Solar Cells: Sunlight to Electricity

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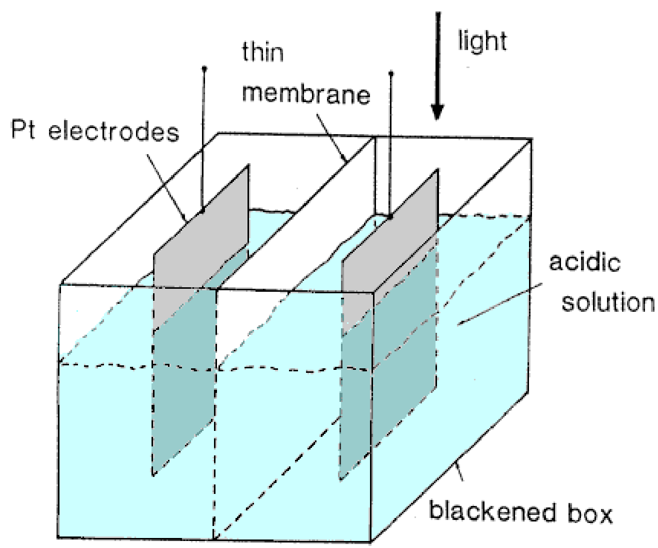
The photoelectric effect describes the interactions of light and electricity

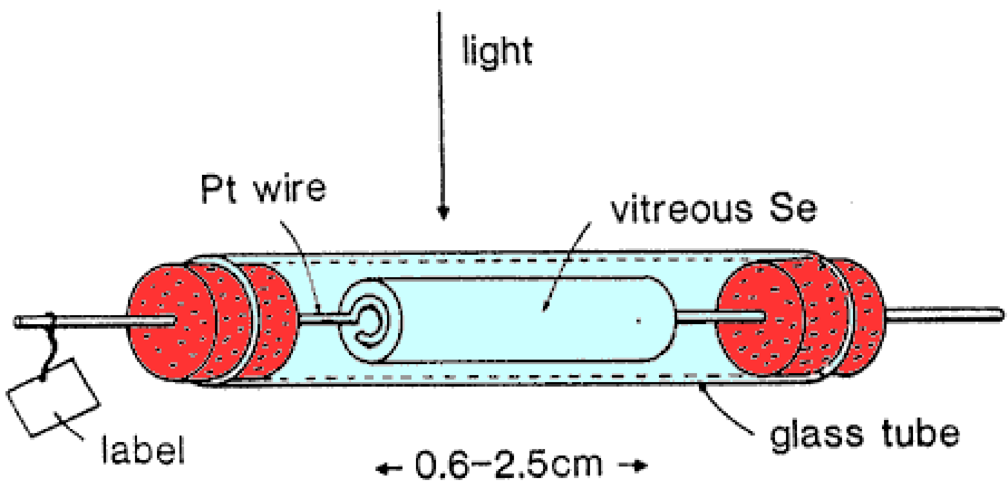
When we think about solar energy, we may not think about solar cookers and southern exposures, we think about those solar panels on top of our houses. It was only about 70 years after DaSaussure's work with solar ovens that Becquerel discovered something very fascinating about light and electricity. In 1869 Edmund Becquerel discovered the photoelectric effect (also called the photovoltaic effect). Amazingly, he was only 19 years old when he discovered this. His setup involved placing two metal electrodes into an electricity-conducing solution. A setup of his apparatus is shown **(Figure a).**



Caption (a): An example of Becquerel's setup.
Source: http://pvcdrom.pveducation.org/MANUFACT/Images/BECQ.GIF

Becquerel found that different colors and types of light had different effects. The best results were those from lights of lower wavelengths, mostly blue lights and ultra-violet colored light. Even coating different materials on the electrodes produced different results, the best of which appeared to be Silver Chloride AgCl or Silver Bromide AgBr. Though Becquerel is credited as the first to discover this effect, he was not the one to explain it. We will need to wait about another 70 years for that explanation.   In the meantime, solar energy grew in its applications!   For example, in the 1860s, August Mouchet, a French mathematician proposed ways that solar energy could be used to power engines to do tasks such as making ice (when he hooked up his steam engine powered by the sun to his refrigeration device). Some argue that August Mouchet is the father of modern solar energy.

