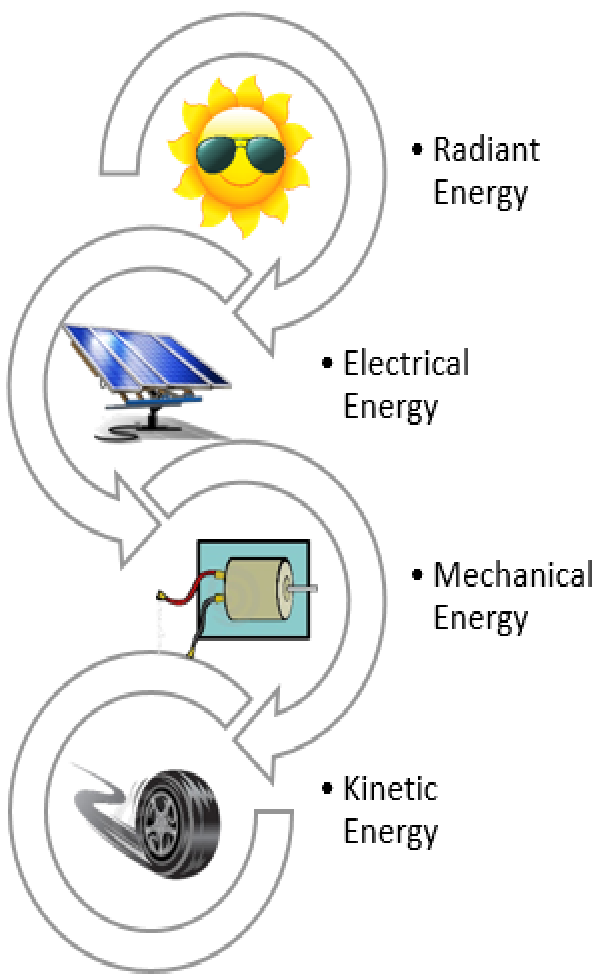
# *APPENDIX A:* **Background Information to help you design your car:**

## Solar Cars:

A solar car is an automobile that is powered by the sun. Recently, solar power has seen a large interest in the news as a way to help us reduce our carbon footprint and still power the technology of the future. Here at QESST, we are interested in helping further this goal. That is why we are actively involved in research improving solar cell design and manufacturing. However, once a solar cell is assembled, there is still more to consider before we can use the power to run our device. Namely, how do we connect the solar cells to our devices, and how does this affect their performance? These are exciting questions, and we will discuss them more below. But, maybe we are getting a little ahead of ourselves. First we need to consider: just what is a solar car?

Like all cars, a solar car converts a form of energy into motion. In most automobiles today, gasoline provides the energy, and the engine and drivetrain converts that energy into motion. For solar cars, the sun's rays carry the energy. Solar energy is captured by the solar cells and converted into electrical energy. This, in turn, is converted into motion by the motor. Maximizing the energy captured by the solar panels and transferred to the wheels is crucial in designing a good solar car.



These ideas are captured by two engineering fields: mechanical and electrical. The *mechanical design* will consider things such as gear ratios, wheel alignment, and weight of the vehicle in order to maximize the energy transferred from the engine to the wheels. The *electrical design* will consider the energy absorbed by the solar cell and converted into turning power (torque) in the motor. We will treat each one of these separately below

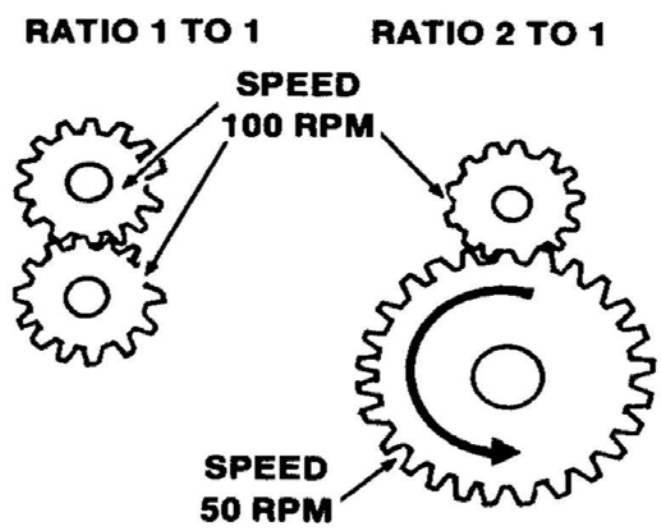
## Mechanical Design (Maximizing your motion given a certain amount of power):

