Solar cells
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1 Abstract

In this experiment we investigate how the performance of solar cells are dependant on different factors, ranging from the distance of the light source, angle of incident radiation and load to the light profile incident on the solar cells.All of these experiments resulted in a better understanding of the limitations of solar cells.
when investigating the load's resistance we found that the power output peaks when the load resistance is equal to the internal resistance of the solar cell, this resistance was observed to be 1533Ω, with the internal resistance being measured at 1176Ω, thus giving us an error of 23.4%, this is further discussed in section 6. We also calculated the fill factor to be 0.1779.
On the other hand, when investigating the power output with respect to the angle of incidence of the incoming radiation, we found that the power increases linearly with the increasing angle of attack, this produced a maximum power output when the plane of the solar cells was perpendicular to the angle of attack and a minimum when parallel.
We also discovered that the power output obeys an inverse square relationship when the distance of the light source is increased while keeping everything else constant, leading to the conclusion that the number of photons incident is directly responsible for the generation of power. Furthermore we investigate how the light profile influences the power output, after some analysis in section 5, we managed to reach a conclusion, that being, in general terms, photons with a higher wavelength are responsibly for the majority of the power produced by the solar cells.

2 Introduction

The world is always looking to solve the problems that manifest themselves as the result of the advancement of our technology, the biggest of which at the current time is global warming. Thanks to the abundance of cars, our use of fossil fuels have become a bad hobbit that's harming the primary human home. Earth which accommodates 100% of the human population, is constantly getting warmer, thus raising the sea levels, which in turn endangers human and wild lives.

To fix this problem the use of fossil fuels will have be decreased dramatically and even better is for their use to be completely stopped. However a replacement is required, and it has to be just as good or even better for it to be accepted by world leaders, as any endangerment to their status will result in them not adopting the newly agreed-upon method of energy generation. This is where Solar Cells come in, they are 'a junction between two semiconductor materials' [1]. this structure allows light to strike the material and produce electron-hole pairs, this creates a potential difference across the junction which can be then be used to light a bulb, drive an eclectic motor or do anything that needs electricity.

Though solar cells are a source of unlimited clean energy which is due to fact that sun is a constant and unlimited source of energy, they aren't efficient enough to instantly make fossil fuels obsolete, this results in competition between the two sources of energy production. Which brings us to the purpose of this experiment, which is to understand the limitations of solar cells by investigating how they operate, with the aim in the long term being to improve the the efficiency of solar cells, thus making their use more appealing in houses, farms and other large energy consumer sectors. The procedure used in this investigation is discussed in section 3.

3 Procedure

3.1 Equipment [1]

- solar cells
- Lamp
- Heating system
- Two cassy's
- Light meter
- 10 k ohm calibrated Potentiometer
- 750 ohm
- Multimeter
- Tape measure

3.2 Objectives [1]

1) To determine the output characteristics of a solar cell.
2) To understand what factors affect the performance of a solar cell

3.3 Equations

[1]

$$I = \frac{\epsilon}{R_l + r} \tag{1}$$

Equation 1 is the equation use for calculating the current going through a circuit. where ϵ is the emf produced by the solar cell, R_l is the resistance of the load and r is the internal resistance of the solar cells.

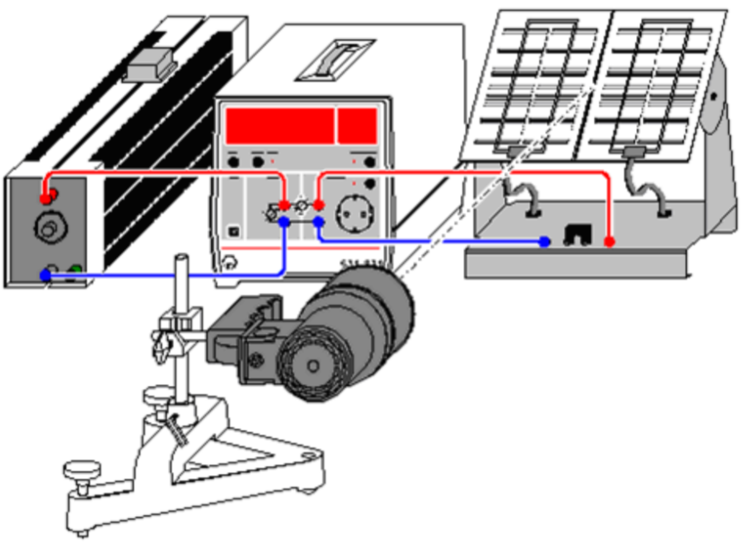
$$P = I^2 R_l \tag{2}$$

Equation 2 is the equation used to calculate the power using the current and the resistance of the load.