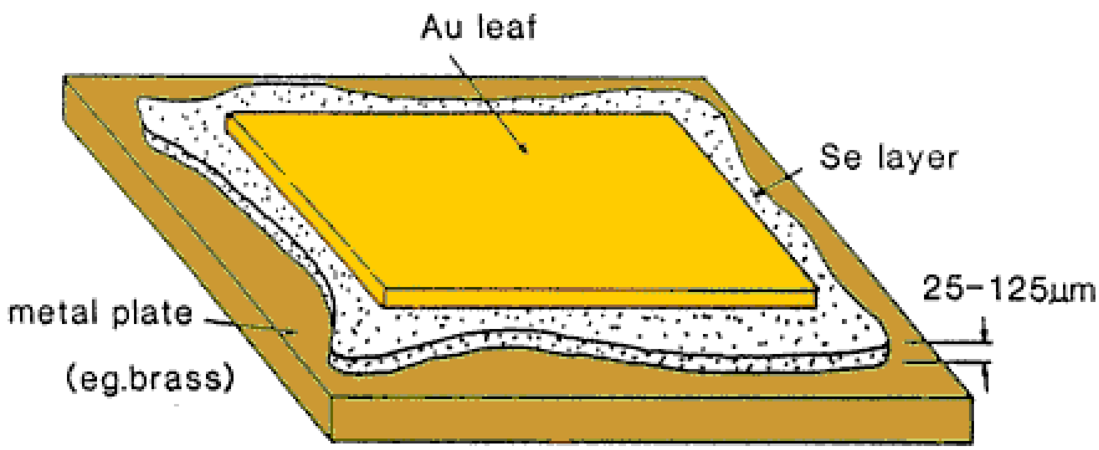
Other substances exhibit the photoelectric effect - such as Selenium (Se). What makes Selenium so special? Well, it was first discovered in 1873 that it has photoconductive properties by Willoughby Smith. Then, in 1876 William Adams and Richard Day were able to use it to produce electricity. Though the amount of electricity it produced was so small it couldn't power electrical motors, it showed for the first time that a solid material, as opposed to a liquid, could create electricity without the need for moving parts or thermal energy **(Figure b)**.



Caption (b): Adams and Days' Selenium glass tube.
Image name: http://pvcdrom.pveducation.org/MANUFACT/Images/VSELEN.GIF

Adams and Day credited the current generated by the light to crystallization on the Selenium bar. Again, it was several years before scientists truly understood what was going on. But, it was only another seven years until the next big step for solar energy was discovered, something that very closely resembles to what we think of today when we think of solar energy.

In 1883 Charles Fritts, an American Inventor, made a solar cell of very thin Selenium wafers **(Figure c)**. Fritts was able to create very thin Selenium films by compressing the molten selenium and then compress them to two different metals such as gold and brass.



Caption (c): Fritts' thin-film Selenium wafer from 1883.
Source: http://pvcdrom.pveducation.org/MANUFACT/Images/THINSEL.GIF

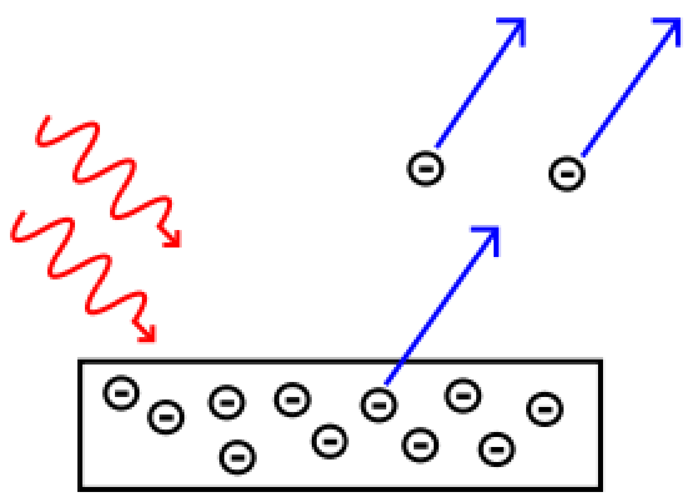
Fritts realized the great potential of these devices. For one, the devices were relatively inexpensive to make, thus they could make a lot of them. Furthermore, the current created by the devices could be used immediately, or stored in batteries for a time when it was needed. Lastly, the current could also be transmitted through wires to distances far away from where it was created. Later, in 1902 it was discovered by Philip Eduard Anton von Lenard that when the frequency of the light on the materials increased, so did current production.