Each team is provided a motor for the solar car obstacle course challenges. Motors perform the important function of converting the incoming energy into rotational motion. Each motor comes with a specific power output and other specs. For this challenge this is a *design constraint*. (Remember to include design constraints in your **NOTEBOOK).**

The gear ratio controls the distribution of power to the wheels. A familiar example of this occurs while riding a bike. As you are riding a bike the power is limited (that is the power of your legs). Suddenly, when you go uphill the bike doesn't want to go as fast. You cannot just switch out your legs to get larger muscles so instead you gear down.

What does it mean to *gear down*? Gear down means controlling the number of turns of the pedal per turn of the wheel. If there are more turns of the pedals per turn of the wheel it requires less power. How does this work? A lower gear moves you a shorter distance for each spin of the pedals, which makes it easier to pedal (but slower).

For the solar car challenge it will be important to consider the gear ratio. This is because the power from the engine is limited and might be less than you want. However, with the proper gear ratio the car can move and (possibly) even do so fast.

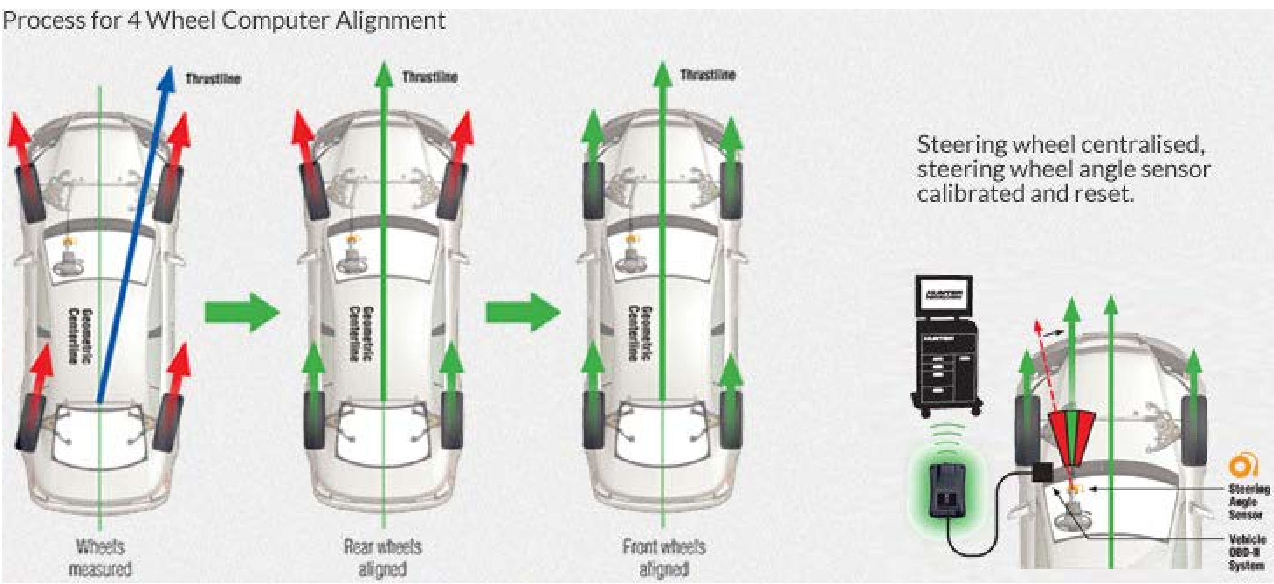


The wheels are another important design parameter. There are two important things to consider:

1. The friction of the wheels
2. The alignment

Low friction on the wheel's axle will help transfer the most power to move your car forward. The wheels need enough friction so that they can push the car forward. Choice of wheel material and bearing type is important. Your team should experiment with these variables (and log your experiments in your NOTEBOOK).

