

SEMICONDUCTORS

Diodes

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Electrical Engineering – SS 2019 – Duke TIP

INTRO TO SEMICONDUCTORS

What is a semiconductor?

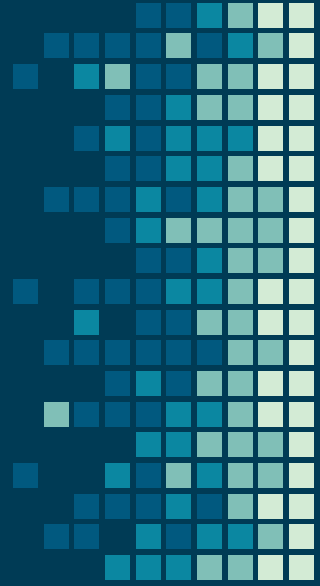
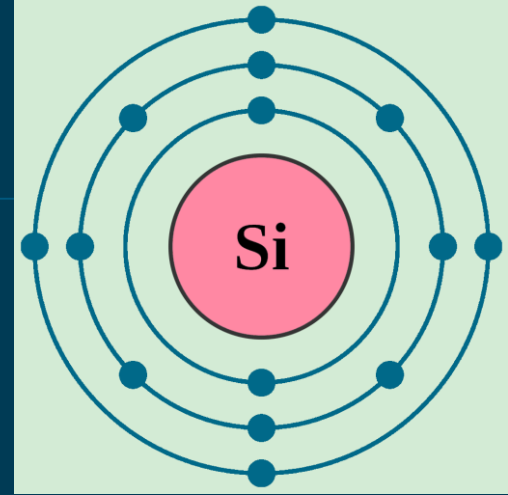
- Conductor – material with number of free electrons.
- Insulator – material with few or no free electrons.
- So is a semiconductor something in between?

Semiconductor

- Semiconductor – a material whose conductivity falls between that of a conductor and an insulator.
- Have several properties that we will exploit:
 - Passes current in one direction more easily than the other direction.
 - Has a variable resistance.
 - Sensitivity to light or heat.
- Common semiconductors: silicon, germanium
- Fun Fact: Silicon Valley was named after the semiconductor silicon. Why?

Silicon

- A great, plentiful semiconductor.
- Has 4 valence electrons, but wants 8.
- It shares electrons with neighboring atoms.
- Holes – opposite of electrons, space in shell where an atom wants an electron.
 - Holes flow in the opposite direction of electrons
 - Holes flow + to - (same as current convention)
- Silicon has 4 electrons and 4 “holes”.

