A **Light Sensor** generates an output signal indicating the intensity of light by measuring the radiant energy that exists in a very narrow range of frequencies basically called “light”, and which ranges in frequency from “Infra-red” to “Visible” up to “Ultraviolet” light spectrum.

The light sensor is a passive devices that convert this “light energy” whether visible or in the infra-red parts of the spectrum into an electrical signal output. Light sensors are more commonly known as “Photoelectric Devices” or “Photo Sensors” because the convert light energy (photons) into electricity (electrons).

Photoelectric devices can be grouped into two main categories, those which generate electricity when illuminated, such as *Photo-voltaics* or *Photo-emissives* etc, and those which change their electrical properties in some way such as *Photo-resistors* or *Photo-conductors*. This leads to the following classification of devices.

- Photo-emissive Cells – These are photodevices which release free electrons from a light sensitive material such as caesium when struck by a photon of sufficient energy. The amount of energy the photons have depends on the frequency of the light and the higher the frequency, the more energy the photons have converting light energy into electrical energy.
- Photo-conductive Cells – These photodevices vary their electrical resistance when subjected to light. Photoconductivity results from light hitting a semiconductor material which controls the current flow through it. Thus, more light increase the current for a given applied voltage. The most common photoconductive material is Cadmium Sulphide used in LDR photocells.
- Photo-voltaic Cells – These photodevices generate an emf in proportion to the radiant light energy received and is similar in effect to photoconductivity. Light energy falls on to two semiconductor materials sandwiched together creating a voltage of approximately 0.5V. The most common photovoltaic material is Selenium used in solar cells.
- Photo-junction Devices – These photodevices are mainly true semiconductor devices such as the photodiode or phototransistor which use light to control the flow of electrons and holes across their PN-junction. Photojunction devices are specifically designed for detector application and light penetration with their spectral response tuned to the wavelength of incident light.

The Photoconductive Cell

A **Photoconductive** light sensor does not produce electricity but simply changes its physical properties when subjected to light energy. The most common type of photoconductive device is the *Photoresistor* which changes its electrical resistance in response to changes in the light intensity.

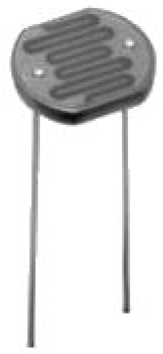
Photoresistors are Semiconductor devices that use light energy to control the flow of electrons, and hence the current flowing through them. The commonly used *Photoconductive Cell* is called the **Light Dependent Resistor** or **LDR**.

The Light Dependent Resistor

As its name implies, the **Light Dependent Resistor** (LDR) is made from a piece of exposed semiconductor material such as cadmium sulphide that changes its electrical resistance from several thousand Ohms in the dark to only a few hundred Ohms when light falls upon it by creating hole-electron pairs in the material.

The net effect is an improvement in its conductivity with a decrease in resistance for an increase in illumination. Also, photoresistive cells have a long response time requiring many seconds to respond to a change in the light intensity.

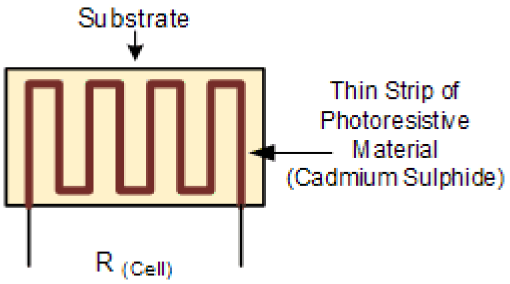
Materials used as the semiconductor substrate include, lead sulphide (PbS), lead selenide (PbSe), indium antimonide (InSb) which detect light in the infra-red range with the most commonly used of all photoresistive light sensors being **Cadmium Sulphide** (Cds).

