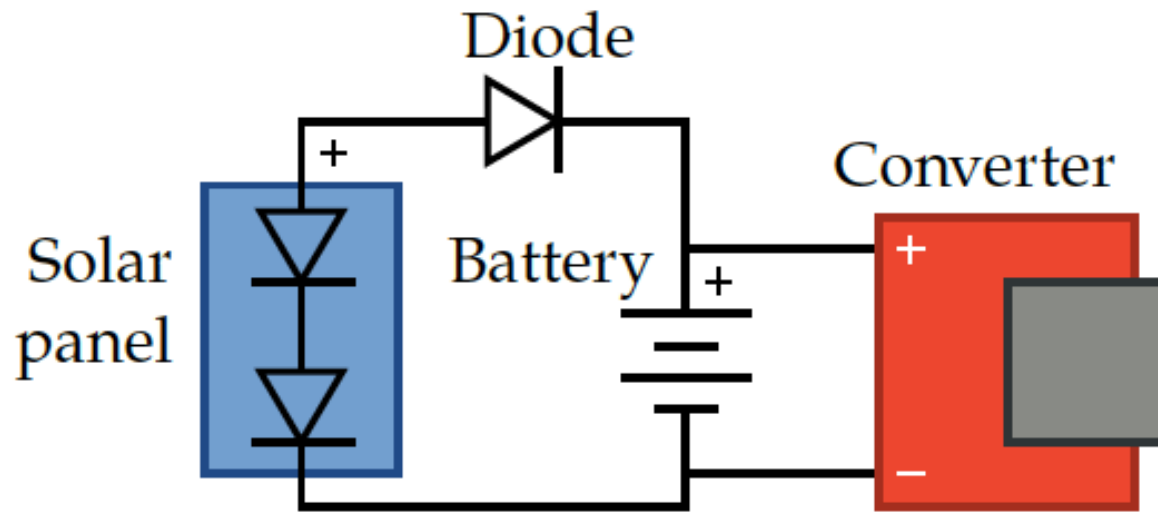

E40M

Device Models, Resistors, Voltage and Current Sources, Diodes, Solar Cells

Understanding the Solar Charger – Lab Project #1



We need to understand how:

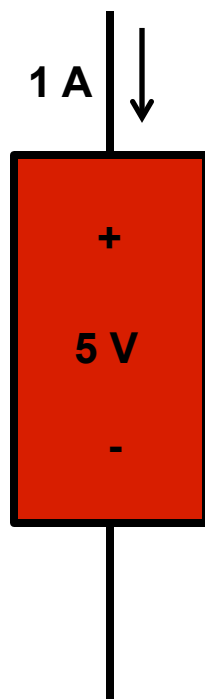
1. Current, voltage and power behave in circuits
2. Electrical devices constrain current and voltage
3. Diodes including solar cells work
4. Voltage converter works (later in the quarter).

Reading For These Topics

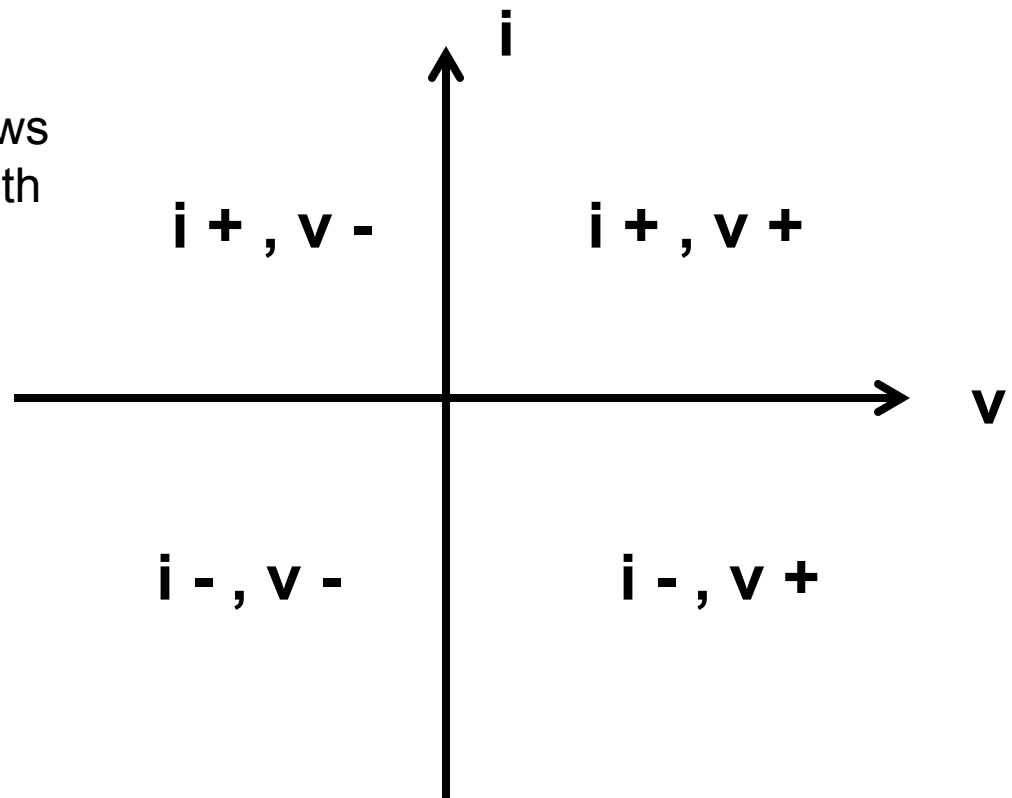
- Chapter 2 in the course reader
- A&L 1.6-1.7 - Two terminal elements
 - Voltage source; resistor; wires

Device Models

- A general way to show the relationship between two variables
- That is what we will do for our different types of electrical devices

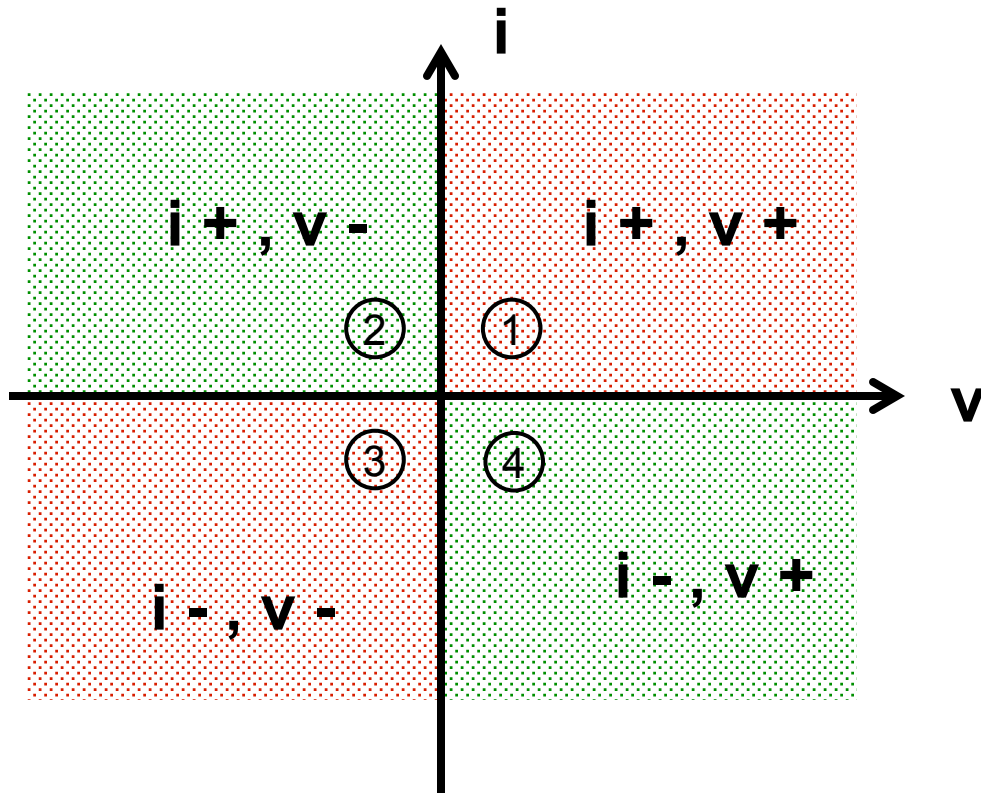
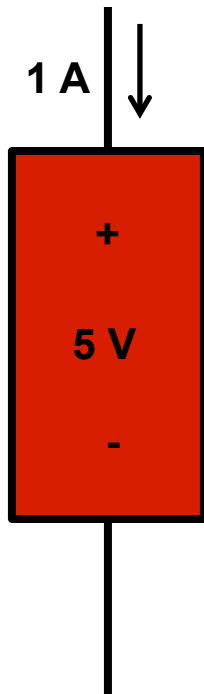