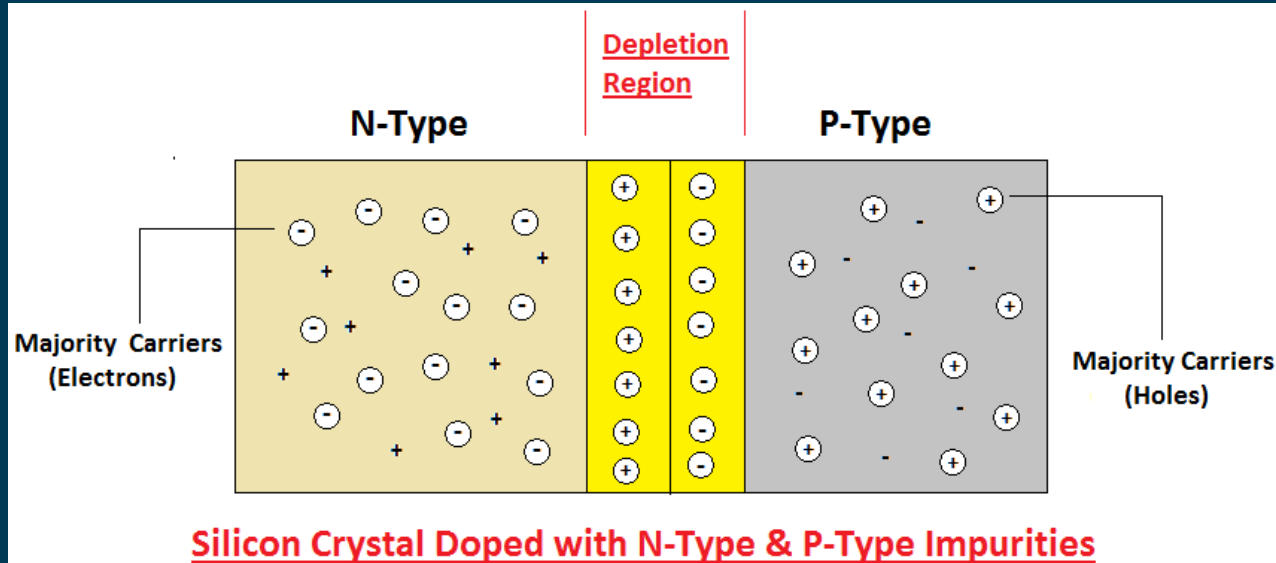


Doping

- Silicon on its own isn't very useful.
- We mix it with other atoms like boron or phosphorus to make it have very useful electrical properties.
 - Boron – has 3 valence electrons. When clustered with a silicon atom, it has 1 hole.
 - P-Type - electron deficient (P=positive)
 - Phosphorous – has 5 valence electrons. When clustered with a silicon atom, it has 1 additional e⁻.
 - N-Type – extra electron (N=negative)

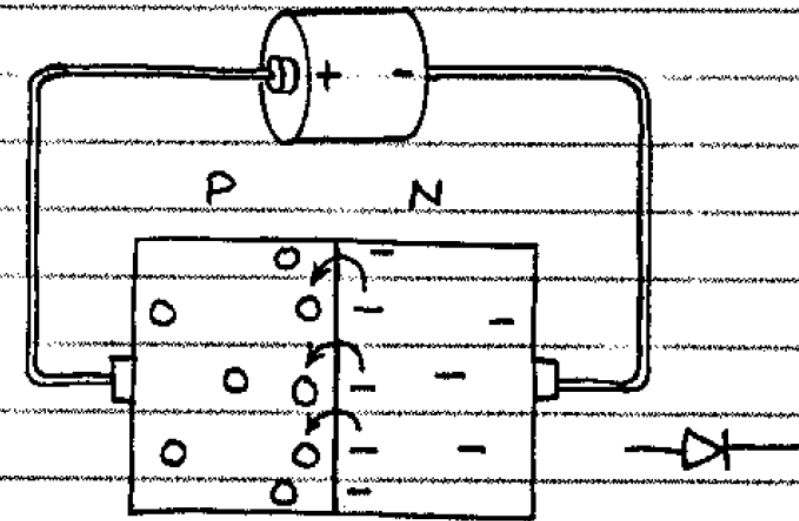
P-N Junction

- Both P-type and N-type will conduct electricity. Not very useful.
- By adding a P-type material with an N-type material, we can create a much more interesting and useful component leveraging this P-N Junction.



