Power and Power Measurement

ENGR 10 – Intro to Engineering

College of Engineering

San Jose State University

(Ping Hsu and Ken Youssefi)

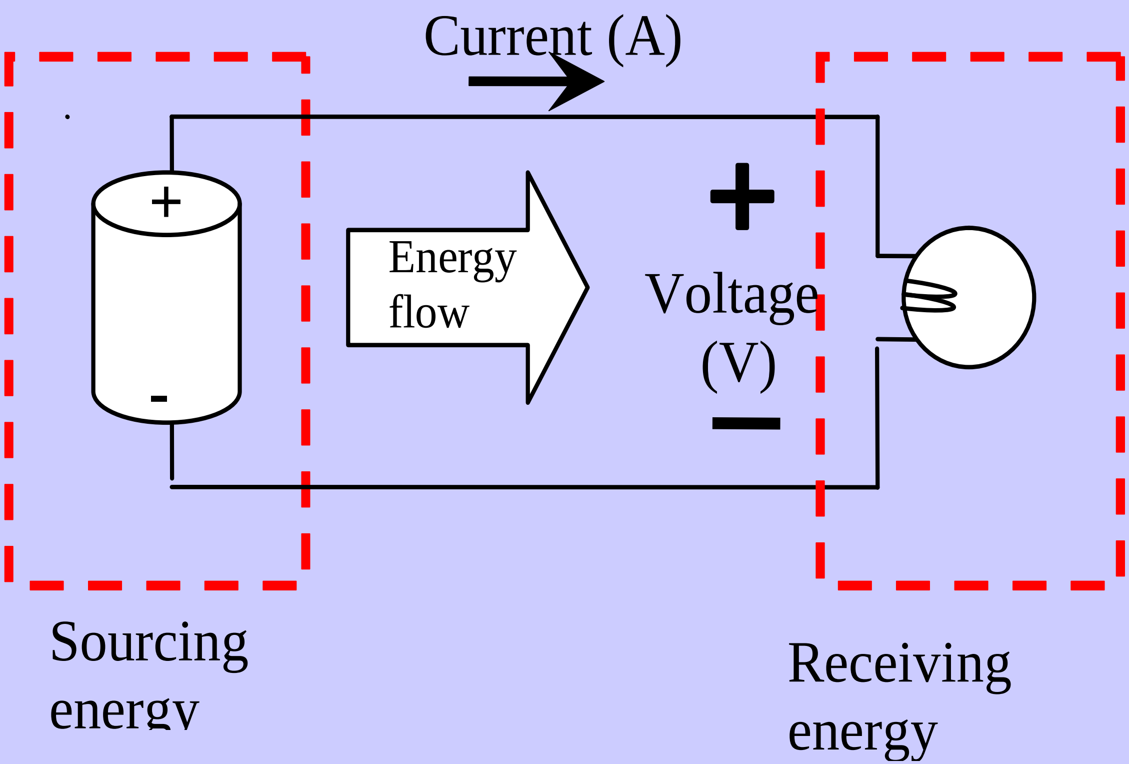
Power is

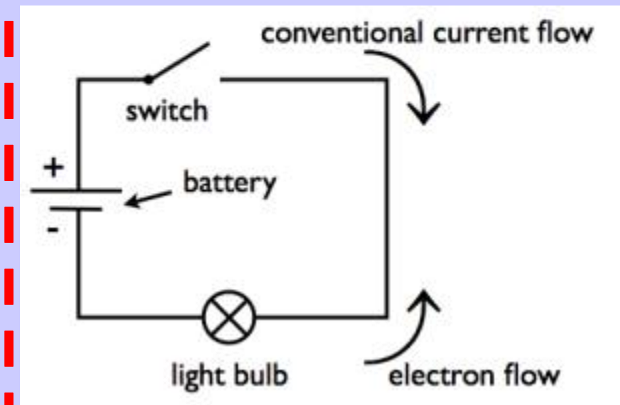
Electric power is the rate at which electric energy is transferred by an electric circuit

Mechanical power is the combination of forces and movement. Force x velocity or torque x rotational speed.

Hydraulic, chemical, thermal, nuclear, ….

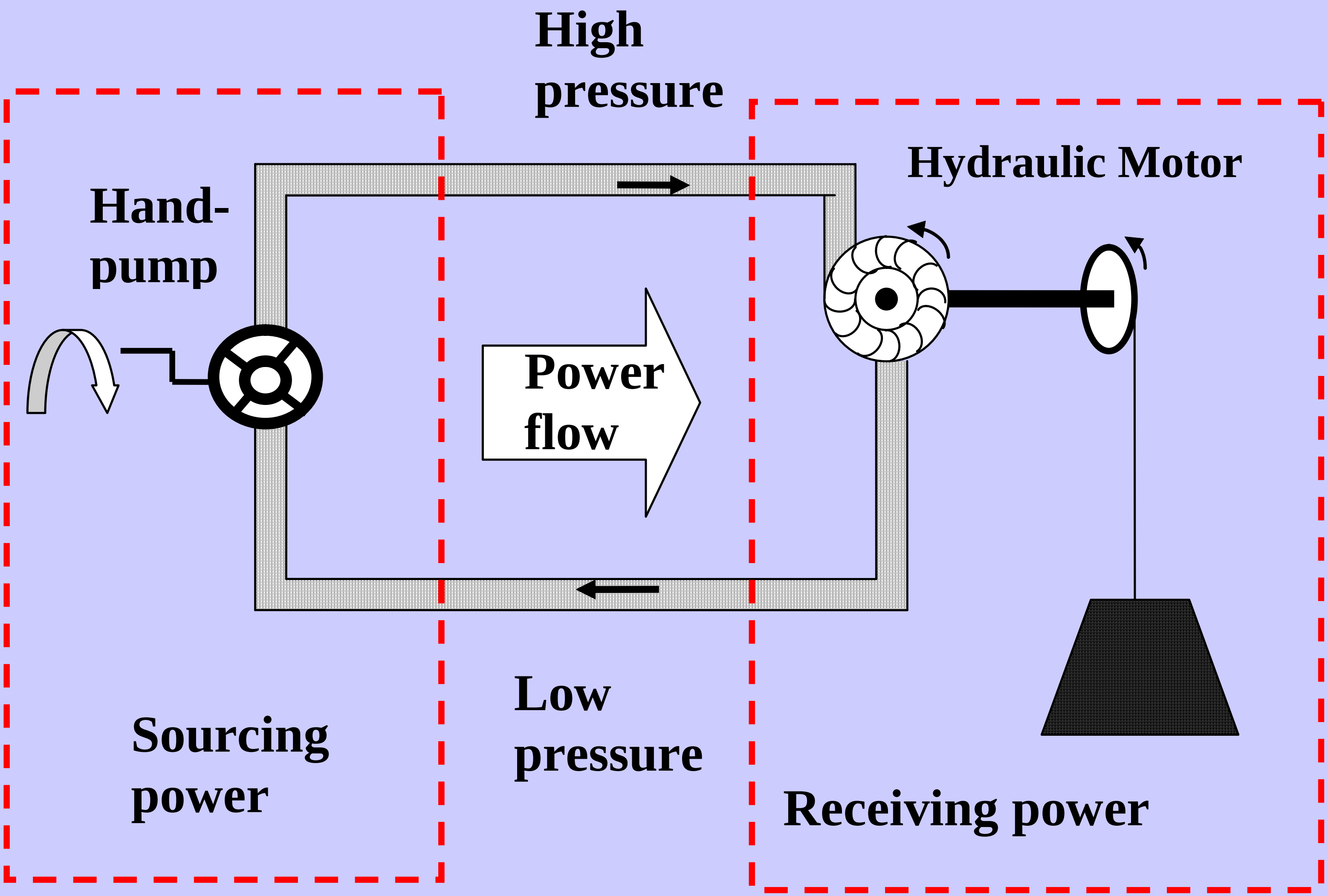
In the following circuit, energy is carried by the wires from the battery to the light bulb.





