A Paper on Photovoltaics

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Introduction:

The modern world must seek out alternates for current energy sources. There are a number of problems with the current energy supply including issues with the environment and climate change, aesthetic concerns, national security, the instability of fossil fuel prices, and the fact that eventually these supplies must be replaced anyway since fossil fuels by their very nature will be depleted regardless of efficiency or waste in their use.

The search for a replacement has yielded a number of options with potential, such as wind, fusion, geothermal energy, and photovoltaics. Wind power has the potential to meet the current energy needs of the United States, but the feasibility of global implementation is a serious problem. The power from the fusion process could meet the world's energy demands easily if researchers developing it could vastly improve the energy returned to energy invested ratio. Geothermal energy is only feasible in certain parts of the globe as not all parts of the Earth's crust have sufficient temperatures to be a viable energy source. Solar power can be applied in any region outside of the Arctic and Antarctic circles and could supply ten times the current world energy supply, making it effectively unlimited. Figure 1 in Appendix A illustrates the amount of land area that solar panels would require supply global energy demands. Furthermore, the graphic only assumes 8% efficiency in solar panels, but it is not unreasonable to expect 15% efficiency from a photovoltaic device today. This drastically reduces the demand on land area while still providing the same level of output. Ultimately, many feel that the way to power the future will be a diverse energy portfolio instead of laying all the eggs in a single basket.

The major hurdle to integrating solar energy as a greater part of our energy supply has been the cost. Solar power under favorable conditions can more than pay for itself over its lifetime even without government subsidies in large part due to the durability of photovoltaics. As there are no moving parts, nothing can break down. A little maintenance work (i.e. removing grime from the panel, protecting it from accidental damage) can lead to panel lifetime of 25 years or longer. It is uncertain exactly how long one can expect a solar panel to last; the research is ongoing. The issue for prospective investors is that the vast majority of the costs involved with the projects are upfront costs. According to Coughlin and Cory, a four kilowatt system (enough to run an efficient home) can cost $32k or more[1]. Were it possible to significantly reduce the cost for a given supply of power, the implementation of solar as a significant portion of power used would become significantly easier.

A plethora of methods to improve the return on investment of solar cells are being researched and implemented. These have ranged from using mirrors to increase the light incident upon the panel to tilting the panels to optimize the panels for the latitude at which they are placed. Work is also being done in the area of solar tracking, the moving of the panel to maintain a noon-time orientation in relation to the Sun. In addition to these methods, there is the seemingly more obvious choice of increasing efficiency. To increase the efficiency, one expands the areas of the electromagnetic spectrum in which the panel is active or producing electricity. Therefore, a theoretically 100% efficient panel would convert the energy of all wavelengths into electricity.

Project:

This project was to determine how much the different wavelengths of the visible light spectrum would contribute to the energy output by the photovoltaic system. For this project, a simple photovoltaic panel, a voltmeter, an ammeter, a light-bulb (something to serve as a load on the system) and a set of light filters for the visible light spectrum. To see a picture of the equipment, please refer to Appendices A and B. In this project, the role of light filters was served by “Jewel CD cases.” The cases came in 5 colors and were taped together to cover the entirety of the light-collecting area. The cases did not come in every color of the light spectrum but instead left out indigo and orange. It was not believed that this would be a tremendous set-back as orange and indigo were in the middle of the spectrum and therefore should follow the trends that emerged. Additionally, the cases were all the same thickness, 5mm. The photovoltaic panel is rated at 10W and had a sunlight catching area of 722.26 cm^2. There were no accessories that aided the process of producing power in any way. Additionally, something was necessary to provide a load on the electrical circuit created. For this paper, a small light-bulb like one would find in a dashboard was used.

