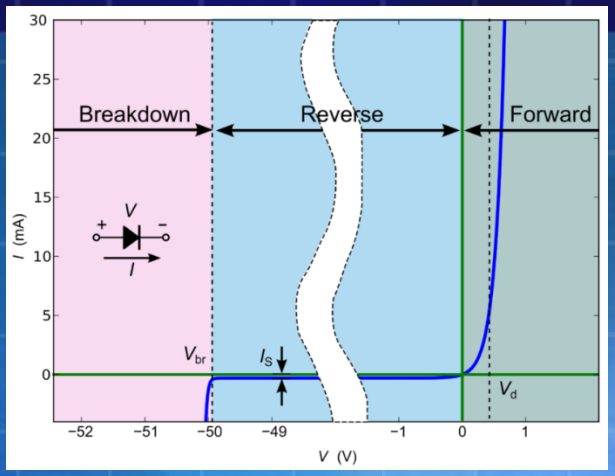
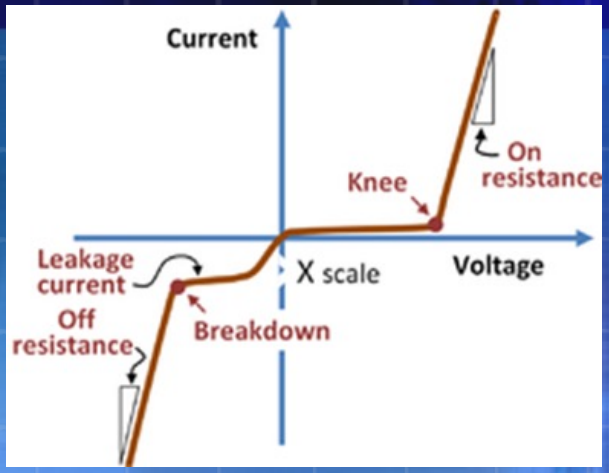



# Circuit Lab

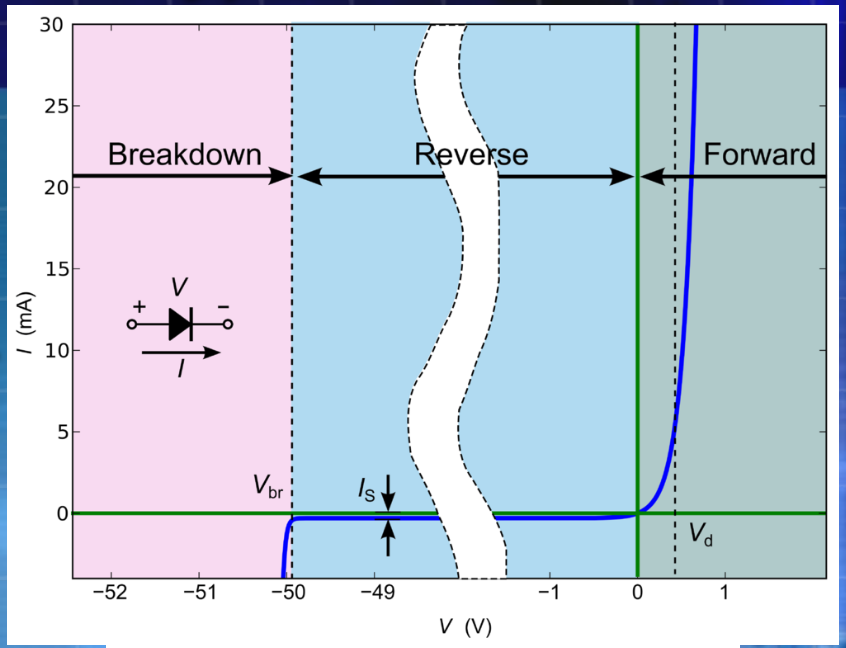
## Practice #14—PN Junctions

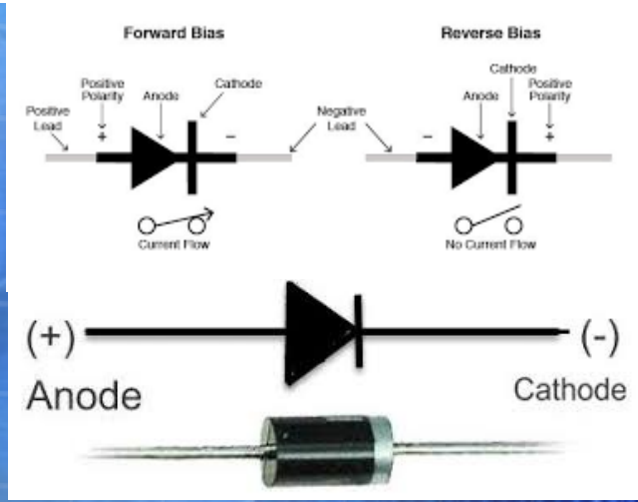
Mr. Burleson
geaux15@hotmail.com

# Diode
## (Division C Only)

- A diode is a two-terminal electronic component that conducts current primarily in one direction (asymmetric conductance); it has low (ideally zero) resistance in one direction, and high (ideally infinite) resistance in the other
- Ideally can be replaced with
  - A short (0Ω) when forward biased or closed switch
  - An open (∞Ω) when reverse biased or open switch
- When forward biased has a small resistance and a bias depending upon semiconductor material
  - 0.6-0.7V for Si Diodes
  - 0.25 to 0.3V for Ge Diodes
  - LEDs can be as high as 4.0V