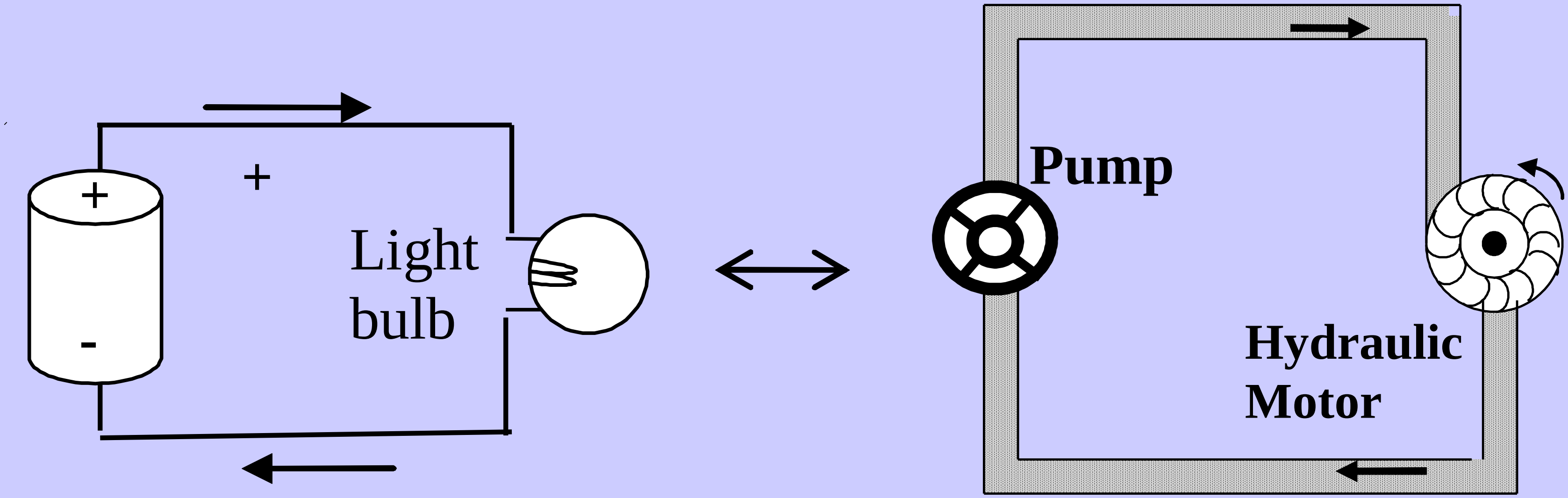
Power (J/s or Watt) = Voltage (Volts) x Current (Amperes)

Mechanical Power (Hydraulic)

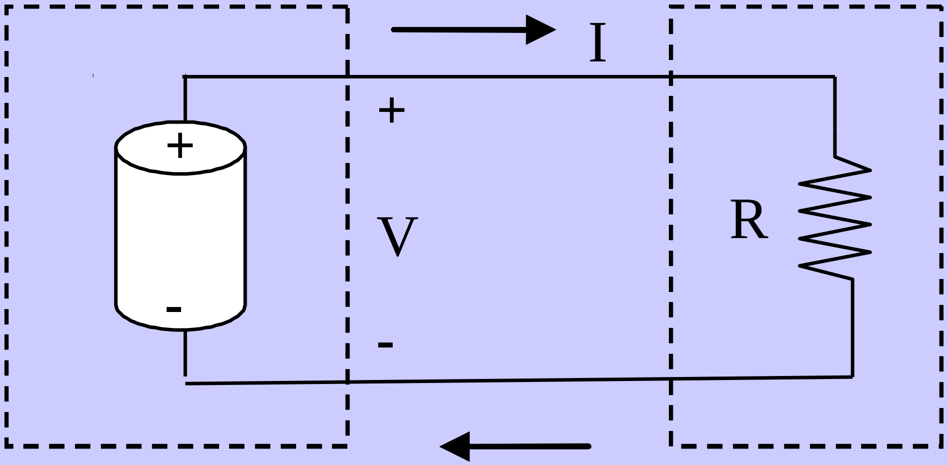


Analogy

Electrical Circuit		Hydraulic system
Voltage (V)	←→	Pressure (psi)
Current (A) (Charge flow rate)	←→	Fluid flow rate (gal/sec)



Ohm's Law



If the 'circuit' is a simple resistor, the voltage, current, and the resistance of the resistor is related by **Ohm's Law**:

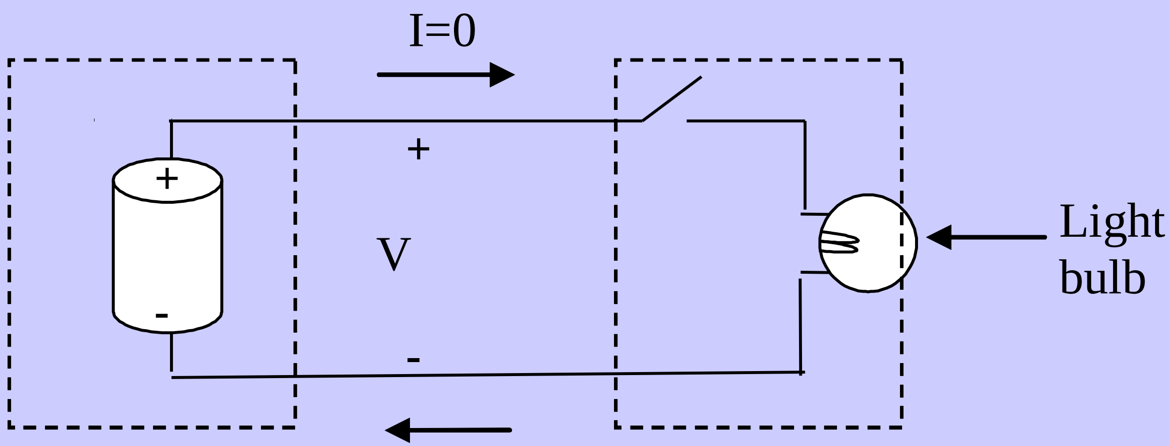
$$I = \frac{V}{R}$$

Resistance is measured in Ohm (Ω)

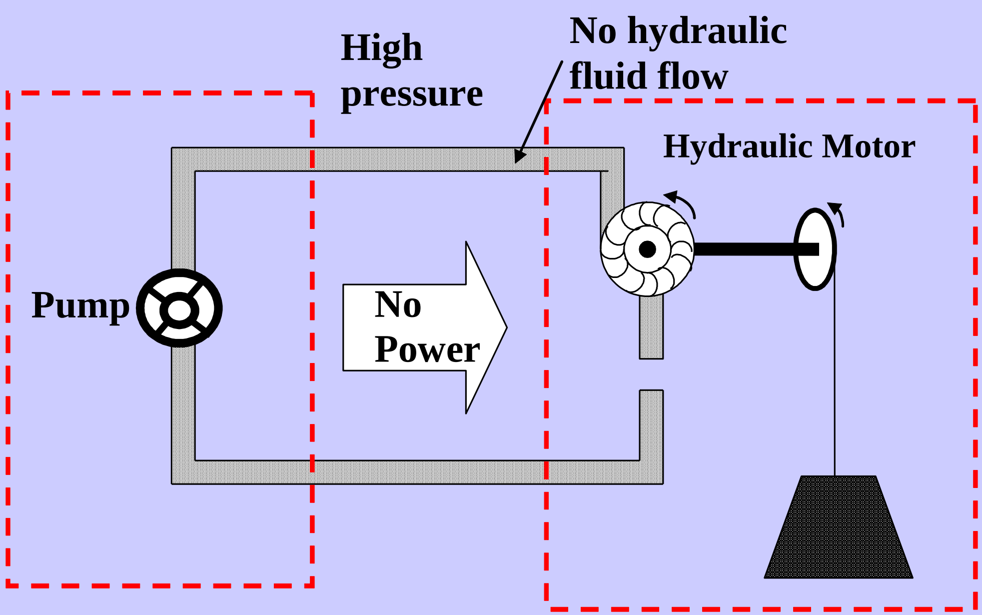
In the above circuit, V = 12 volts, R=3Ω

What is the current I =? I = V/R = 12/3 = 4 amps

“Open Circuit” Case



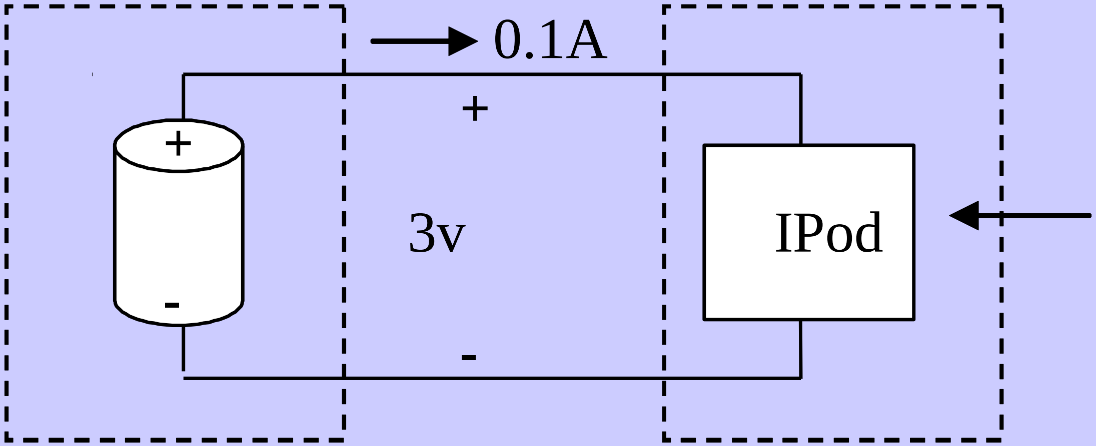
Power = V×I = V×0 = 0



Power = Pressure × 0 = 0

Clicker Question

1 - From the values given in the diagram below, what is the resistance (R) of an IPod?