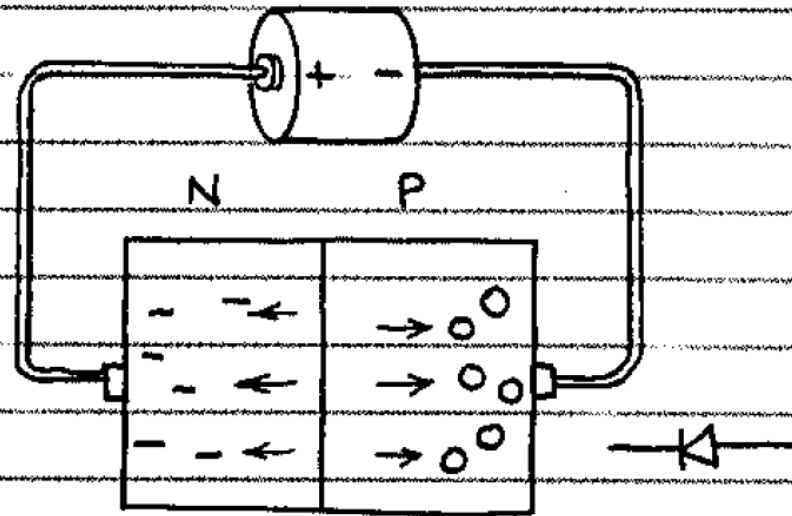
Forward & Reverse Bias

FORWARD BIAS



← ELECTRON FLOW
→ HOLE FLOW

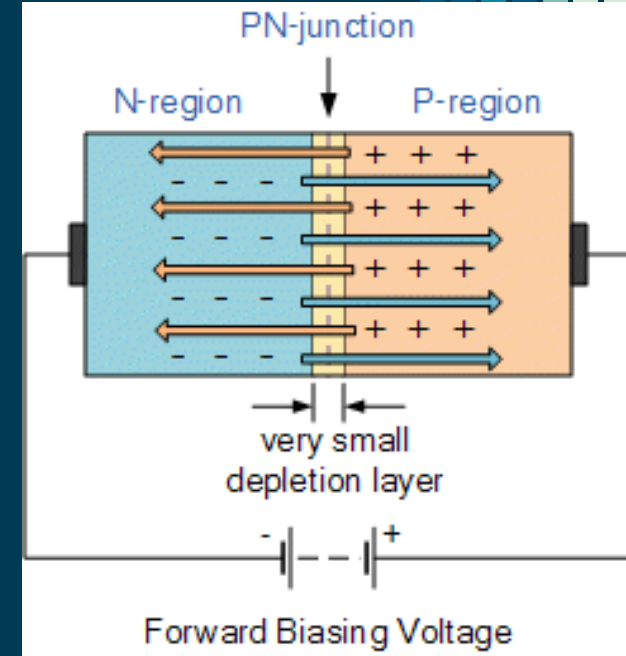
REVERSE BIAS



NO
CURRENT FLOW

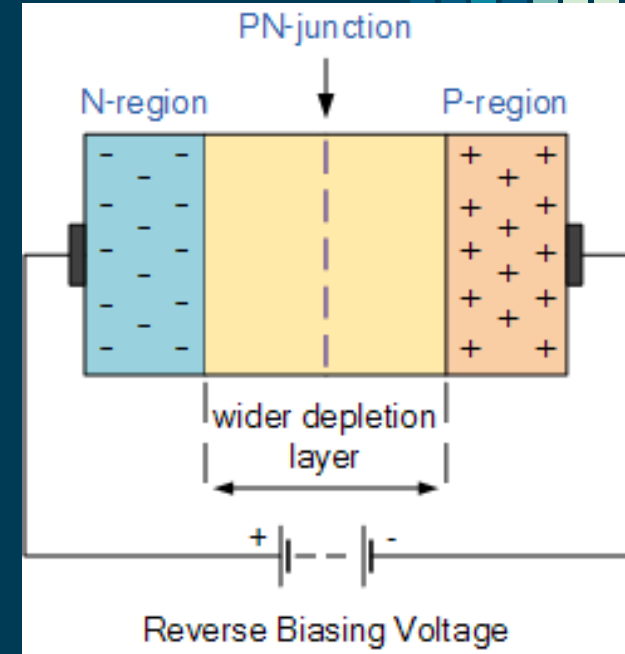
Forward Bias

- P-type region connected to the positive terminal.
- N-type region connected to the negative terminal.
- The charge from the battery repels holes and electrons towards the junction.
- If the voltage exceeds the forward voltage (~ 0.7 V for silicon), then the electrons will cross the junction to combine with the holes and current will flow.