3.4 Method

The apparatus used is shown in figure 1, every part of this experiment uses this apparatus where one entity is selected to be the variable while all others are constant. These variables are: the load resistance, illumination angle, distance of the light source from the solar cell and the light profile.

Figure 1: Showing the apparatus used [1]

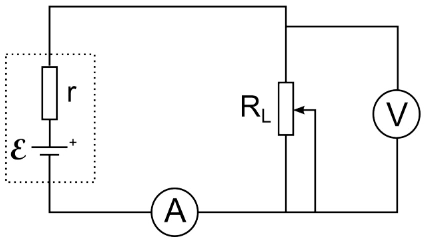


We carried out four different investigations in this experiment each of which is described below.

A) Measuring the power output as a function of load.

In this part of the experiment we investigate how the load resistance which is produced by the $10k\Omega$ effects the power output of the solar cells. We first set up the Circuit shown in figure 2, where r is the internal resistance of the solar cell, ϵ is the emf, R_l is the resistance of the load and A and V represent the ammeter and voltmeter respectively which are attached to the Cassy. In the Cassy configuration we set it to measure the Voltage and Current from the Voltmeter and the Ammeter respectively and we defined the power which was $P = Voltage \times Current$, thus we have three readings in the Cassy, Voltage,Current and power.
We proceed by setting the the resistance R_l to zero and increased it up-to $10k\Omega$ with an increment of $0.2k\Omega$. This will provide a set of values showing us how the solar cell behaves as R_l varies, the results are shown in section 4.

Figure 2: showing the circuit used for part A [1]



B) Effect of illumination angle on the power output.

Using the same circuit configuration as in figure 2 but this time R_l is a constant resistive load with resistance 700Ω.
Given that everything about the circuit is constant we can treat the angle of illumination as our variable. The angle of illumination was changed from 0* to 90*, 0* is where 0% of the incident light hits the solar cells. The angle is increased by an increment of 4.5*. The results of this part are shown in section 4

C) Dependence of power output on the distance from the light source.

This part is about how the distance of the light source effects the power output, we are still using the same configuration of the circuit from part (B), we place the lamp at 50cm away from the solar cells and we increase the distance with an increment of 10cm up to a maximum of 150cm, with each increment we use the Cassy to measure the Voltage,Current and Power. We repeat the same measurement however this time we start from 20cm instead of 50cm. Now with two different data sets we plot them both against an inverse relation, the results are shown in section 4.

D) Determining the effect of the wavelength of the illuminating light.

In this part of the experiment we keep the distance, angle and the circuit variables constant, our only variable is the light profile which is changed using the provided filters 218,203,202 and 201, each of which provides a unique light signature. We will investigate how the different filters effect the solar cell outputs. Using the provided light meter, we are now able to measure the light intensity at the distance where the solar cell is located. placing the lamp at 34.6cm away from the solar cell we start measuring the output characteristics of the solar cells when each of the provided filters is placed in front of the lamp, then we normalise the intensity and use the normalised intensity to normalise the output power. The results of this part shown in section 4.

Figure 3: showing the light profiles produced by the provided filters [1]

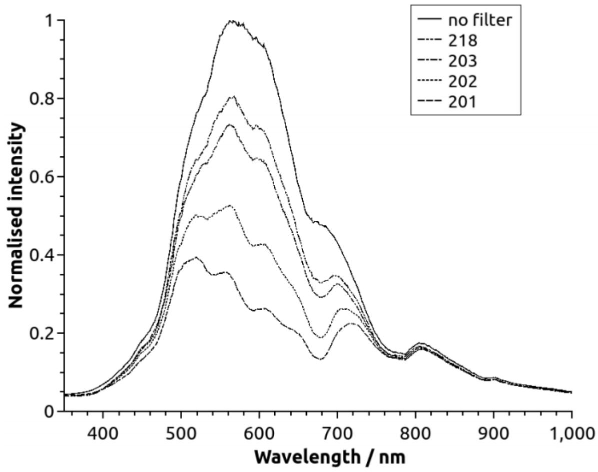


Figure 4: showing characteristics of the individual filters [1]

Filter	Colour temperature (K)	Transmission (%)	Absorption
201	3200-5700	34.0	0.47
202	3200-4300	54.9	0.26
203	3200-3600	69.2	0.16
218	3200-3400	81.3	0.09

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The discussion for each of parts of the experiment are discussed in section 5.