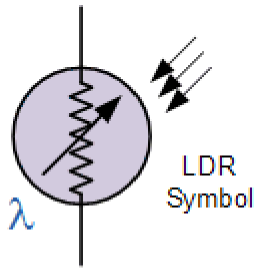


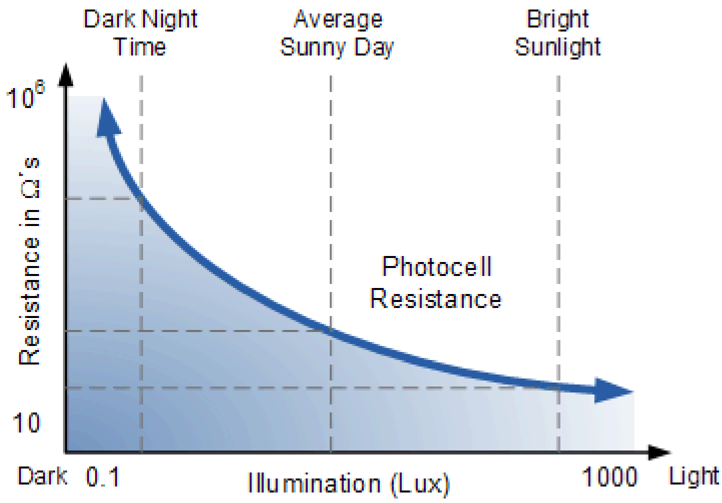
Typical LDR

Cadmium sulphide is used in the manufacture of photoconductive cells because its spectral response curve closely matches that of the human eye and can even be controlled using a simple torch as a light source. Typically then, it has a peak sensitivity wavelength (λp) of about 560nm to 600nm in the visible spectral range.

The Light Dependent Resistor Cell







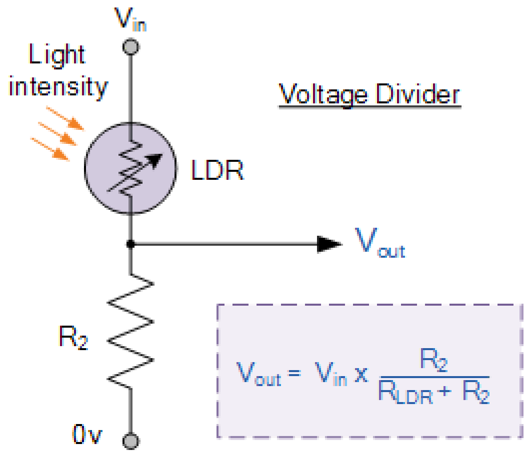
The most commonly used photoresistive light sensor is the **ORP12** Cadmium Sulphide photoconductive cell. This light dependent resistor has a spectral response of about 610nm in the yellow to orange region of light. The resistance of the cell when unilluminated (dark resistance) is very high at about 10MΩ's which falls to about 100Ω's when fully illuminated (lit resistance).

To increase the dark resistance and therefore reduce the dark current, the resistive path forms a zigzag pattern across the ceramic substrate. The CdS photocell is a very low cost device often used in auto dimming, darkness or twilight detection for turning the street lights "ON" and "OFF", and for photographic exposure meter type applications.

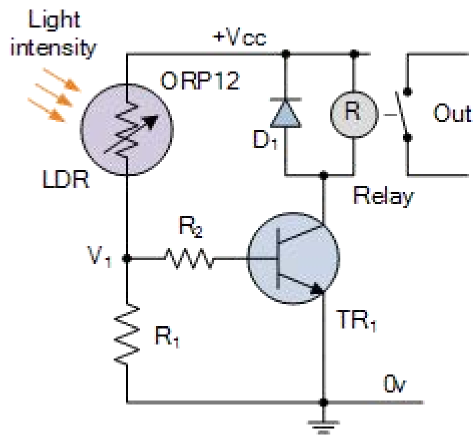
Connecting a light dependant resistor in series with a standard resistor like this across a single DC supply voltage has one major advantage, a different voltage will appear at their junction for different levels of light.

The amount of voltage drop across series resistor, R_2 is determined by the resistive value of the light dependant resistor, R_{LDR}. This ability to generate different voltages produces a very handy circuit called a "Potential Divider" or **Voltage Divider Network**.

As we know, the current through a series circuit is common and as the LDR changes its resistive value due to the light intensity, the voltage present at V_{OUT} will be determined by the voltage divider formula. An LDR's resistance, R_{LDR} can vary from about 100Ω in the sun light, to over 10MΩ in absolute darkness with this variation of resistance being converted into a voltage variation at V_{OUT} as shown.