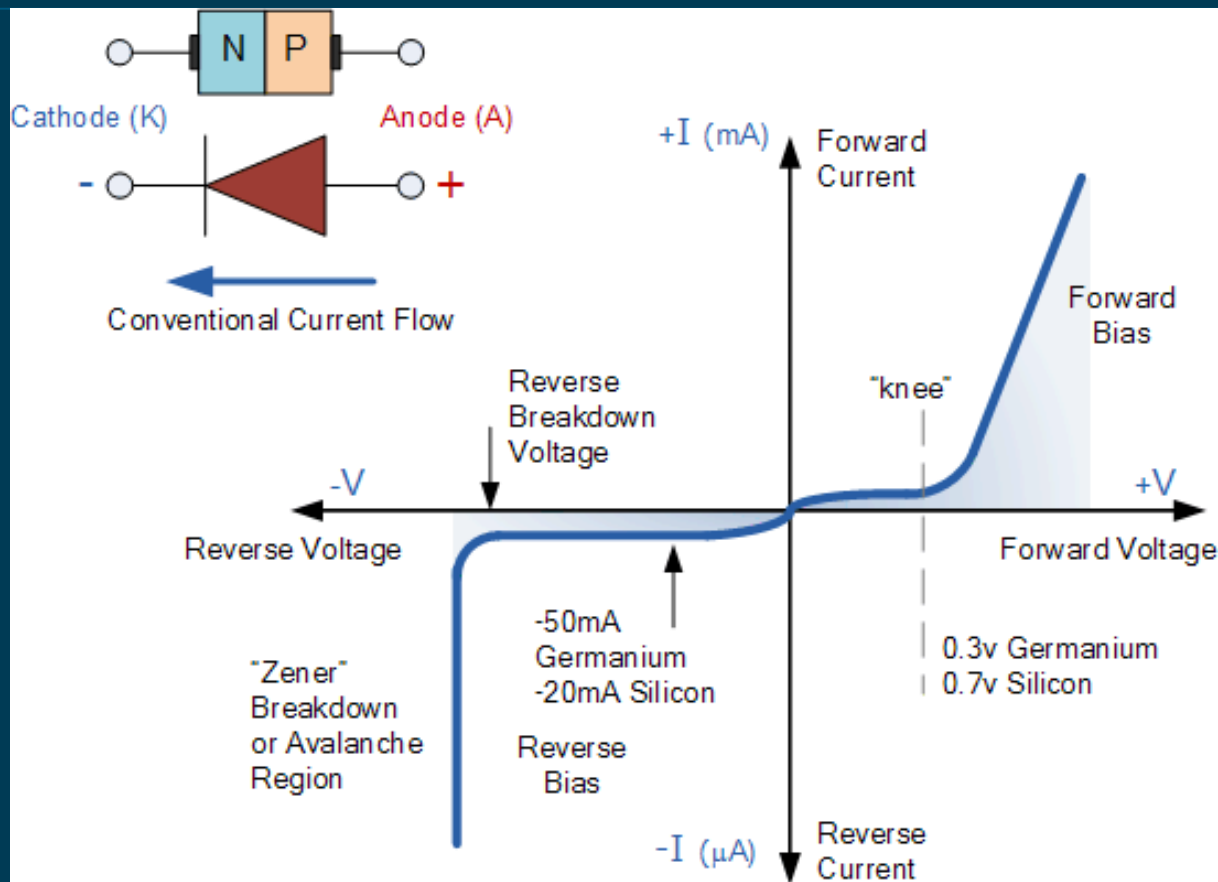


Reverse Bias

- P-type region connected to the negative terminal.
- N-type region connected to the positive terminal.
- The charge from the battery attracts holes and electrons away from the junction.
- Therefore, no current can flow.



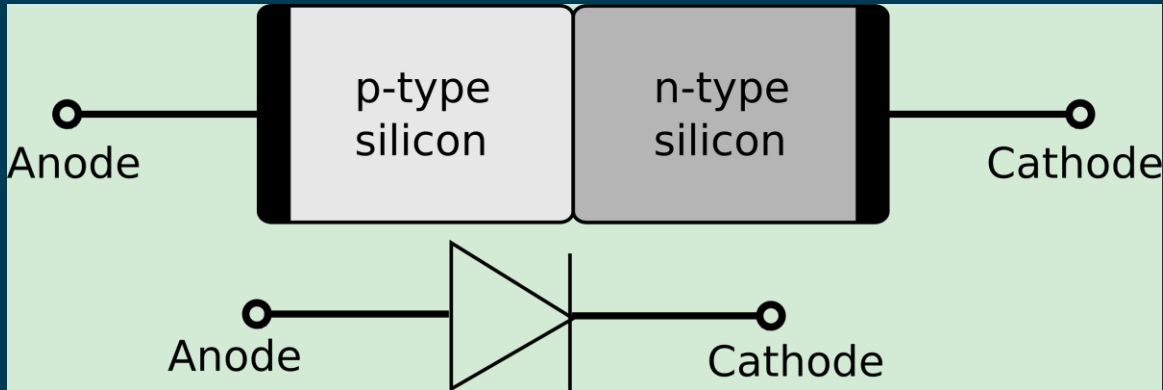
I-V Curve



DIODES

Diode

- A diode is just a P-N junction!
- Diode - a two-terminal electronic component that conducts current primarily in one direction
- It has low (ideally zero) resistance in one direction, and high (ideally infinite) resistance in the other.