https://en.wikipedia.org/wiki/Diode

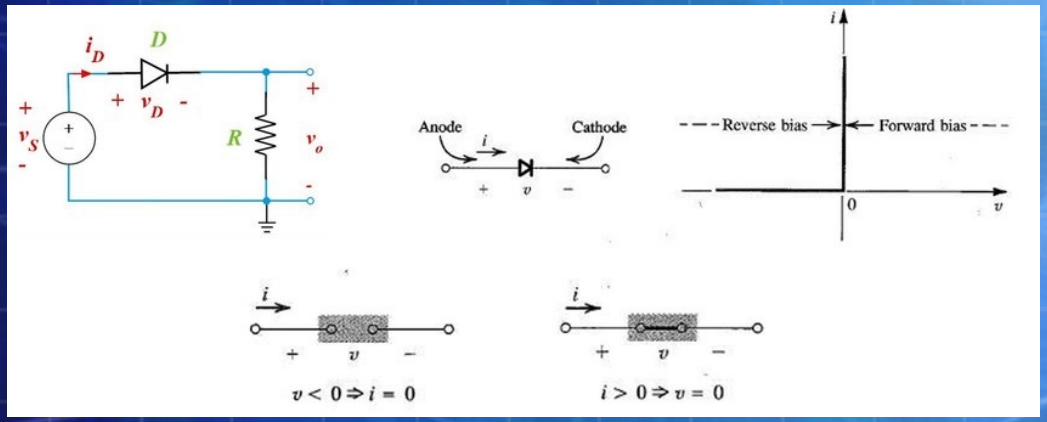


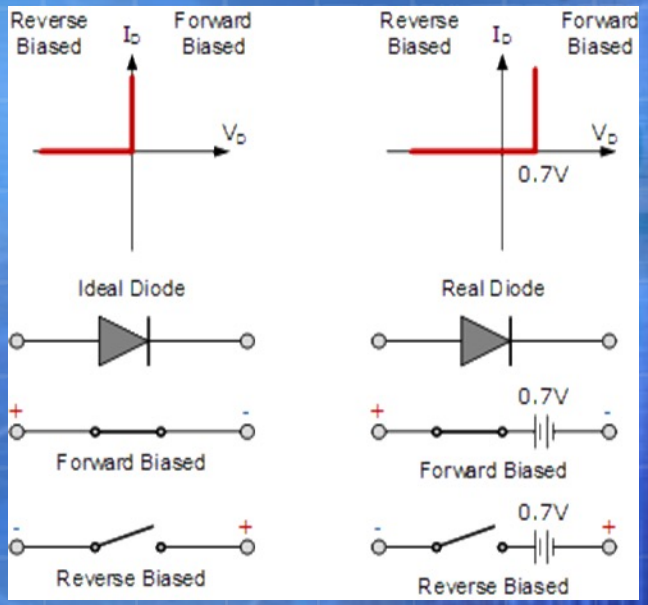



# Ideal Diode

- Ideal diode has zero resistance in Forward Bias with the forward bias voltage and infinite resistance in Reverse Bias.
- Note that normally they assume the bias voltage is for Si ~0.7V

- In Examples below:
  - If $v_S >= 0.7V$, then the diode is in forward bias, no resistance by still account for $v_D = 0.7V$, therefore $v_o = v_S - 0.7V$
  - If $v_s < 0.7V$, the diode is in reverse bias and can be treated as open

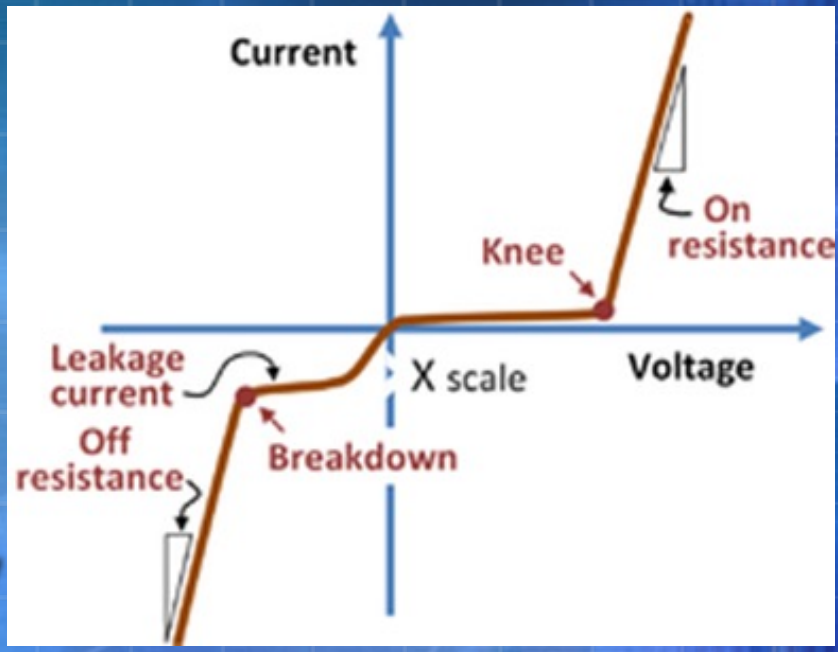



https://www.researchgate.net/figure/A-circuit-with-Ideal-Diode-its-i-v-characteristic-and-equivalent-circuits-in-the_fig12_316098112
https://www.electronics-tutorials.ws/diode/diode_3.html

