

# Module: Resistive Sensors

## Introduction

In your Sparkfun kit, among other parts and components, you will find a plastic bag full of a variety of smaller devices. Many of the devices in the bag are sensors – devices that react to their environment by transforming a movement, a change in temperature, or a change reflectivity of a surface into a voltage. This voltage or signal can be used in a circuit to perform an operation based on the output voltage of the sensor. In this module you will learn to characterize and use a subset of these sensors – those that react to their environment by changing resistance. Other sensors use diodes, transistors, or special material properties to work but a large class of sensors simply change resistance in response to external stimuli. In our kits we have several resistive sensors – see table below.

My bag of sensors






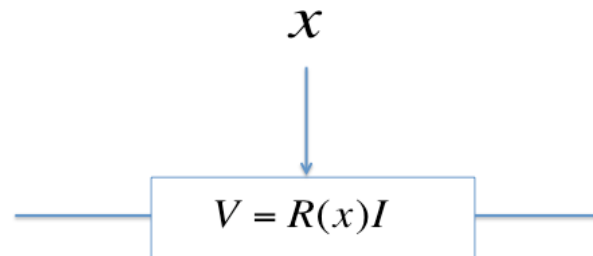
	sensor	description
	thermistor	Changes resistance in response to changes in temperature
	Flex sensor	Changes resistance in response to changes in the amount that the sensor is bent
	photocell	Changes resistance in response to changes in the amount of light hitting the sensor

Table showing the resistive sensors in the Sparkfun kit

A useful abstraction for all of these passive sensors is to consider them as a two terminal resistor with an added input (labelled  $x$  in the figure below) that quantifies the phenomenon that changes the resistance. As a part of this module you will characterize  $V = R(x)I$  experimentally and use that information to design the circuitry needed to interface the sensor to external circuitry.



$x$  represents the variable input used to change the resistance. The input might be the temperature near the sensor, the light intensity hitting the sensor, or the amount of physical flexing of the sensor.

Using the photocell as an example, this module will step you through the process of integrating a resistive sensor into a design. This module is organized so that you will: first gain an understanding of how the sensor works. This knowledge leads to asking the pertinent question about how the environment affects the resistance.

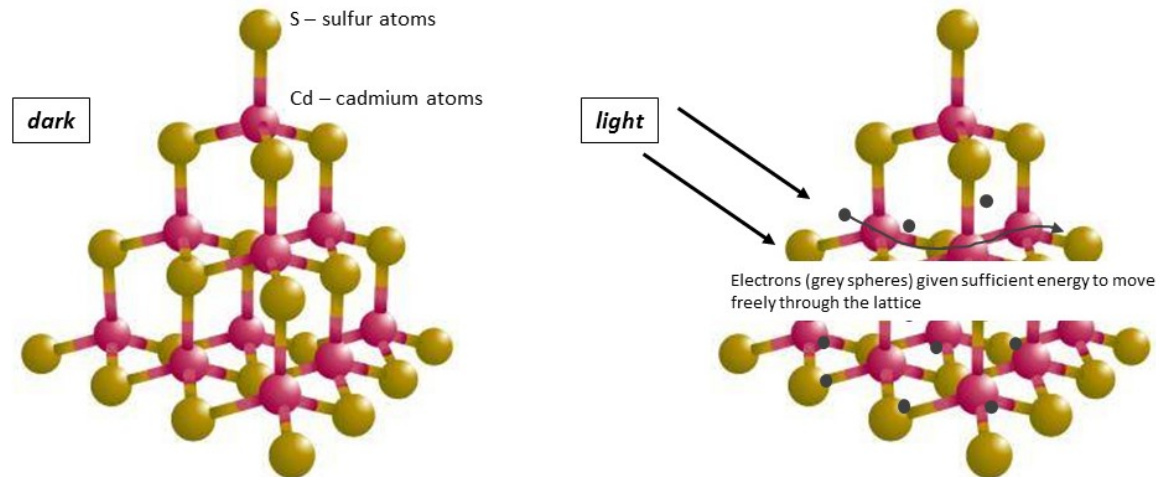
For this type of sensor the most important questions will be –

- i) As the interesting parameter changes, what range is useful for your project?
- ii) Within the range of operation, how does the resistance of the device change?
- iii) What are the characteristics of the circuit that the sensor will be connected to?
- iv) What circuitry do you need to integrate the sensor into your design?