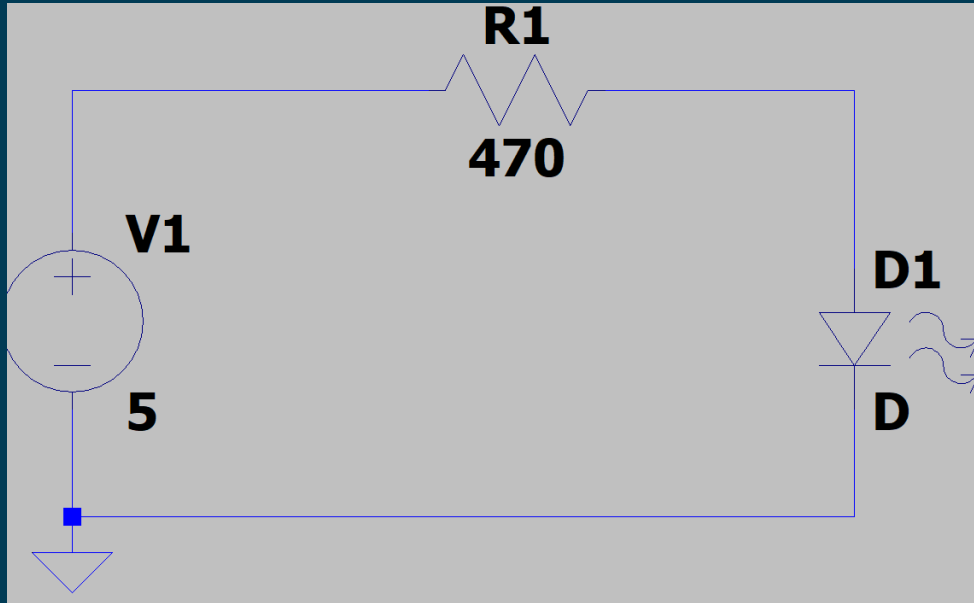
An LED is a diode!



- LED – Light Emitting Diode
- LED - a semiconductor light source that emits light when current flows through it.
- Electrons in the semiconductor recombine with holes, releasing energy in the form of photons.

Activity: LED Circuit Activity

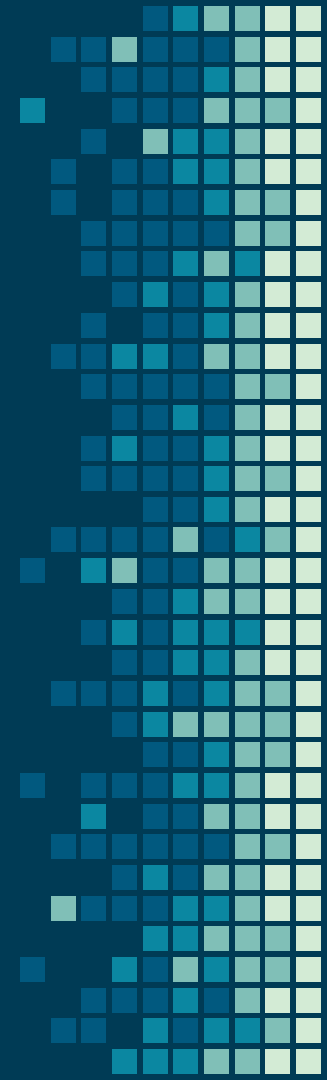
- What happens if you flip the polarity?
- Why do we need the resistor? What happens if you remove it?



Diode Uses

- Voltage regulation
- Voltage rectification
- Surge protection
- Voltage blocking or reverse voltage protection
- Producing light
- Oscillation generators