Once you maximize the rotation of each of the wheels, you need to synch them with each other. This process is called *alignment*. The idea of alignment is to make sure all the wheels are pointing in the same direction and not tilted in or out. Without good alignment it doesn't matter how you design your car, it will not move as desired. The image below shows good and bad alignment. It is also important to make sure that all the wheels are at the same height and not tilted in the other directions (for more information, google "*toe caster camber*").




[http://areamotorsport.co.uk/work/alignment-frsu/](http://areamotorsport.co.uk/work/alignment-frsu/)

## Electrical Power:

Solar cars use sunlight to create energy. Each solar cell on your car converts light to electrical power using *photovoltaics*. Electrical power (*P*) is calculated by multiplying the current (*I*) by the voltage (*V*). We can write this as:

$$P=IV$$

*Electrical Power* (*P*) is the rate at which electrical energy is converted to another form, such as your car traveling down the track!
*Current (I)* is the amount of electrical charge.
*Voltage (V)* is the rate at which you can draw or use the current.

The more current and/or the more voltage you have, the greater the power.

## Current and Solar Cells:

The more sunlight the solar cell collects, the more current the solar cell generates. The more current the solar cell generates, the more potential power you gain for your car.

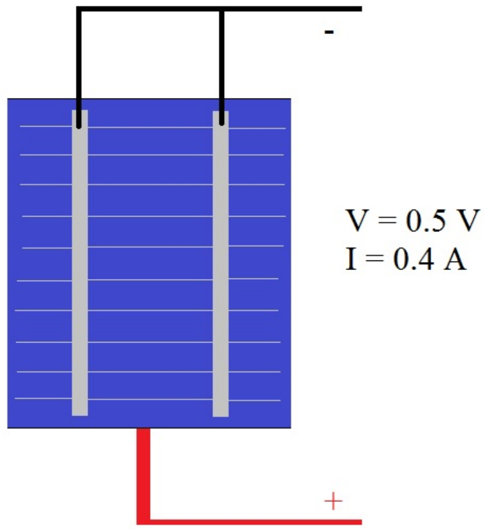
A. What happens if we double the amount of light that the solar cell collects?
   Answer: The current will double.
B. What happens if we double the area of the solar cell (or use two solar cells of equal size)?
   Answer: The current will also double.
C. What happens if we half the amount of light?
   Answer: We will get half the current.
D. What happens if we half the area of the solar cell?
   Answer: We will get half the current.

These are not the only factors that control the amount of current the solar cell generates, but they are some the main factors. The amount of current coming out of a cell is proportional to the amount of light it collects. Power requires both current and voltage. Unfortunately, there is a tradeoff. The more current a solar cell has to provide, the lower the voltage will be.

The next section will show you different examples of how to connect your solar cells in order to achieve the optimal power for your car.

## **<u>How to Connect Your Solar Cells to Get the Optimal Current (*I*) and Voltage (*V*):</u>**

One solar cell looks something like this:




In this scenario, if we generate a small amount of current, let's say 0.1 A, the solar cell will run close to or above 0.5 V.

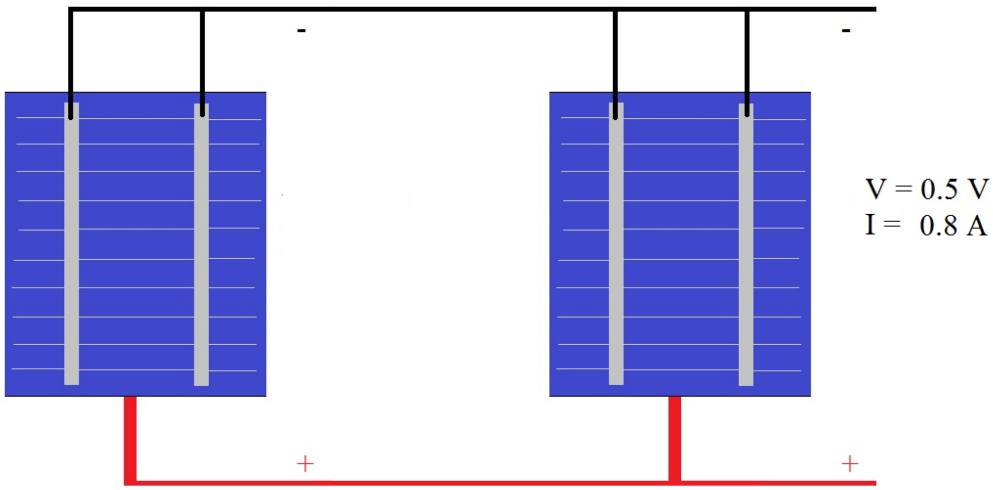
If we generate a large amount of current, close to 0.4 A, the solar cell will run closer to 0.3 or 0.4 V.