Sign convention:
positive current flows
into the terminal with
the + voltage label



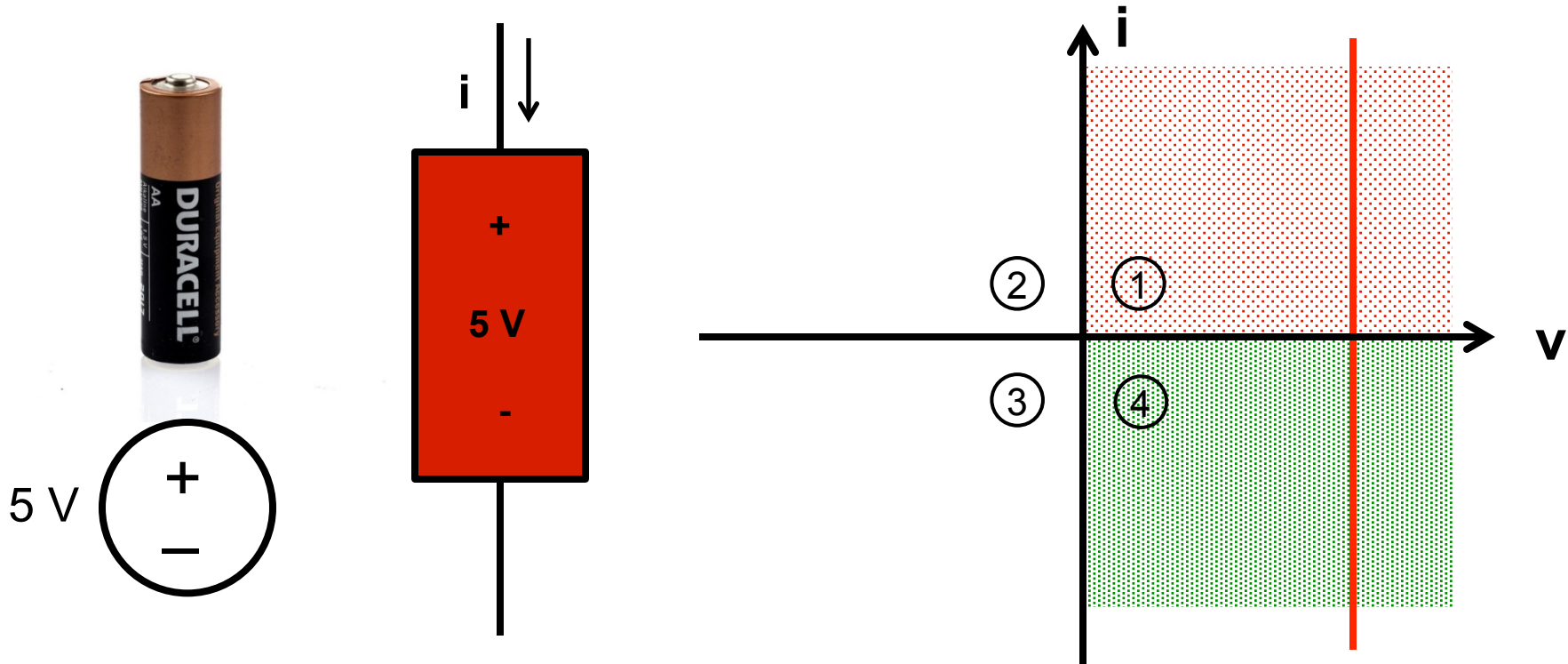
Device Models

- Note that the energy is dissipated by the device in quadrants 1 and 3, and power is generated by the device in quadrants 2 and 4.



Device Models – Battery, Voltage Source

- A battery or a voltage source provide a fixed out put voltage no matter what current they are asked to provide or consume (“sink”).
- In quadrant 1 energy is consumed, in quadrant 4 energy is provided.
- Quadrant 1 = battery charging, quadrant 4 = battery discharging.



Device Models – Resistors

- Current is proportional to voltage

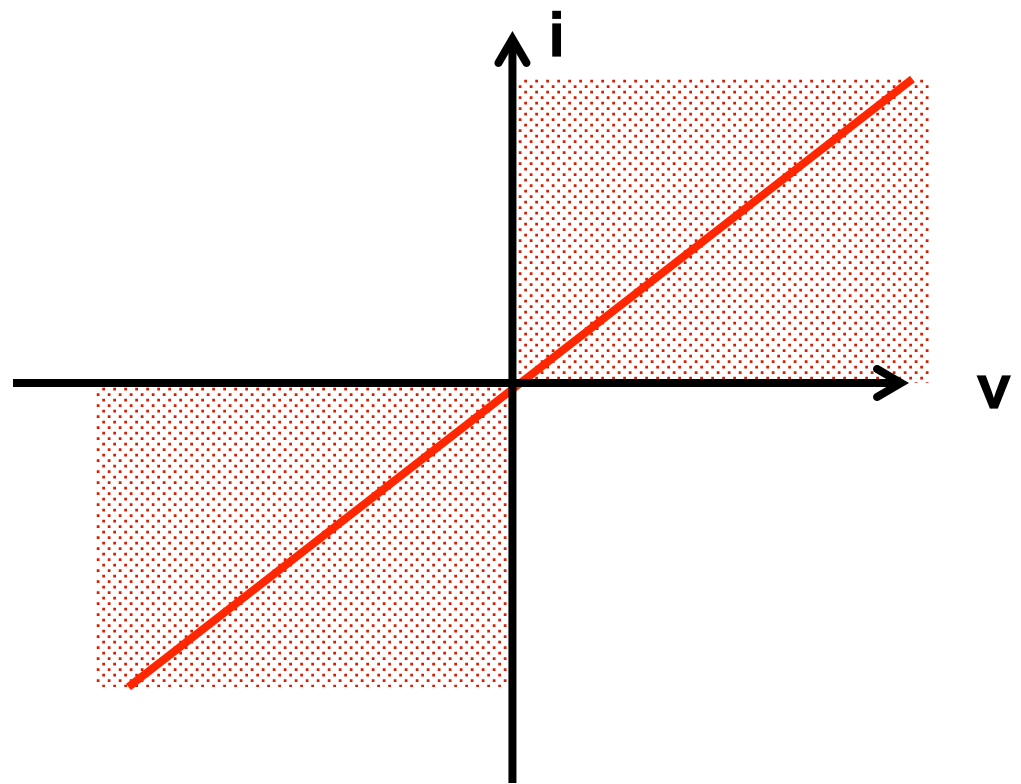
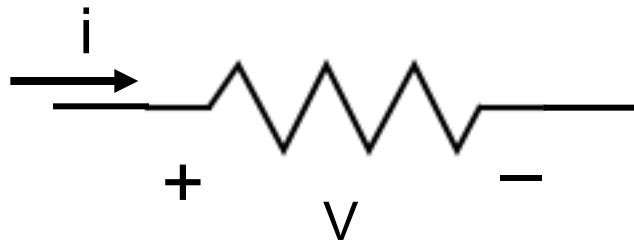
$$V = i \cdot R \quad \text{Ohm's Law}$$

- The book also uses G

$$\text{Conductance} = 1/R$$

$$i = G \cdot V$$

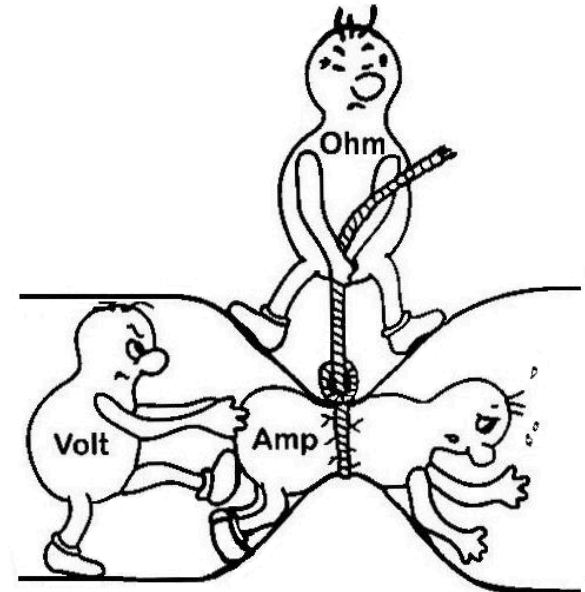
- Symbol



Why Does Resistance Exist?

