Module: Active Sensors- Optical

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 probe the environment by continuously transmitting a signal, and then generating a voltage based on how much signal is reflected back to the device. The transmitted signal is usually generated by a light emitting diode (LED) that emits in the InfraRed (IR) portion of the electromagnetic spectrum. The receiver is usually a phototransistor, or phototransistor circuit whose output voltage is proportional the intensity of the signal hitting the base of the transistor.

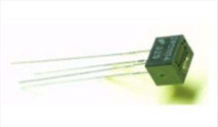
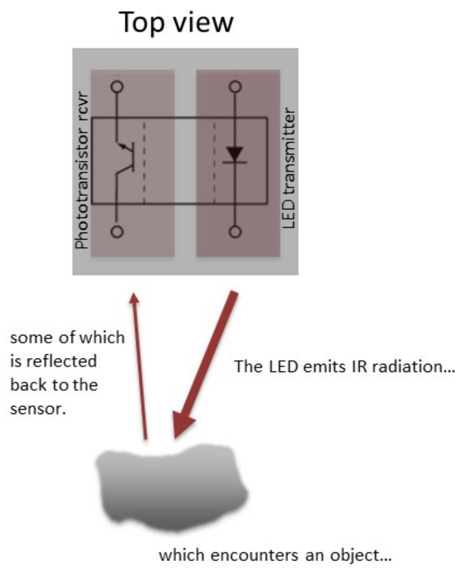
	device	description
	Optical Detector/Phototransistor	This sensor uses an infrared emitting diode combined with an infrared phototransistor to detect the reflected infrared signal. Ideal for sensing black-to-white transitions or can be used to detect nearby objects (.5-1cm)
	IR Emitters and Receivers	Side-looking IR separate transmitters and receivers. The red dot indicate The device is the receiver and a yellow dot indicates the emitter.
	Line Sensor Breakout	A small circuit that incorporates an IR transmitter and receiver. The sensor outputs IR radiation and the receiver measure how much is reflected. This type of sensor is often used in line following circuits.

Table showing the Active Optical sensors in the Sparkfun kit

My bag of sensors

Notes:

Most sensors of this type integrate the LED transmitter and the phototransistor receiver – if you look at the device you will see two 'window' on for transmit and one for receive. The figure below shows a typical sensor indicating the diode and the phototransistor and the windows. The amount of signal that returns is reflected from the surrounding environment. The strength of the reflected signal depends on several parameters: i) the size of the objects in the surrounding environment, ii) the proximity of objects, and iii) the reflectivity of the objects.



The limitation of these sensors is that most terrestrial environments are rife with infrared radiation so they are most effective only when they are very close to the object(s) of interest. The dependence on reflectivity make these sensor the go-to solution for most line-following robots. When positioned looking down at a flat surface at the correct height they are very effective at distinguishing between different shades from dark to light (color is not so important) if the surface is not too shiny.

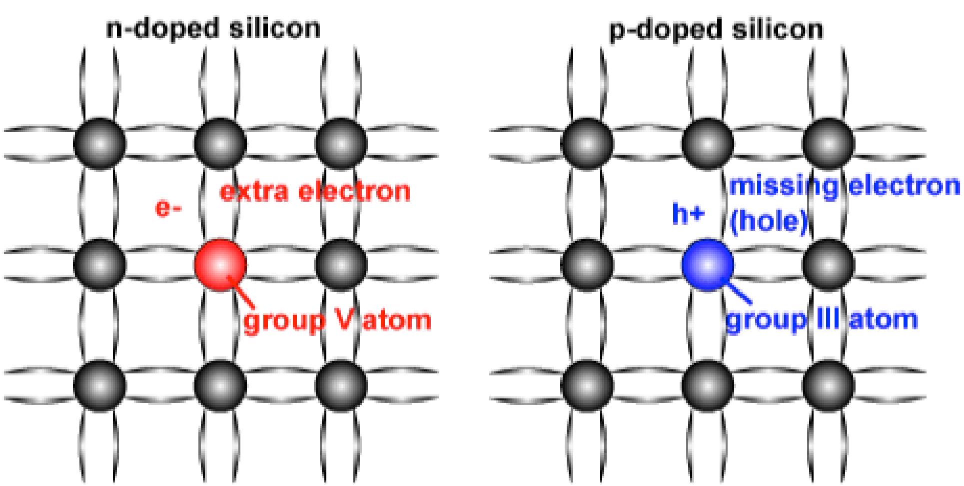
Notes:

Physics of the LED and Phototransistor

Light Emitting Diode

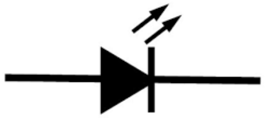
The LED differs from a garden-variety diode because once the device has been turned ON and current is flowing the electrons emit light as they lose energy. Lose energy? Let's start with how a diode works.