Einstein explained the photoelectric effect

It wasn't until 1905 that the photoelectric effect was explained. The man credited with the explanation was Albert Einstein. This was also the year that he published his influential paper on relativity. However it wouldn't be until 1921 when he receives a Nobel Prize for his work on the photoelectric effect. In order to understand the photoelectric effect, we need to understand a little bit about the debate of what light actually is, or was thought to be at that time.

Anton von Lenard's work in 1902 challenged the current ideas of how light behaved. The prevailing theory of the time of how light behaved was proposed by James Clerk Maxwell. Maxwell believed that light was a wave based on his diffraction experiments. If this were true then you would only need to increase the amount of the light to increase the energy in the substance. Einstein was able to solve this issue (as described in the next paragraph). He believed that light consisted of photons, or rather discrete quanta's of energy. Another way to say this is that a quanta of light is a small bundle of a specific amount of energy.

Light is a form of energy. When it hits a substance, if the energy is high enough, then it will excite the electrons in the material and it will cause them to leave, thus creating a moving charge which, by definition is a current **(Figure)**. Einstein realized that the energy had to be above a certain level in order to excite the electrons. According to Maxwell, if we simply increased the number of the waves then the energy on the surface would increase. This increase in energy would then be enough to excite the electrons. Sadly, Maxwell was mistaken. Anton van Lenard found that the frequency needed to be increased to increase the energy. Einstein believed that the energy of each photon was equal to its frequency multiplied by some constant (which later was called Planck's constant). If a photon had a frequency high enough, then it had enough energy to kick out an electron from the substance, thus creating the photo-electric effect.



Caption: Electrons being excited from light which depicts the photoelectric effect.
Source: https://en.wikipedia.org/wiki/Photoelectric_effect

You might wonder why, if Einstein was able to theorize this, why did it take so long for him to get the Nobel Prize for his work? Typically, a Nobel Prize is not awarded until someone else can also demonstrate that groundbreaking research is correct. Ironically, the man who helped verify Einstein ideas set out to initially disprove Einstein's theory- Robert Millikan. Though Millikan was more commonly known for his oil drop experiment, he spent almost a decade trying to prove Einstein wrong.   The reason he spent so much time to prove him wrong was that there was so much evidence that light was a wave. If Einstein was correct, then what modern scientists believed at the time was wrong, or at the very least, had to be modified.   However, more than a decade after Einstein theorized his work in 1905, Millikan's experiments confirmed Einstein's theories in every detail in 1916.

Solar Cells: The Greatest Invention that Almost Never Was

While Einstein and Millikan worked on explaining the photoelectric effect, other scientists were discovering new ways to collector solar energies, such as, discovering the photoelectric effect in other materials, and finding ways to produce more silicon crystals. All of these advancements helped develop the solar panels that we use today. It wasn't until about 1954 that solar panels started to have any real type of efficiency that made them practical for use in generating electricity.

Some people say that 1954 was the birth year of modern photovoltaic technology. Scientists Daryl Chapin, Calvin Fuller and Gerald Pearson worked at Bell Laboratories and in 1954 they created the silicon photovoltaic cell or also known as a "PV cell". This was the first time that solar cells created enough energy that they could actually run equipment. The scientists at the labs later made solar cells that have efficiencies at 6% and then in 1960 Hoffman Electronics got efficiency up to 11%. What is so fascinating about this discovery is that Pearson did not actually set out to create a better solar collector. Pearson was looking at silicon for its applications with electronics, not with solar cells. However, like many things in science, he accidently discovered that it made a far better efficient solar cell then those cells made with selenium. The New York Times went on record to say that this is "the beginning of a new era, leading eventually to the realization of harnessing the almost limitless energy of the sun for the uses of civilization."

What saved solar cells?