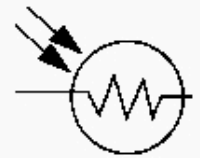
## Physics of the Photocell

It is always good to know as much about how a device works as possible so that you can use it in wide variety of applications. When using the resistive sensors the information that you need the most is the change in resistance of the device as it is subjected to the chosen range of the environmental stimulus. In the case of the photocell, you are interested in the change in resistance in response to changes in the intensity of light hitting the sensor area.

Exploring the physics behind the working of the device often brings you to googling “photocell” / “photoresistor” (or for those of us who remember books consulting a good book written at the appropriate level – insert reference). From Wikipedia I found that the device changes resistance when photons with a frequency greater than certain value hit the surface of the photocell. This happens because the device is made of a special material – a specially made *semiconducting* material that has the property that when photons in the right frequency band hit its surface, electrons inside the material are knocked free of the influence of the stationary atoms. This means that any voltage applied to the terminals of the device (if at least a little light is shining on it) will induce a current to flow because there are electrons that can now move freely through the material lattice. As the intensity of light is increased more electrons are knocked free of the relatively stationary atoms making up the photocell. More available electrons means that for a given voltage the current increases as the intensity of light increases. From Ohm’s law  $V = RI$ , for the same voltage, an increase in current implies that total resistance of the device is lowered.



Cadmium and Sulfur atoms bonded to form semiconducting solid - Cadmium Sulfide. At room temperature the electrons that make up the cadmium and sulfur atoms do not have enough energy to escape the influence of the more stationary atoms forming the solid. Like a rocket trying to escape the influence of the earth’s gravitational field, the electrons need to have sufficient energy to escape. In this case the energy is provided by light of a certain color. Once the electron has escaped it is free to move throughout the material sustaining an electric current. Figure by courtesy of NASA Marshall Space Flight Center.



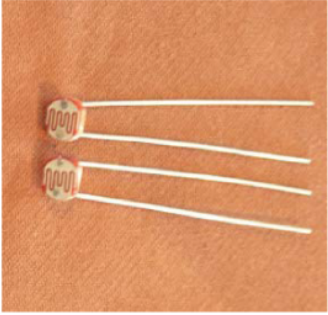
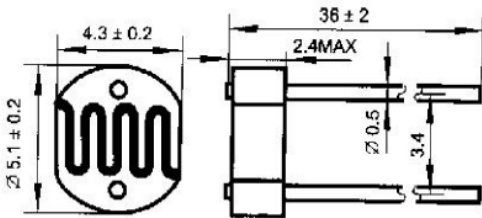
The symbol for a photoresistor

## Pertinent information about the Electrical Characteristics of the Photocell

A good place to start looking for quantitative information about the photocell and application notes is the Sparkfun website – they put your kit together so most of the knowledge about the devices can be found by starting your quest there. They are only one of many companies that provide parts targeted at the ever-growing community of electronics project hobbyists. Using the search box to find the page describing the photo sensor (or use this URL <https://www.sparkfun.com/products/9088> remembering that it could change). For most of the parts you usually find a small photo of the device, some description of the device, a link to the datasheet for the device, and often a link to a tutorial on how to use the device. When looking for information on other parts - Sparkfun has an odd naming convention so you may need to look at the parts list to find their name for the part.

## Using the datasheet

This section will step through the information available in the datasheet that you found at the Sparkfun website. As you use more and different types of devices you will find that there is no standard form for a datasheet or spec(ification) sheet.