One simple use of a *Light Dependent Resistor*, is as a light sensitive switch as shown below.



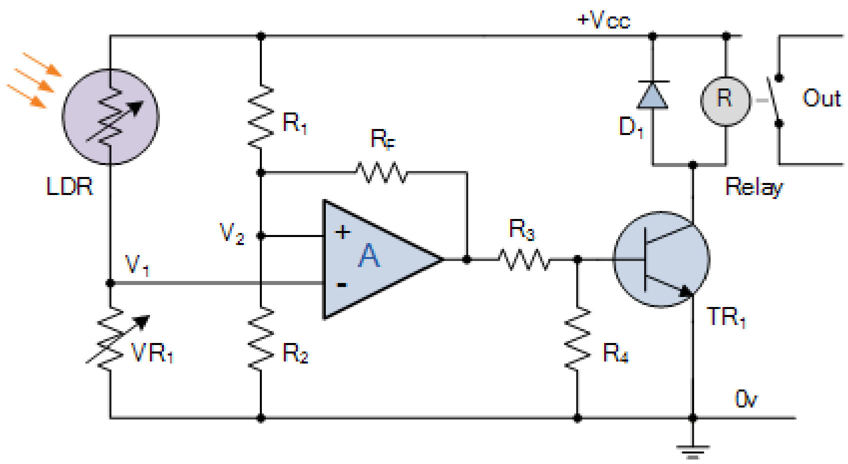
LDR Switch

This basic light sensor circuit is of a relay output light activated switch. A potential divider circuit is formed between the photoresistor, LDR and the resistor R1. When no light is present ie in darkness, the resistance of the LDR is very high in the Megaohms (MΩ) range so zero base bias is applied to the transistor TR1 and the relay is de-energised or "OFF".

As the light level increases the resistance of the LDR starts to decrease causing the base bias voltage at V1 to rise. At some point determined by the potential divider network formed with resistor R1, the base bias voltage is high enough to turn the transistor TR1 "ON" and thus activate the relay which in turn is used to control some external circuitry. As the light level falls back to darkness again the resistance of the LDR increases causing the base voltage of the transistor to decrease, turning the transistor and relay "OFF" at a fixed light level determined again by the potential divider network.

By replacing the fixed resistor R1 with a potentiometer VR1, the point at which the relay turns "ON" or "OFF" can be pre-set to a particular light level. This type of simple circuit shown above has a fairly low sensitivity and its switching point may not be consistent due to variations in either temperature or the supply voltage. A more sensitive precision light activated circuit can be easily made by incorporating the LDR into a "Wheatstone Bridge" arrangement and replacing the transistor with an Operational Amplifier as shown.

Light Level Sensing Circuit



In this basic dark sensing circuit, the light dependent resistor LDR1 and the potentiometer VR1 form one adjustable arm of a simple resistance bridge network, also known commonly as a *Wheatstone bridge*, while the two fixed resistors R1 and R2 form the other arm. Both sides of the bridge form potential divider networks across the supply voltage whose outputs V1 and V2 are connected to the non-inverting and inverting voltage inputs respectively of the operational amplifier.

The operational amplifier is configured as a Differential Amplifier also known as a voltage comparator with feedback whose output voltage condition is determined by the difference between the two input signals or voltages, $V1$ and $V2$. The resistor combination $R1$ and $R2$ form a fixed voltage reference at input $V2$, set by the ratio of the two resistors. The $LDR - VR1$ combination provides a variable voltage input $V1$proportional to the light level being detected by the photoresistor.

As with the previous circuit the output from the operational amplifier is used to control a relay, which is protected by a free wheel diode, $D1$. When the light level sensed by the LDR and its output voltage falls below the reference voltage set at $V2$ the output from the op-amp changes state activating the relay and switching the connected load.

Likewise as the light level increases the output will switch back turning "OFF" the relay. The hysteresis of the two switching points is set by the feedback resistor Rf can be chosen to give any suitable voltage gain of the amplifier.