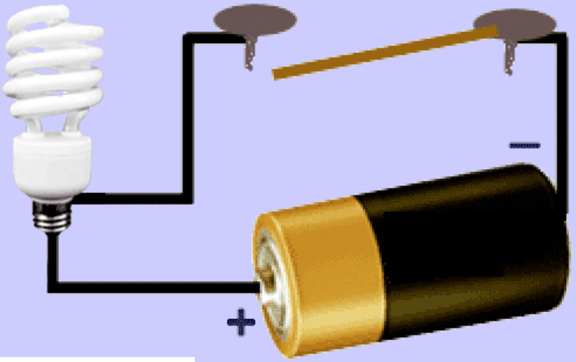


A. 0.3 Ω
B. 3.1 Ω
C. 0.03 Ω
D. 0.9 Ω
E. 30 Ω

You receive 10 points for answering all three questions (right or wrong), you also get 5 points for answering each question correctly. So if we have three iClicker questions in a session and you answer all questions correct you receive 25 points

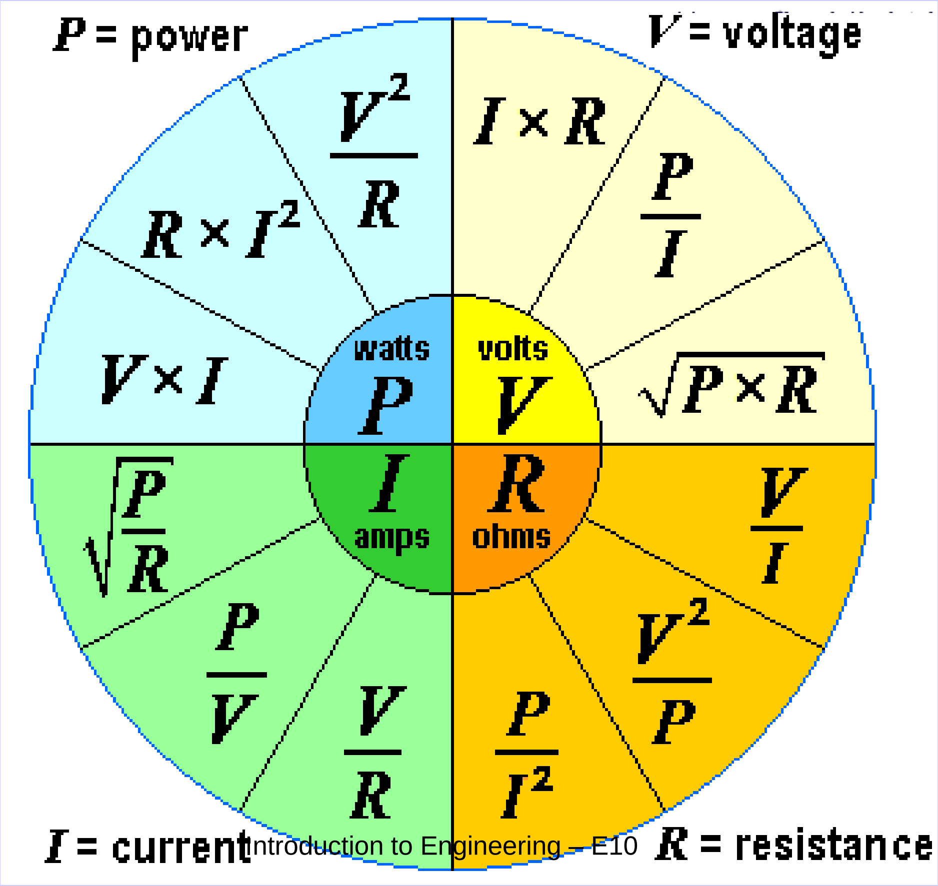
Basic Principles of Electric Circuits

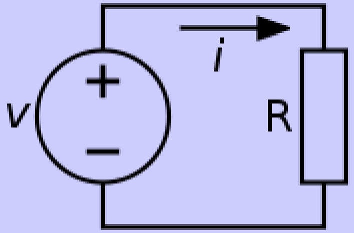
Relationships between a simple circuit's parameters



$$V = I*R$$

$$P = V*I = V^2/R$$





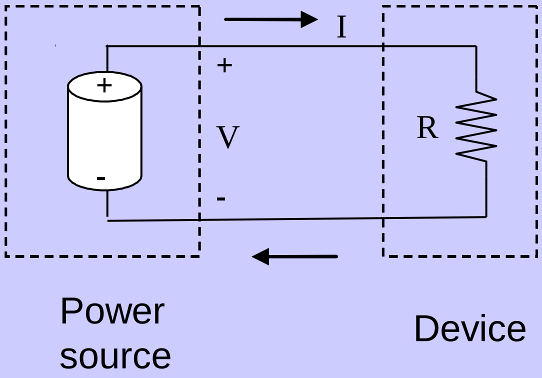
Energy Source in a Circuit

Power supplies are specified by Voltage and Current, 12 V DC at 300 mA (rated current)

The output voltage from a typical power source stays the same regardless of its output current (I) so long as it is less than the sources' rated current value. Within this range, the output current (I) only depends on the resistance (R) of the equipment (i.e., the load) connected to the source.

$$I = V/R$$

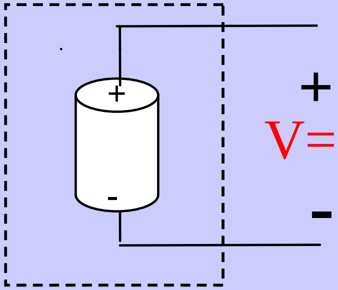
and the power is $P = V*I = V^2/R$



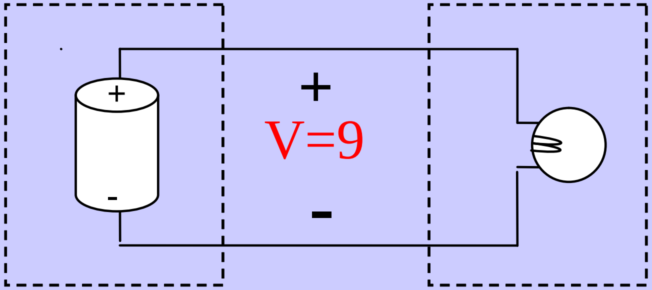
The smaller the resistance is, the higher the output current (and the power), but V stays the same <u>as long as the current is less than rated current of the source.</u>

Load down effect

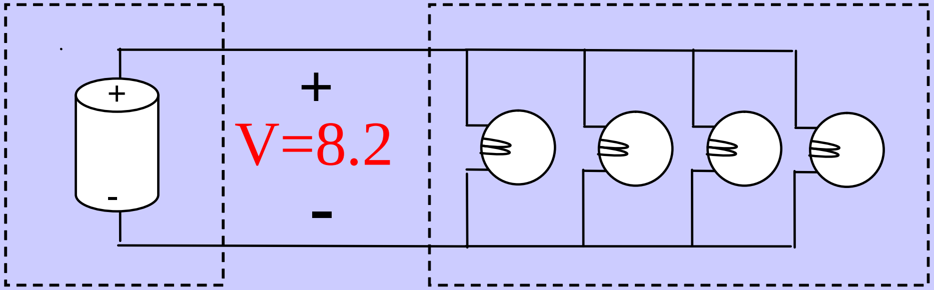
If an equipment tries to draw higher than rated current of the source (having a really small load resistance). The voltage will sag. This condition is called “***Load down***”.



No load



Normal load



Over load (Voltage is loaded down.)

The maximum output power of a source can be determined by varying load resistance from high to low.

V = IR

Normal operating range.