<b>CdS PHOTOCONDUCTIVE CELLS</b>		<b>GL5528</b>														
		<ul style="list-style-type: none"> <li>▲ Epoxy encapsulated</li> <li>▲ Quick response</li> <li>▲ Small size</li> <li>▲ High sensitivity</li> <li>▲ Reliable performance</li> <li>▲ Good characteristic of spectrum</li> </ul>														
<table border="0"> <tr> <td>Light Resistance at 10Lux (at 25°C)</td> <td>8~20KΩ</td> </tr> <tr> <td>Dark Resistance at 0 Lux</td> <td>1.0MΩ(min)</td> </tr> <tr> <td>Gamma value at 100-10Lux</td> <td>0.7</td> </tr> <tr> <td>Power Dissipation(at 25°C)</td> <td>100mW</td> </tr> <tr> <td>Max Voltage (at 25°C)</td> <td>150V</td> </tr> <tr> <td>Spectral Response peak (at 25°C)</td> <td>540nm</td> </tr> <tr> <td>Ambient Temperature Range:</td> <td>- 30~+70°C</td> </tr> </table>	Light Resistance at 10Lux (at 25°C)	8~20KΩ	Dark Resistance at 0 Lux	1.0MΩ(min)	Gamma value at 100-10Lux	0.7	Power Dissipation(at 25°C)	100mW	Max Voltage (at 25°C)	150V	Spectral Response peak (at 25°C)	540nm	Ambient Temperature Range:	- 30~+70°C	<b>Outline</b> 	
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Most datasheets contain a photo or drawing of the part, often highly detailed with measurements that allow you to design a physical circuit that provides the proper room for the part, the proper sized holes, and information needed to connect the part to the rest of the circuit usually by soldering.

Usually a summary of the important parameters are put at the beginning of the datasheet and are often all you need to know about the device. The company deemed that these were the most useful parameters:

PARAMETER	
Light Resistance at 10 Lux (at 25°C)	(8-20)KΩ
Dark Resistance at 0 Lux	1.0MΩ(min)
Gama value at 100-10 Lux	0.7
Power dissipation (at 25°C)	100mW
Maximum voltage (at 25°C)	150V
Spectra Response Peak (at 25°C)	540nm
Ambient Temperature Range	-30-70°C approx..

The first two entries tell us the most important facts about the photocell – when some fairly dim light (10Lux specifies a light intensity of a very dim lamp) hits the photocell the device appears to have a **resistance** between 8-20 KΩ. When the photocell is in the total darkness it has a **resistance** of 10MΩ or more.

**Question 1:** A brief description of the parameters is given in the sidebar. Discuss how each (except the gamma value unless you are up to it) might be important in an application. For example, the spectral peak response occurs at 540nm meaning that the wavelength of the light hitting the sensor responds best to light that is green. Suppose you want to use it in a photo dark room developing photographs the old fashion way. The only light available is red (around 70nm). The resistance of the device will still change in response to changes in the intensity of the red light but not as much as if the light were green.

The remainder of the data sheet describes how the numbers in the table were measured or computed, gives other parameters, and in this case two graphs showing the device (actually 3 different devices each made of a different material responding to different colors of light). As the table above indicates the peak response of your photocell occurs near 540nm so the semiconducting material used is Cadmium Sulfide (CdS). The other graph is the one that you will design an experiment to determine – the characterization of  $R(x)$ . Note the graph shows the range of resistances for a given intensity of light underscoring

Notes:

**gamma value** gives the trend in the change of resistance of the photocell as the illumination is varied because the dependence is not linear. This parameter is not immediately valuable for our experiment here.

**Power Dissipation** is important in designing the circuitry required to use the photocell and if there is enough power available from the battery and any circuitry like the Arduino. You will revisit this when you are ready to build the circuit.

**Spectrum response peak** occurs at light with a wavelength of 540nm range is greenish. This means that green light is most effective at freeing the electrons, the spectral response is not given in detail yet.

The **Ambient temperature** value shows you that in any temperature range that is reasonable the part will work well.

the need to test each sensor individually. You need to understand the behavior of the device under different lighting conditions in order to incorporate it into your design applications.