The operation of this type of light sensor circuit can also be reversed to switch the relay "ON" when the light level exceeds the reference voltage level and vice versa by reversing the positions of the light sensor $LDR$and the potentiometer $VR1$. The potentiometer can be used to "pre-set" the switching point of the differential amplifier to any particular light level making it ideal as a simple light sensor project circuit.

Photojunction Devices

Photojunction Devices are basically PN-Junction light sensors or detectors made from silicon semiconductor PN-junctions which are sensitive to light and which can detect both visible light and infra-red light levels. Photo-junction devices are specifically made for sensing light and this class of photoelectric light sensors include the *Photodiode* and the *Phototransistor*.

The Photodiode.

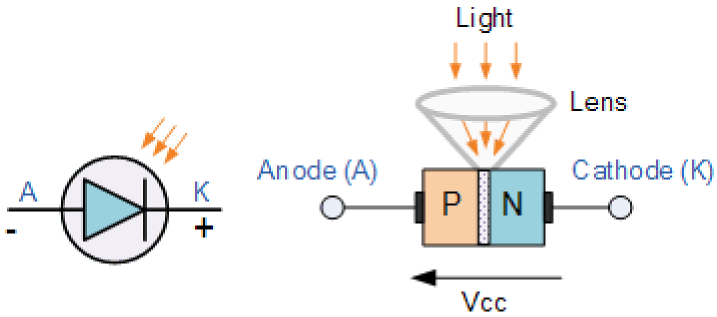
The construction of the **Photodiode** light sensor is similar to that of a conventional PN-junction diode except that the diodes outer casing is either transparent or has a clear lens to focus the light onto the PN junction for increased sensitivity. The junction will respond to light particularly longer wavelengths such as red and infra-red rather than visible light.

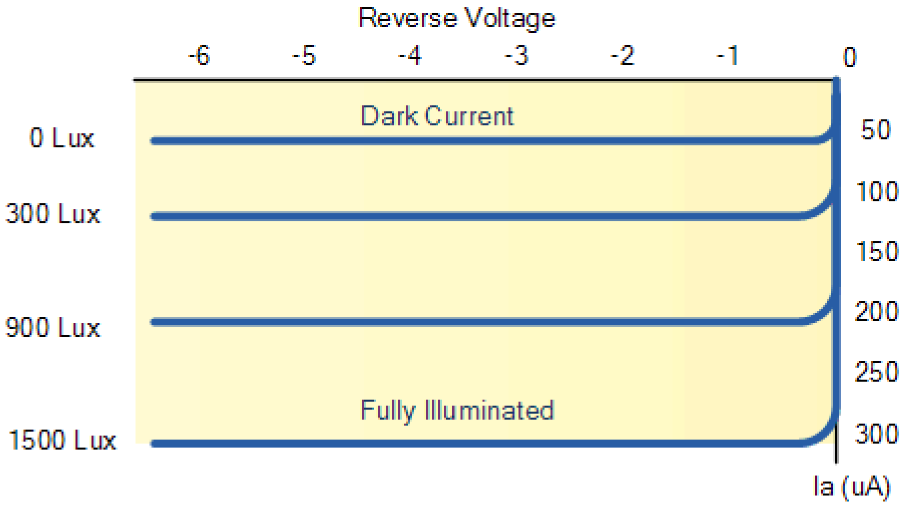
Photo-diode

This characteristic can be a problem for diodes with transparent or glass bead bodies such as the 1N4148 signal diode. LED's can also be used as photodiodes as they can both emit and detect light from their junction. All PN-junctions are light sensitive and can be used in a photo-conductive unbiased voltage mode with the PN-junction of the photodiode always "Reverse Biased" so that only the diodes leakage or dark current can flow.

The current-voltage characteristic (I/V Curves) of a photodiode with no light on its junction (dark mode) is very similar to a normal signal or rectifying diode. When the photodiode is forward biased, there is an exponential increase in the current, the same as for a normal diode. When a reverse bias is applied, a small reverse saturation current appears which causes an increase of the depletion region, which is the sensitive part of the junction. Photodiodes can also be connected in a current mode using a fixed bias voltage across the junction. The current mode is very linear over a wide range.