What Went Wrong:

The project did not work because the project was delayed by procrastination. When it came time to perform the experiment in the week before the paper was due, the weather was uncooperative. During several attempts, the weather proved to be too cloudy and overcast to produce valid results. In overcast weather, the panel’s output is significantly decreased as one can expect. However, the other thing that also happens is that the readings are typically not stable; they fluctuate significantly. This fluctuation is particularly troublesome for taking accurate measurements and generating analysis and conclusions. After the week of overcast weather an exceedingly long-lasting storm system combined with the hard rains made testing impossible over the weekend. Essentially the only thing produced was a trial run in which the apparatus was shown to work, but beyond that, there was no data produced.

When the project does work, the panel is placed outside in sunlight. A measurement for the voltage and the current are taken. By multiplying the voltage and the current together, a measurement for power in Watts is produced. What one would expect to see and what was observed in the limited testing available, is a decrease in the power output. In terms of physical observations, the bulb switches from burning quite brightly to a much dimmer glow. Provided the filter removes enough of the light, one can also watch the bulb reduced to a red filament because the filament is heating up from the current flowing through it but it's not enough to produce a significant light source.

Had the project actually been implemented, one would have expected to see the power produced by the solar cell increase with increasing frequency. This means that the energy produced would be look like this red<yellow<green<blue<violet< no filter. One area of interest that was going to be delved into was to see if the sum of the energies produced by the filtering was equivalent to the energy output without a filter. Also, it would have been interesting to see if a ratio emerged between the filters.

The Development of Photovoltaics:

The phenomenon that allows photovoltaics to work was first observed in 1839. Physicist Edmund Bequerel noticed that when light produced a current from silver coated platinum electrode submersed in an electrolytic solution. This is the first documented case of the photovoltaic effect. In 1876, this work was expanded upon by William Adams and Richard Day. Adams and Day contacted selenium with platinum instead of using silver. This work was significant in that this effect was a spontaneous effect; they did not have to input an external power supply. The work remained rather stagnant until the 1950's with the advent of silicon wafer technology. It was in this time that the first definitively photovoltaic device was built when Bell Laboratories manufactured their solar battery.[2] Interest was reinvigorated in the 1970's with an energy supply crisis. Many photovoltaic technologies were developed in this time period including work with band gaps and increasing efficiencies. Finally, the current boom in interest of solar cell technologies was started in the 1990's.[3]

The Physics Behind Solar Cells:

As has been briefly mentioned, the phenomenon that allows photovoltaics to work is the aptly named photovoltaic effect. This effect or an exaggeration of this effect is most readily apparent in some of Einstein's work, specifically the photoelectric effect. The photoelectric effect is the phenomenon observed when a metal loses an electron when light is shined upon it. The light carries energy which is transferred to the metal causing the electron to enter an excited or high-energy state. This high-energy state is unsustainable and the electron quickly resumes its ground or low-energy state. Also, it should be mentioned that the electron can be in one level at a time and it does not spend time between states, the electron "jumps." Incidentally, when the electron transitions from its excited state to grounded state, the excess energy is emitted as light. This in turn has become particularly useful for fluorescent light-bulbs.

Scientists at the time were having a particularly hard time determining the specifics of what was happening with the photoelectric effect because the details in the process were dependent on their characterization of light. With the famed double-slit experiment, scientists had seemingly shown that light could not be a particle, but Max Planck's work indicated that the energy of light was correlated with discrete "packets of energy," or multiples of Planck's constant. Planck's work was revolutionary in that it refuted the idea of wave mechanics to some extent because under wave mechanics, the energy would only depend on the amplitude of a wave making wavelength/frequency irrelevant whereas Planck's work indicated that amplitude was important in determining how far the electrons jumped but frequency was also relevant. Take for instance two waves of identical amplitude but of differing wavelengths. The wave of smaller wavelength which is blue for the purposes of this example will cause the electron to jump just as far as the higher wavelength –which is red. However, since the blue wave has a much smaller wavelength, it has a much higher frequency than the red wave; this means that more electrons will be jumping to the excited state when exposed to the blue light. This means that electromagnetic radiation with smaller wavelengths will have a higher energy than the EM radiation from larger wavelengths.