# Linear Approximation to Non-Ideal Diode

- $V_D < V$ is Forward Biased and has a small "On" Resistance
- $0 < V < V_D$ is off with very little current
- $-V_Z < V < 0$ is off with very little Leakage current
- $V < -V_Z$ is in Zener or Avalanche Reverse Bias mode and has a very small "Off" Resistance

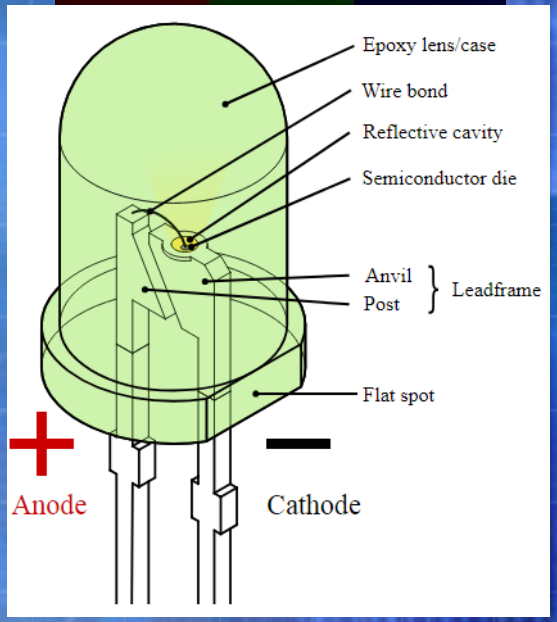


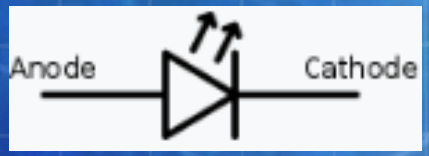

https://en.wikipedia.org/wiki/P%E2%80%93n_diode

# Light Emitting Diodes (LEDs)

Exploring the World of Science

- A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p–n junction diode that emits light when activated
- Color is determined by the energy band gap of the semiconductor, which also affects the voltage drop
  - Full table has been put in the Homework Generator, LED Datasheet tab
  - https://en.wikipedia.org/wiki/Light-emitting_diode#cite_note-79

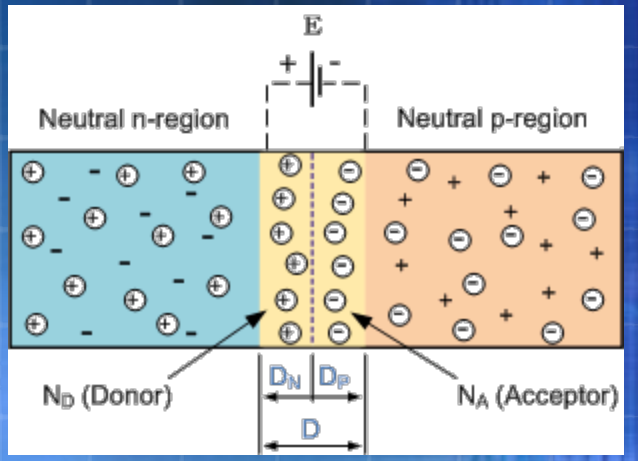


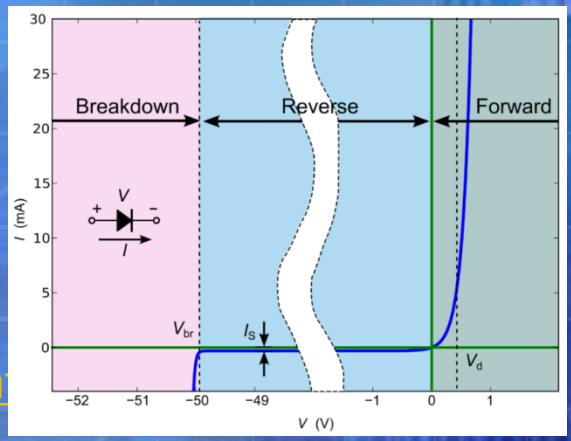




https://en.wikipedia.org/wiki/Light-emitting_diode

# PN Junctions

- A p–n junction is a boundary or interface between two types of semiconductor materials, p-type and n-type, inside a single crystal of semiconductor
  - P (positive) side contains an excess of holes, free positive charges in the outer shells of the doped atoms
  - N (negative) side contains an excess of electrons, free negative charges in the outer shells of the doped atoms
- This allows electrical current to pass through the junction only in one direction—a diode