Photo-diode Construction and Characteristics





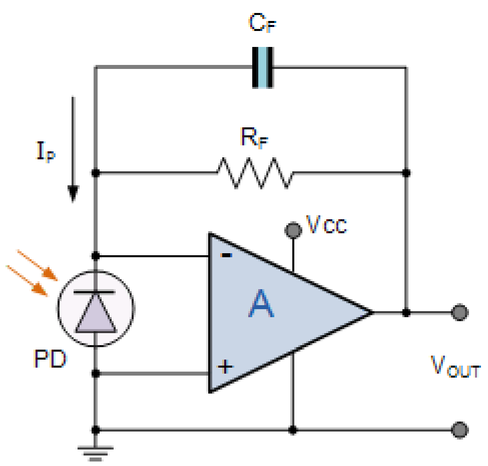
When used as a light sensor, a photodiodes dark current (0 lux) is about 10uA for geranium and 1uA for silicon type diodes. When light falls upon the junction more hole/electron pairs are formed and the leakage current increases. This leakage current increases as the illumination of the junction increases.

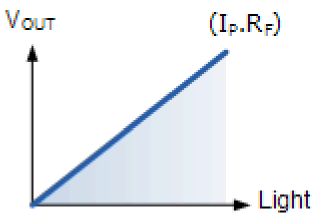
Thus, the photodiodes current is directly proportional to light intensity falling onto the PN-junction. One main advantage of photodiodes when used as light sensors is their fast response to changes in the light levels, but one disadvantage of this type of photodevice is the relatively small current flow even when fully lit.

The following circuit shows a photo-current-to-voltage converter circuit using an operational amplifier as the amplifying device. The output voltage (Vout) is given as $Vout = I_P * R_f$ and which is proportional to the light intensity characteristics of the photodiode.

This type of circuit also utilizes the characteristics of an operational amplifier with two input terminals at about zero voltage to operate the photodiode without bias. This zero-bias op-amp configuration gives a high impedance loading to the photodiode resulting in less influence by dark current and a wider linear range of the photocurrent relative to the radiant light intensity. Capacitor C_f is used to prevent oscillation or gain peaking and to set the output bandwidth ($1/2\pi RC$).

Photo-diode Amplifier Circuit





Photodiodes are very versatile light sensors that can turn its current flow both “ON” and “OFF” in nanoseconds and are commonly used in cameras, light meters, CD and DVD-ROM drives, TV remote controls, scanners, fax machines and copiers etc, and when integrated into operational amplifier circuits as infrared spectrum detectors for fibre optic communications, burglar alarm motion detection circuits and numerous imaging, laser scanning and positioning systems etc.