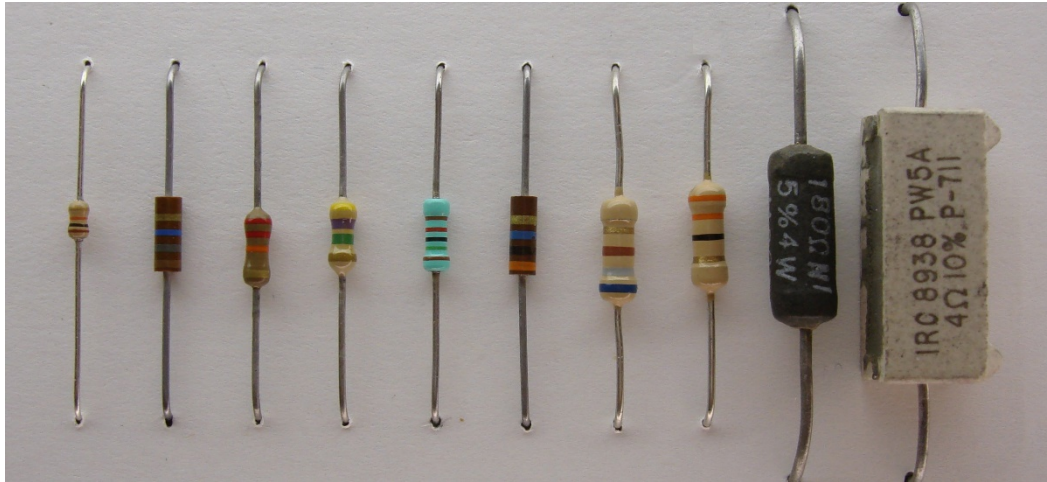
(What Physical Effect Does it Model?)

- Conductors are not perfect
 - They use a little energy to get current to flow through a wire¹
- Since the energy flow into the wire is ($i \Delta V$)
 - There must be a voltage drop along the wire
 - Generally this drop is proportional to the current
 - $V = k \cdot i$
 - We call the constant of proportionality “Resistance”
- Make resistors by using material that doesn't conduct well



¹Well except for superconductors which are “magical.” They have interesting properties, including that current can flow in a loop forever! Superconductors are used in MRI machines to generate large magnetic fields efficiently.

Resistors



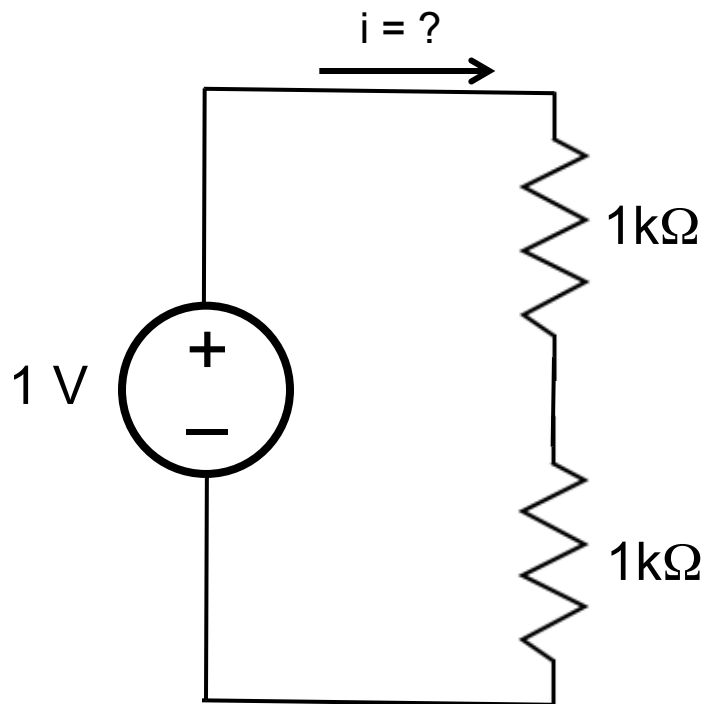
<http://ecee.colorado.edu/~mathys/ecen1400/labs/resistors.html>

- You'll begin to work with these this Friday in the Prelab lecture.



<http://www.instructables.com/id/Reading-Surface-Mount-Resistor-codes/>

Resistance Problem #1

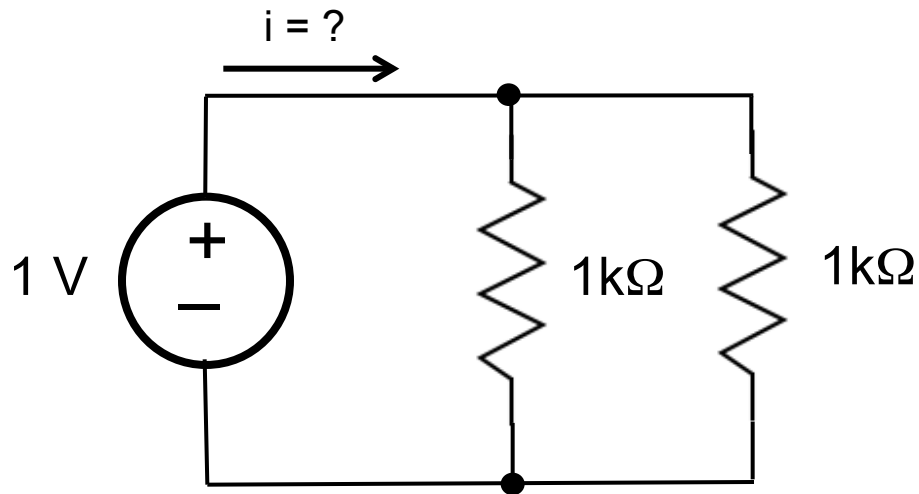


What current flows in the loop?

What is the voltage across the bottom resistor?

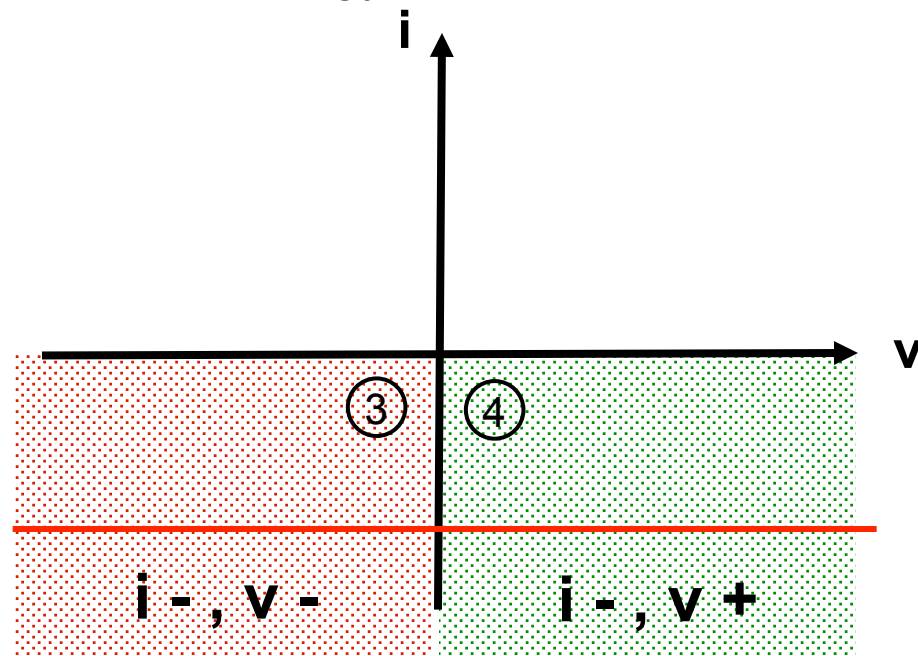
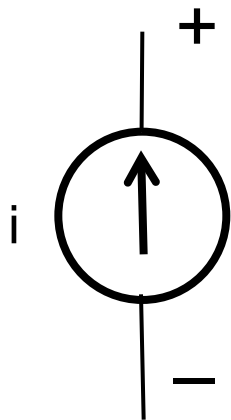
Resistance Problem #2

What is the current i ?