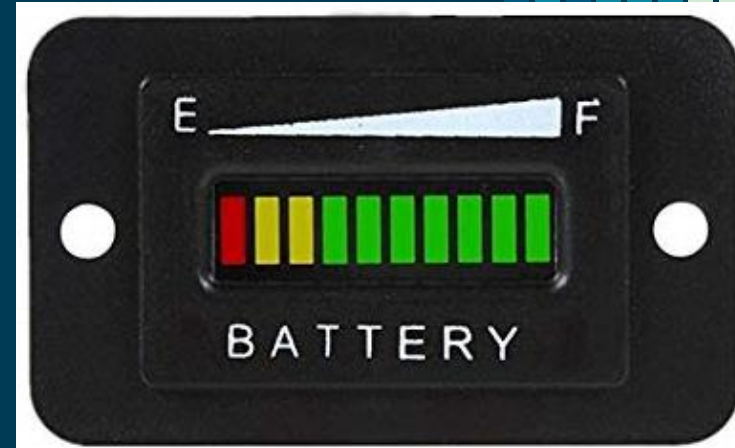
PRACTICE PROBLEMS



ACTIVITIES

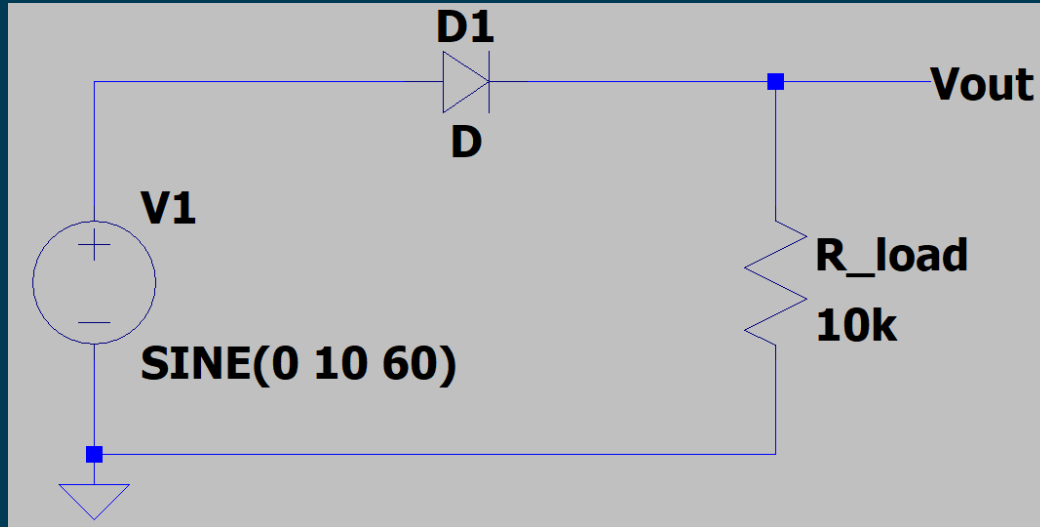
Activity: Battery Indicator Circuit

- We want to design a circuit that turns on 5 LEDs based on the voltage level.
 - 1 Green LED for high
 - 2 Yellow LEDs for medium
 - 2 Red LEDs for low
- If it is at the full 12 V, all LEDs should be on.
- Do not turn it up past 12 V !



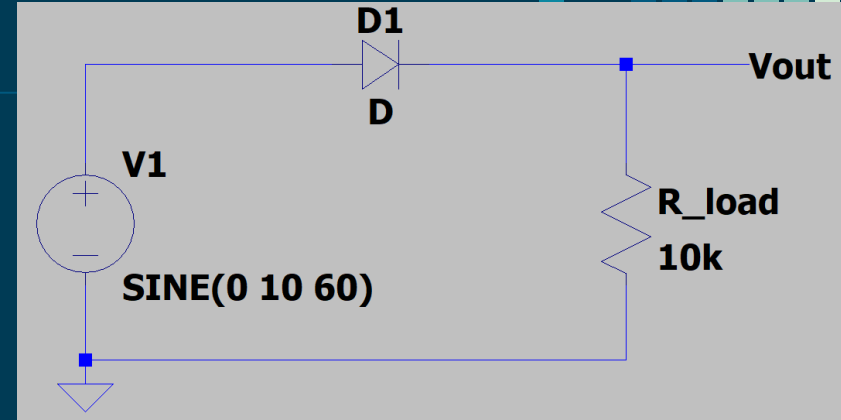
Activity: Diode Rectifier

- What does the output voltage V_{out} look like if the input voltage is an AC sinusoidal signal?
- What does it look like if the diode is reversed?