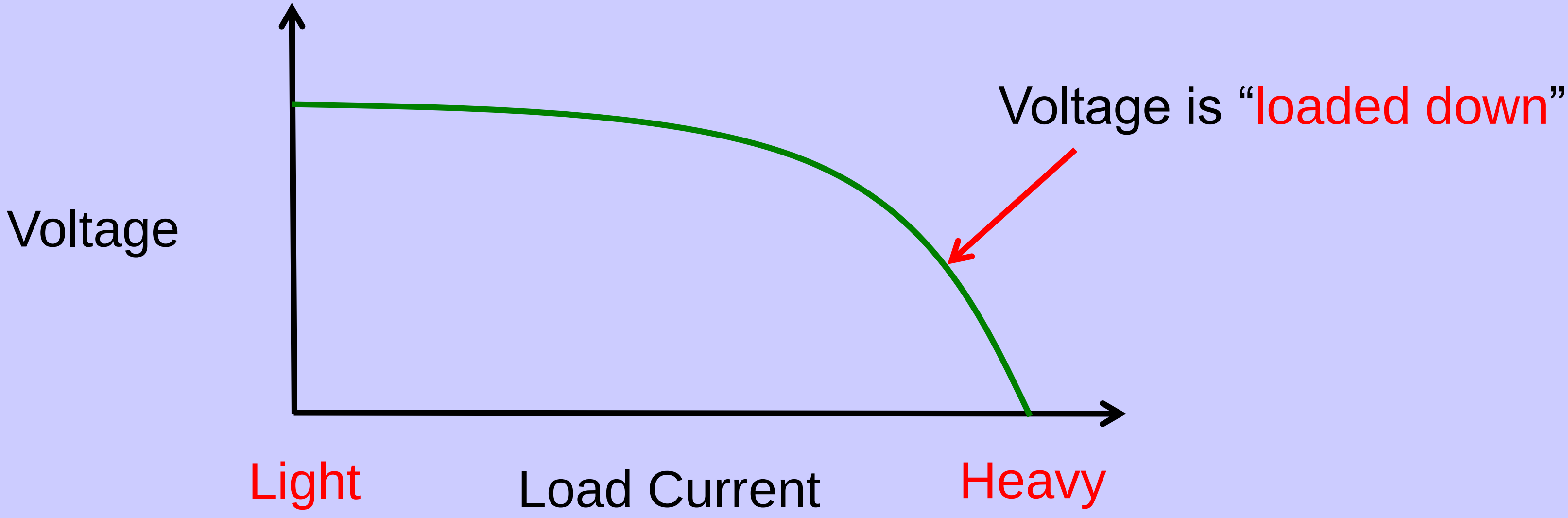
The voltage is loaded down.

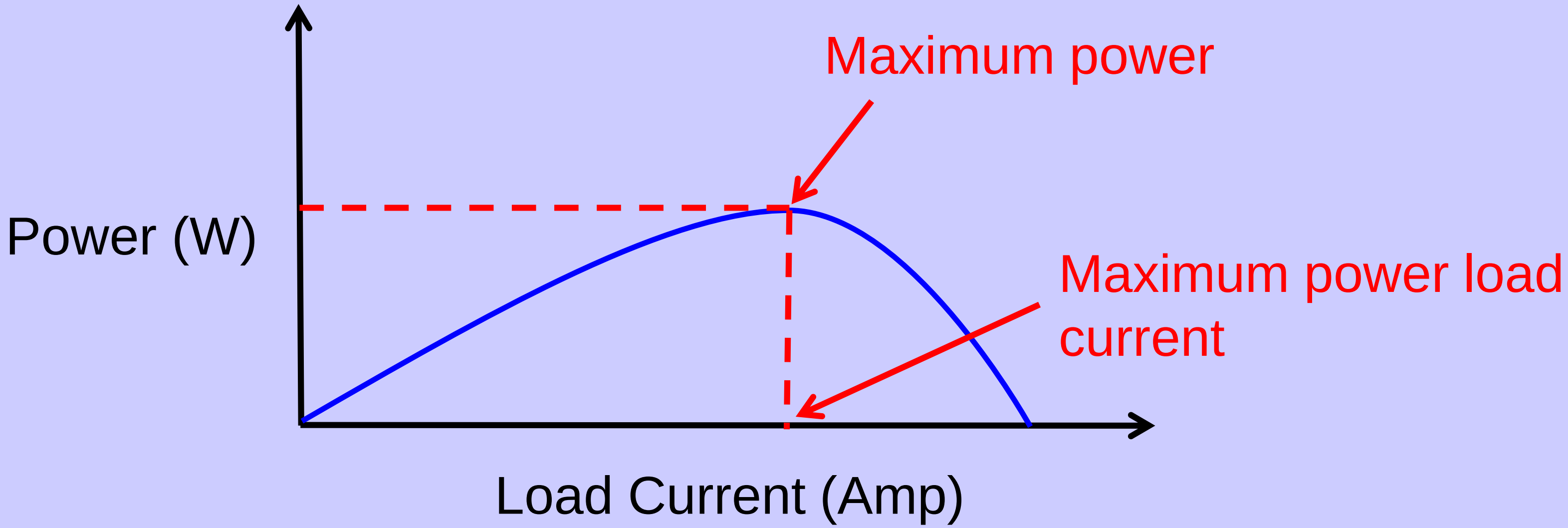
Maximum output power of the source

Maximum output current

Voltage (Volt)	Current (Amp)	Power (P = VI)	Equivalent loading resistance V/I
10	0	0	infinite (open circuit)
10	2	20	5 Ω (Light load)
9.8	4	39.2	2.45 Ω (Normal)
9.4	5	47	1.88 Ω (Normal)
8.5	**6**	**51**	1.41Ω (**MAX POWER)**
7.2	7	50.4	1.03 Ω Over load
5.2	8	41.6	0.65 Ω (Over load)
3.0	9	27	0.33 Ω (Over load)
0	10	0	0 (shorted)

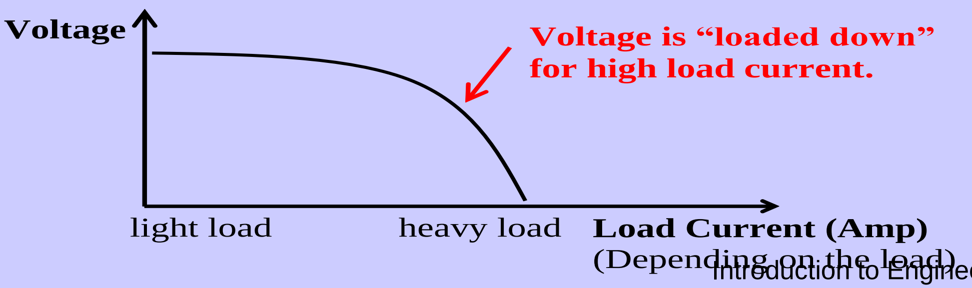
Voltage vs. current and Power vs. current of a source

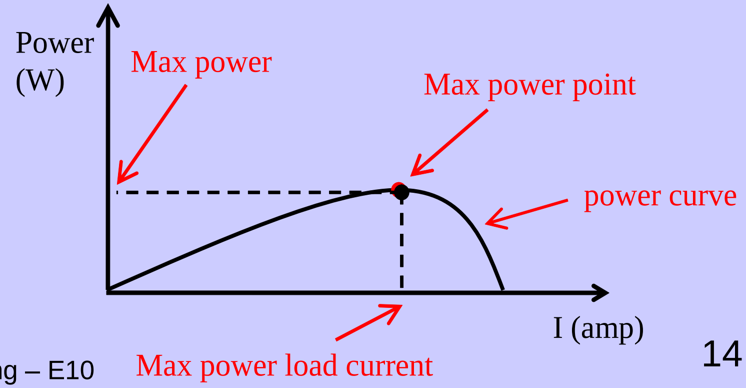




Key Concepts

- A source's output voltage drops when 'too much' current is drawn from it (namely, the "load down" effect.)
- While it is possible to increase output current even when the voltage is loaded down, the output power (voltage x current) stops increase due to decreasing voltage.
- A source outputs its maximum power at a specific output voltage and current. (A very important parameter for characterizing solar cell).





Clicker Question

2 - Which of the following statements is **false**?

A) A source’s voltage varies with output current.

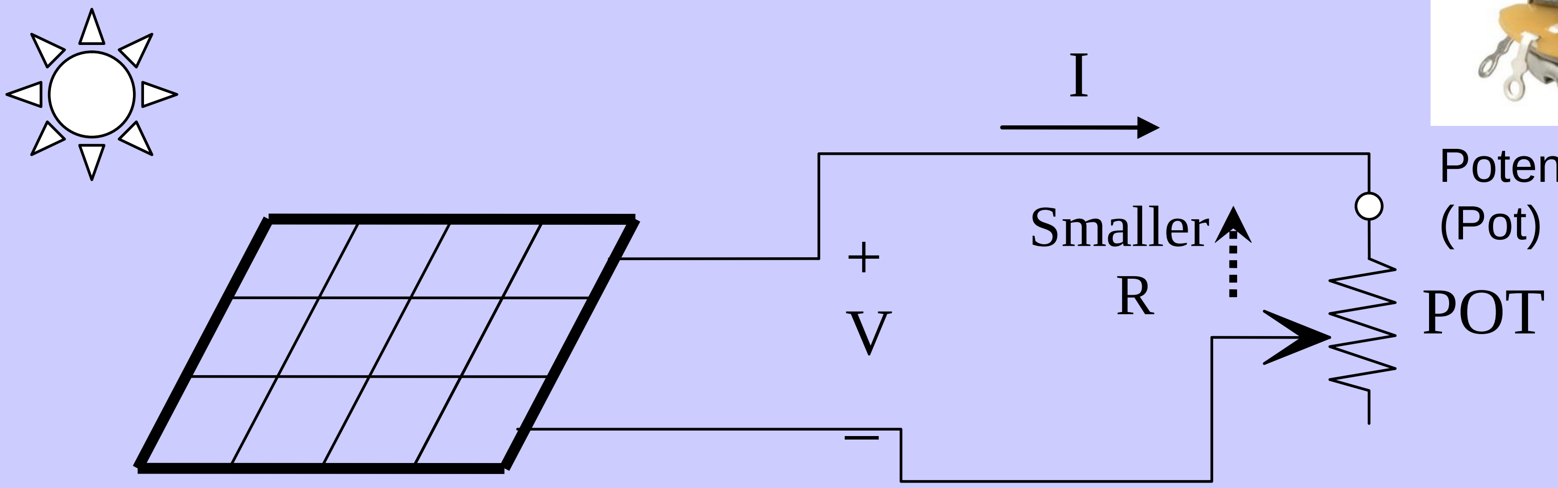
B) A source’s current varies with output power.