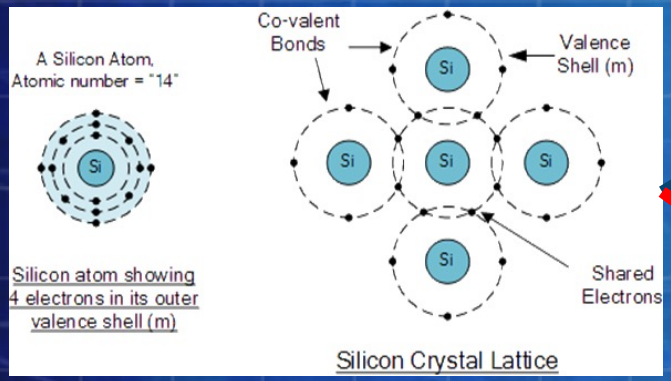



http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjun.h
https://www.electronics-tutorials.ws/diode/diode_1.html
https://en.wikipedia.org/wiki/P%E2%80%93n_junction

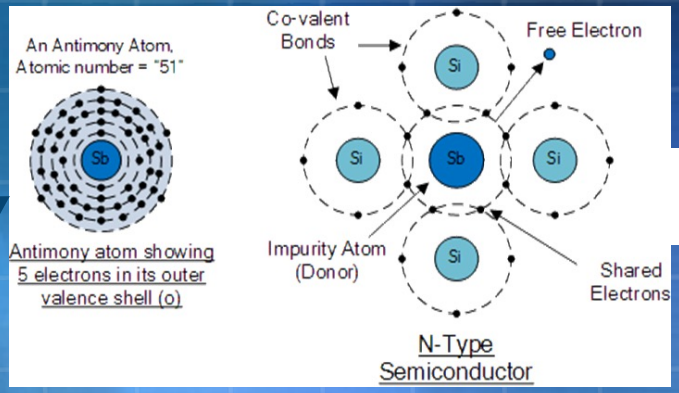
# Semiconductor Doping

- Semiconductors can be doped with different materials to provide excess holes (positive charges) or electrons (negative charges)



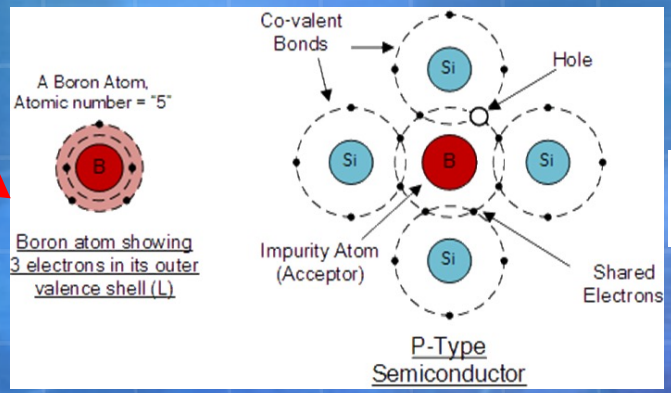

**Neutral Silicon Semiconductor**

**Antimony (n) doping**




**n-Type Silicon Semiconductor**

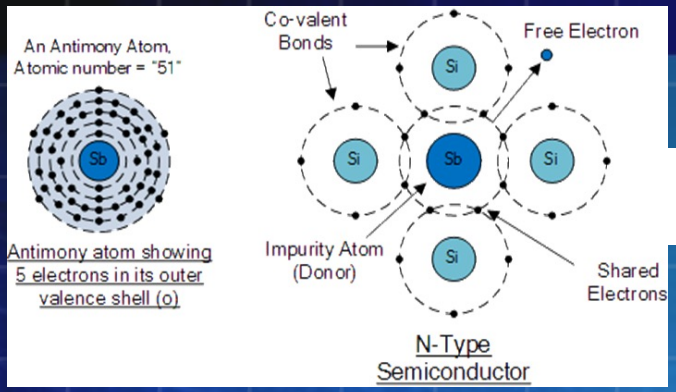
**Boron (p) doping**



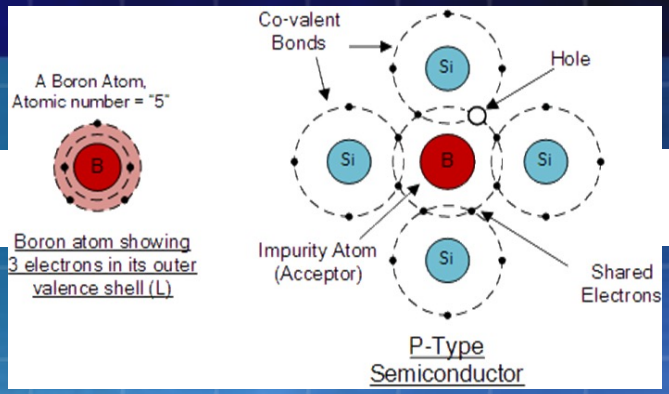

**p-Type Silicon Semiconductor**

http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjun.html
https://www.electronics-tutorials.ws/diode/diode_1.html
https://en.wikipedia.org/wiki/P%E2%80%93n_junction