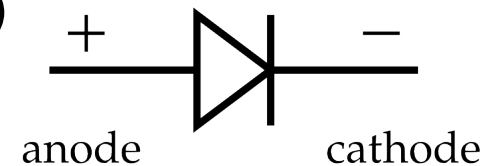
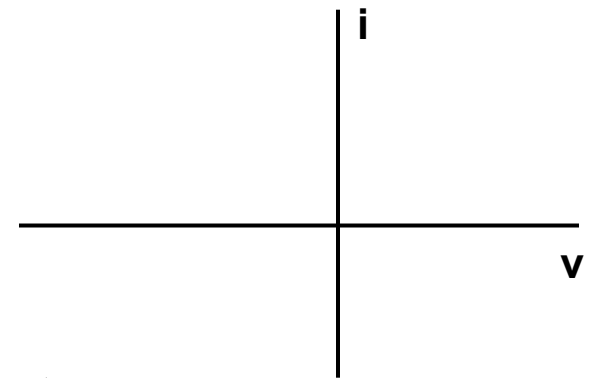
New Device: Current Source

- Current is constant, independent of voltage; i is negative in this case because it flows out of the $+$ terminal
- In quadrant 4 the current source is providing energy, in quadrant 3 the current source consumes energy.

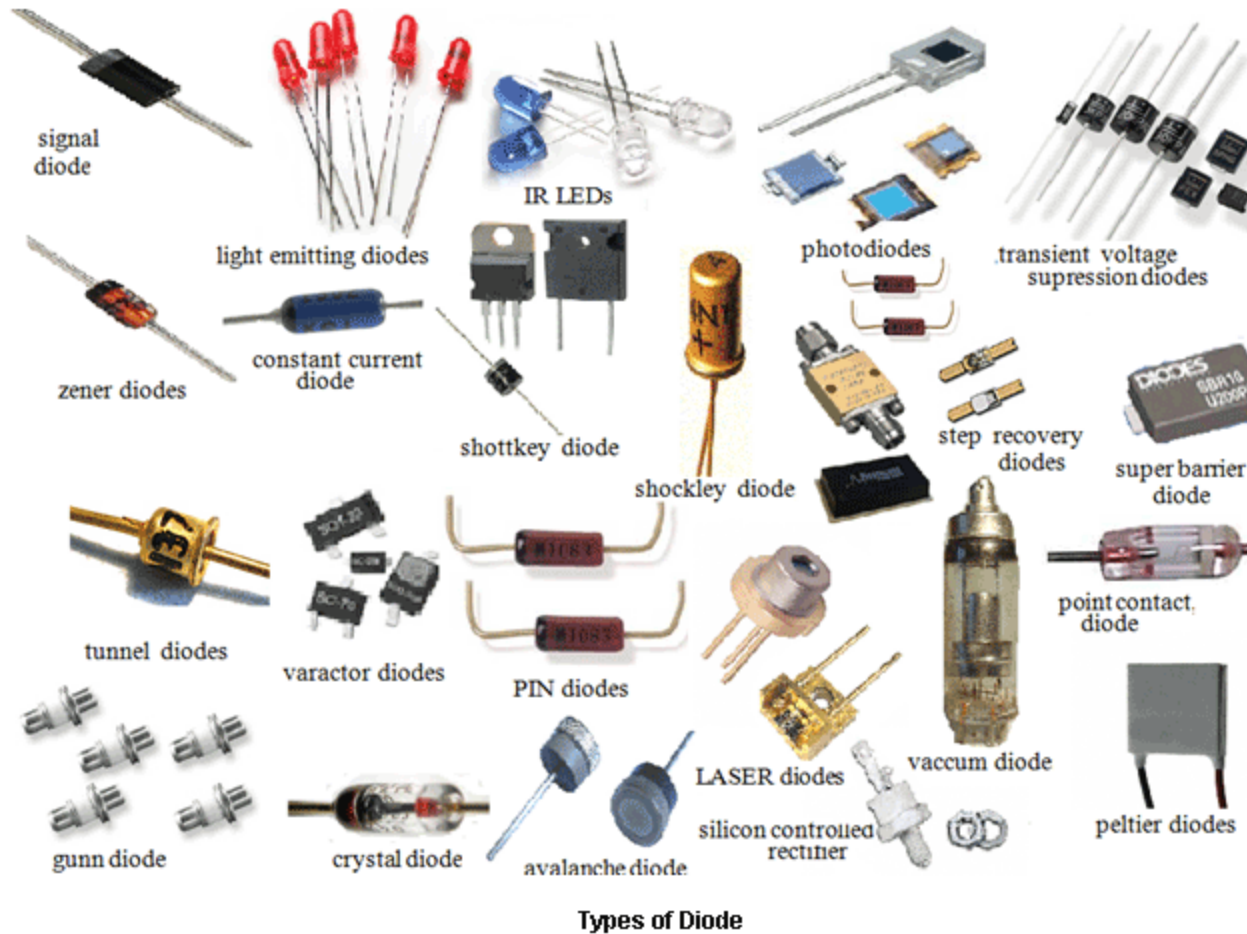


New Device – Diode

- Diode is a one-way street for current
 - Current can flow in only one direction
- An ideal diode
 - If the current is positive
 - Voltage drop is zero independent of current
 - Looks like a wire (short circuit)
 - If the voltage is negative
 - Current is always zero independent of voltage
 - Looks like the device is not there (open circuit)
- The plus end of the diode is called the anode
 - The minus end of the diode is called the cathode



There Are Many Types of Diodes



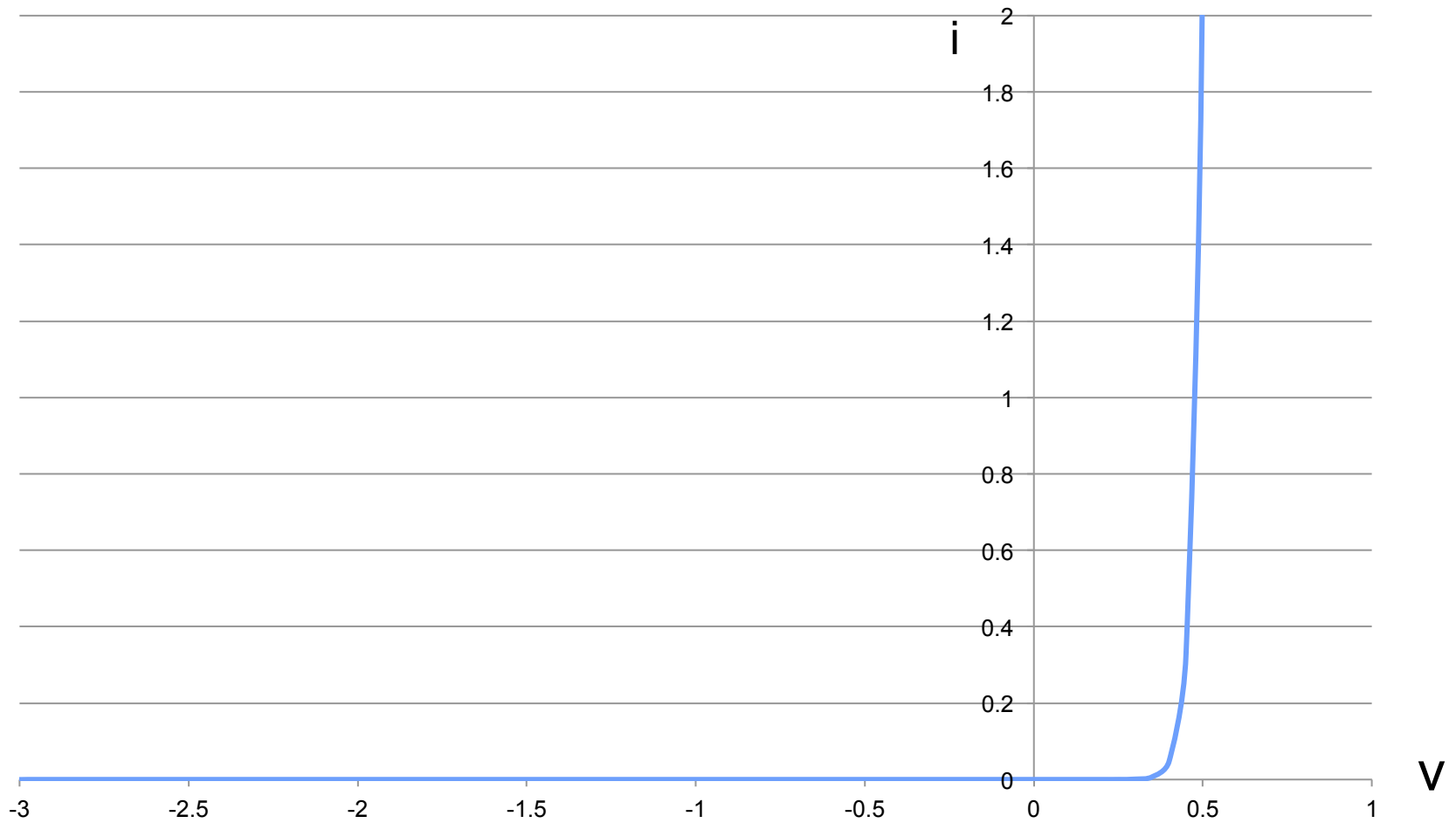
<http://www.instructables.com/id/Types-of-Diodes/>

