65$

$\Delta un\ LDR = \Delta un\ of\ R + \Delta un\ of\ built - in\ resistor \qquad \Delta un\ R = 0.65\% \times 315 = \pm 2\ \Omega$

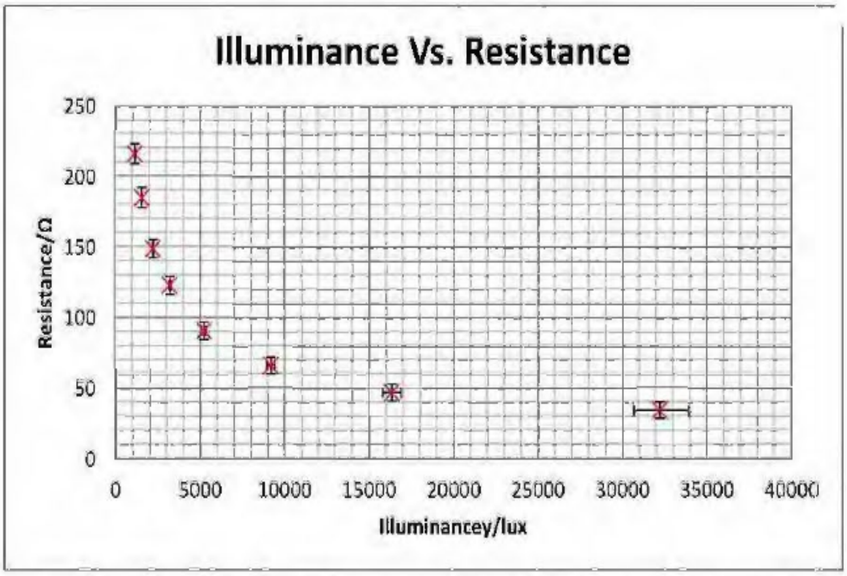
$\%un\ built\ in\ resistor = 5\% \qquad \Delta un = \frac{5}{100} \times 100 = \pm 5\ \Omega$

→ $\Delta un\ LDR = 2 + 5 = \pm 7\Omega$

Repeat for all distances:

| Distance (m) | 0.300 | 0.260 | 0.220 | 0.180 | 0.140 | 0.100 | 0.060 | 0.020 |
|---|---|---|---|---|---|---|---|---|
| Resistance (Ω) | 215 | 184 | 148 | 122 | 90 | 66 | 47 | 34 |
| Absolute R un (±Ω) | 7 | 7 | 6 | 6 | 6 | 6 | 6 | 6 |

7




Exponential trend therefore a log graph was made. Microsoft Excel was used to generate the logs of both I and R:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| log illuminance | 3.073 | 3.198 | 3.351 | 3.509 | 3.718 | 3.963 | 4.213 | 4.509 |
| log resistance | 2.333 | 2.266 | 2.171 | 2.099 | 1.957 | 1.818 | 1.679 | 1.531 |

### 3. Error bars calculations:

$difference_1 = |Log\ of\ original\ value - Log\ of\ (orgianal\ value + uncertainty)|$

$difference_2 = |Log\ of\ original\ value - Log\ of\ (original\ value - uncertainty)|$

$difference_1 = |Log\ (1182) - Log\ (1182 + 33)|$=0.01196

$difference_2 = |Log\ (1182) - Log\ (1182 - 33)|$=0.01230

$\Delta\ uncertainty = biggest\ difference$=$\pm$0.012

| Log Resistance | Vertical error bars |
|---|---|
| 2.333 | 0.014 |
| 2.2659 | 0.017 |
| 2.171 | 0.019 |
| 2.088 | 0.023 |
| 1.956 | 0.030 |
| 1.818 | 0.041 |
| 1.670 | 0.057 |
| 1.531 | 0.080 |

| Log illuminance | Horizontal error bars |
|---|---|
| 3.073 | 0.012 |
| 3.1984 | 0.0050 |
| 3.3508 | 0.0029 |
| 3.5092 | 0.0066 |
| 3.7181 | 0.0092 |
| 3.963 | 0.012 |
| 4.213 | 0.015 |
| 4.509 | 0.023 |

### 4. Finding exponent

$exponent = best\ fit\ line\ slope = -$ 0.5685

## 5. Steepest and shallowest lines:

Steepest:

Coordinate 1:

$x_1 = x\ value + horizontal\ error\ bar_1$ =3.073+ 0.012 =3.085

$y_1 = y\ value + vertical\ error\ bar_1$ =2.333+0.014=2.348

Coordinate 2:

$x_2 = x\ value - horizontal\ error\ bar_2$ =4.509-0.023 =4.486

$y_1 = y\ value - vertical\ error\ bar_2 = 1.531 - 0.080 = 1.451$

$slope = \frac{y_2 - y_1}{x_2 - x_1}$ $slope = \frac{1.451 - 2.348}{3.486 - 3.085} = -0.6403$

Shallowest:

Coordinate 1:

$x_1 = x\ value - length\ of\ horizontal\ error\ bar_1$ $x_1 = 3.060$

$y_1 = y\ value - vertical\ error\ bar_1$ $y_1 = 2.319$

Coordinate 2:

$x_2 = x\ value + horizontal\ error\ bar_2$ $x_2 = 4.531$

$y_2 = y\ value + vertical\ error\ bar_2$ $y_2 = 1.611$

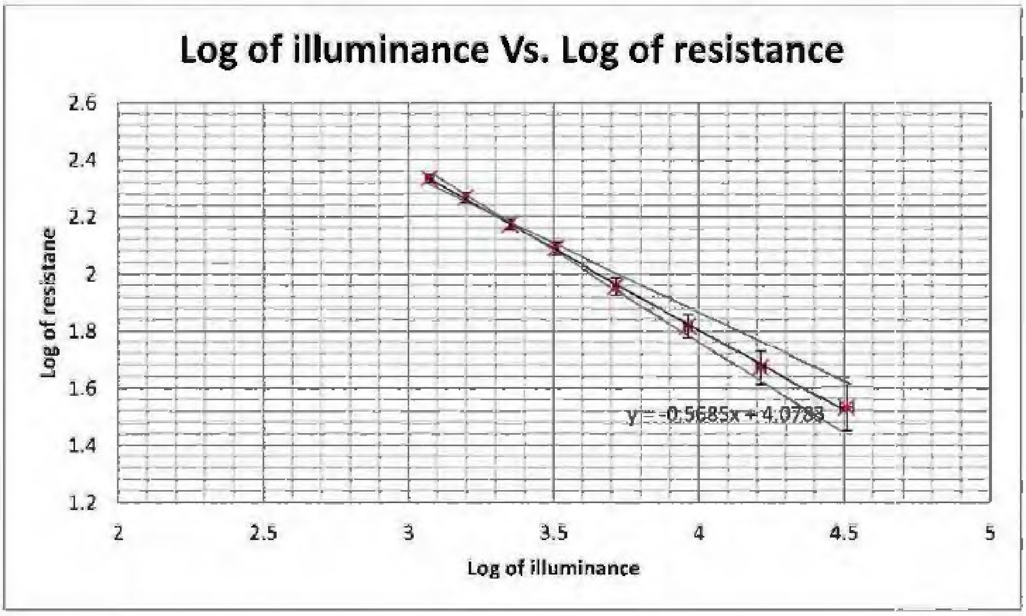
$slope = -0.4814$

## 6. Uncertainty of exponent

|-0.5685-(-0.6403)|=0.0716 |-05685-(-0.4814)|=0.0087 $\Delta uncertainty = \pm 0.07$

*Final exponent value:* -0.57 $\pm$ 0.07

Percentage Uncertainty: $\%uncertainty = \frac{\Delta uncertainty}{value}$ $\%uncertainty = \frac{0.07}{0.57} = 12.3 \approx \pm 10\%$




Graph 1

### 7. Percentage Error:

For inversely proportional:

$$\%error = \frac{|theoretical - experimental|}{|theoretical|} = \frac{0.4315}{1} \approx 40\%$$

For inverse square root:

$$\%error = \frac{|theoretical - experimental|}{|theoretical|} = \frac{0.0685}{0.5} \approx 10\%$$

## Data Processing for impact of LDR sensor area:

### 1. Calculating surface area

$$Surface\ area = \pi r^2$$

$$r = radius \qquad r = \frac{diameter}{2}$$

| Diameter | Radius | Surface area ($10^{-7}$) $m^2$ |
|---|---|---|
| 0.008 | 0.004 | 502.655 |
| 0.007 | 0.0035 | 384.845 |
| 0.006 | 0.003 | 282.743 |
| 0.005 | 0.0025 | 196.35 |
| 0.004 | 0.002 | 125.664 |
| 0.003 | 0.0015 | 70.6858E |
| 0.002 | 0.001 | 31.4159E |
| 0.001 | 0.0005 | 7.85398E |