4 Results

4.1 A

Figure 5: Showing how the current varies with the voltage

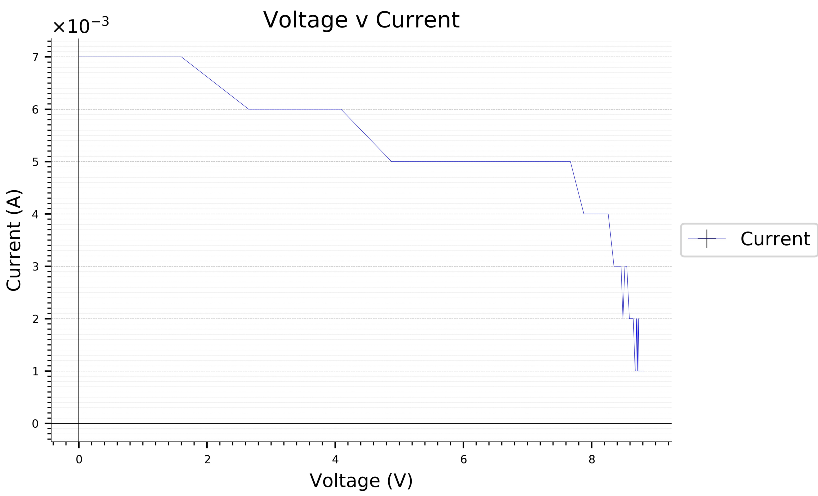
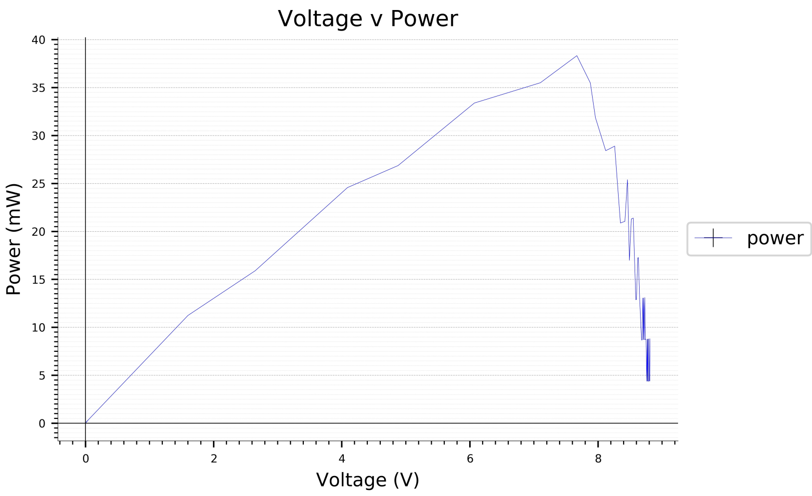


Figure 6: Showing how the power varies with the voltage



4.2 B

Figure 7: showing how the current varies with the angle

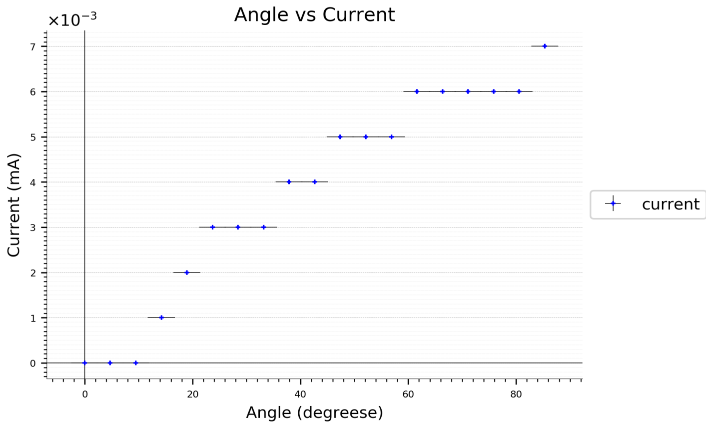


Figure 8: Showing how the power output of the solar cells varies with the angle of illumination