C) A source’s output current varies with load

D) A source’s maximum output power is its maximum output voltage times its maximum output current.

$$P_{max} = V_{max} \times I_{max}$$

Solar Lab



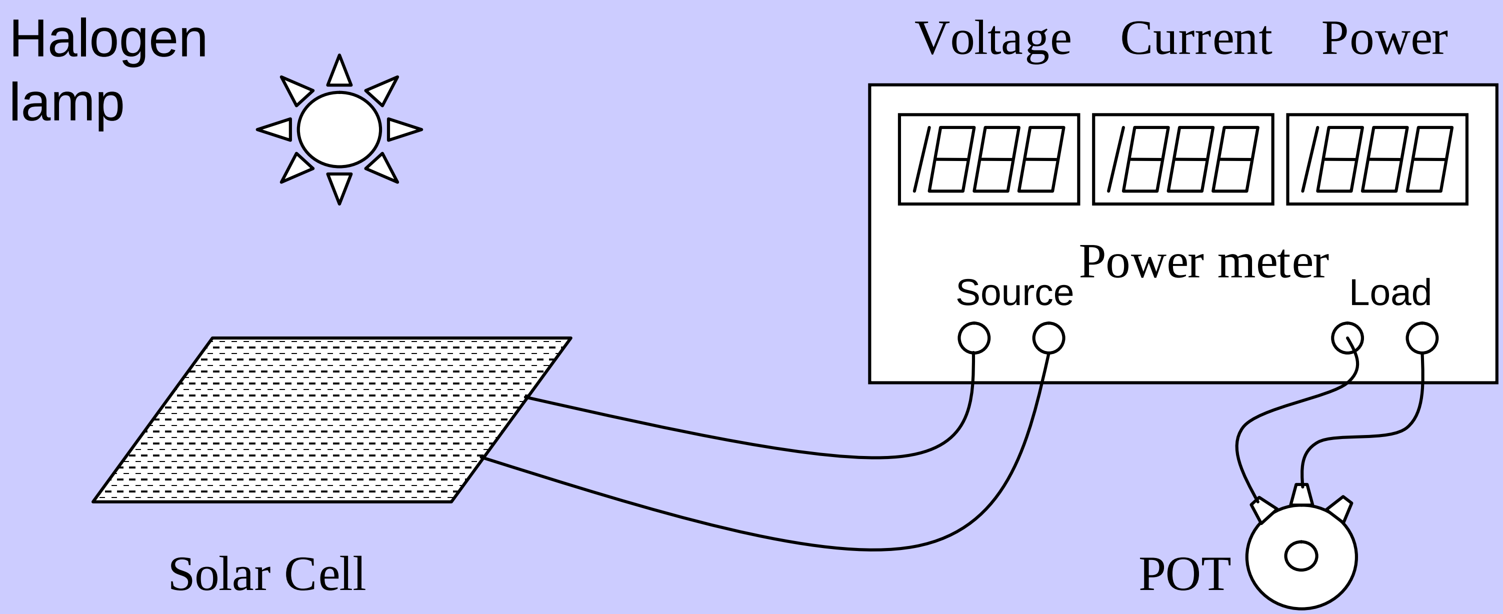
Potentiometer (Pot)

To the circuit, the solar cell is an energy source.

A variable resistor (potentiometer or POT) is used as the load in experimentally determining the V vs. I curve of a solar cell.

The same procedure is used in the wind turbine experiment.

Solar Cell lab basic setup



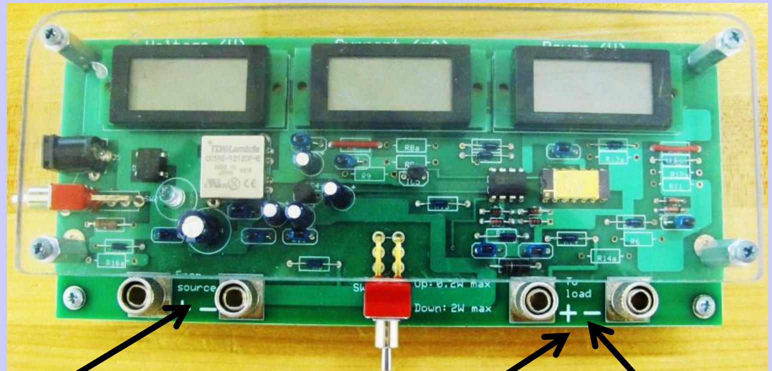
By changing the POT resistance, the current drawn from the solar cells can be varied.

The output voltage, current, and power is recorded at each current level, from high to low.

A voltage vs. current and power vs. current can be plotted from the data.

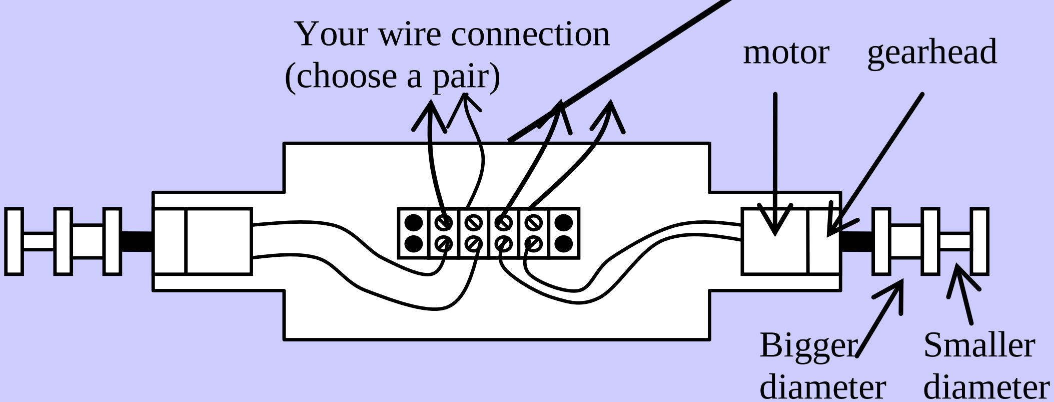
Solar lab components

Power meter



Solar cells

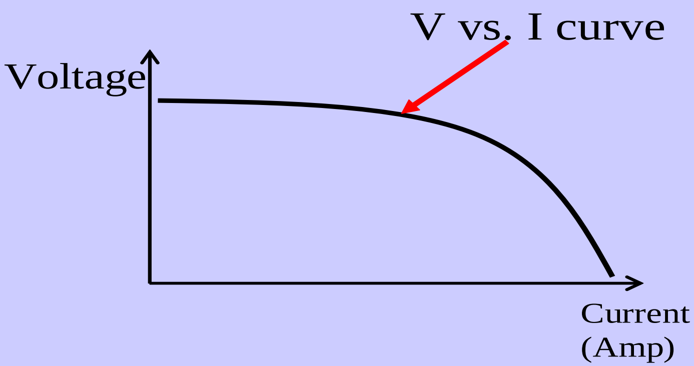
Solar meter measures solar intensity

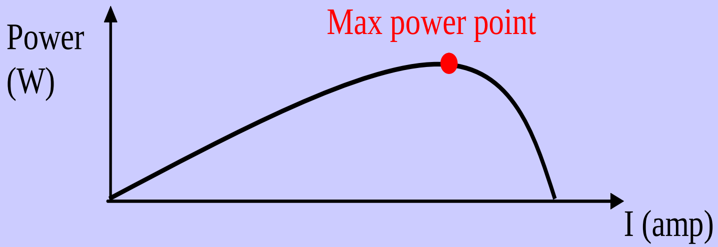


Motor, gearhead and pulley assembly

Potentiometer (Pot)

Solar cell voltage, current, and power output





- For most applications (i.e. laptop computer), we only draw as much current (or power) as needed from the source.

- For solar energy generation, however, we want to draw as much power as it can generate. Therefore, it is important to find this maximum power point.