<u>Uncertainty:</u>

Example with 0.008 m:

$$\Delta uncertainty\ r = \frac{\Delta uncertainty\ of\ diameter}{2}$$

$$\Delta uncertainty\ r = \frac{0.0001}{2} = 0.00005$$

$$\%un\ r = \frac{0.00005}{r} \quad \%un\ A = 2 \times \%un\ of\ r$$

$$\Delta uncertainty\ of\ SA = \%uncertainty\ A \times A$$

| Area ($m^2$) | Uncertainty ($\pm m^2$) |
|---|---|
| 0.000050 | 0.000001 |
| 0.000038 | 0.000001 |
| 0.0000283 | 0.0000009 |
| 0.0000196 | 0.0000008 |
| 0.0000126 | 0.0000006 |
| 0.0000071 | 0.0000005 |
| 0.0000031 | 0.0000003 |
| 0.0000008 | 0.0000002 |

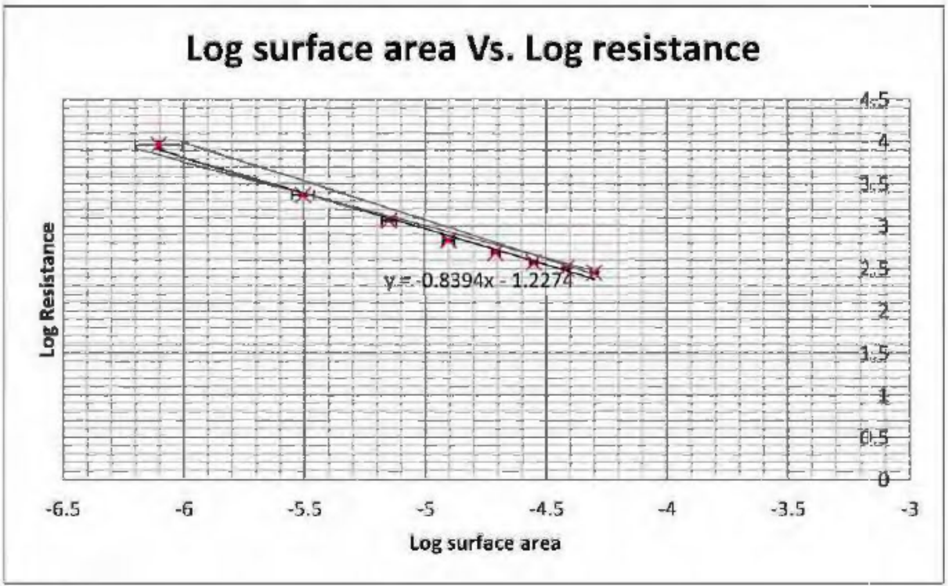
### 2. Repeat previous methods to calculate R and its uncertainty

| Resistance (Ω) | Uncertainty (±Ω) |
|---|---|
| 286.0335 | 7.7153 |
| 322.0238 | 8.1073 |
| 375.5663 | 8.7253 |
| 485.0379 | 10.1897 |
| 682.5776 | 13.4256 |
| 1163.4409 | 24.5475 |
| 2324.6753 | 73.1734 |
| 9016.2791 | 862.328286 |

(intermediate step ∴ sig fig rules not taken into consideration in this table)

### 3. Repeat previous methods to find logs and their uncertainty

| Log A | uncertainty | Log R | uncertainty |
|---|---|---|---|
| -4.30 | 0.01 | 2.46 | 0.01 |
| -4.41 | 0.01 | 2.51 | 0.01 |
| -4.55 | 0.01 | 2.57 | 0.01 |
| -4.71 | 0.02 | 2.686 | 0.009 |
| -4.90 | 0.02 | 2.834 | 0.009 |
| -5.15 | 0.03 | 3.066 | 0.009 |
| -5.50 | 0.05 | 3.37 | 0.01 |
| -6.10 | 0.10 | 3.96 | 0.04 |




Graph 2

4. **Find exponent and its uncertainty:**

Use same method previously applied: $exponent = -0.84 \pm 0.09$

Percentage uncertainty: $\%uncertainty = 10\%$

5. **Percentage error:**

For inversely proportional:

$$\%error = \frac{|theoretical - experimental|}{|theoretical|} = \frac{0.1605}{1} \approx 20\%$$

## Conclusion:

The value of the exponent illuminance (and consequently intensity) needs to be raised to in order for it to be directly proportional with the resistance was determined through the data processing to be -0.57±0.07 (or - 0.57±10%). The data isn't very precise since 10% is a significant percentage uncertainty. However the points aren't very scattered, they are all close to the line of best fit and there is no outlier. The line of best fit passes through all the error bars which shows the value found is plausible. The data collected suggests that perhaps the relationship proposed by the website Studytronic is inaccurate because when compared to the experimental value there is a 40% source of error. Since absolute uncertainty is 0.07 a possible exponent could be -0.50 meaning there is possibility for the relationship to be $R\alpha \frac{1}{\sqrt{I}}$ If this was the case the percentage error would only be 10 %, but it would still remain significant. The theoretical value is not certain, it isn't a well-known accepted value, only a few sources state it without graphs to accompany the statement, maybe they simply meant negative correlation. It is therefore challenging to find the true percentage of error and determine the accuracy of the exponent value found.