If we had multiple solar cells, how would we get more current?

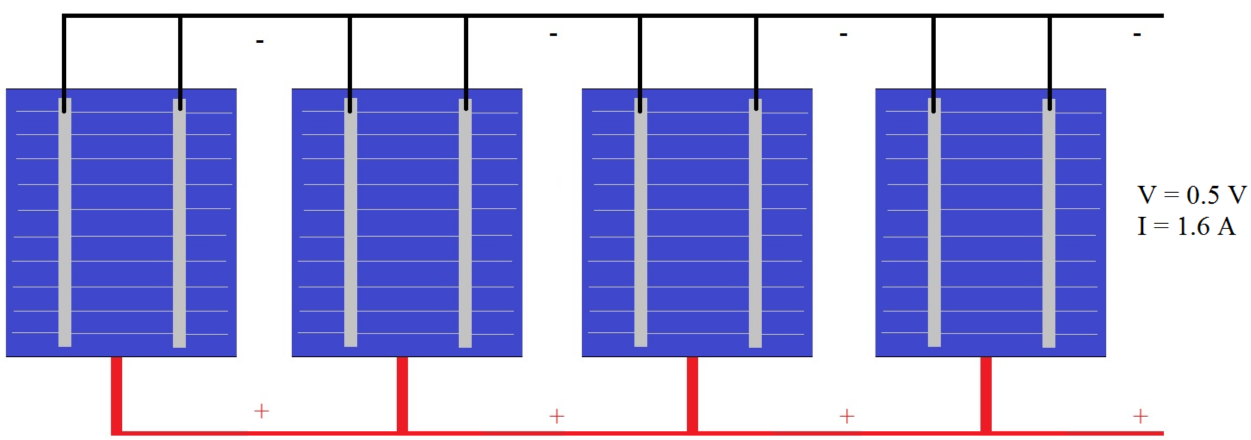
# *APPENDIX B: Examples of Parallel and Series Circuit*

## Parallel Connections:

If we take two similar or identical solar cells and connect the negative terminals together (negative to negative) and then connect the positive terminals together (positive to positive), we will create a solar cell that has twice the area (collects twice as much sunlight) and generates twice as much current. This is shown in the schematic below.




Now the new, larger solar cell can provide more current without the voltage dropping as much. If we had three or four solar cells and continued to connect them in parallel, we would continue to increase the current that the solar module would generate. Again, this is shown below:



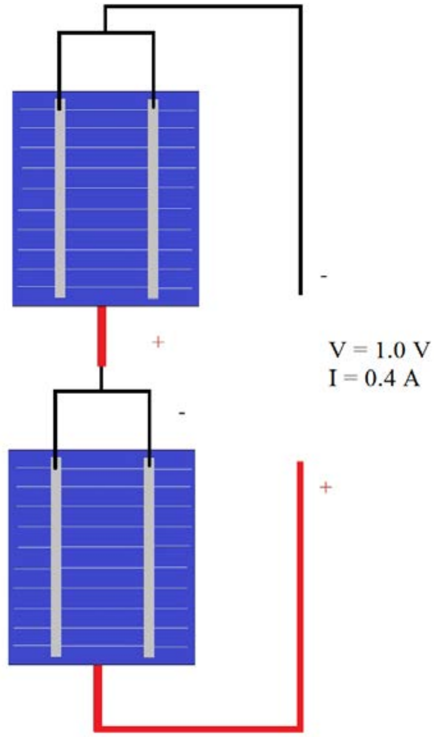

This module (made up of four solar cells connected in parallel) is capable of producing four times the current of any one of the cells. **Parallel connected solar cells provide more current while operating their optimal voltage.**

All we've done so far is increase the current of the system. Is there a way to increase the voltage?