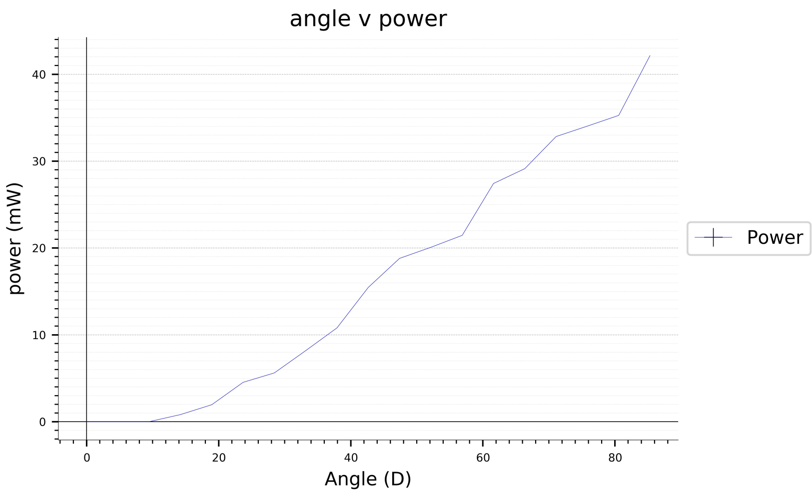
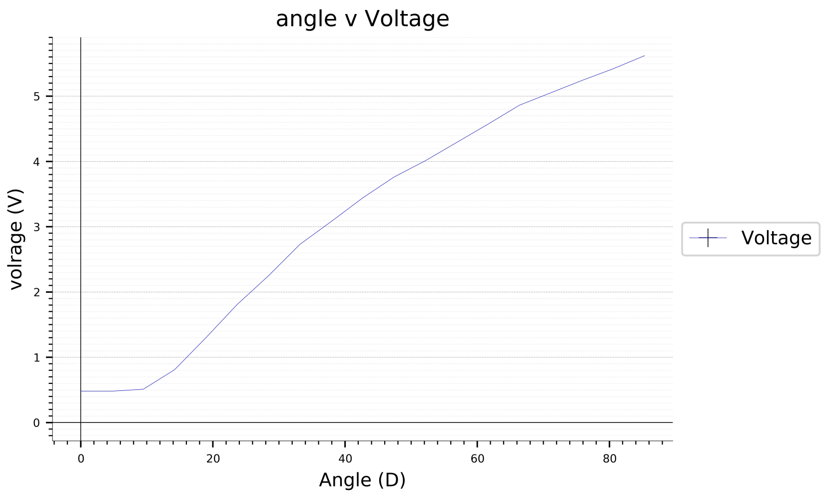