# N-Type and P-Type




**n-Type Silicon Semiconductor**




**p-Type Silicon Semiconductor**

- The Donors are positively charged.
- There are a large number of free electrons.
- A small number of holes in relation to the number of free electrons.
- Positively charged donors.
- Negatively charged free electrons.
- Supply of energy gives:
  - Negatively charged free electrons
  - Positively charged holes

- The Acceptors are negatively charged.
- There are a large number of holes
- A small number of free electrons in relation to the number of free electrons.
- Negatively charged acceptors.
- Positively charged holes
- Supply of energy gives:
  - Positively charged holes
  - Negatively charged free electrons

http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjun.html
https://www.electronics-tutorials.ws/diode/diode_1.html
https://en.wikipedia.org/wiki/P%E2%80%93n_junction

# What to use for doping?

- Single semiconductors come from Group 14 of the Periodic Table (Si, Ge, C)
- P-Type doping usually comes from Group 13—one less electron
- N-Type doping usually comes from Group 15—one extra electron
- GaAs is a semiconductor as well (notice how they cancel out)

p-Type doping | Neutral Semiconductor | n-Type doping

Periodic Table of Semiconductors

| Elements Group 13 | Elements Group 14 | Elements Group 15 |
|---|---|---|
| 3-Electrons in Outer Shell (Positively Charged) | 4-Electrons in Outer Shell (Neutrally Charged) | 5-Electrons in Outer Shell (Negatively Charged) |
| (5) Boron ( B ) | (6) Carbon ( C ) | |
| (13) Aluminium ( Al ) | (14) Silicon ( Si ) | (15) Phosphorus ( P ) |
| (31) Gallium ( Ga ) | (32) Germanium ( Ge ) | (33) Arsenic ( As ) |
| | | (51) Antimony ( Sb ) |

https://www.electronics-tutorials.ws/diode/diode_1.html

# PN Junctions

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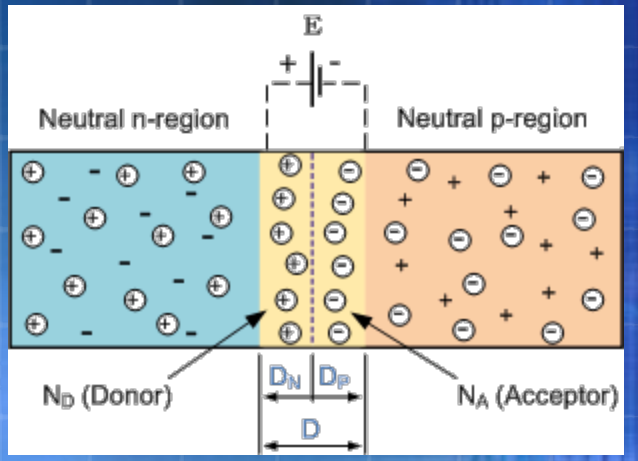