Yes there is! We can use **series connections.**

**<u>Series Connections:</u>**

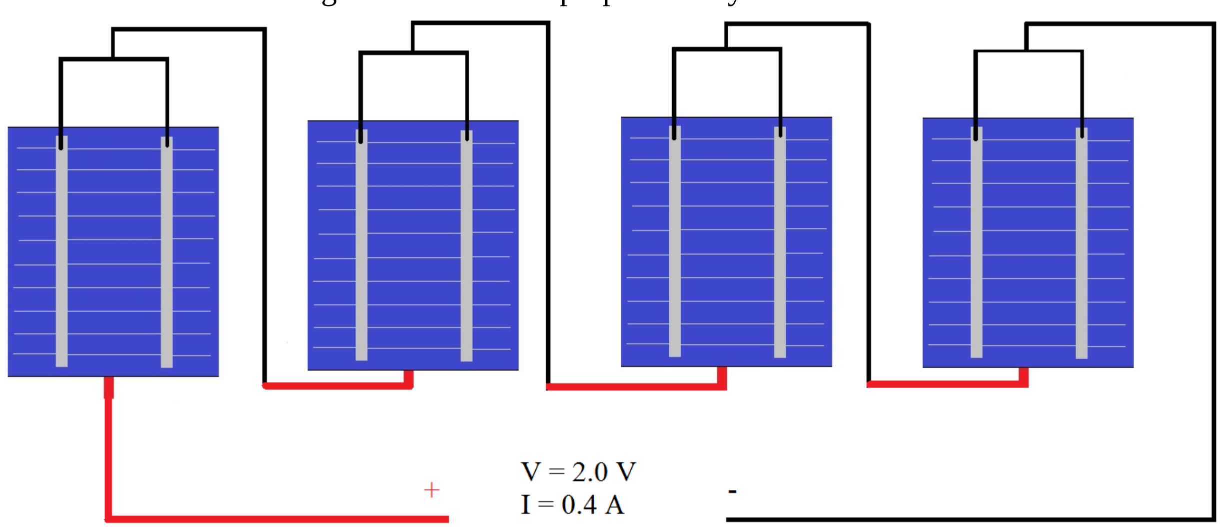
If we take two cells with the same current and connect one negative terminal to one positive terminal, then the remaining two connections will produce two times the voltage with the same current as before.




This new module is capable of producing more voltage than the single solar cell, but it does not have more current than the single solar cell.

What would happen if we connected three or four solar cells in series?

Answer: The voltage would increase proportionally.



Can we increase the current **and** the voltage at the same time? Yes! We have to use a series-parallel configuration.

**Series-Parallel Connections:**

So far, we have dealt with identical solar cells, so we haven't had to match currents or match voltages. However, when you create series-parallel connections, it gets a little tricky.

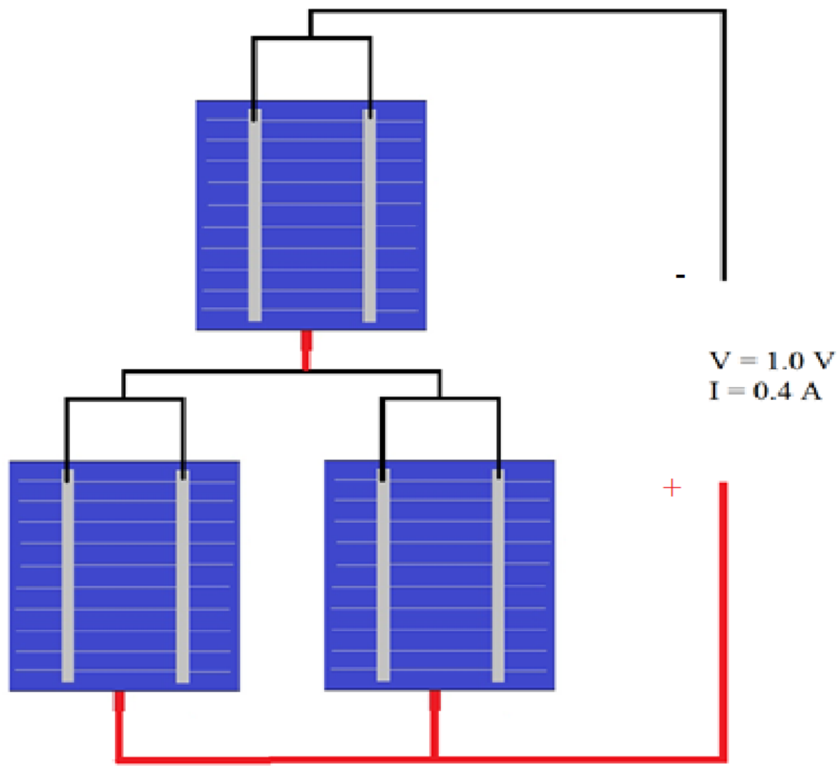
In a series connection, each solar cell has to produce the same amount of current. **If one produces a little less, then the new module will produce less.** This is called **current mismatch**.