Notes:

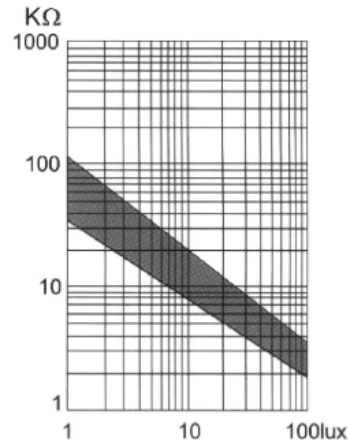
### Measuring Conditions

1. Light Resistance: measured at 10 lux with standard light A (2854k color temperature) and 2h pre-illumination at 400-600 lux prior to testing.
2. Dark Resistance: measured 10 seconds after pulsed 10 lux.
3. Gamma Characteristic: between 10 lux and 100 lux and given by  

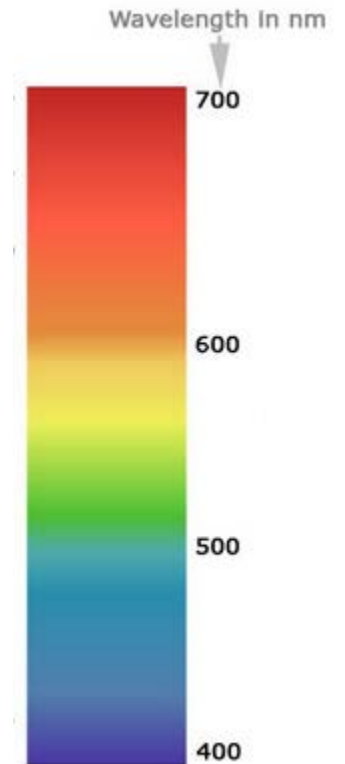
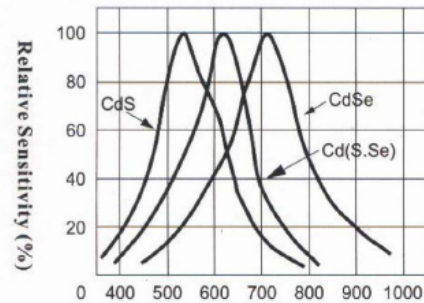
$$T = \frac{\log(R_{10}/R_{100})}{\log(100/10)} = \log(R_{10}/R_{100})$$

R<sub>10</sub>, R<sub>100</sub> cell resistance at 10 lux and 100 lux.  
 The error of T is +0.1.
4. P<sub>max</sub>: Max. power dissipation at ambient temperature of 25°C.
5. V<sub>max</sub>: Max. voltage in darkness that may be applied to the cell continuously.

### Illuminance Vs. Photo Resistance



### Spectral Response



### *Using the tutorial*

Also available on the Sparkfun website is a link to a tutorial that, in their opinion, gives the simplest most straightforward description of how to use the part. The tutorial on the photocell is linked to a **Bldr** tutorial and is good at helping you use the photocell in an application using the Arduino. But you are engineers not simply hobbyists so you will be required to understand the devices, testing methods, and elements of design then you will understand the choices made in the examples. You will know why a particular value of resistor is chosen. And why a particular voltage is used as an input to the Arduino. The tutorials are mostly just recipes - to modify the design for your needs you need knowledge beyond the simple recipe. But the tutorials remain valuable as references for projects where you just want to play and get something cool to work.



## Characterizing the Photocell

The first step in designing the photocell into a design is to characterize just how the device behaves when exposed to light. For the purposes of this exercise design a circuit to be mounted on your vehicle so that the car will move towards the light. We can restate the list of important things to consider when using a resistive sensor to apply to the photocell. In this section you will address the first two questions.