Data Collection Form

ENGR 10 Solar Cell Characterization Lab

Lab Sec #: ____ Date: ________ Names: 1. __________________ 2. ____________________
3. __________________ 4. ____________________

Solar Intensity measured with solar meter (W/m^2) ____________________

A. Single Cell Measurements

	Voltage V	Current mA	Power W	Comments
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

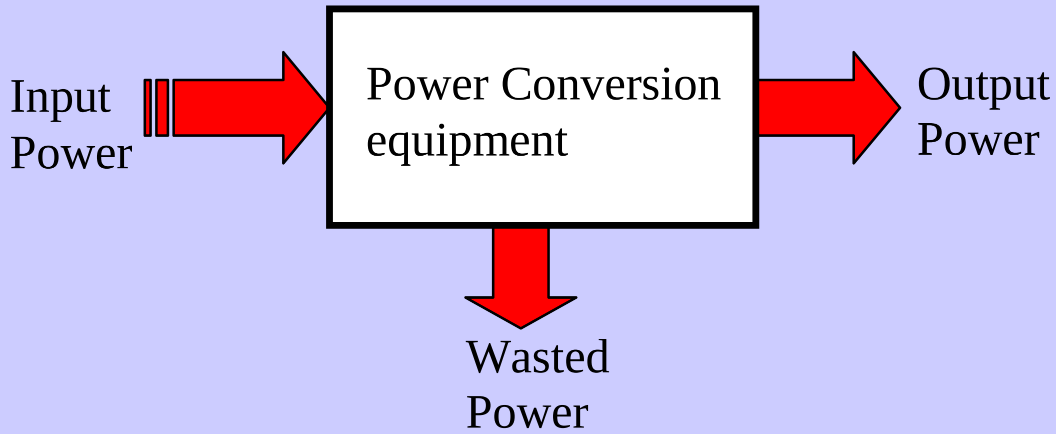
B. Serial Cell measurements				C. Parallel Cell Measurements			
	Voltage V	Current mA	Power mW		Voltage V	Current mA	Power mW
1				1			
2				2			
3				3			
4				4			
5				5			
6				6			
7				7			
8				8			
9				9			
10				10			

D. Weight Lifting Experiment

		Circle the selected set up bellow:
1	Cell Combination:	(a) 4 Series (b) 4 Parallel (c) 2S/2P
2	Gear Rotation	(a) 30:1 (red) (b) 190:1 (gray)
3	Spool Diameter	(a) Smaller (b) Larger
4	Selected Weight:	
5	Power @15 sec:	
6	Height @15 sec:	

- Write a tech. report on this project as specified in lab guidelines and include:
- Plots of V vs. I and P vs. I for all cell combinations tested.
- Define
  1. Input/output energy per Lab Guidelines
  2. Efficiency of the motor/gear-head assembly?
  3. Discuss the maximum power usage of the weight lifting setup.

Power Conversion Efficiency



In an energy conversion process, the ratio between the desired output power and the input power is the efficiency of this process.

Efficiency = output power / input power

In the process, some power is inevitably converted to a form that we don't care about (such as heating of the panel).

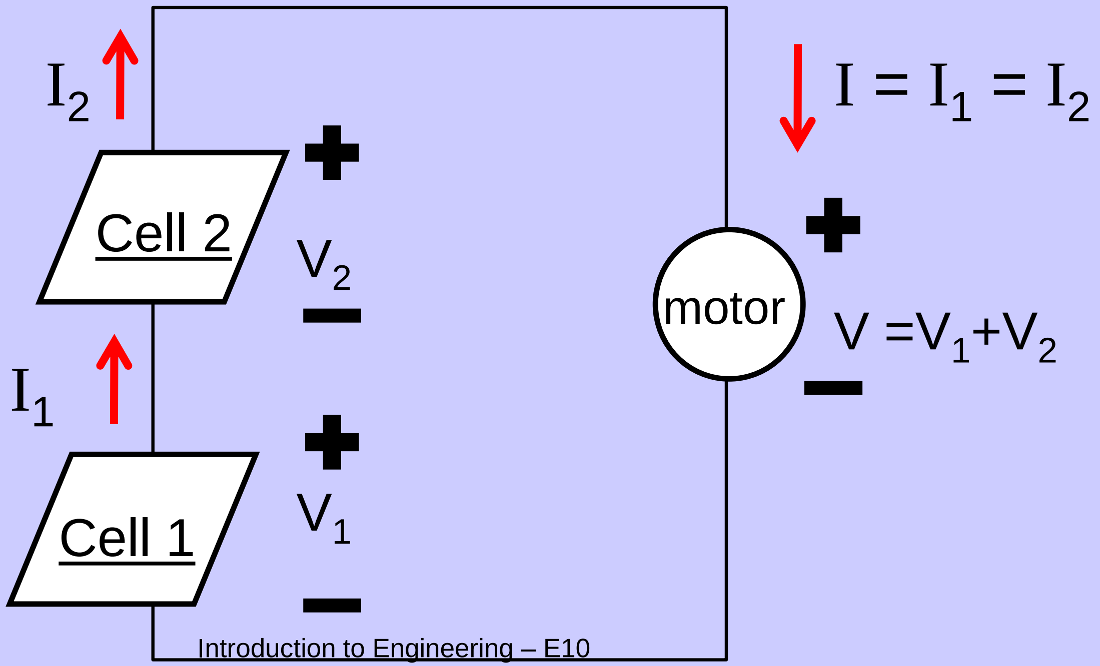
Solar Lab: Solar to Electrical energy efficiency and Solar or Electrical to Mechanical energy efficiency.

Solar Cells in series

Two or more cells can be connected in a cascade configuration (in ***series***).

- The combined output voltage is the sum of cells output voltages.
- The combined output current (and the current rating) is the same.
- The combined power (and the power rating) is the sum of the individual cells' power.

$$P = (V_1+V_2)I_1 = (V_1+V_2)I_2 = (V_1+V_2)I$$

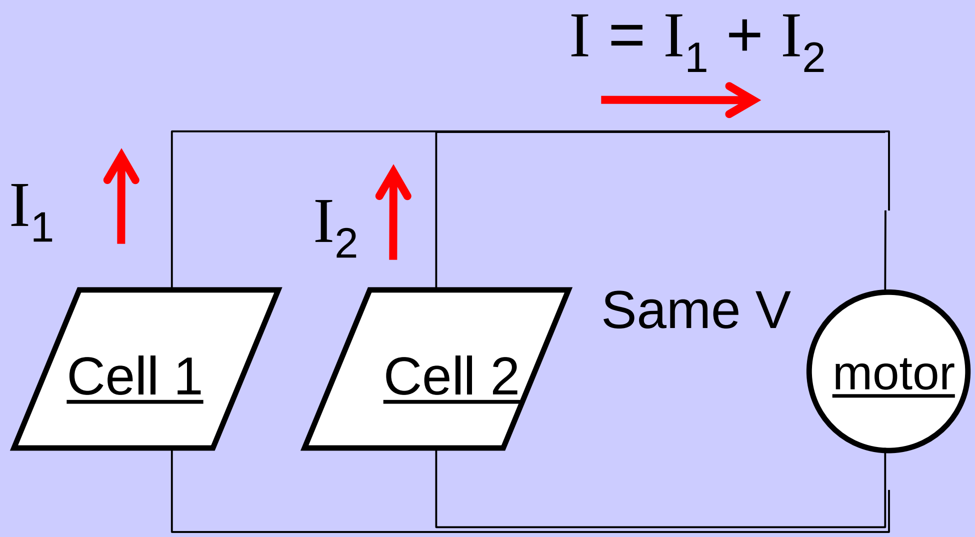


Solar Cells in parallel

Two or more cells can be connected in ***parallel***.

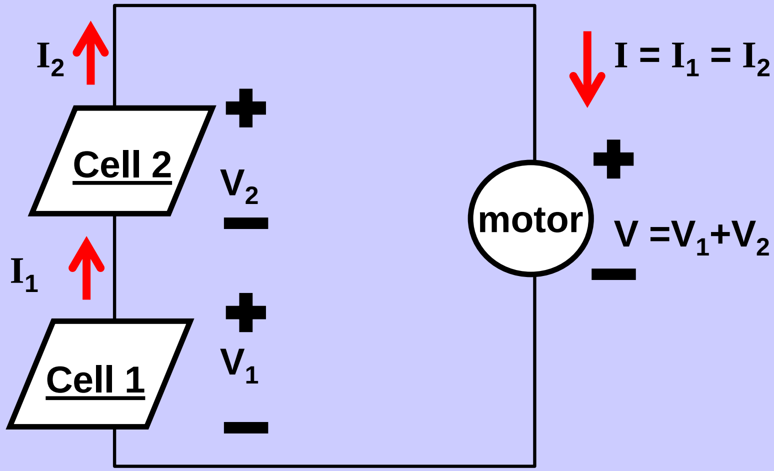
- The combined output current (and current rating) is the sum of cells output current.
- The combined output voltage is the same.
- The combined power (and power rating) is the sum of the individual cells' power.

$$P = V(I_1+I_2) = VI$$

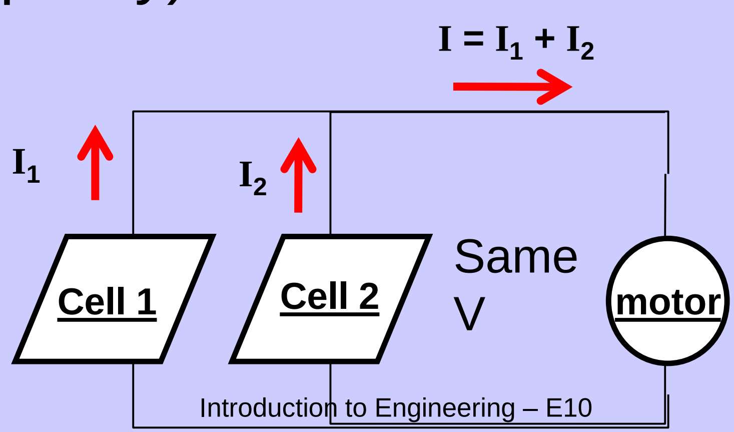


Series and Parallel Connection

Series --- Voltage is the sum and current (and current capacity) is the same.