Real Diodes

- Do conduct current in only one direction
 - But they have some forward voltage drop
 - And their voltage does increase with current, but
 - Current is exponential on voltage!
 - and voltage is logarithmic on current.
 - So the voltage is not very dependent on current level
- Their drop depends on the type of diode
 - Schottky diodes are around 0.3 V
 - Normal silicon PN diodes are generally around 0.6 V
 - Other semiconductor materials have larger voltages

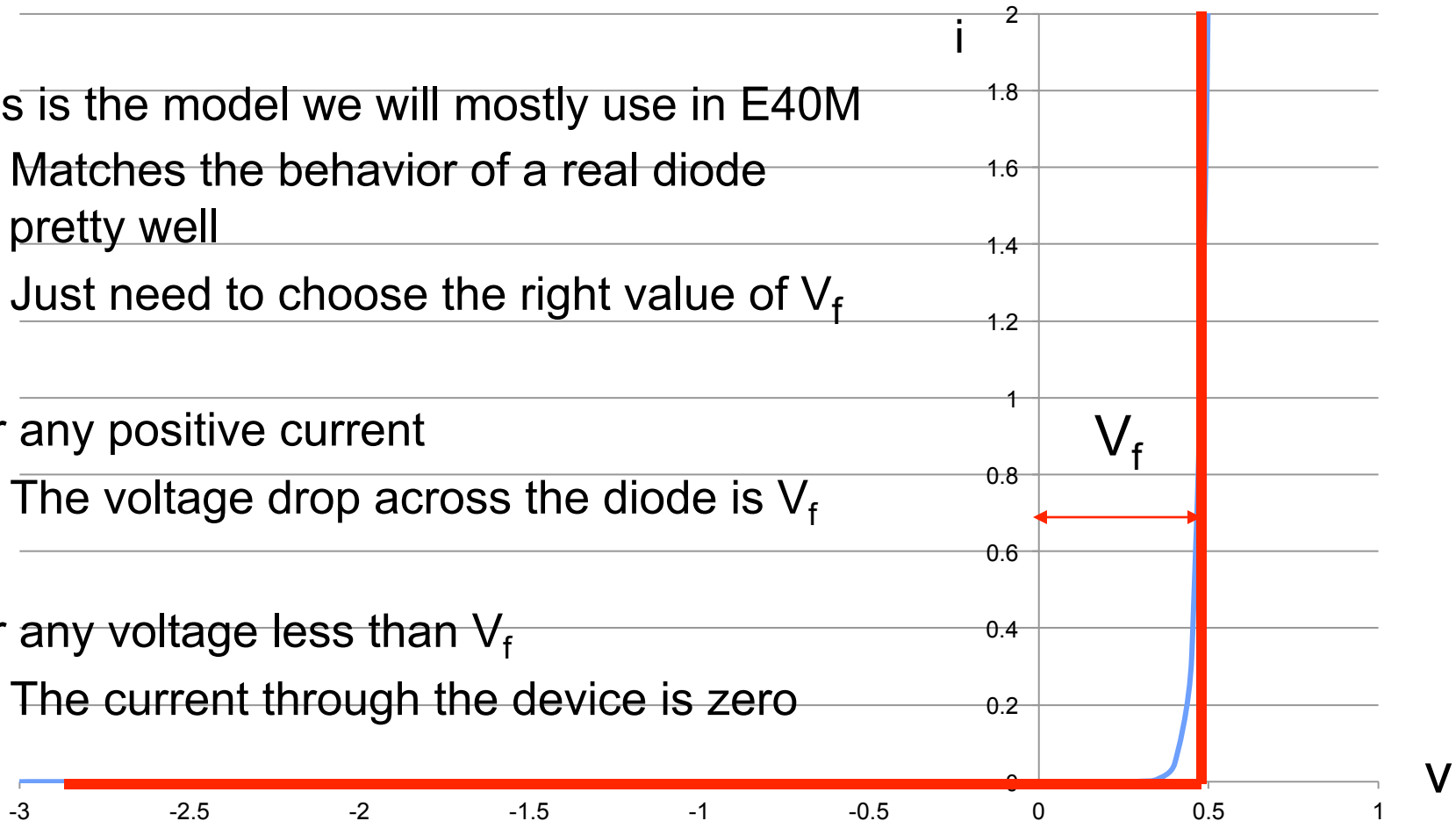
$$I = I_o \exp\left(\frac{qV}{kT}\right)$$

Diode iv

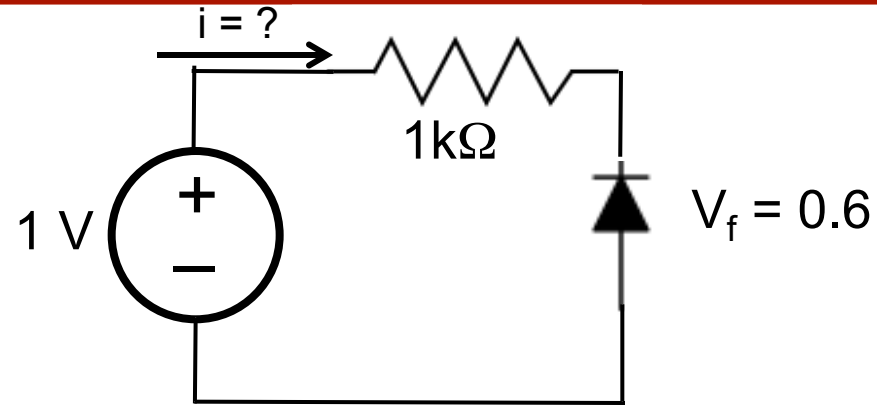
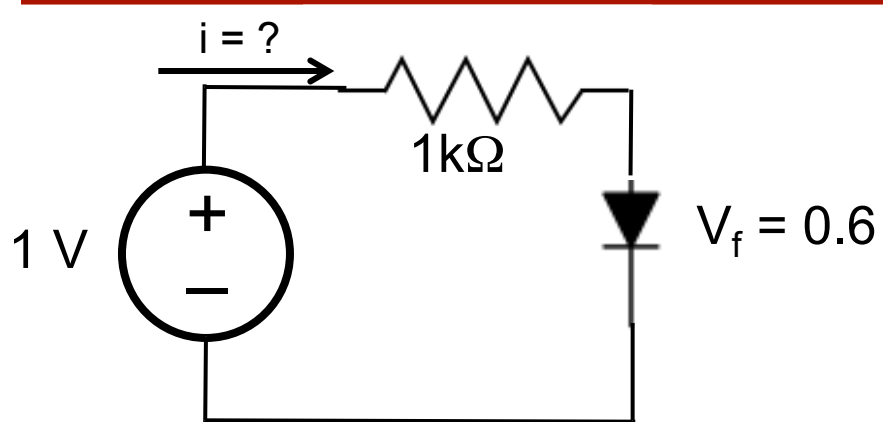