The next matter to discuss is the relevance of the photoelectric effect to a photovoltaic panel. The photoelectric effect is immensely significant to the field of photovoltaics because photovoltaics use the light that reaches the Earth from the Sun to bounce the electrons from a metal, semi-conductor, or some similar material into a circuit. The preferred element of the industry is silicon for a number of reasons. Silicon is a semi-conductor and therefore has a set of particularly useful properties. Additionally, there is much work being done with silicon as a result of the microelectronics movement. Normally, the electrons bounce from their ground state into the excited state and then quickly return because the ground state is the more stable configuration. However, in photovoltaics, the system is designed into an orientation such that the high-energy electron is pulled away from the panel and into a load-bearing circuit. The freed electrons are moved toward a circuit by creating an electric field with silicon (the material of choice). The work done by Max Planck and Albert Einstein proved to be very important in the field of photovoltaics; they showed that the frequency of the electromagnetic waves changed the energy of the wave because a larger frequency means that more electrons are getting knocked off. This correlates to a higher reading in the current since more charge is being moved. Now, scientists and engineers can design cells to operate at desired parts of the spectrum by modulating the band gap requirement.

Calculations:

In this section, the calculations showing the varying energies of the different wavelengths will be presented. The equation for determining the energy of a wave is given by $E = \frac{hc}{\lambda}$ where E is the energy of a single photon, h is Planck's constant (6.626 x 10^{-34} Js), c is the speed of light in a vacuum, and λ is the wavelength of the light. Using this equation and some values for the wavelengths of the light, it is not difficult to find some base values for the energy of the photons.

Color	Wavelength (nm)	Energy for 1 photon (J)
Red	650	3.06 x 10^{-19}
Yellow	570	3.49 x 10^{-19}
Green	510	3.90 x 10^{-19}
Blue	475	4.18 x 10^{-19}
Violet	400	4.97 x 10^{-19}

Results:

As one can see from the above table, the energy by these different wavelengths have quite a substantial divide between one end and the other. In comparing the different wavelengths, each step up (or down depending on the perspective) along the visible light spectrum indicates a significant change in energy. These jumps in energy are around the 10% mark. In other words, each change in color represents around a 10% change in energy. Of course, there is no one single wavelength for each color. Rather, each color represents a range of wavelengths. The process here was to identify that range and find a good median value. However, the point is still valid; there are significant amounts of energy to be picked up just in changes within the visible light spectrum which constitutes only a fraction of the entire electromagnetic spectrum. The wavelengths along the electromagnetic spectrum range from hundreds of meters in wavelength to picometers across. However, the larger wavelengths are probably not worth the effort to try and pull in as the energy per photon is really quite small.

Conclusions:

The primary reason the project failed is a lack of proper planning. This combined with poor solar cell testing weather made the demonstration impractical. However, enough testing was done such that the apparatus worked; there just was not enough time to record reliable data. In terms of raw physics learned, a much better grasp of the photoelectric effect is now at hand. Furthermore, an appreciation developed for just how radical and ground-breaking the work on photoelectric effect was.

There were a number of lessons to be taken from this experience. Chief among them was a renewed desire to cut down on procrastination and an urgency to develop more multitasking capabilities. However, the paper proved to be very beneficial because it allowed for more research into an area of personal interest.