Figure 9: Showing how the voltage varies with the angle of illumination



4.3 C

Figure 10: showing the power output with varying distances, starting at 50cm

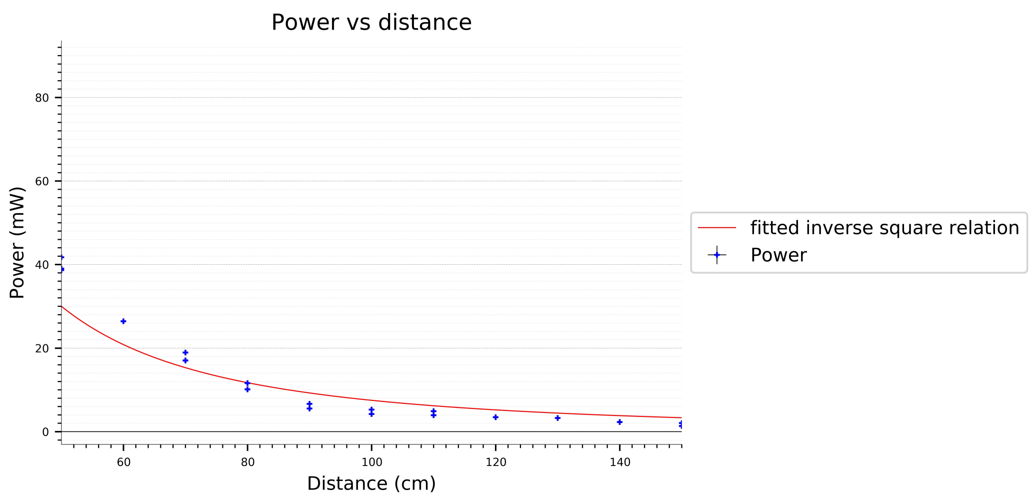
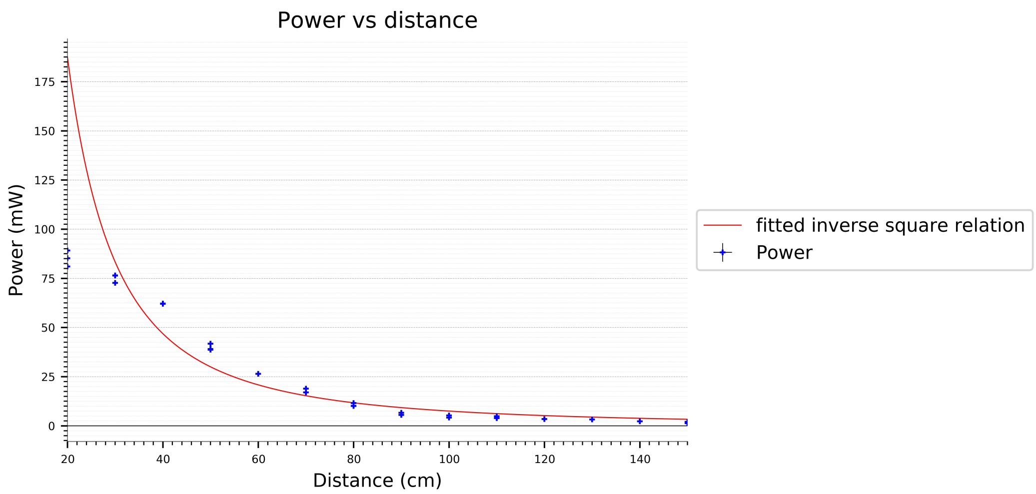


Figure 11: showing the power output with varying distances, starting at 20cm



4.4 D

Table 1: Results for the

filter	normalised illuminance	normalised power
none	1.00	66.09
218.00	0.95	50.59
203.00	0.89	47.17
202.00	0.88	40.19
201.00	0.49	26.40

5 Discussion

5.1 Results in section 4.1

For part A of the experiment, we looked at how the load resistance effects the output characteristics of the solar cells, figure 5 and 6 show the plots obtained by plotting the Voltage against the Current and power respectively.
On figure 5 we can see that as the voltage increases the output current from the solar cells decreases linearly, until a voltage of 7.6V is achieved, after this voltage the current decreases dramatically down to 1mA at 9V. On the other hand figure 6 shows how the power output of the solar cells changes with voltage, we see that the power increases from 0mW when the voltage is zero at a linear rate, until it stops increasing at 7.6V and starts decreasing rapidly down to 4.8mW at 9V.
This sudden decrease in current and power is caused by the increasing resistance, as the resistance increases the power output increases and the current decreases slightly, until a threshold resistance is reached where both the current and power output decrease dramatically.
We calculated the resistance of load at 7.6V using equation 2 and the values for current and power at 7.6V, which turned out to be 1533Ω, comparing this value to the internal resistance of the cell which was observed to be 1176Ω, we see that the maximum power output of a solar cell is achieved when the load resistance is roughly equal to the internal resistance of the solar cell, However due to the large margin of error involved with this experiment, our calculation has an unreasonably large uncertainty of ±23.4%, this is further discussed in section 6.Furthermore as the resistance of the load increases past the internal resistance of the solar cells, we observe that the efficiency of the solar cells dramatically decreases, they're un-able to generate an electromotive force anymore, thus we observe the large decrease in power output.
Upon further calculations using $\frac{I_{sc}V_{oc}}{I_m V_m}$, we found the value of the fill factor of the solar cells which turned out to be 0.1779, the fill factor is an indicator of how efficient the solar cells are, a value of 0.1779 is quiet low for solar cells, this means that those solar cells are very inefficient.

5.2 Results in section 4.2

For part B of the experiment, we are investigating how illumination angles effects the power output of the solar cells, using the apparatus shown in figure 1 we were able to change the angle of illumination from 0*, which indicates that the plane of the solar cells is parallel to the incident light therefore at 0* the power output is zero, this is shown in figure 8.However as the angle increases we can see that the voltage, current and power all increase linearly with changing angle, shown in figures 7,8 and 9.
This result occurs because at 0* no photons are making contact with the solar cells therefore no electron hole pairs are produced, as the angle increases, the likely hood of photons making contact with the solar cells, producing electron hole pairs and generating power is linearly increased.