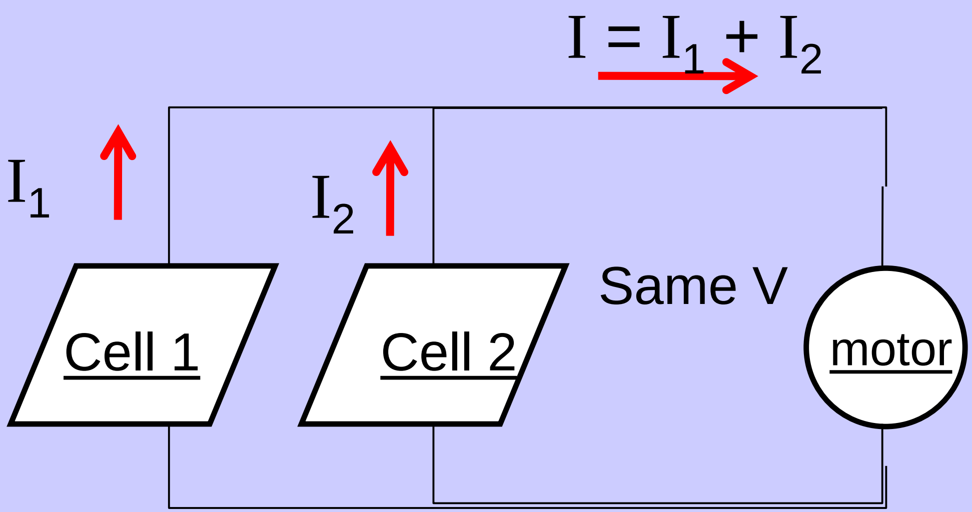
Parallel --- Voltage is the same and current (and current capacity) is the sum.



Solar Cells in parallel

Example: A solar cell is rated 3 volts @ 3 amp. How many cells are required to power a circuit that needs 3 volts @ 5 amp?

Answer: Two cells in parallel. This circuit provides 3V and has a rating of 6 amps (therefore, it can certainly supply 5 amps).



Note: A source rated 3v @ 3 amp outputs 3v regardless of how much current is drawn from it by the load as long as it is below 3 amp.

Example Question

There are 2 solar cells. Each one is rated 1 volt @ 2 Amp. To power a load that needs 1 volt @ 3 Amp, how should these two cells be connected?

a) In parallel. √
b) In series.
c) back-to-back
d) by glue
e) there is no way.

Clicker Question

3 - There are 2 solar cells. Each one is rated 3 volt @ 2 Amp. To obtain output of 4 volt and 4 Amp, how should these two cells be connected?

a) In parallel.

b) In series.

c) back-to-back

d) by glue

e) there is no way.

Parallel: 3V, 4A

Series: 6V, 2A

Example Question – 4 Cells

There are 4 solar cells. Each one is capable of output 1 volt voltage and 2 Amp current. To obtain output 2 volts and 8W, how should these 4 cells be connected ?

Series --- Voltage is the sum and current is the same.

Parallel --- Voltage is the same and current is the sum

a) All in parallel.

b) All in series.

c) make two 2-in-parallel sets and connect these two sets in series

d) 3 in series and 1 is not connected

e) 2 in series and 2 are not connected.

What is the output current in this case?