In a parallel connection, each solar cell has to produce the same voltage. **If one produces a little less, then the new module will produce less.** This is called **voltage mismatch**.

Let's look at some configurations that have these problems.

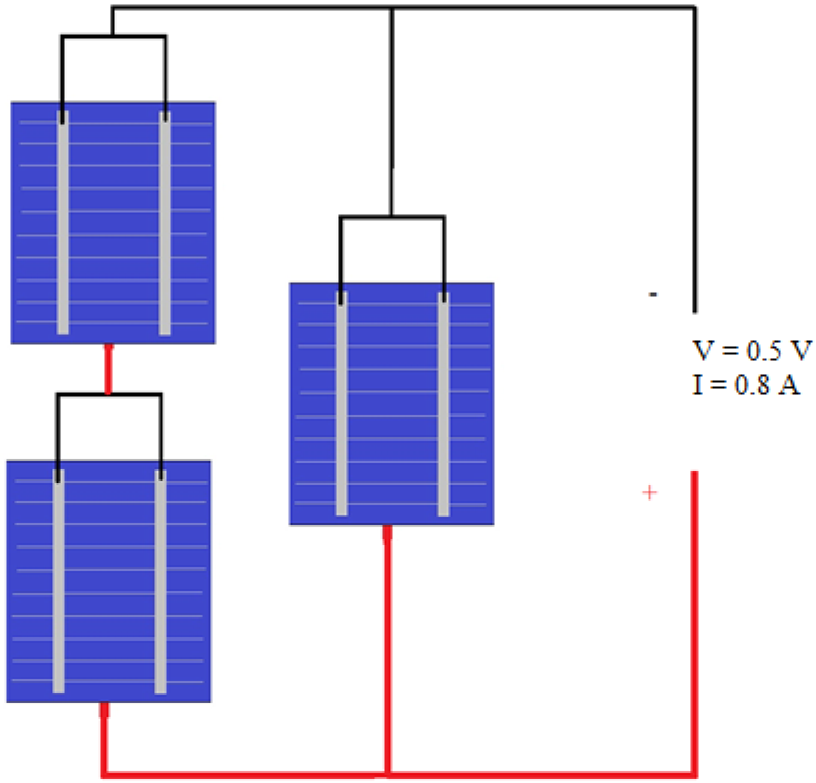
**Current Mismatch**

This is when the current of the system is limited by one or more solar cells.




Here, the top cell only wants to produce 0.4 A of current, even though the bottom two cells are trying to produce 0.8 A. Ultimately, this makes a solar module that is limited to the least performing part of the circuit, the 0.4 A solar cell.