Appendix A:

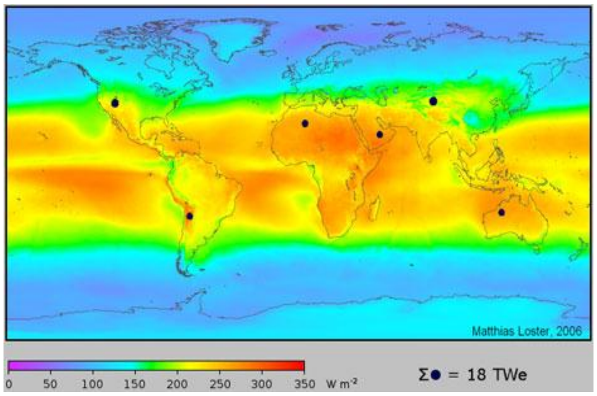

Figure 1: Land mass required for solar panels (8% efficiency) to supply global energy demands

Figure 2: Solar Panel

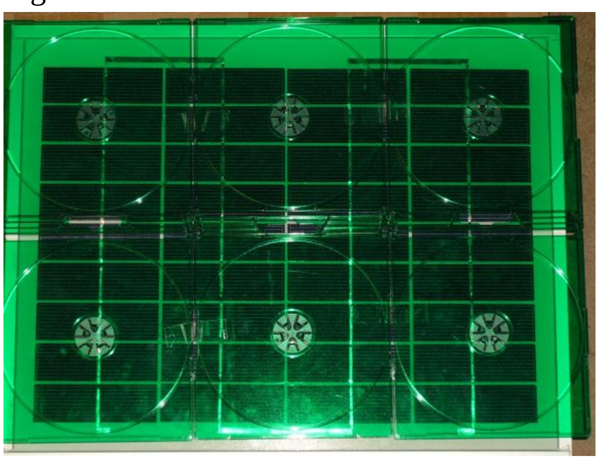

Figure 3: Solar Panel with Light Filter

Appendix B:

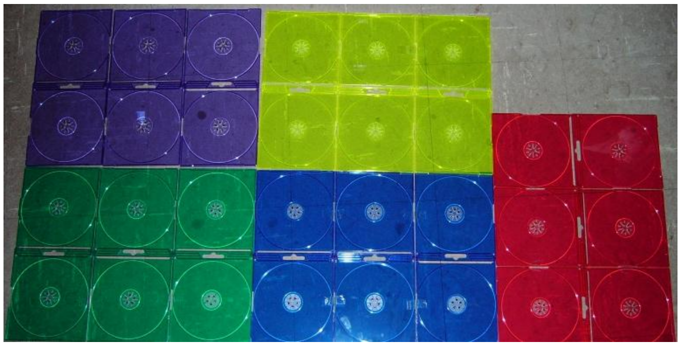

Figure 4: All of the Color Filters

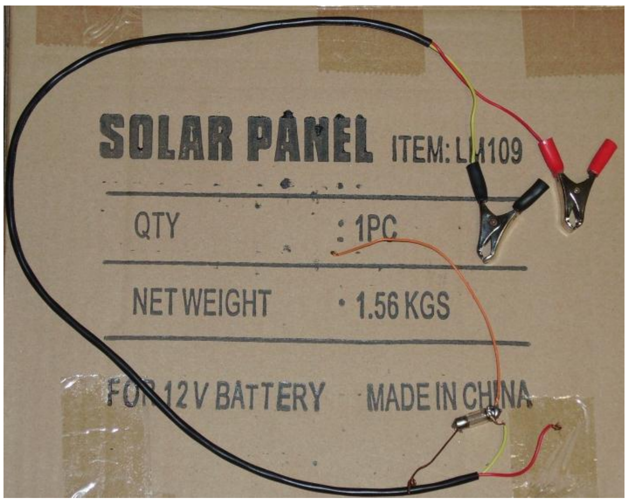

Figure 5: The bulb and wiring that constituted the circuit

References:

1.) Coughlin, Jason, and Karlynn Cory. "Solar Photovoltaic Financing: Residential Sector Deployment." Technical Report. (2010): 154. Print.

2.) Knier, Gil. "How do Photovoltaics Work?." 2002.http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/ (accessed 4/24/11).

3.) Nelson,Jenny. The Physics of Solar Cells. 1 ed. London: Imperial College Press, 2003.