Idealized Diode iv

- This is the model we will mostly use in E40M
 - Matches the behavior of a real diode pretty well
 - Just need to choose the right value of V_f
- For any positive current
 - The voltage drop across the diode is V_f
- For any voltage less than V_f
 - The current through the device is zero

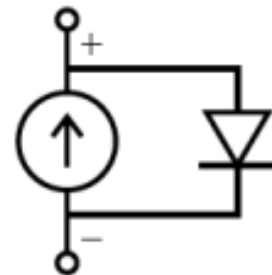


Diodes in Simple Circuits



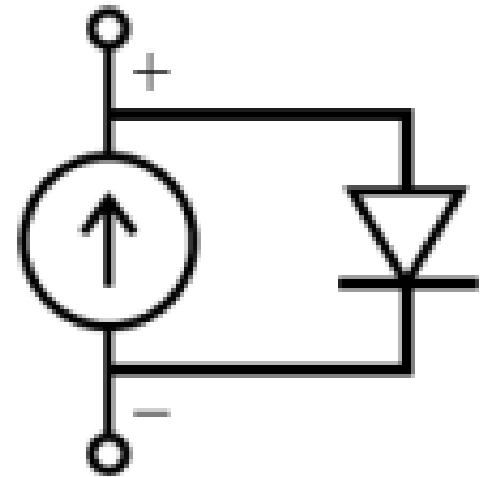
Some Diodes Are Light Sensitive

- These diodes are called **solar cells**
- When you shine light on the cell
 - The light generates a current which runs in parallel to the diode
 - The value of the current is proportional to the light
- This generates electrical energy
 - Actually converts energy in the light to electrical form

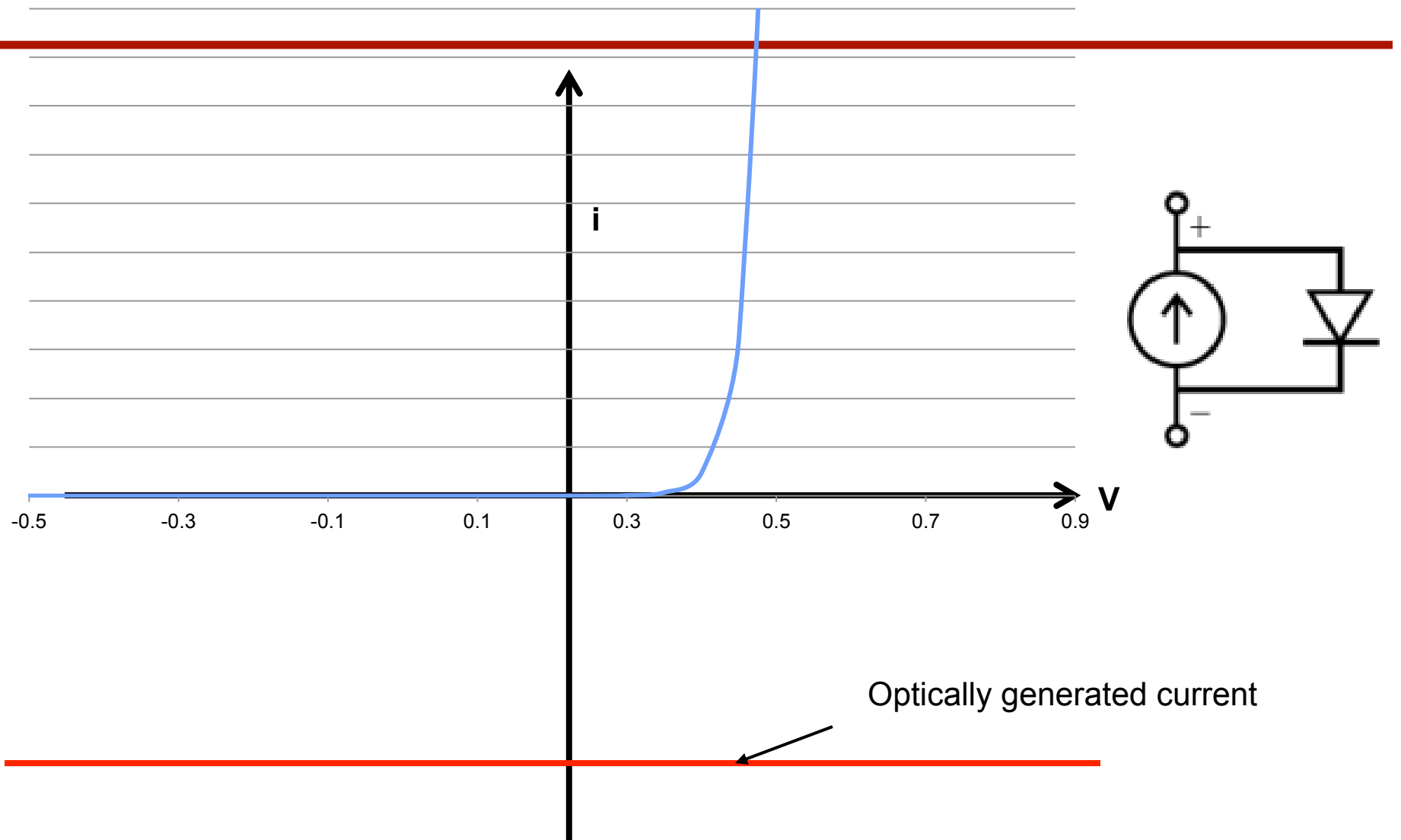


Solar Cell

- Remember a solar cell is a diode
 - So we represent it by a diode symbol
- When light shines on the diode
 - The light generates a current
 - We represent this current by a current source.
 - The value of this current is proportional to the light shining on the diode
 - Notice the direction of the current
 - Flows out of + terminal of diode