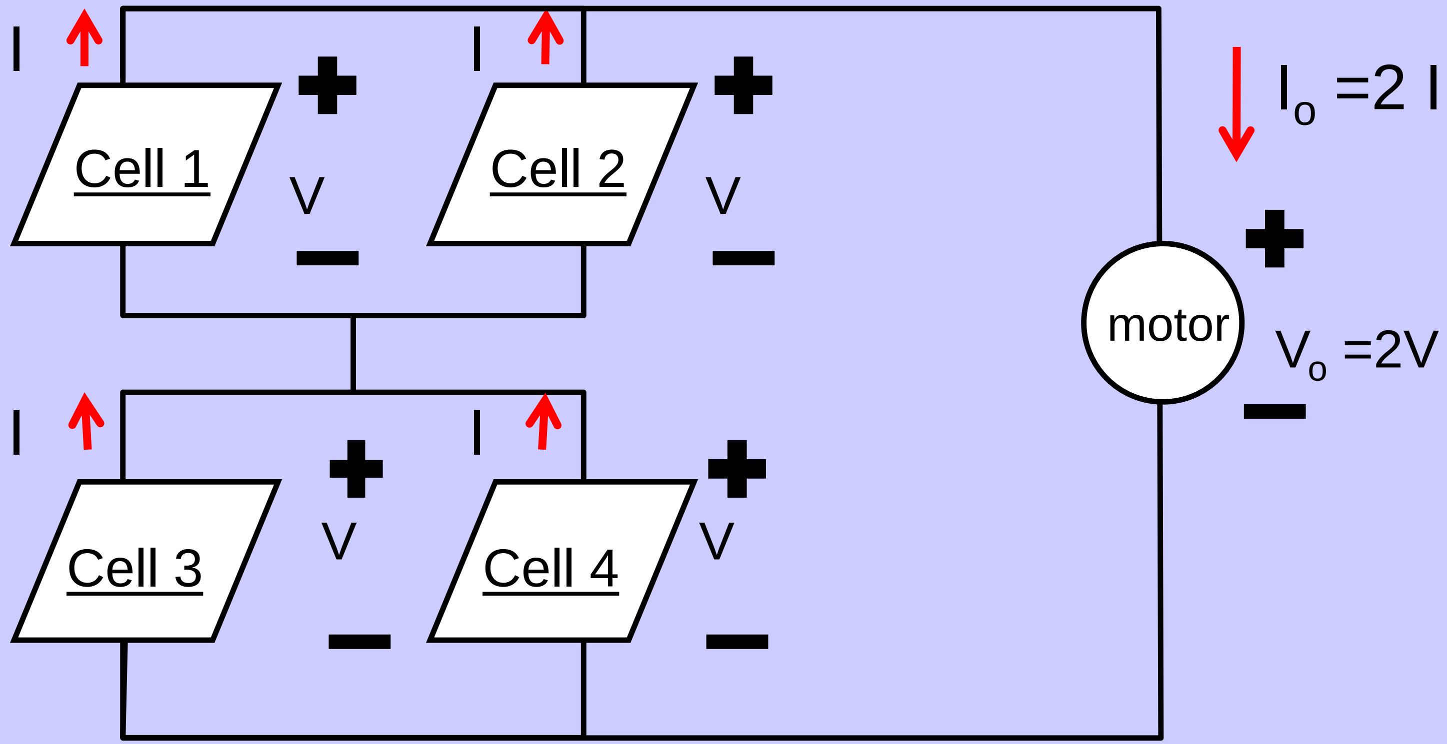
(a) 1A (b) 2A (c) 3A (d) 4A (d) 5A

Answer to 4 Cells Question

Where I =2,   V=1. The total output current is I_o = 2x2 =4 Amp

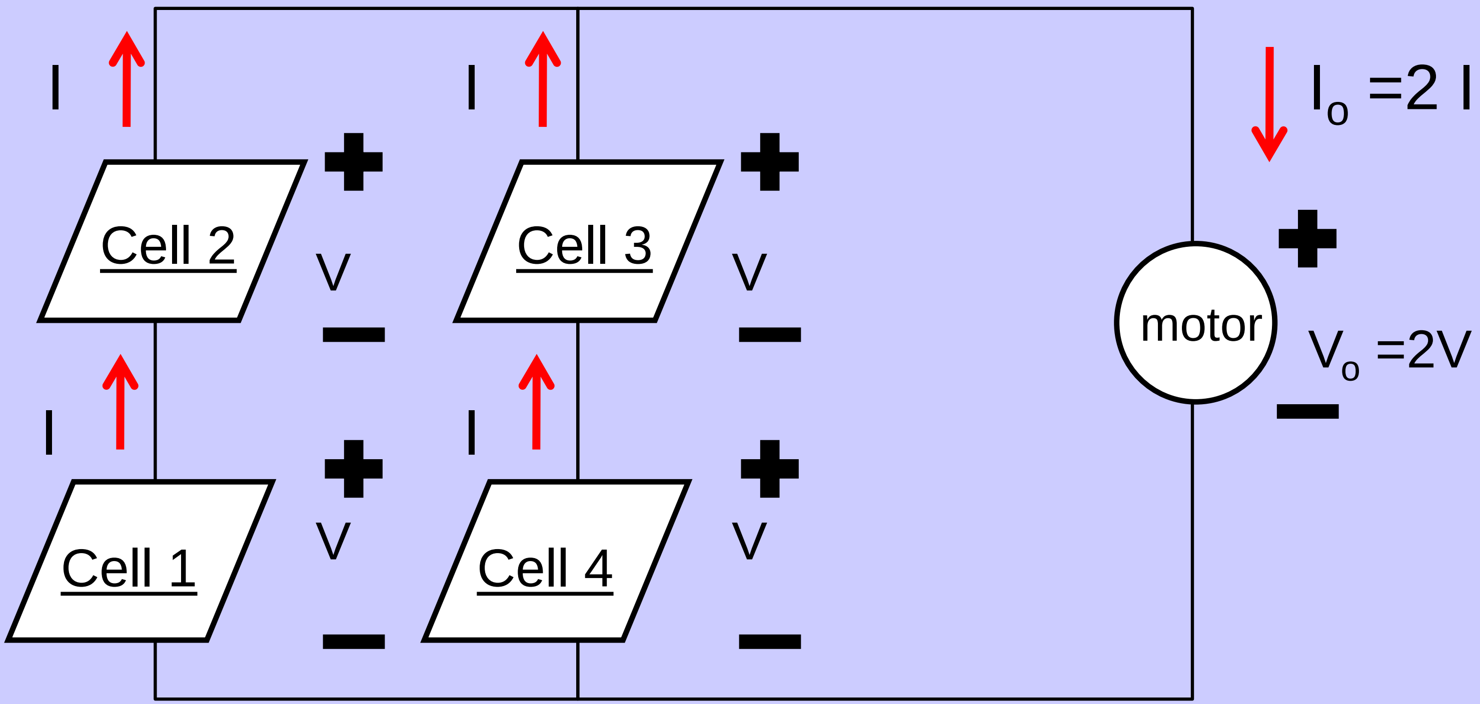
Output voltage is V_o= 2V = 2 volts

Output power is I_o x V_o= 4 x 2 = 8W.



Alternate answer to 4 Cells Question

The same output voltage, current, and power can be achieved by connection two 2-in-series sets first and then connect these two sets in parallel.



Pros and Cons of Electrical Power

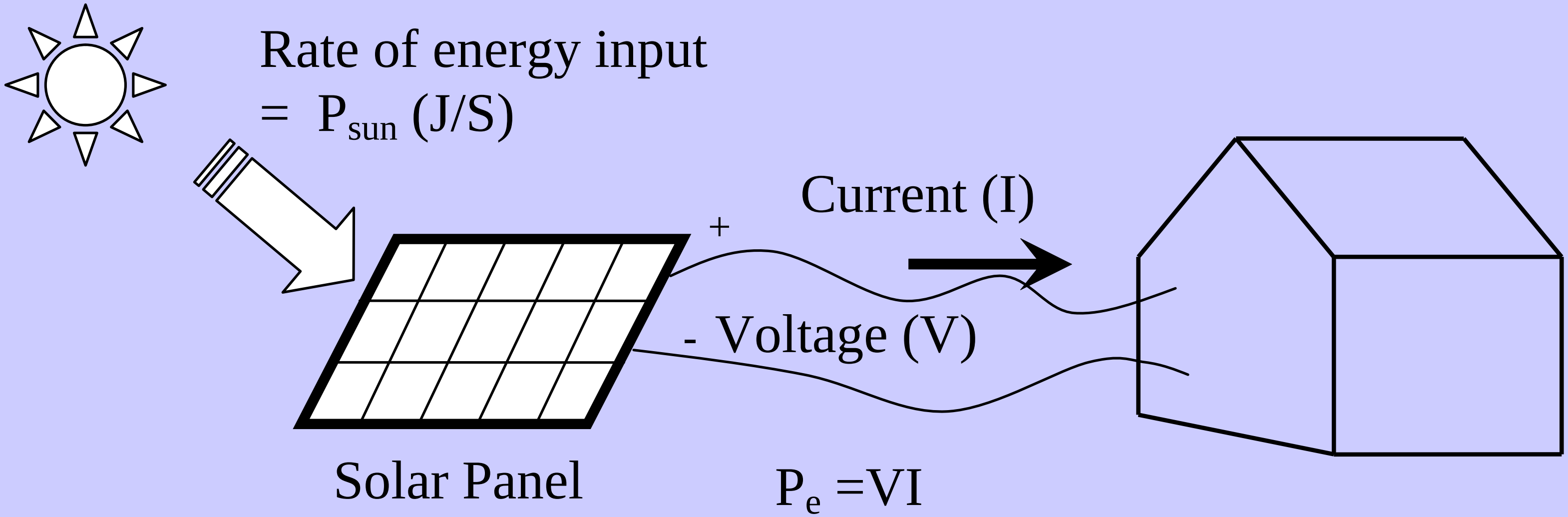
Pros: Convenience for transmission and distribution, clean, easy to control, easily transformed into many forms of power (mechanical, heat, light, etc.)

Cons: Requiring power conversion equipment (solar panels, heaters, motors, etc.). There is always some conversion loss.

39% of the power used in the US is converted into electric form first.

The pros clearly outweighs the cons.

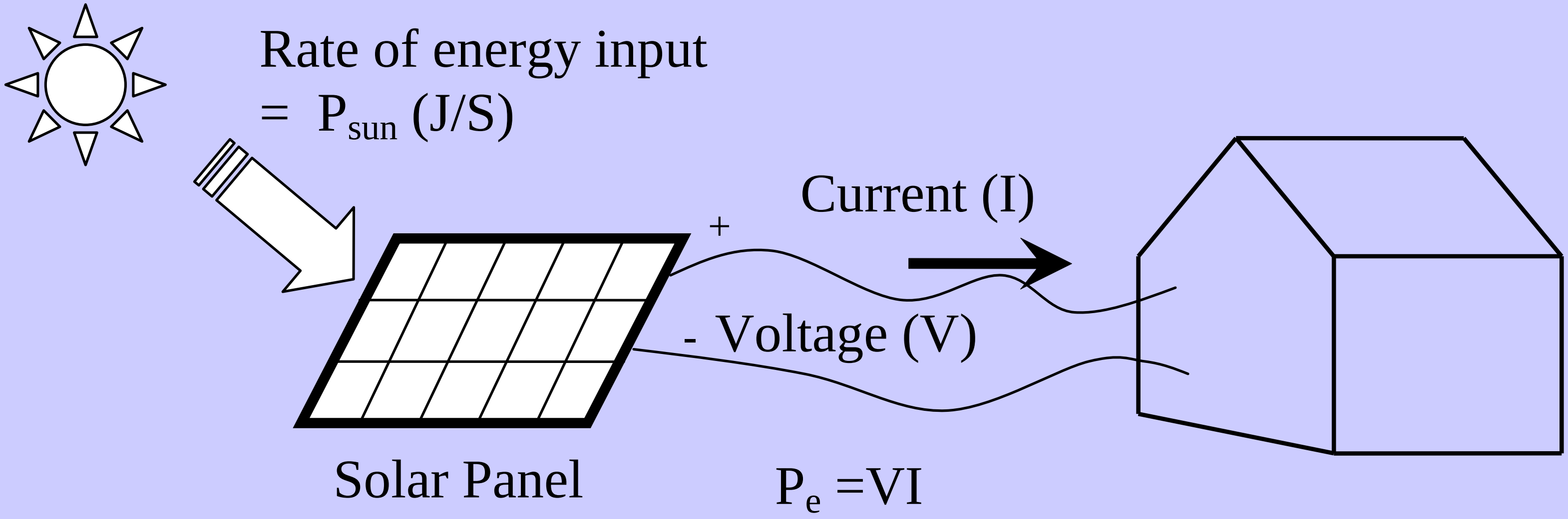
Power Conversion



The solar panel converts the power from sunlight to electric power. If 100% of the power from the sun is converted, the following equality holds.

$$P_{sun} = P_e = V*I$$

In reality, however, only a fraction of the sun power (typically 15%) can be converted.



Power from the sun on earth at noon is about 1350 W/m^2. For a solar panel of the size of 2 m^2, with an efficiency of 15%, the output power is

$$1350\ \text{W/m}^2 \times 2\ \text{m}^2 \times 0.15 = 405\ \text{W}.$$

At this output power level, if the output voltage of the panel is 50 V, the output current is 8.1 amp.