As discussed in lecture a diode is made a semiconducting material like silicon. In solid form silicon can be fabricated to crystalize into a very regular lattice of atoms. If a voltage is applied to the terminals of a uniform piece of silicon it would be have like a resistor with an enormous resistivity. Silicon alone is about 10 orders of magnitude less conductive than copper. Its usefulness in fabricating integrated circuits come from the property that if impurities are forced to become part of the silicon crystal structure the conductivity of the resulting material can be manipulated.



As can be seen from the figure above two types of impurities can be introduced: i) an atom whose outer electron shell holds 1 electron more than silicon (n-type or n-doped silicon) which holds 4, and ii) an atom whose outer shell holds 1

Notes:

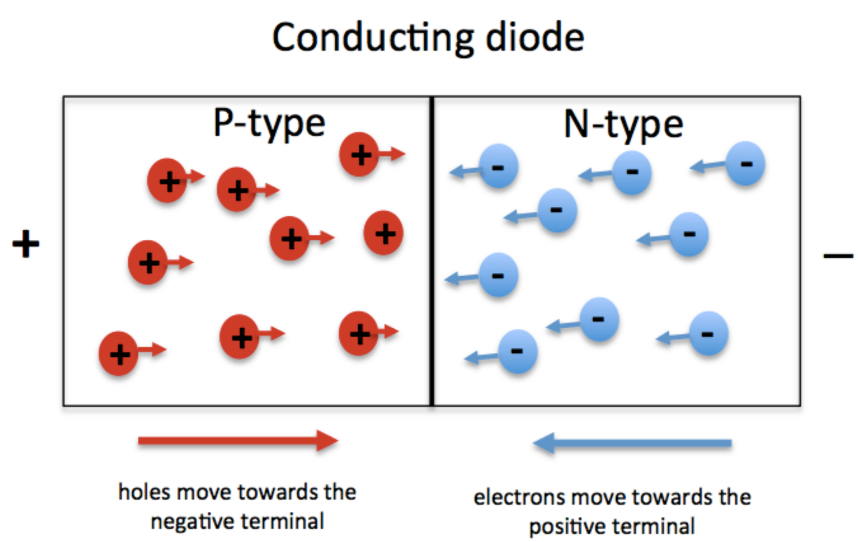


Circuit symbol

Notes:

fewer electrons than silicon (p-type or p-doped silicon). In the first case – the n-doped silicon – the "extra" electron is easy to liberate from its atom so it can roam freely through the material. The material itself remains electrically neutral but now electrons can move through the material to support a current. The lattice site left behind is missing an electron so very close to the impurity site there is a slight positive charge, but the lattice structure shields the electrons lowering the probability of being recaptured. In the second case – the p-doped silicon – the impurity lattice sites are distorted when made part of the silicon lattice and have strongly positive sites throughout the material. It is convenient to think of these positive sites as positively charged particles that have been named holes.

When these two materials are connected and a large enough voltage is applied across the resulting geometry current will flow. The free electrons move in response to the applied voltage towards the higher potential and the holes move toward the lower potential.

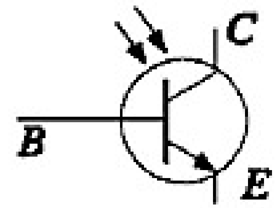


But only the electrons move really. As the electrons enter the p-doped side some are captured by the positively charged lattice. The kinetic energy lost by the electron is emitted as light. This process is termed *electroluminescence*. Each electron leaves a vacant positively charged lattice site behind so it appears as if a hole has moved toward the negative terminal. The construction of the diode and the materials used determine the wavelength of light that is emitted.