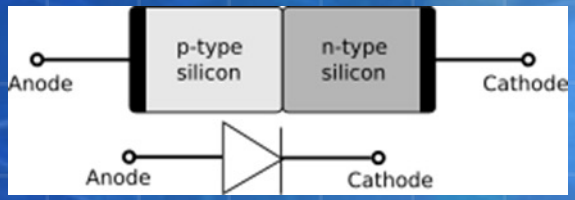


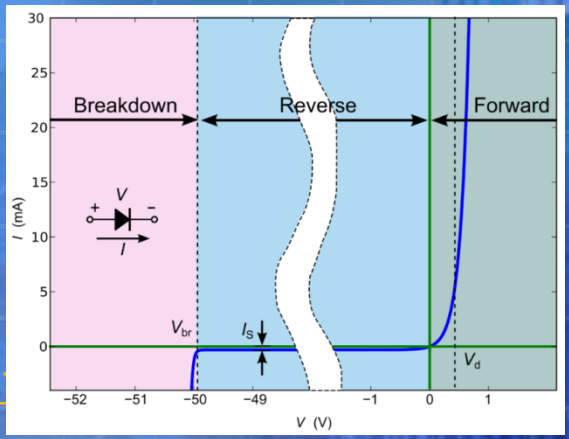


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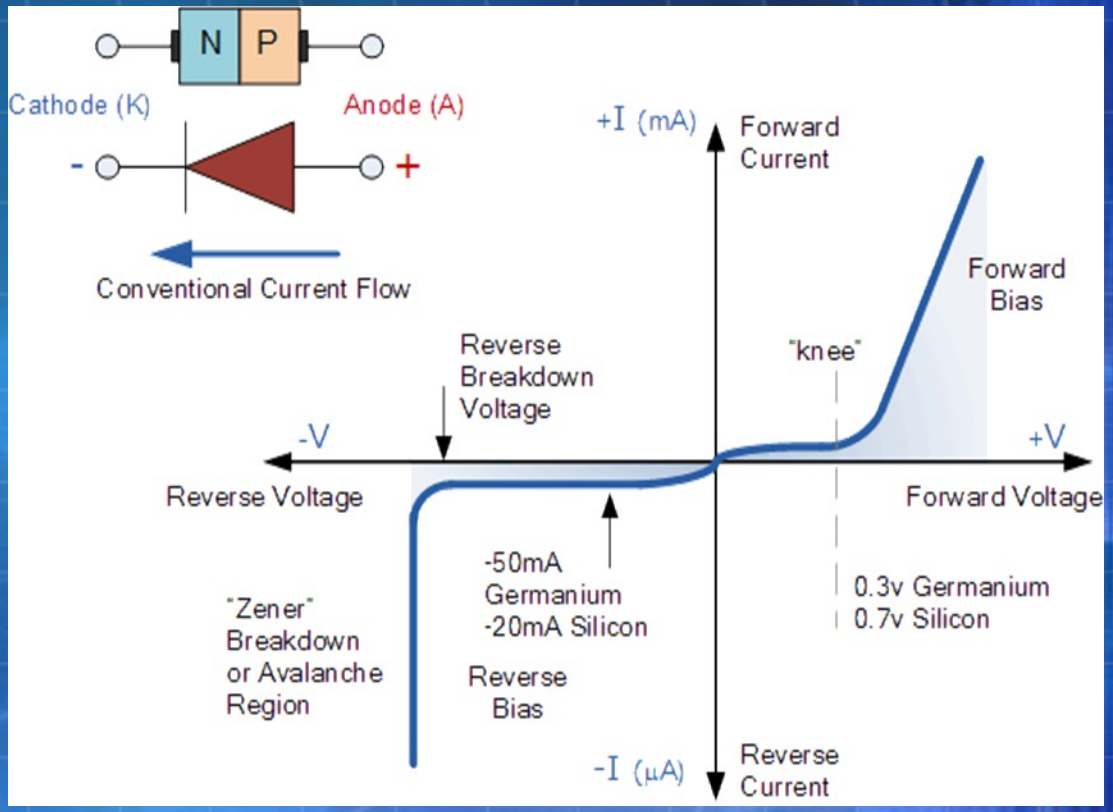
https://www.electronics-tutorials.ws/diode/diode_1.html
https://en.wikipedia.org/wiki/P%E2%80%93n_junction

# PN Junctions I-V Characteristics

- A p–n junction or junction diode usually allows current through in two main modes
  - Forward Bias (or on) with relatively low resistance, but a forward bias voltage occurs above the Forward Bias voltage (0.3V for Ge and 0.7V for Si)
  - Reverse Bias (or off) with very little current/high impedance below the Forward bias voltage up to the Reverse Breakdown Voltage
- Below the Reverse Breakdown Voltage the current avalanches through the PN junction and we have a Zener Breakdown or Avalanche current with very high reverse current
  - Some diodes are specifically designed to operate in this region, others will be damaged

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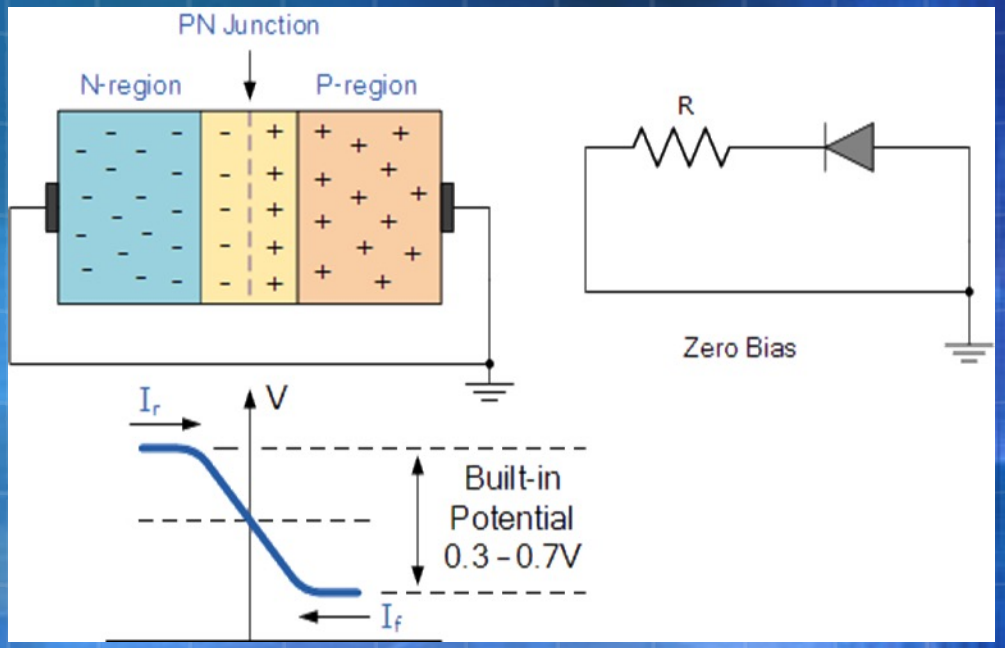
https://www.electronics-tutorials.ws/diode/diode_1.html
https://en.wikipedia.org/wiki/P%E2%80%93n_junction