The exponent for LDR sensor surface in a directly proportional relationship with resistance was found to be $-0.84 \pm 0.09$ $(or\ -0.84 \pm 10\%)$. The precision is similar to the other investigation; percentage uncertainty once again 10 %. The data is slightly reliable due to only a very light scattering of the points, and an uncertainty which isn't exuberant however 10% remains non-negligible. In this scenario the value of the exponent is slightly closer to the exponent for an inversely proportional relationship proposed by the datasheet however the 20% percentage of error remains significant. There is no certainty on whether the high percentage is a result of experimental errors or of an inaccurate proposed value; these results don't enable to confirm the relationship. More experiments would need to be conducted for both parts of the experiment by other members of the scientific community so they could be compared.

The graphs do however confirm the general theory. When the surface area of the LDR is greater more photons were incident on the LDR and absorbed thus increasing electrons' energy and decreasing resistance. When illuminance of the light was increased, the intensity was by consequence higher as well so more power, energy were transferred, there were more photons for certain area and time. The resistance therefore decreased because more electrons were able to conduct electricity by transitioning to the valence band.

## Evaluation:

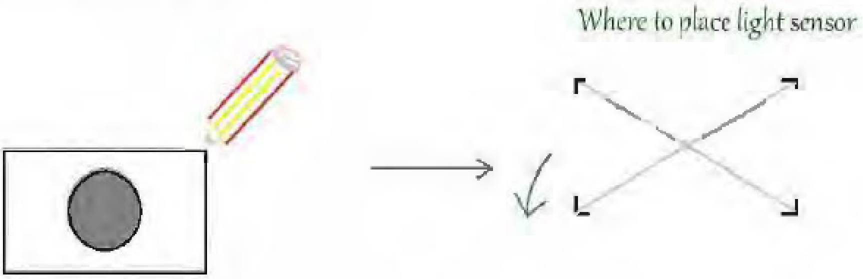
The numerous sources of error which could have impacted the accuracy and precision of the data collected decreases the reliability of the specific values found through the data processing. First of all, when illuminance was recorded, the probe was placed as close to the sensor as possible however since it wasn't exactly in the same place as the LDR the detected value doesn't accurately represent the illuminance of the light at the same location as the LDR. The closer the lamp came to the LDR the more significant this error became since the angle of deviation from the center of the light increases. The light also emits heat energy and the closer it was brought towards the LDR the more it heated it, since resistance changes with temperature this is another source of error. After the closest distance, the LDR's heat had flagrantly increased to the touch. A rise in temperature is also inevitable throughout the experiment because of the nature of circuits due to the current that is going through it which increases average kinetic energy of atom and thus LDR temperature. The window blinds were shut to prevent interference from exterior lighting but not completely shut, to let small amount of light from exterior for safety reasons. Since light from outside isn't constant the illuminance/intensity therefore doesn't remain constant during the trials. This could have also been caused by the light of the lamp which also has small fluctuations. The amount of independent variable level is restricted; not only is there a limited amount of data points to base the trend on but the data is also only applicable for a limited range. The small range and data set for the sensor surface area are not fixable errors; the range is set by the fixed area of the LDR and there is a limited number of disks available.