Notes:

Phototransistor

The phototransistor works much like a normal bipolar junction transistor (BJT) except that the base is constructed to respond to light. The device is constructed so that there is no external contact with the base of the transistor like a standard BJT. Many phototransistors only have two leads. The base of the transistor is exposed to the environment and when enough light hits the surface of the transistor base electrons in the base material are knocked free from the lattice atoms. When enough electrons are freed the transistor “turns on” and current can flow between the base and emitter. These devices are designed so that the output voltage is proportional to the amount of reflected radiation.



Circuit symbol

Notes:

Pertinent information about the Optical Detector

A good place to start looking for quantitative information about these devices 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/246 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. In this case there is even a video. SPOILER ALERT: well OK it is a 27 sec. video showing that you can in fact use this device as a proximity detector. 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.

Notes:

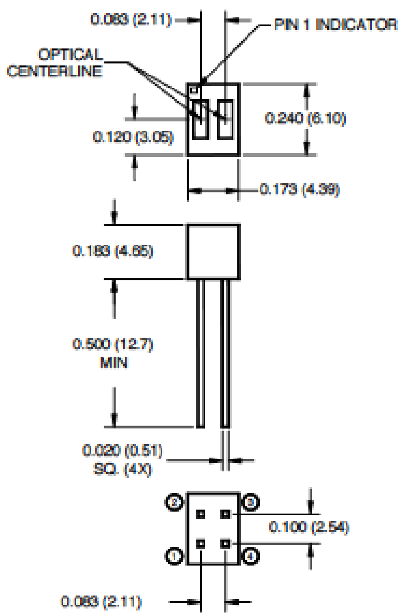
Using the datasheet

The first portion of the datasheet (shown below) summarizes the main characteristics of the device – i) a description of the special features of this particular reflective object sensor (the more common name of these sensors), ii) dimensions of the package so the part can be designed into more permanent projects, and iii) a schematic representation of the device with pin numbering referenced when looking at the device from the bottom (Note: pin 1 indicator shown in package dimensions section).

FAIRCHILD SEMICONDUCTOR™

QRD1113/1114
REFLECTIVE OBJECT SENSOR

PACKAGE DIMENSIONS



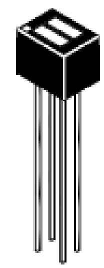
PIN 1 COLLECTOR
PIN 2 EMITTER
PIN 3 ANODE
PIN 4 CATHODE

NOTES:

1. Dimensions for all drawings are in inches (millimeters).
2. Tolerance of ± .010 (.25) on all non-nominal dimensions unless otherwise specified.
3. Pins 2 and 4 typically .050" shorter than pins 1 and 3.
4. Dimensions controlled at housing surface.

FEATURES

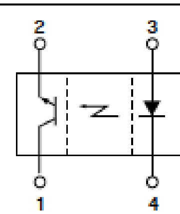
- Phototransistor Output
- No contact surface sensing
- Unfocused for sensing diffused surfaces
- Compact Package
- Daylight filter on sensor



NOTES (Applies to Max Ratings and Characteristics Tables.)

1. Derate power dissipation linearly 1.33 mW/°C above 25°C.
2. RMA flux is recommended.
3. Methanol or isopropyl alcohols are recommended as cleaning agents.
4. Soldering iron 1/16" (1.6mm) from housing.
5. As long as leads are not under any spring tension.
6. D is the distance from the sensor face to the reflective surface.
7. Cross talk (I_{CX}) is the collector current measured with the indicator current on the input diode and with no reflective surface.
8. Measured using an Eastman Kodak neutral white test card with 90% diffused reflecting as a reflective surface.

SCHEMATIC



Notes:

The notes give miscellaneous information about which flux to use when soldering, how close you can get the soldering iron to the plastic housing, what solvents to use when cleaning, etc…

The next table summarizes the important information that you need to use the part. The first few entries give the temperature ranges for operating, storing, and soldering. As you will not be using the devices in space (yet) or to monitor an erupting volcano the temperature ranges experienced in the lab fall well within the allowable ranges. It is the ABSOLUTE MAXIMUM RATING (their emphasis) for the emitter and sensor that concern the external circuitry used with the device.