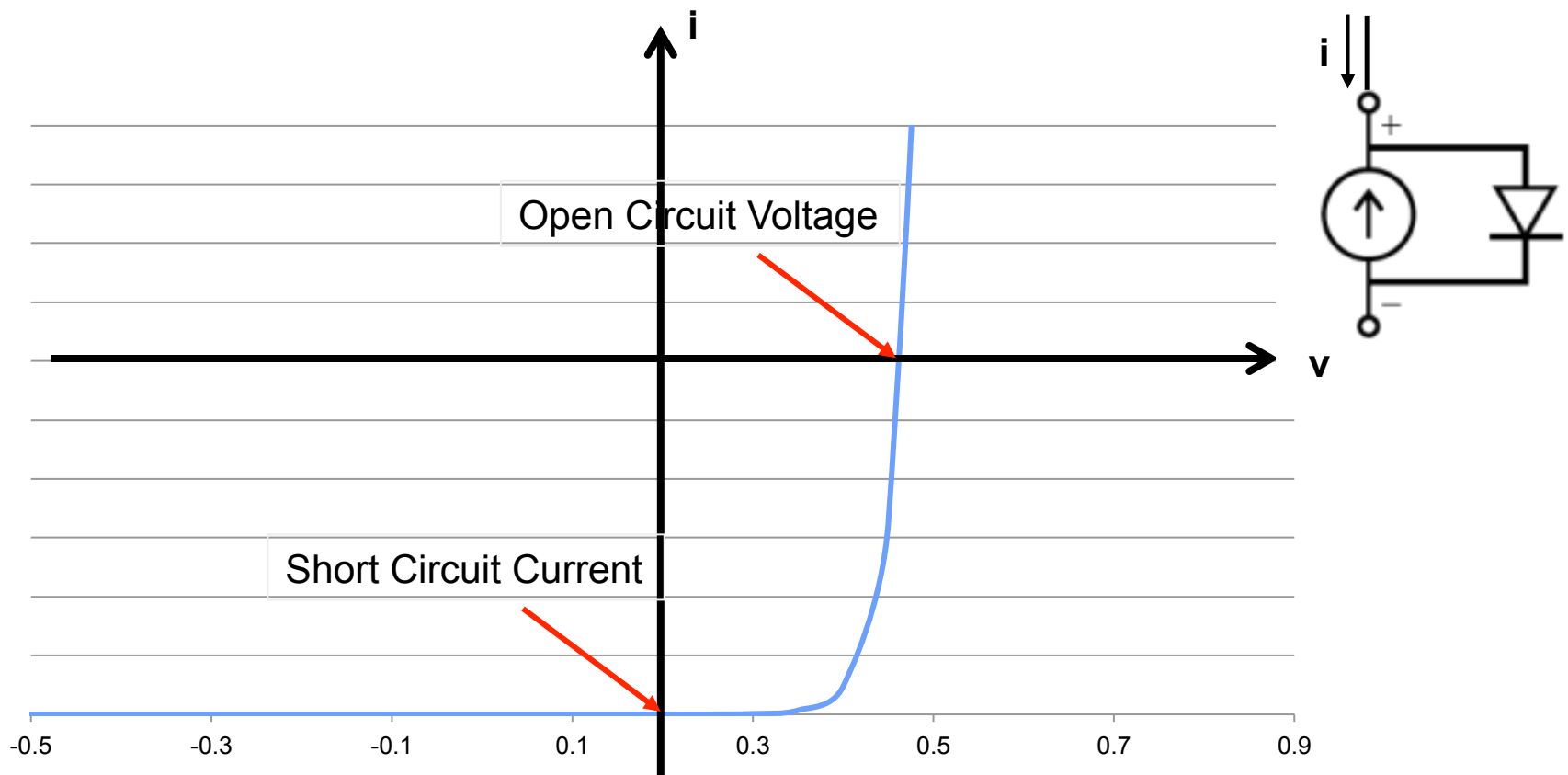


Solar Cell i-V Curve



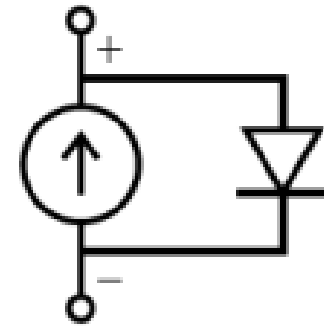
Open Circuit Voltage Short Circuit Current

- What is the voltage when zero current flows out of the device?
- What is the current when there is no voltage across the device?

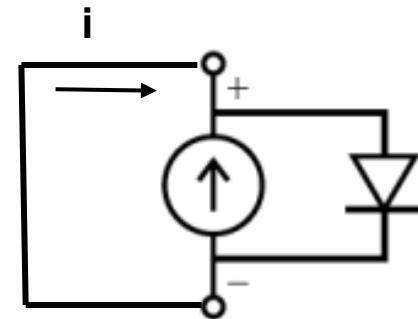


What Sets the Open Circuit Voltage and the Short Circuit Current?

- If there is no path for current (open source voltage case)
 - It will flow into the diode
 - KCL must still hold
 - $V_{\text{diode}} = V_F$

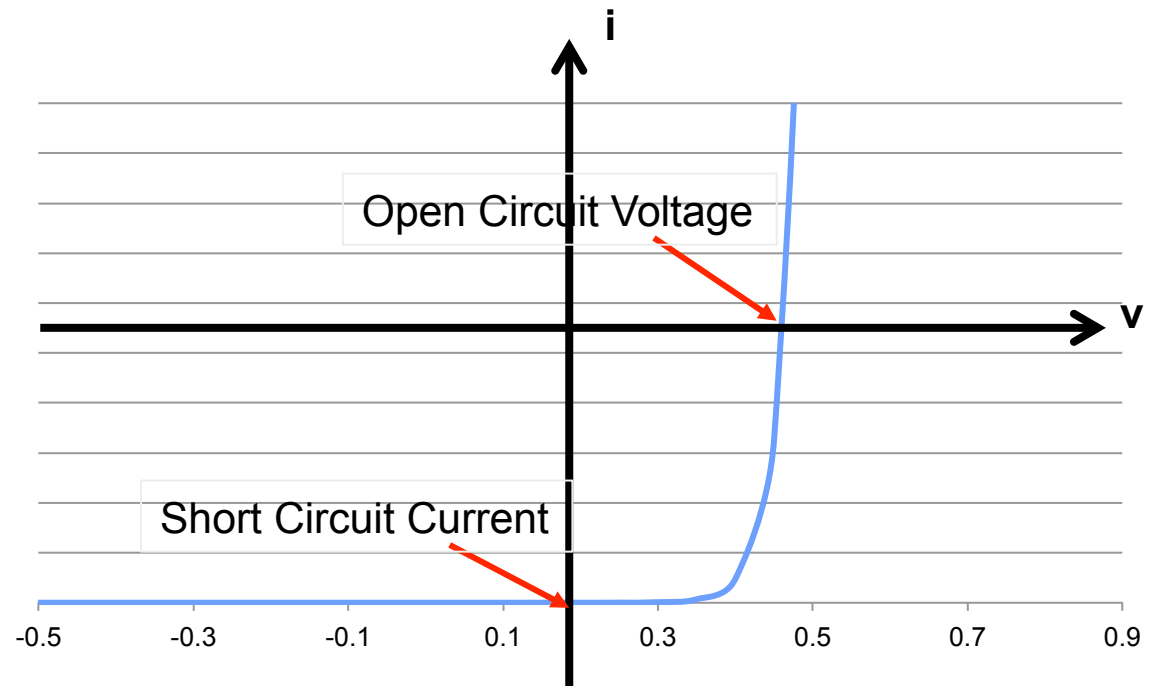


- If you short the diode out (short circuit current)
 - You measure all the optically generated current