The Phototransistor

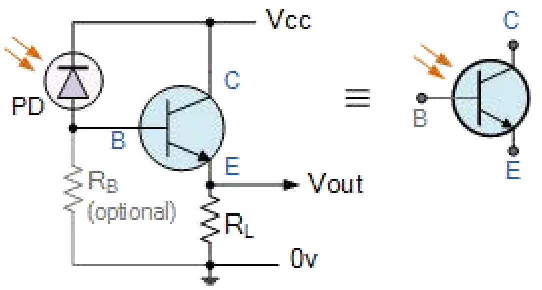


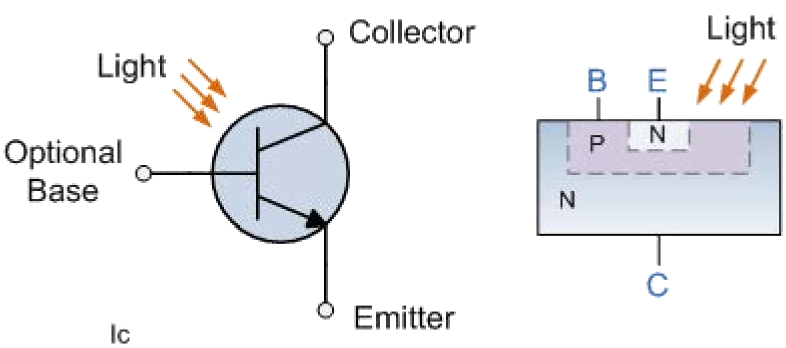
Photo-transistor

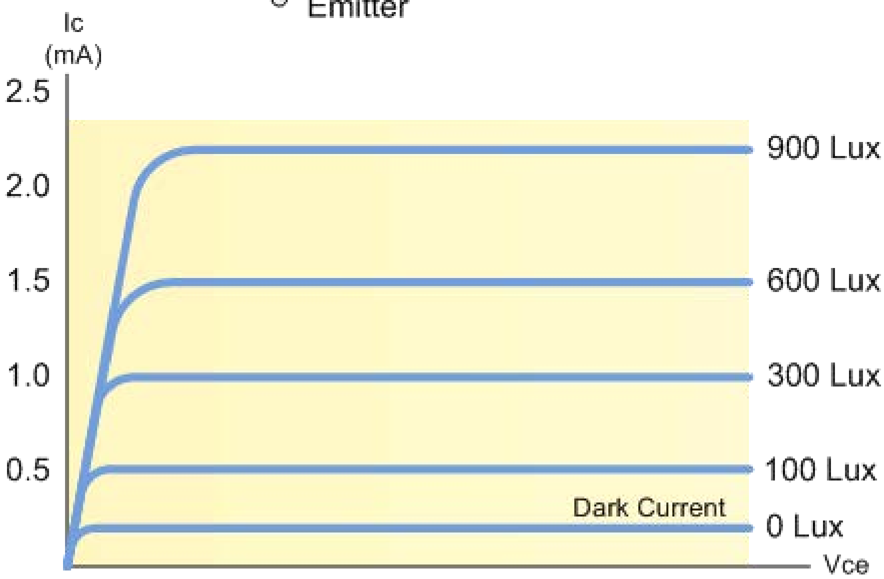
An alternative photo-junction device to the photodiode is the **Phototransistor** which is basically a photodiode with amplification. The Phototransistor light sensor has its collector-base PN-junction reverse biased exposing it to the radiant light source.

Phototransistors operate the same as the photodiode except that they can provide current gain and are much more sensitive than the photodiode with currents are 50 to 100 times greater than that of the standard photodiode and any normal transistor can be easily converted into a phototransistor light sensor by connecting a photodiode between the collector and base.

Phototransistors consist mainly of a bipolar NPN Transistor with its large base region electrically unconnected, although some phototransistors allow a base connection to control the sensitivity, and which uses photons of light to generate a base current which in turn causes a collector to emitter current to flow. Most phototransistors are NPN types whose outer casing is either transparent or has a clear lens to focus the light onto the base junction for increased sensitivity.

Photo-transistor Construction and Characteristics





In the NPN transistor the collector is biased positively with respect to the emitter so that the base/collector junction is reverse biased. therefore, with no light on the junction normal leakage or dark current flows which is very small. When light falls on the base more electron/hole pairs are formed in this region and the current produced by this action is amplified by the transistor.

Usually the sensitivity of a phototransistor is a function of the DC current gain of the transistor. Therefore, the overall sensitivity is a function of collector current and can be controlled by connecting a resistance between the base and the emitter but for very high sensitivity optocoupler type applications, Darlington phototransistors are generally used.

Photodarlington transistors use a second bipolar NPN transistor to provide additional amplification or when higher sensitivity of a photodetector is required due to low light levels or selective sensitivity, but its response is slower than that of an ordinary NPN phototransistor.

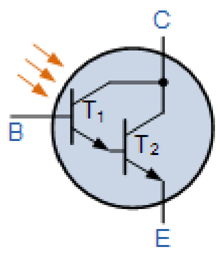


Photo-darlington

Photo darlington devices consist of a normal phototransistor whose emitter output is coupled to the base of a larger bipolar NPN transistor. Because a darlington transistor configuration gives a current gain equal to a product of the current gains of two individual transistors, a photodarlington device produces a very sensitive detector.

Typical applications of **Phototransistors** light sensors are in opto-isolators, slotted opto switches, light beam sensors, fibre optics and TV type remote controls, etc. Infrared filters are sometimes required when detecting visible light.