ABSOLUTE MAXIMUM RATINGS (T_A = 25°C unless otherwise specified)

Parameter	Symbol	Rating	Units
Operating Temperature	T_{OPR}	-40 to +85	°C
Storage Temperature	T_{STG}	-40 to +85	°C
Lead Temperature (Solder Iron)(2,3)	T_{SOL-I}	240 for 5 sec	°C
Lead Temperature (Solder Flow)(2,3)	T_{SOL-F}	260 for 10 sec	°C
EMITTER Continuous Forward Current	I_F	50	mA
Reverse Voltage	V_R	5	V
Power Dissipation(1)	P_D	100	mW
SENSOR Collector-Emitter Voltage	V_{CEO}	30	V
Emitter-Collector Voltage	V_{ECO}		V
Power Dissipation(1)	P_D	100	mW

While you can get by with only the information about the maximum current and power ratings to optimize the behavior of the device you need other information. For example, you know that when a diode is in the ON state there is a constant voltage drop across the diode. With this additional information you can design external circuitry to both protect the device from too high a current level while also optimizing the light intensity of the emitter. This information and additional information about the phototransistor are in the next table in the data sheet.

Notes:

This table contains the parameters describing how the device works and interfaces with other devices.

The data provided about the ***emitter*** – the LED – are i) the forward voltage at 1.7V – this as you now is approximately the voltage across the diode when it is ON. You model a diode in the ON state by an ideal voltage source and for this LED 1.7V is that value. The reverse current and peak emission are parameters you won't need for now – if you check 940nm is light with a wavelength in the Infra-Red part of the spectrum.

The data provided about the ***receiver*** – the phototransistor – are not useful to you either since you will never drive this part into breakdown. Hopefully…

The section labeled *coupled* has some interesting information the most useful of which is the Collector Emitter Saturation Voltage. This is the voltage between the collector and emitter when the transistor is fully ON – in saturation mode. For this device that is 0.4V

ELECTRICAL / OPTICAL CHARACTERISTICS ($T_A = 25°C$)

PARAMETER	TEST CONDITIONS	SYMBOL	MIN	TYP	MAX	UNITS
EMITTER Forward Voltage	$I_F = 20$ mA	V_F	—	—	1.7	V
Reverse Current	$V_R = 5$ V	I_R	—	—	100	μA
Peak Emission Wavelength	$I_F = 20$ mA	λ_{PE}	—	940	—	nm
SENSOR Collector-Emitter Breakdown	$I_C = 1$ mA	BV_{CEO}	30	—	—	V
Emitter-Collector Breakdown	$I_E = 0.1$ mA	BV_{ECO}	5	—	—	V
Dark Current	$V_{CE} = 10$ V, $I_F = 0$ mA	I_D	—	—	100	nA
COUPLED QRD1113 Collector Current	$I_F = 20$ mA, $V_{CE} = 5$ V D = .050" (6,8)	$I_{C(ON)}$	0.300	—	—	mA
QRD1114 Collector Current	$I_F = 20$ mA, $V_{CE} = 5$ V D = .050" (6,8)	$I_{C(ON)}$	1	—	—	mA
Collector Emitter Saturation Voltage	$I_F = 40$ mA, $I_C = 100$ μA D = .050" (6,8)	$V_{CE\ (SAT)}$	—	—	0.4	V
Cross Talk	$I_F = 20$ mA, $V_{CE} = 5$ V, $E_E = 0$ (7)	I_{CX}	—	.200	10	μA
Rise Time	$V_{CE} = 5$ V, $R_L = 100\ \Omega$	t_r	—	10	—	μs
Fall Time	$I_{C(ON)} = 5$ mA	t_f	—	50	—	μs

From this table we want to remember $V_F = 1.7V$ and $V_{CE\ (SAT)} = 0.4V$

Characterizing the Optical Detector

This device is not passive like one of the sensors whose resistance changes in response to a change in the environment. A passive device does not need power to operate. An active device, like the optical detector needs power to make the devices work properly. Power is needed by the LED to continuously emit IR radiation. Power is also needed so that the phototransistor can provide a voltage proportional to the amount of light hitting the base.