5.3 Results in section 4.3

For part C of the experiment, we were investigating how the distance of the light source effects the performance of the solar cells, we placed the lamp at a known distance and increased the distance by a known interval then took measurements, this resulted in the plots shown in figures 10 and 11.
In figure 10, we are showing a plot of the distance against the power output, together with the fitting line which is simply the relation $y = \frac{A}{R^2}$ where A is the fitting factor and R is the distance, this relation is a good fit to our first set of data, therefore we can conclude that from a distance of 50cm-150cm the power output of a solar cell is dependant of the inverse square law.However as we take another look and

retake measurements from 20cm-150cm instead of 50cm-150cm, we find that the power output of the solar cells doesn't fit the theoretical curve of the inverse square law (figure 8), as the theoretical curve rises below 50cm, we find that our experimental results reaches a maximum before decreasing. This result is explained by considering heat. As the light source gets closer, the temperature of the solar cells increase. Therefore more giggling of atoms that makeup the solar cell. Somehow the increased motion of these atoms decreases the likely hood of more electron hole pairs being made, a further discussion of quantum mechanics is needed to fully explain this phenomenon.

5.4 Results in section 4.4

For part D of the experiment, we are looking at how varying the light profile effects the power output of the solar cells.Table 1, shows the obtained normalised illuminance and the normalised power.The normalised illuminance was obtained by dividing each obtained value of the illuminance by the larges value in the data set, furthermore the normalised power was obtained by multiplying the power with the corresponding normalised illuminance.

For this discussion we will need to look at tables 1 and 4 as well as figure 3. we can generally see that every filter applied, decreases the power output of the solar cells and the power is decreased a lot more by filters that has a high absorption coefficient. This is due to less photons making it thought the filter and into the solar cells to make electron hole pairs, therefore resulting in a decreased power output.

Furthermore when analysing the obtained results in table 1, specifically looking at the difference in the normalised power obtained for different filters, power from(218) - power from(203) compared to p(202)-p(201), the difference in normalised power directly co-responds to the difference in normalised intensity when considering the 500nm section on figure 3. This indicated that the 500nm profile of the light is responsible for the majority of the power output because a change twice as big caused a relatively large decrease in the power output of the cells. This conclusion is supported by the fact that the energy of the photon corresponds to it's wavelength, governed by the equation: $E = \frac{hc}{\lambda}$, where h is the plank constant, c being the speed of light and λ is the weave length of the photon. A photon with an energy of 4eV is capable to making two electron hole pairs thus providing double the energy as a photon with an energy of 2eV.

6 Error analysis

A lot of systematical errors were present in this experiment, for example the distance from the light source to the solar cells was constantly inaccurate, this is because we measured the distance from the metal frame of the lamp and not from where the bulb was, the difference was however measured to 2.5cm from the metal frame to the bulb, meaning, our data in figures 10 and 11 should be slightly shifted to the right, this results in a better fitting to the theoretical curve.

On the other hand, another big source of error was bad design by the manufacturers, the solar cells were mounted on a rotating platform with a protractor of non a standard scale, meaning from 0-90* instead of going up e.g in 5* the scale went up in an odd fraction, this increased the odds of human error as it induced slight confusion.We also took the uncertainty in the angle to be 4.5* as this was the closest to the systematical uncertainty of the protractor.

Furthermore we managed to control the environment's light input by turning off any bad lamps and simply shutting the blinds, this made sure that we are not getting any fluctuations of light caused by sources other than the primary light source we were using.

7 Conclusion

Overall the performance of solar cells is constantly improving, as our understanding of materials and our ability to manipulate their structures improves there will be an inevitable overcoming of some of the major limitations of solar cell technology and thus make for a faster transition to cleaner energy sources, e.g by finding a way to stop solar cells from being inefficient under hot temperatures we can start to deploy them in hot climates, thus opening many new markets for the technology, furthermore if we can find a way to increase the fill factor to it's theoretical maximum we could possibly make fossil fuels obsoletes as we would no longer need them for abundance of energy. However further and more detailed studies are needed, this is so we can further understand what we can do at the atomic scale to influence the performance of this technology, as Nano technology evolves we will inevitably find a new way to improve upon this technology.

References

[1] school of physical sciences UKC. "Solar cells". In: (2019). URL: https://moodle.kent.ac.uk/2019/mod/resource/view.php?id=55608.