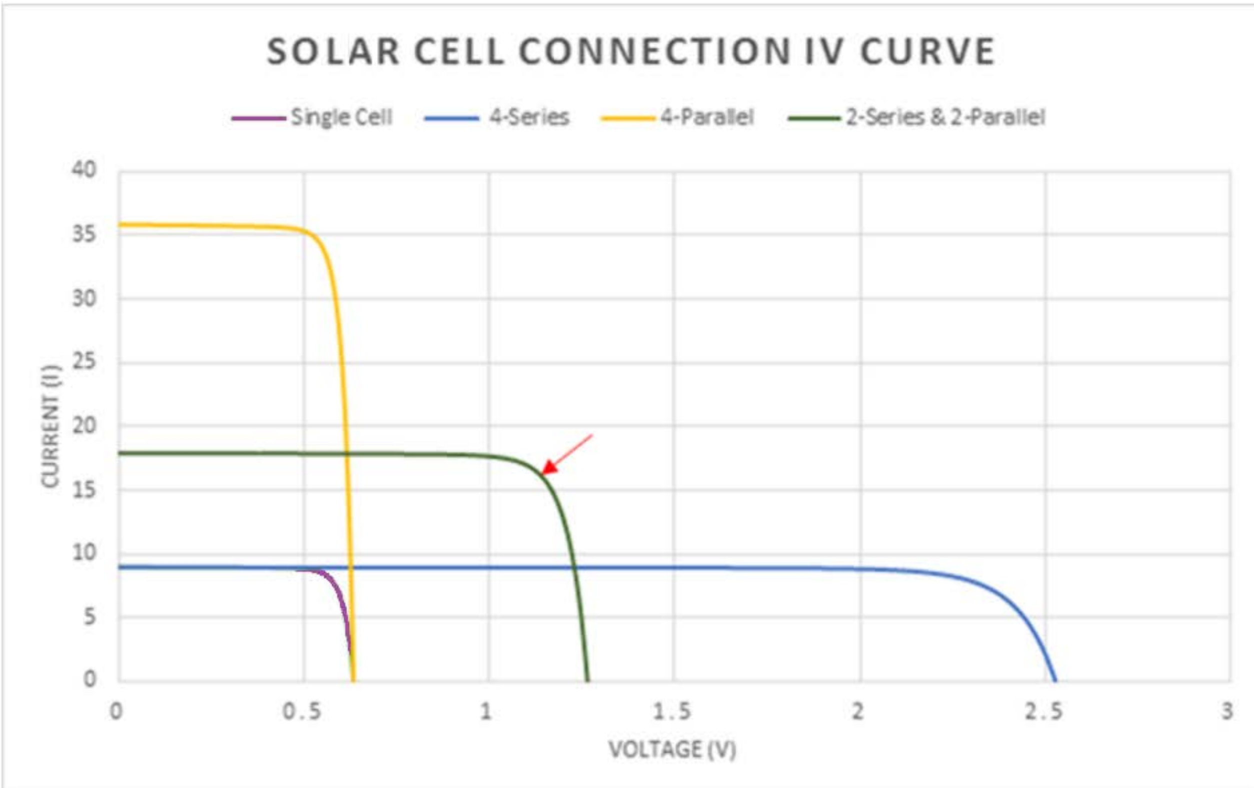
**Voltage Mismatch**
This is when the voltage of the system is limited by one or more solar cells.




Here, the cells on the left are connected in series and want to produce 1.0 V, but the cell on the right only wants to produce 0.5 V. Ultimately this makes a solar module that is limited to the least performing part of the circuit, the 0.5 V of the solar cell.

**Cell Connection Summary**

How will you connect your cells to get the optimal power? Remember:  P = IV




The above graph represents how electrical performance is dependent upon the connections of your solar cells. The purple curve shows the electrical performance of a typical solar cell, with a small current (I) and small voltage (V). The blue curve shows that when 4 solar cells are connected in series the current will remain the same while the voltage increases. The yellow curve shows how current increases and voltage remains the same when you place all 4 cells in a parallel connection. The dark green curve shows how the current and voltage adds together when you place 2 series connected cells in parallel (series-parallel connections).

To get the maximum power you need the maximum product of current and voltage, not just one or the other, where does that happen on the graph? The red arrow shows the place with highest power given the solar cells available. However, this would be something that you could easily test and verify for yourself (**and record in your notebook**.) Which setup works best for you?