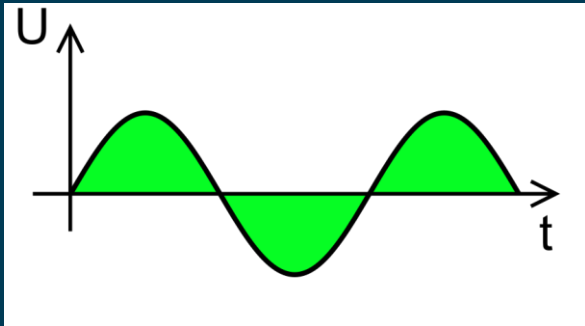


Activity: Diode Rectifier

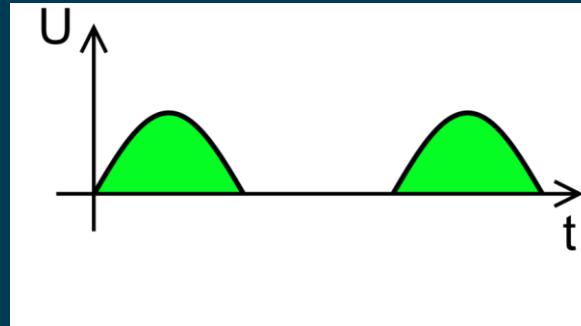
- This circuit is what is called a half-wave rectifier.



Input



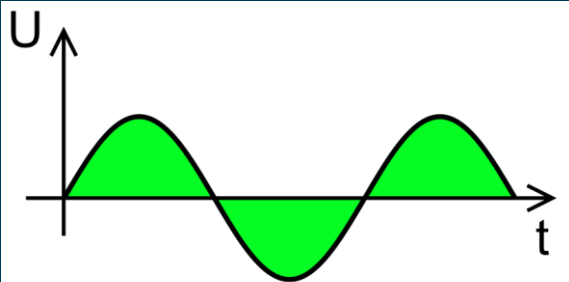
Output



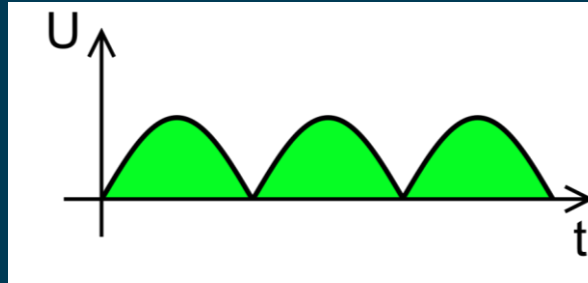
Activity: Rectifying AC to DC

- How could we make a DC voltage out of an AC sinusoidal signal using 4 diodes and a capacitor?
- After the 4 diodes, voltage waveform should look like the output waveform on the bottom right.
- The capacitor is added to smooth the output voltage.

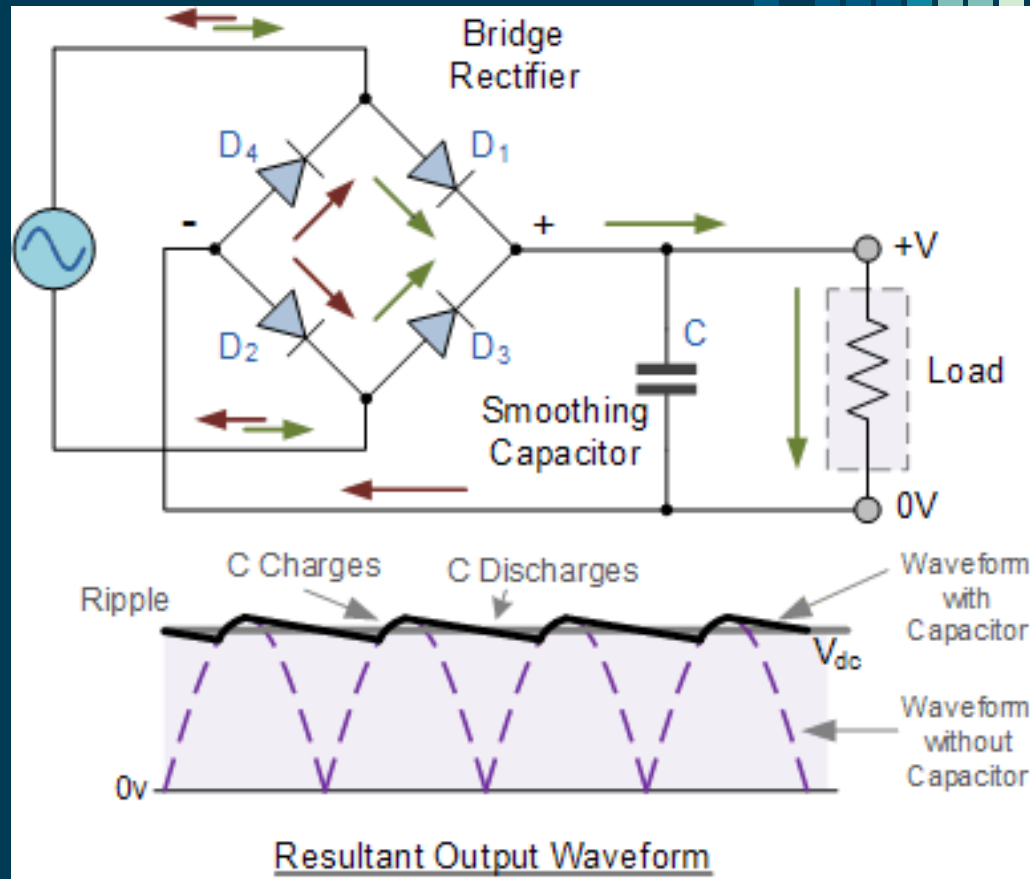
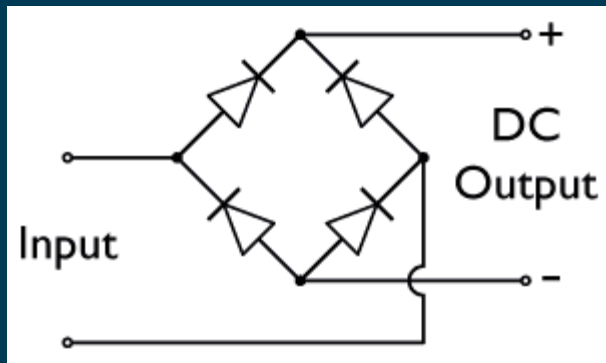
Input