# Zero Biased PN Junction

- A p–n junction with zero voltage has a built in potential (0.3V for Ge and 0.7V for Si).
  - At this point the diode is considered off
  - The area in between the n and p regions is called the depletion area
  - When the depletion area is large, no current can flow

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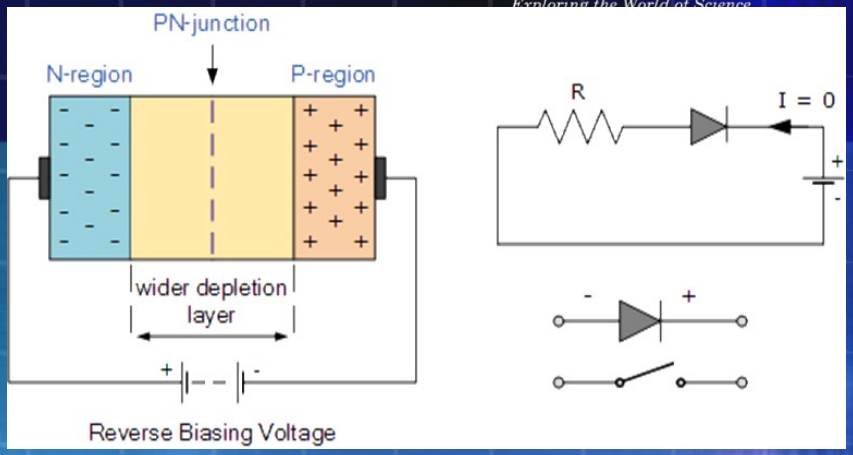
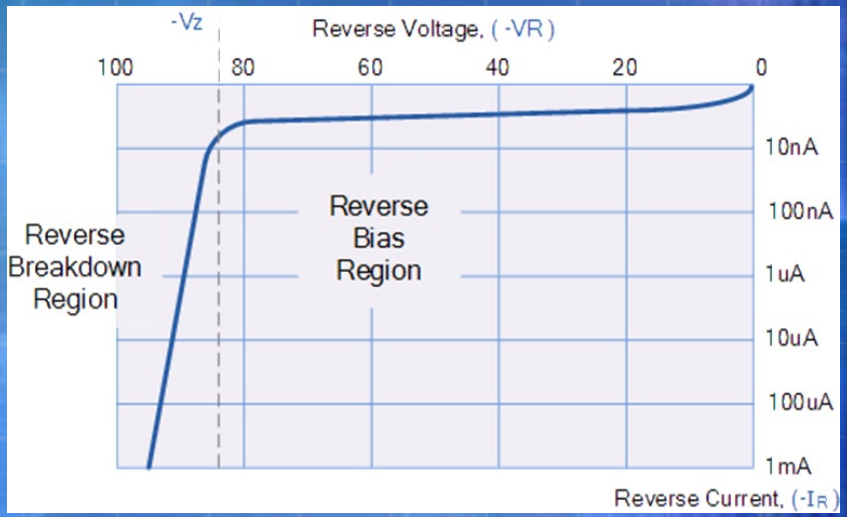
https://www.electronics-tutorials.ws/diode/diode_1.html
https://en.wikipedia.org/wiki/P%E2%80%93n_junction

# Reverse Biased PN Junction

- A p–n junction with a voltage below the Forward Bias voltage is called Reverse Biased.
  - At this point the diode is considered off
  - The area in between the n and p regions is called the depletion area
  - In reverse bias, the depletion area is becomes larger and virtually no current can flow