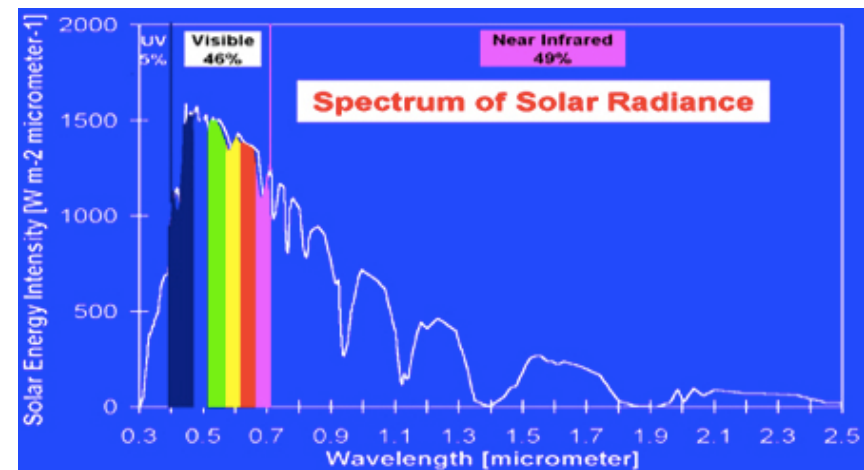
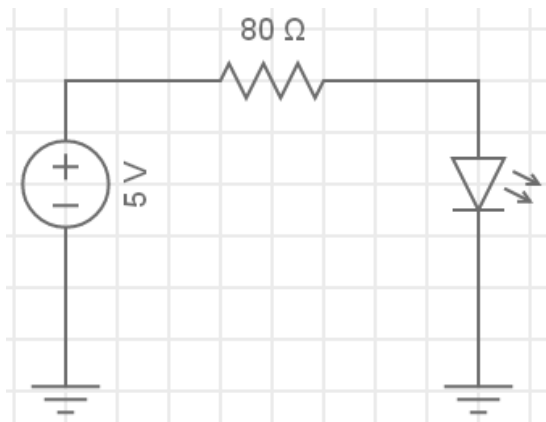
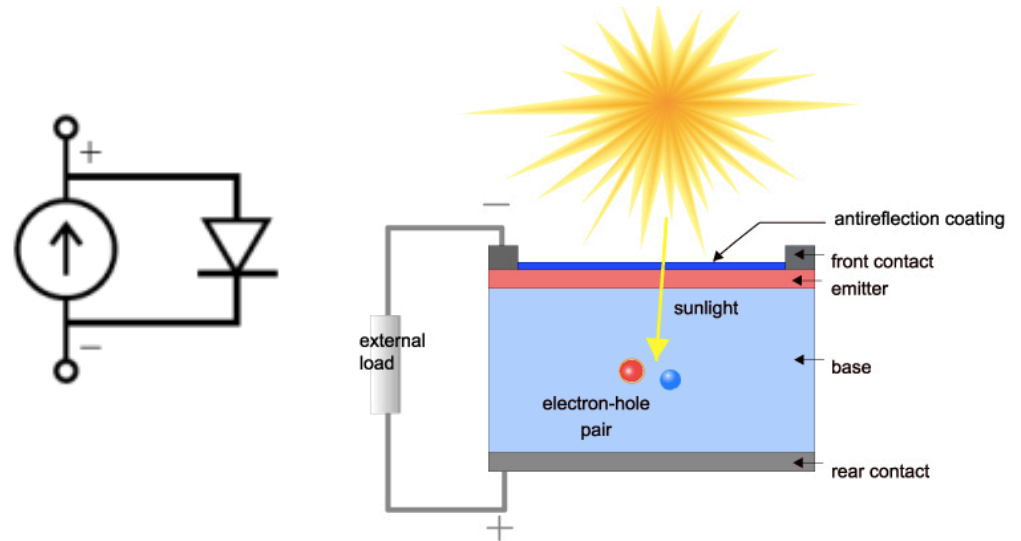
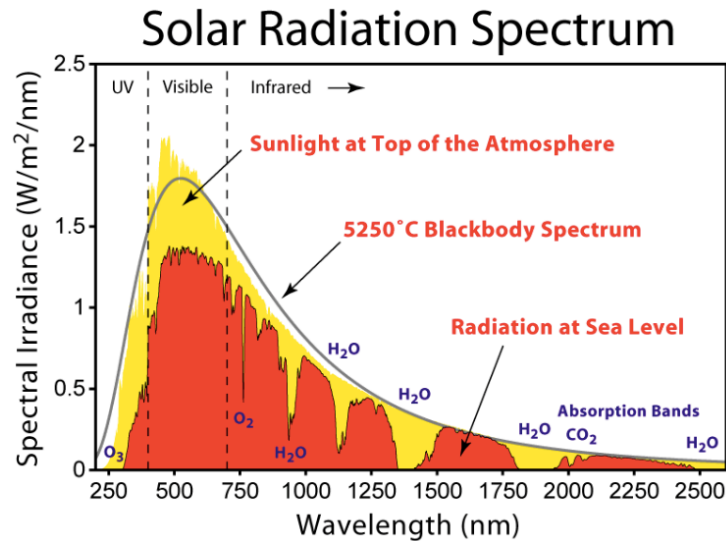


Extracting Power from a Diode

- Power is $i \cdot V$
 - So in neither of these cases do we get power from the diode
- Actual power will be less than:
 - V_{OC}, i_{SC}
- You'll actually measure these parameters on your solar array next week.

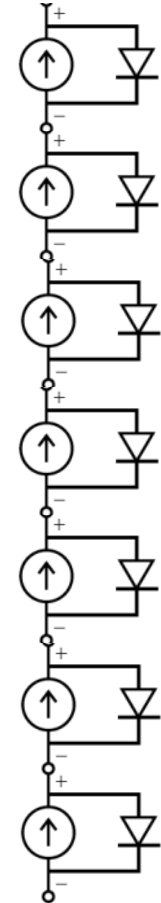


FYI – How Do Light Emitting Diodes and Solar Cells Actually Work?

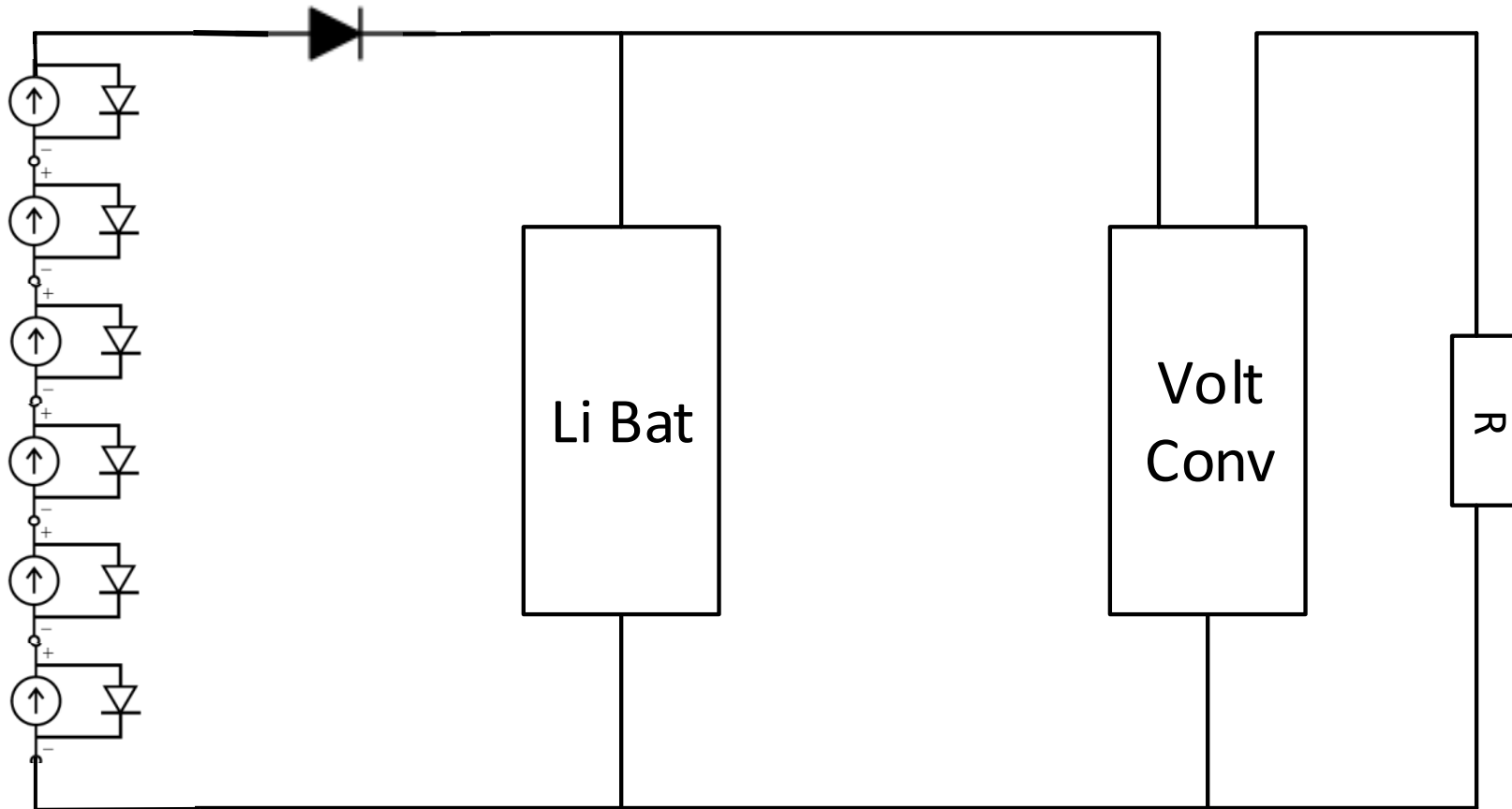


Generating Enough Voltage

- There is one weak point for solar cells
 - Each cell provides $< 0.5\text{ V}$
 - We need around 5 V , so we bought a panel with many cells stacked in series
- Commercial photovoltaic arrays also use this approach
- How do we figure out voltages and currents here?



Or Here?



In the next set of lecture notes we'll develop methods to analyze circuits by extending the KCL and KVL ideas we've already discussed.

Learning Objectives for These Notes

- Understand the device i - V curve of a resistor
- Understand the device i - V curve of a voltage source
- Understand the device i - V curve of a current source
- Understand the operation of a diode, and its symbol