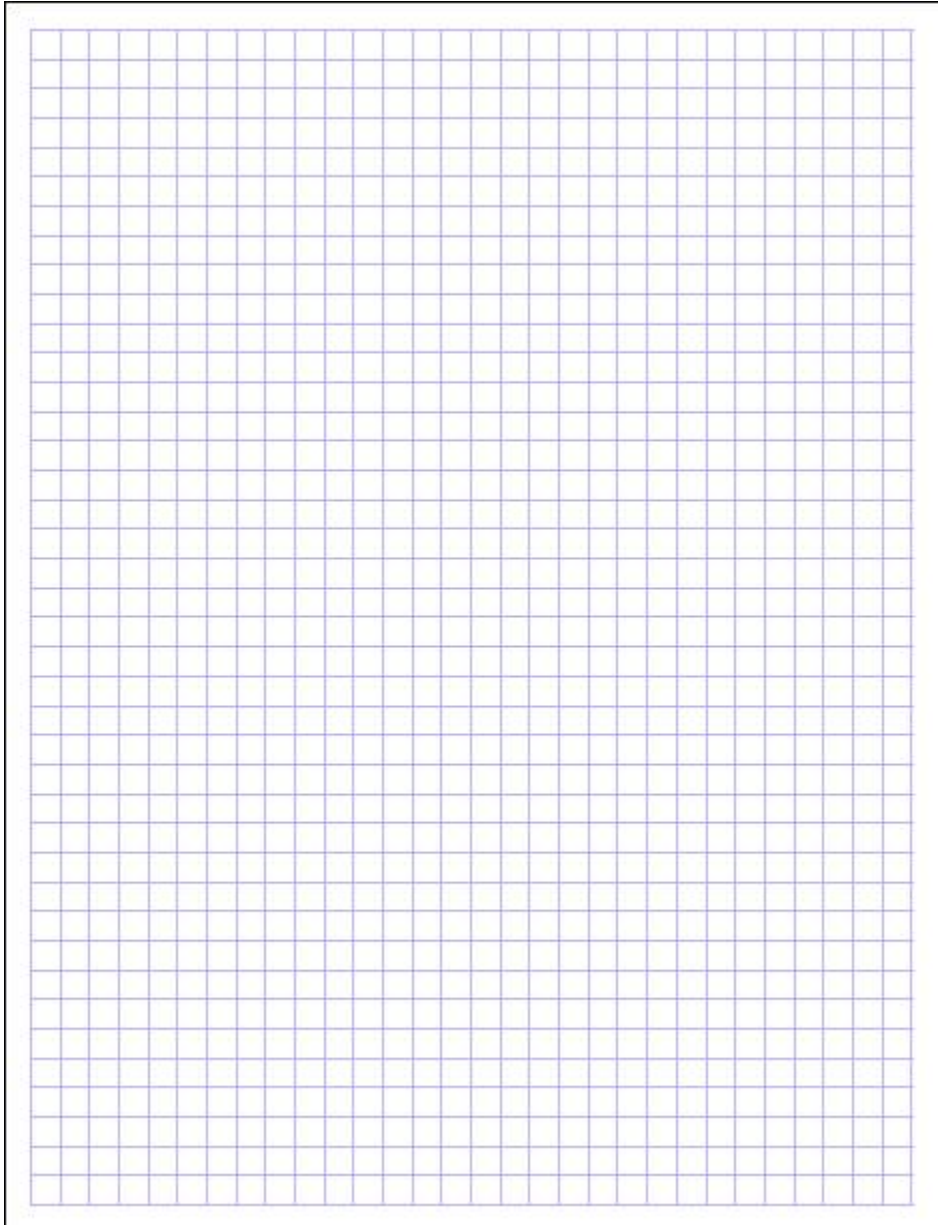
1. What range of light conditions do you expect?
2. Within this range of operation, how does the resistance of the device change?
3. What are the characteristics of the circuit that the sensor will be connected to?
4. What circuitry do you need to integrate the sensor into your design?

### Response of the Photocells Resistance to Varying Light Intensity –

**Question 2:** Qualitatively describe the range of light conditions you expect the photocell to see in general terms.

**Question 3:** Using a photocell, a protoboard, a flashlight (even better your phone), and a DMM, design the physical layout of an experiment that measures the change in resistance as different amounts of light hit the photocell. Use drawings and descriptions to clearly describe your setup so someone else can build it. *Have your TA check your design before proceeding.*





Notes:

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