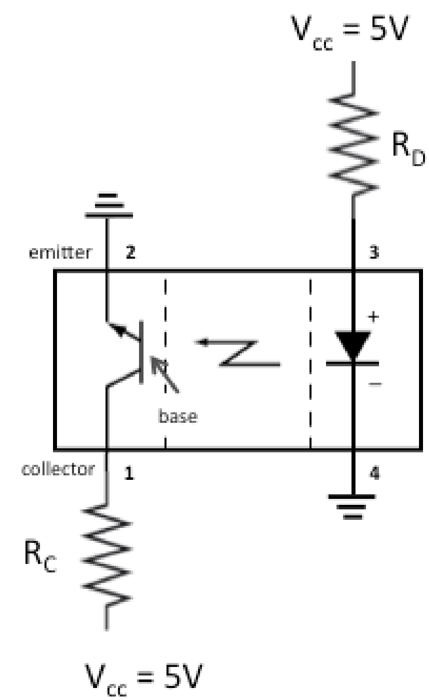
The circuit diagram at right illustrates the basic design that sets up both the LED emitter and the phototransistor to operate using a 5V supply. Consider the emitter – the LED – first. For most applications the diode is biased so that it is always on (but turning it on and off might open up other project possibilities). The 5V provides more than enough voltage to turn the diode on, the only consideration is to not toast the diode. To protect the diode a resistor R_D is chosen so that the maximum current flowing through the device is less than 50mA and the maximum power is 100mW or less. So let's choose a good value for R_D.

Question 1: If you assume that the voltage across the diode is 0V when it is turned on (the simplest model of a diode that is ON) what value of R_D constrains the current to be 50mA?

As you know the voltage across a diode in the ON state is NOT zero it is actually 1.7V This changes the value of the resistance needed to protect the LED.

Question 2: Draw a circuit schematic for the emitter portion replacing the LED with an idealized model where the diode is replaced by an ideal voltage source V_F.

Notes:



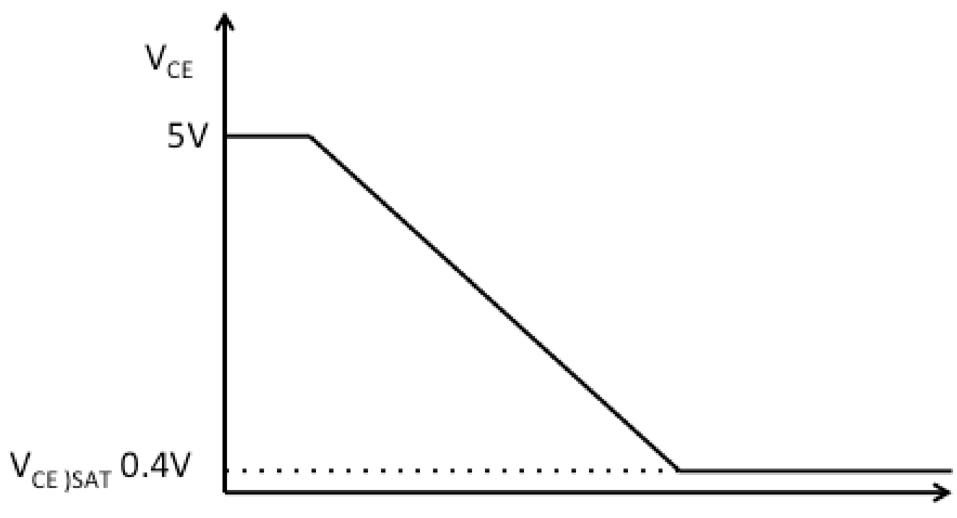
Notes:

Question 3: Using this circuit what value of R_D constrains the current to be 50mA?

Question 4: What is the power dissipated in the LED if this value is chosen for R_D? Is this value greater or less than the maximum power rating of 100W?

The value usually chosen is 2-4 times the minimum value to keep the current well below the maximum so the ubiquitous 330Ω is often used.

Now let's choose a value for the resistor connected to the receiver – the *phototransistor*. To make this choice an understanding of how the transistor works helps. The graph below shows how the collector-emitter voltage – the *output* of the sensor – changes as the voltage across the base changes. As you can see the transistor goes through three states. Before the base-emitter voltage exceeds a threshold voltage the phototransistor is OFF with no current flowing so the collector-emitter voltage is just the 5V supply voltage. Once the base turns the transistor full on into SATURATION the transistor now behaves like a very low resistance device so V_{CE} is quite small ~ 0.4V.