# *APPENDIX C: Example of Student Design Notebook*

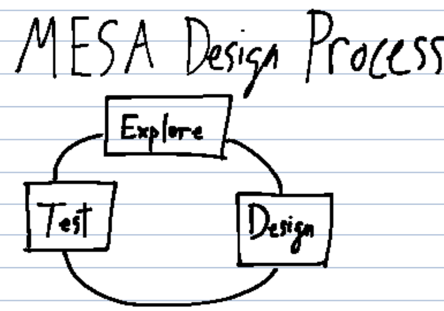
Today's Date 1

Problem Statement

- Build a solar car fitting specific requirements (see below) to compete in three challenges: a speed race, an alignment track, and a strength test; notebook also graded for points
  - Height: 30"
  - Width: 30"
  - Length: 60"
  - Other specs

Important Dates

Weekly meetings: Tuesdays, 3:00 PM
MESA Regionals
Other MESA-related events




Materials

Provided:

1) 4 small solar panels
2) Motor
3) Gears

} Find specs

Team Members

Danny Simonet – SolidWorks, PSPICE, solar
Kathie Beckman – circuits, SolidWorks, PSPICE

Today's Date 2

Today's Goals

1) Find all specs and dimensions of materials given
2) Tinker (free exploration) with solar panels and gears
   a) What gears actually fit together? All? Some?
3) Take notes on information in packet and do research
   a) Google?

Notes

From packet

Voltage: electric potential over an object, e.g. a battery (measured in *volts*, V)

Current: flow of electrons (measured in *amps*, A)

From pveducation.org:

Power = IV

Team Check

Ways we could improve as a team:

- Better time management
  - Create a calendar for the weeks
- Remember to build on each other's ideas more

Explore



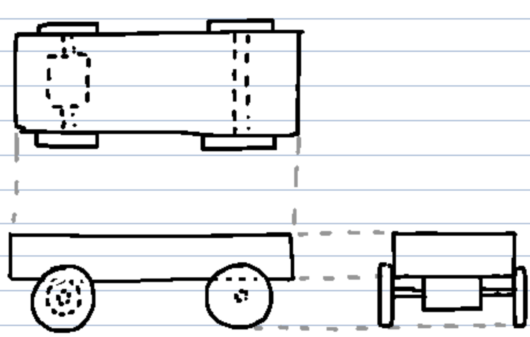


Today's Date 3

Goals

1) Create a basic circuit to try to power the motor
   a) Make various circuit designs to see how the motor is affected
2) Begin brainstorming a general body structure of the car for the panels
3) Ask about tips on making cars run

Design #1



Wheel radius: x inches

Axel radius: y inches

- Flat body to hold panels
- Cuts for gears to fit on axels

} Not shown in drawing

- Suggested made out of balsa wood
  - Lightweight

Design

Today's Date 4

Data

| Trial | Time | Comments |
|---|---|---|
| 1 | 22 sec | Not enough |
| 2 | 23 sec | sun? |
| 3 | 27 sec | |

Test

Conclusion
- What went wrong?
  - Was not fast enough
- Solution
  - Create a completely new design

Notes
Talked to QESST graduate student Max Cotton and my uncle (mechanic) about cars
- Research gear ratio
  - What is torque? Power? How do they relate?
  - What is angular velocity? Max said we want to maximize this number for the fastest car
- Also think about different challenges – we don't need lots of speed (angular velocity) when pushing stuff
  - Why?
- Think about "Sketch Up" (computer program)

Explore

# *APPENDIX D: Helpful links to information about solar energy*

## Solar Energy Web Links

1. Conduct experiments related to designing solar cars http://www.nrel.gov/docs/gen/fy01/30826.pdf
2. Get ideas for designing solar cars http://www.nrel.gov/docs/gen/fy01/30828.pdf
3. Learn more about photovoltaics and powering DC motors. Plus, find ideas for solar science fair projects! http://www.makeitsolar.com/solar-energy-information/07-solar-cells.htm
4. Understand how a solar cell works http://www.explainthatstuff.com/solarcells.html
5. See a video explaining how a solar panel works https://www.youtube.com/watch?v=xKxrkht7CpY
6. Here is a lesson on solar concentrators https://www.teachengineering.org/lessons/view/cub_pveff_lesson04
7. See a video about why we do solar engineering research at QESST http://pv.asu.edu/
8. This is a challenging read, but good information about solar energy and photovoltaics http://pveducation.org/pvcdrom
9. AND of COURSE to learn more about what we do at QESST!! https://qesst.asu.edu/

## Acknowledgements:

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