Output

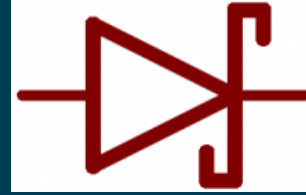


Full Bridge Rectifier



ZENER DIODES

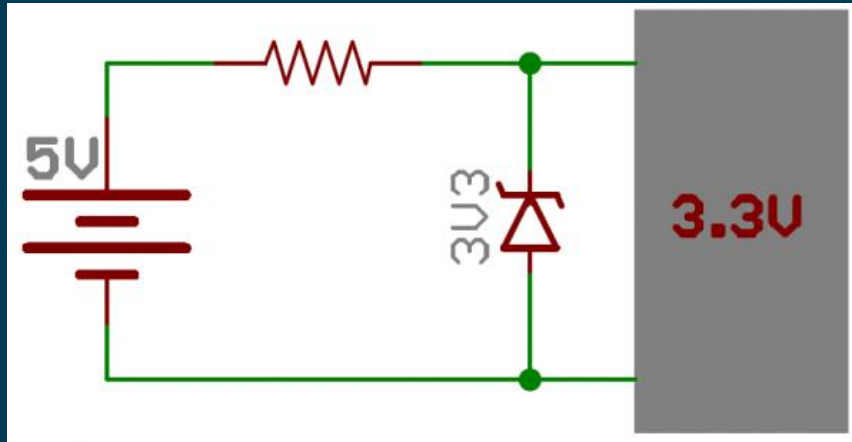
Zener Diodes



- They're usually used to intentionally conduct reverse current.
- We reverse bias them instead of forward biasing.
- Zener's are designed to have a very precise breakdown voltage, called the zener breakdown or zener voltage.
- When enough current runs in reverse through the zener, the voltage drop across it will hold steady at the breakdown voltage.

Zener Circuit Applications

- Taking advantage of their breakdown property, Zener diodes are often used to create a known reference voltage at exactly their Zener voltage.
- They can be used as a voltage regulator for small loads, but they're not really made to regulate voltage to circuits that will pull significant amounts of current.



MORE ACTIVITIES

Activity: Flyback Diode

- We discussed flyback diodes.
- Supply 3V to DC motor and measure voltage across.
- Switch off the DC supply.
- How high does the reverse voltage get?

Designing a 4x4 LED Matrix

- How could we design a 4x4 LED Matrix so that we could individually turn on each LED with as few input voltage wires as possible?
- For example, we could wire them all up using 16 wires for positive voltage supply and 16 wires for our common ground connection. How could we reduce this number?