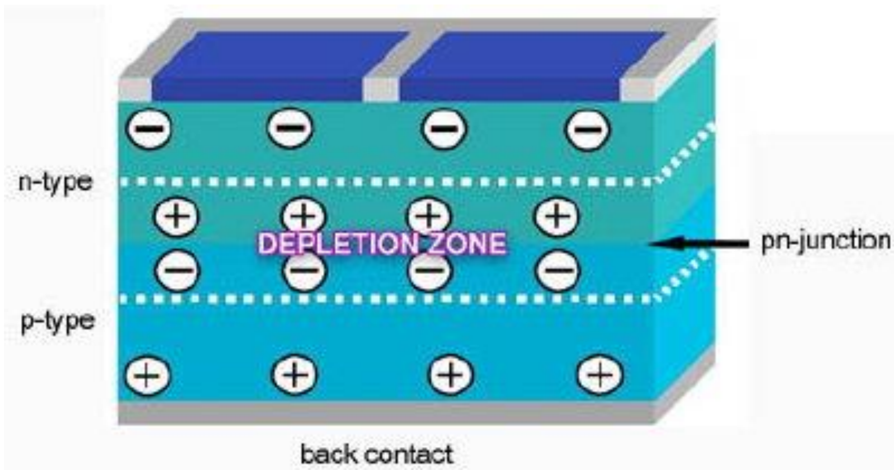
This new discovery opened up many possibilities and allowed for the creation of new products, including toys, solar powered radios, dollar bill changers, and devices that decoded punch cards in early computers. However it was not without its shortfalls. For one, it was very expensive to use with household items. For example, for a power plant to supply a house with one watt would only cost about 50 cents. If a solar cell were used to supply that same one watt, it was estimated that the cost would range from $300 to $1500. With such a huge difference in cost, it seemed like the ability to commercialize the solar cells was doomed. So what saved solar cells?

The answer was the U.S. Military with some help from the Russians. It was around this time that the great Space Race began. Sputnik was launched on October 4th, 1957. This single event spurred the space age and eventually helped lead to the founding of NASA. The U.S. Army and the Air Force were initially joined in a top secret military project but it was later turned over to the Navy. This project involved the creation of earth orbiting satellites. The Navy thought that solar cells would not be a viable power source because they were untried and not yet proven for satellites. They decided to pursue more traditional chemical batteries. This idea met with strong opposition from Dr. Hans Ziegler the leading expert in satellite instrumentation at the time. Ziegler understood that solar cells could power satellites for an extended length of time unlike a chemical battery that would quickly run out, rendering a million dollar satellite useless. After much debate, a compromise was made. The new Vanguard satellites would have a dual power system, a chemical battery and a solar cell. Ironically, just as Ziegler predicted, the chemical batteries died within a week.

The solar cells that were created for these satellites took years to design. While these cells were being created, a very important discovery was made. In fact, that application is still used today. Mandelkorn created a solar cell that has a lower resistance to radiation. This is called an n-on-p cell and is described in the next section.

Modern Solar Cells: N-on-P Cells

What exactly is an "n-on-p" cell? The n portion of the cell is a special type of silicon cell that is a combination of silicon that has bonded with compounds that contain one more valence electron then silicon has, such as Phosphorus. This has a negative charge. Silicon only requires four electrons to bond with it, thus this extra electron is available to be conducted through the material. The p portion is the opposite, it is silicon combined with compounds containing one less valence electron, such as Boron, and has a positive charge. This means that only three electrons are available to bond with the silicon leaving one spot opened for a free electron. A picture of the junction is shown **(Figure)**.



Caption: An n-on-p cell showing the different zones.
Source: https://core.ac.uk/download/pdf/47189488.pdf

The depletion zone is the area where you have electrons moving from the n type to the p type. Moving electrons is current, thus you have the ability to create a current which can be used to power different objects.

The Vanguard I satellite was able to have a very small PV array. Though this array was less than a single watt, it was powerful enough to run the radios. The Vanguard satellite was the first of many that year to use PV power supplies for onboard electronics. Explorer III, Vanguard II and Sputnik -3 were also launched in 1958 and each had PV power supplies. In the following year, Explorers VI and VII were also launched, both containing PV power supplies. In fact, Explorer VI contained 9600 cells each of which were only 1 cm by 2 cm. These silicon solar cells become a cornerstone for all space missions and applications.

Throughout the sixties, the amount of power each solar cell could produce increased. Most of the cells were used in space missions, but others started appearing on buildings. For example, some lighthouses became powered by solar cells as well as the Astronomical Observatory installed a 1000 W cell in 1966 to supply power.

Solar technologies became much cheaper in the 1970s. Dr. Elliot Berman created new solar cells that lowered the cost from $100 per watt to $20 per watt. This drastic reduction in price led to a much larger market for solar cells. For example, at this point became practical to place solar panels as a source of power in remote areas where people cannot hook up to any kind of electrical grid. For example, at the end of the decade, NASA installed a 3.5 kilowatt photovoltaic system in southern Arizona on the Papago Indian reservation. This solar power system provided power for 15 homes which gave them electricity to use for, among other things, pumping groundwater. Other examples include the coast guard who uses solar power for its buoys and lighthouses. Also at this time, the first solar powered railroad crossing sign was created. Other warning lights, like those used on oil rigs started to become solar powered.