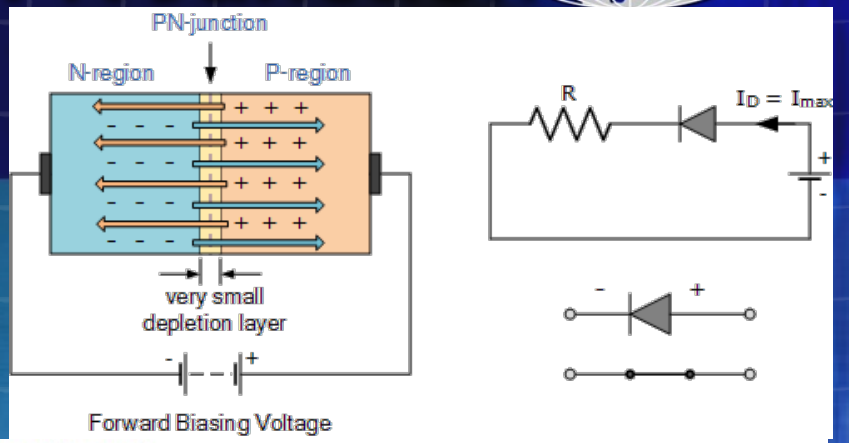



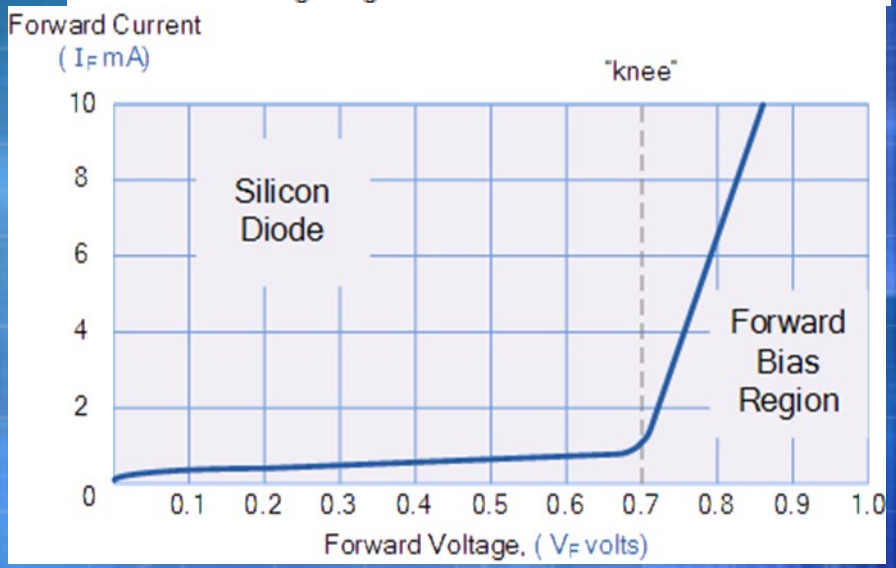

Note the current is a log scale and very low

http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjun.html
https://www.electronics-tutorials.ws/diode/diode_1.html
https://en.wikipedia.org/wiki/P%E2%80%93n_junction

# Forward Biased PN Junction

- A p–n junction with a voltage at or above the Forward Bias voltage is called Forward Biased.
  - At this point the diode is considered on
  - The area in between the n and p regions is called the depletion area
  - In forward bias, the depletion area is very small and current can flow with very little impedance



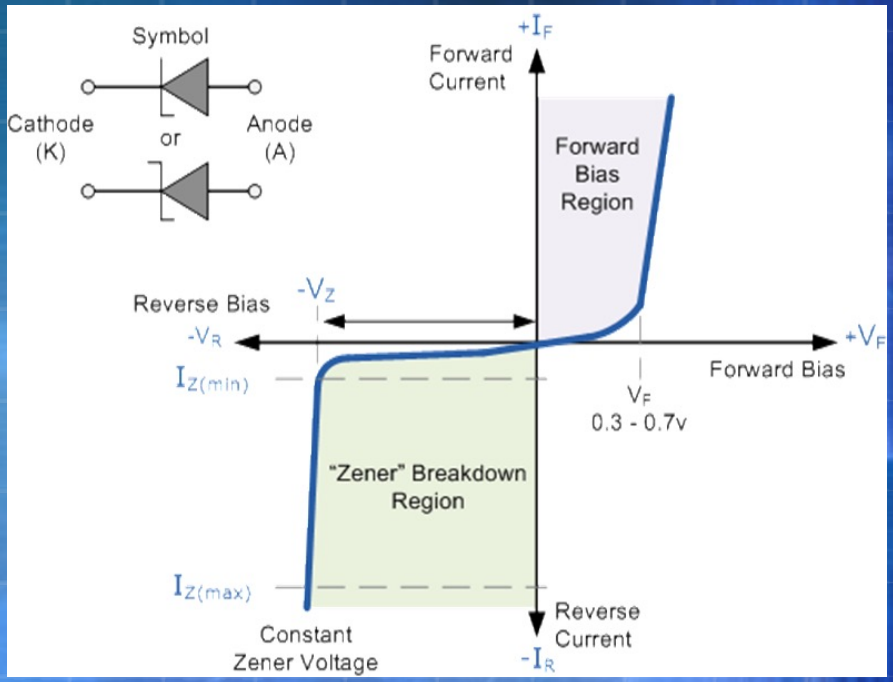




Note the current is linear scale and much higher

http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjun.html
https://www.electronics-tutorials.ws/diode/diode_1.html
https://en.wikipedia.org/wiki/P%E2%80%93n_junction

# Reverse Breakdown Biased PN Junction

- Zener Diode or "Breakdown Diode" are basically the same as the standard PN junction diode but are designed to have a low and specified Reverse Breakdown Voltage which takes advantage of any reverse voltage applied to it.
  - You use these to enter the Breakdown or Zener region to get very low impedance (all voltages below $-V_z$ or Zener Breakdown Voltage)




Note the "on" is now at negative Vz or lower

http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/pnjun.html
https://www.electronics-tutorials.ws/diode/diode_1.html
https://en.wikipedia.org/wiki/P%E2%80%93n_junction

# Homework

- Update your binder to get it competition ready
- Design a circuit using an ideal diode ($V_D$=0.7V) that has an input voltage and the output voltage will be the input voltage when above 3V and near zero when below 3V. Assume idea components.
- Research semiconductor Band Diagrams (or Band Bending Diagrams). For a PN junction diode, show how they work during zero bias, forward bias, reverse bias, and reverse breakdown voltages.
- Update your binder with listings of common diodes and their properties, including Zener Diodes.