There are numerous improvements which if implemented would make the result's precision and accuracy. First of all the probe should be positioned in the same place as the LDR sensor, not simply next to it. Whenever the height of the lamp is altered the LDR would be slightly shifted and the probe would be located in its place. A marker would be used to mark the four corners of the LDR. Two diagonal lines would be drawn through the four corners in order to locate the center and the probe would then be placed at the intersection to measure the illuminance. When the LDR has to be replaced in its original position the four mark of the corner could be used as indication by matching up the four corners of the LDR with the marks. A system should be used in which the lamp has a wider range of movement such as a lamp on a pulley. If it is attached to the ceiling or high up on the wall trials can be executed with higher distances in order to limit the influence of heat. Trials will have bigger difference between the heights making more significant difference for the pattern to be clearer. An additional improvement could be to investigate more levels; having more data points enables the relationships identified to be more reliable. It increases the chances of the shape/nature of best fit line to be appropriate and reduces random error. The trials could go from 20 to 150 cm going up by 5 cm each time. This will provide a larger set of data enabling the relationship to be tested for a wider range. In order to further decrease the impact of heat on the LDR the supply voltage should be reduced from 10 to 5, reducing current thus the heating. To further reduce this, power should be switched off whenever values aren't being read off. The experiment should be done in a basement with no windows/aperture that could let in outside light which fluctuates. A weak white light of constant power should still be used for safety. The fluctuation of that light and the one used in the experiment will be less significant than that of natural light. In order to reduce even more the impact of the white lamp used and reduce random error, illuminance should be recorded before but also after each level.

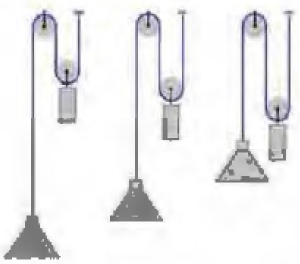
Other experiments can be conducted to further investigate LDRs. The same lamp could be used with constant power and LDR sensor but different color filters could be used over it; thus photons of different frequencies would be emitted each time. This changes the energy of the photons and the energy/power available by the electrons in the LDR to become conductive.

Set-up modifications:

*Bird's eye view of LDR:*




*Pulley lamp:*



"The counterweighted pulley system," instructable, accessed December 10, 2015, http://www.instructables.com/id/Adjustable-Lego-Lamp-Counterweighted/step2/The-counterweighted-pulley-system/.

## Bibliography

"Automatic Street Light Control System." Electrical Technology. Accessed December 10, 2015. http://www.electricaltechnology.org/2013/04/automatic-street-light-control.html.

Berkeley. "Light Basics." Multiverse. Accessed December 10, 2015. http://cse.ssl.berkeley.edu/segwayed/lessons/light/measure3.html.

"The counterweighted pulley system." instructable. Accessed December 10, 2015. http://www.instructables.com/id/Adjustable-Lego-Lamp-Counterweighted/step2/The-counterweighted-pulley-system/.

"Electric Current." HyperPhysics. Accessed December 7, 2015. http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elecur.html.

"Experiment 2." Materials Science and Technology Teacher's Workshop. Accessed September 3, 2015. http://matse1.matse.illinois.edu/sc/b.html.

"Instructions Photo-Resistance System." N.d. PDF.

"Light Dependent Resistor, LDR." ERT. Accessed September 3, 2015. http://www.electronics-radio.com/articles/electronic_components/resistors/light-dependent-resistor-ldr.php.

"Lighting calculations." Physics, Electronics and IT. Accessed December 10, 2015. https://smsbarbados.files.wordpress.com/2015/04/light-calculations.pdf.

"Photodetectors." Studytronics. Accessed August 23, 2015. http://studytronics.weebly.com/photodetector-ldr.html.

"Resistance." the Physics Classroom. Accessed September 3, 2015. http://www.physicsclassroom.com/class/circuits/Lesson-3/Resistance.

"Resistance in a Conductor." Regents Exam Prep Center. Accessed September 3, 2015. http://www.regentsprep.org/Regents/physics/phys03/bresist/default.htm.

Streetman, Ben G. *Solid State Electronic Devices*. Fourth ed.

"Testing the wave-particle duality of light." The Electronic Universe. Accessed December 10, 2015. http://zebu.uoregon.edu/2000/ph101/lec06.html.

"Thermistors and LDRs." BBC. Accessed September 3, 2015. http://www.bbc.co.uk/schools/gcsebitesize/science/edexcel_pre_2011/electricityintheory/voltagecurrentresistancerev6.shtml.

"Understanding Electricity." Leonics. Accessed December 7, 2015. http://www.leonics.com/support/article2_2j/articles2_2j_en.php.

University of Colorado Boulder. "Principles of Semiconductor Devices." Electrical, Computer, Energy and Engineering. Accessed December 8, 2015. http://ecee.colorado.edu/~bart/book/book/chapter2/ch2_3.htm.

"What is the difference between semiconductors, conductors, and insulators depending upon their energy bands?" TheBigger.com. Accessed September 3, 2015. http://www.thebigger.com/physics/conductors-insulators-and-semi-conductors/what-is-the-difference-between-semiconductors-conductors-and-insulators-depending-upon-their-energy-bands/.

Whitehead, Rory. "Website Enquiry." E-mail message to author. August 14, 2015.