Another type of photojunction semiconductor light sensor worth a mention is the **Photo-thyristor**. This is a light activated thyristor or **Silicon Controlled Rectifier**, **SCR** that can be used as a light activated switch in AC applications. However their sensitivity is usually very low compared to equivalent photodiodes or phototransistors.

To help increase their sensitivity to light, photo-thyristors are made thinner around the gate junction. The downside to this process is that it limits the amount of anode current that they can switch. Then for higher current AC applications they are used as pilot devices in opto-couplers to switch larger more conventional thyristors.

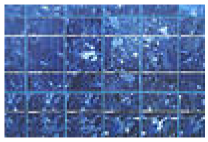
Photovoltaic Cells.

The most common type of photovoltaic light sensor is the **Solar Cell**. Solar cells convert light energy directly into DC electrical energy in the form of a voltage or current to a power a resistive load such as a light, battery or motor. Then photovoltaic cells are similar in many ways to a battery because they supply DC power.

However, unlike the other photo devices we have looked at above which use light intensity even from a torch to operate, photovoltaic solar cells work best using the suns radiant energy.

Solar cells are used in many different types of applications to offer an alternative power source from conventional batteries, such as in calculators, satellites and now in homes offering a form of renewable power.

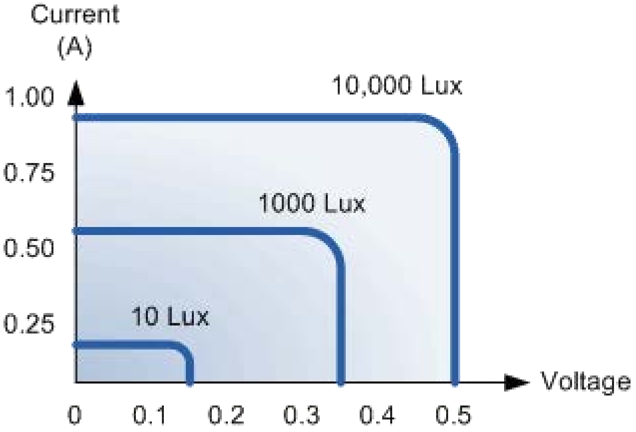
Photovoltaic cells are made from single crystal silicon PN junctions, the same as photodiodes with a very large light sensitive region but are used without the reverse bias. They have the same characteristics as a very large photodiode when in the dark.

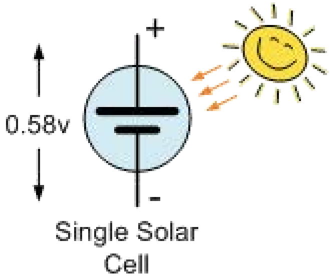

Photovoltaic Cell

When illuminated the light energy causes electrons to flow through the PN junction and an individual solar cell can generate an open circuit voltage of about 0.58v (580mV). Solar cells have a “Positive” and a “Negative” side just like a battery.

Individual solar cells can be connected together in series to form solar panels which increases the output voltage or connected together in parallel to increase the available current. Commercially available solar panels are rated in Watts, which is the product of the output voltage and current (Volts times Amps) when fully lit.

Characteristics of a typical Photovoltaic Solar Cell.





The amount of available current from a solar cell depends upon the light intensity, the size of the cell and its efficiency which is generally very low at around 15 to 20%. To increase the overall efficiency of the cell commercially available solar cells use polycrystalline silicon or amorphous silicon, which have no crystalline structure, and can generate currents of between 20 to 40mA per cm^2.

Other materials used in the construction of photovoltaic cells include Gallium Arsenide, Copper Indium Diselenide and Cadmium Telluride. These different materials each have a different spectrum band response, and so can be "tuned" to produce an output voltage at different wavelengths of light.

In this tutorial about **Light Sensors**, we have looked at several examples of devices that are classed as **Light Sensors**. This includes those with and those without PN-junctions that can be used to measure the intensity of light.

In the next tutorial we will look at output devices called **Actuators**. Actuators convert an electrical signal into a corresponding physical quantity such as movement, force, or sound. One such commonly used output device is the Electromagnetic Relay.