Notes:

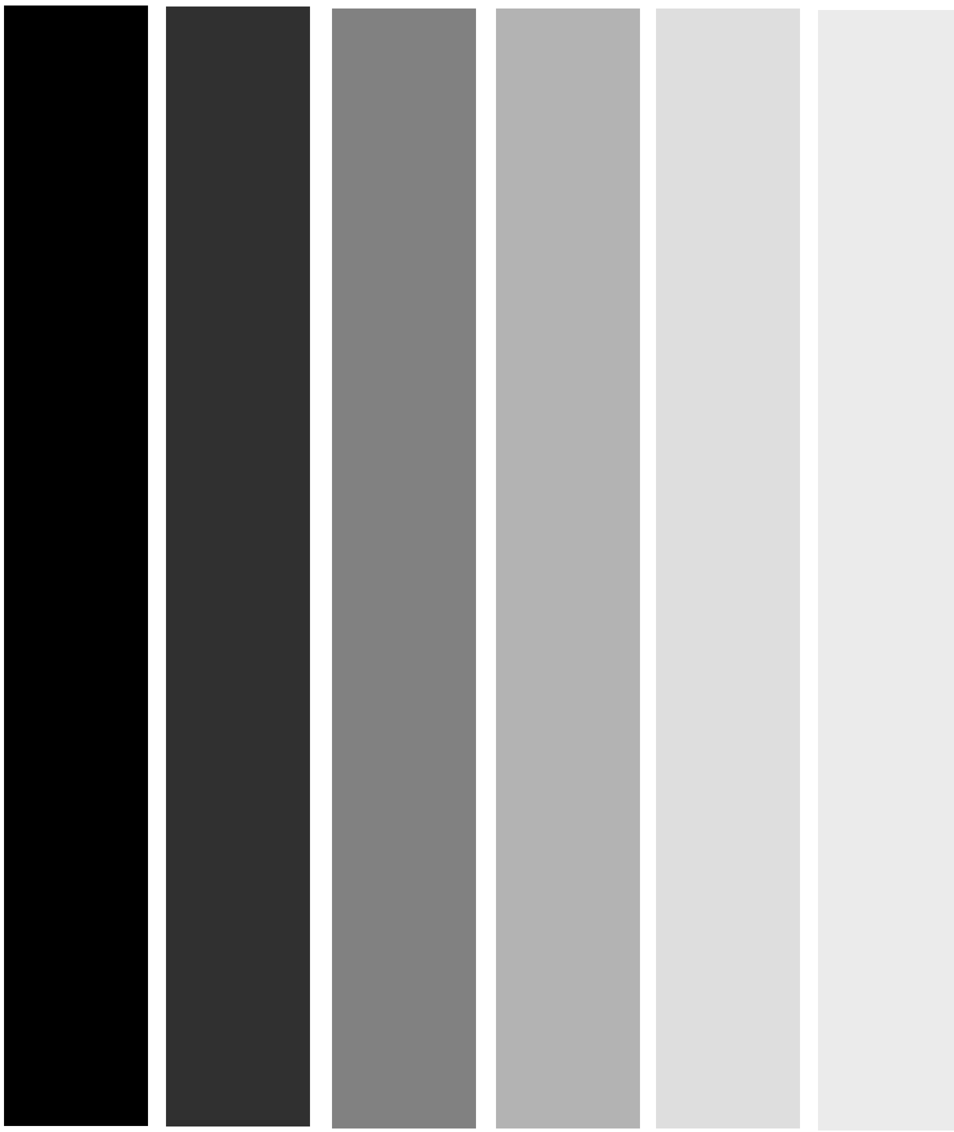
In the configuration where the resistor is connected to the collector (as shown in the schematic) the transistor outputs a high voltage in low light conditions and a low voltage in high light conditions.

As these devices are voltage driven the value of the resistor is chosen to be larger at about 5-10kΩ so once the transistor is put in the correct state it does not take much power to hold the output voltage.

Question 5: Try to come up with a different placement of the resistor and choice of output voltages so that the output voltage is low for low light conditions and higher for high light conditions.

Question 6: Now that the sensor is connected properly let's design an experiment to test the sensor's behavior. Using the optical detector, voltages supplied by the power supply, a variety of objects, and the DMM or an oscilloscope, design an experiment that characterizes the sensor for sensitivity to different objects at the same distance and for sensitivity to your choice of an object at different distances.

Question 7: Which objects produces the highest signal? Since this is an Infra-Red device the color is not important only the ability to reflect Infra-Red or radiate it if the object is red-hot.



Notes: