SEMICONDUCTORS

Prof. Abidi's Excellent Lecture
at
Lahore University of Management Sciences
https://www.youtube.com/watch?v=KqIOGGjPFQU

>58,000 views!

Semiconductors

- We have talked about
  - Conductors
  - Insulators
- Now we will be talking about something in between
  - Neither conductor nor insulator
  - But can be made to conduct rather well
  - And can be configured to be an excellent insulator

Semiconductors & Dopants

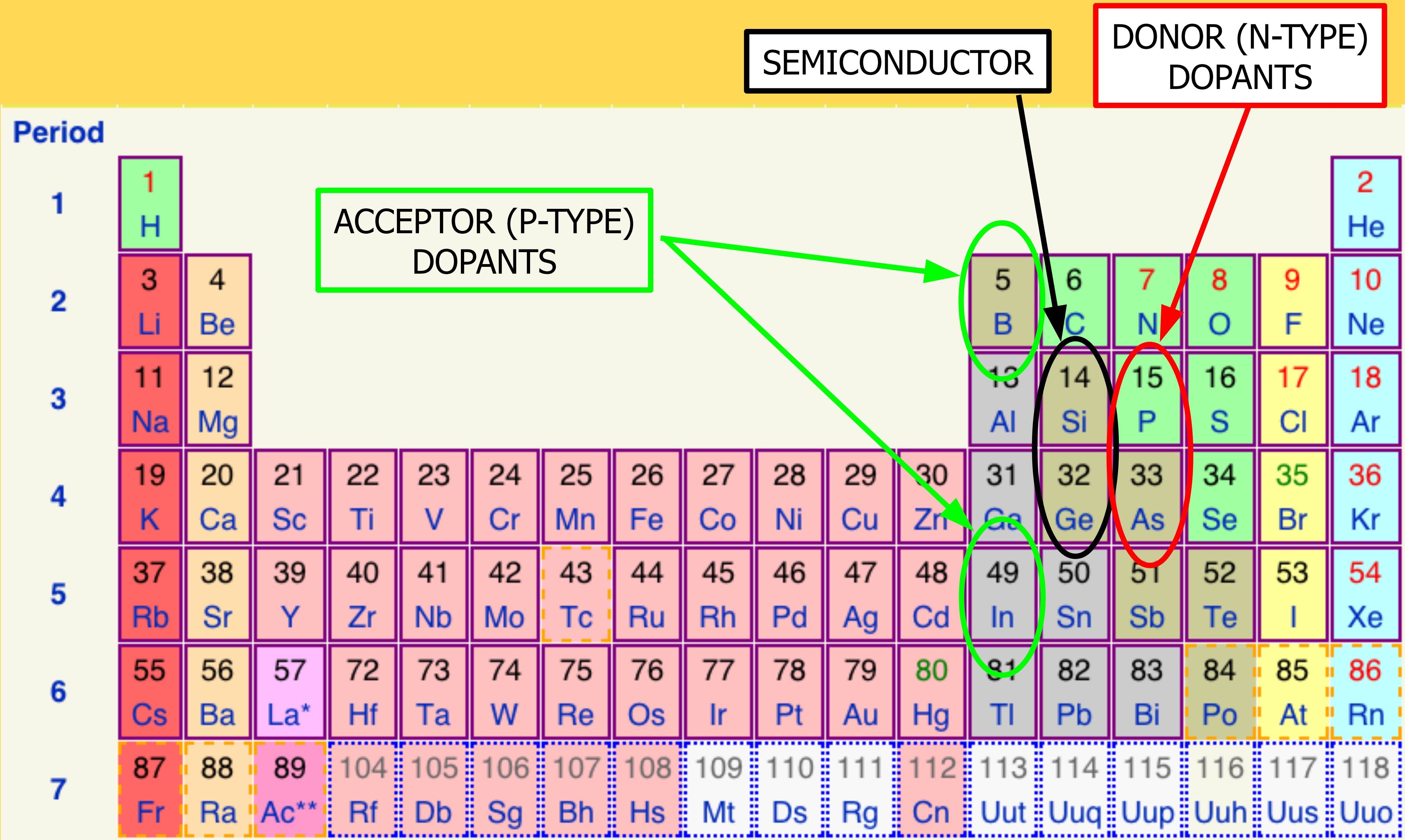


IMAGE SOURCE: Wikipedia

Intrinsic Silicon

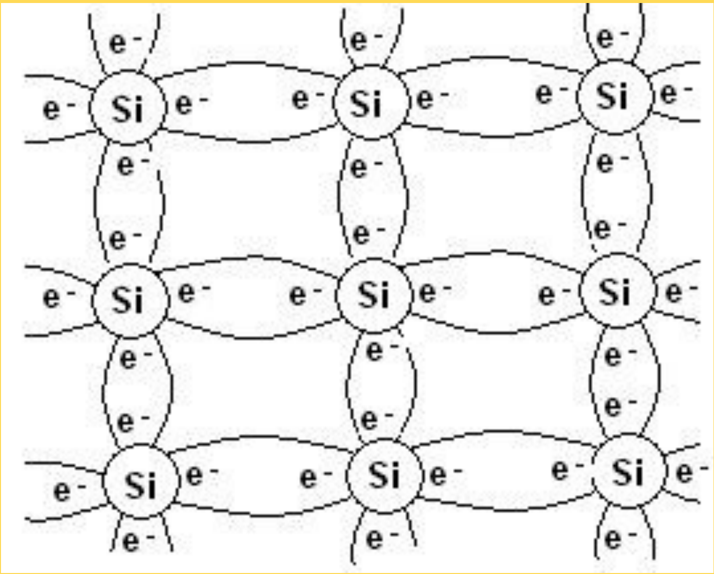


IMAGE SOURCE: http://www.exploreroots.com/a3.html

Donor

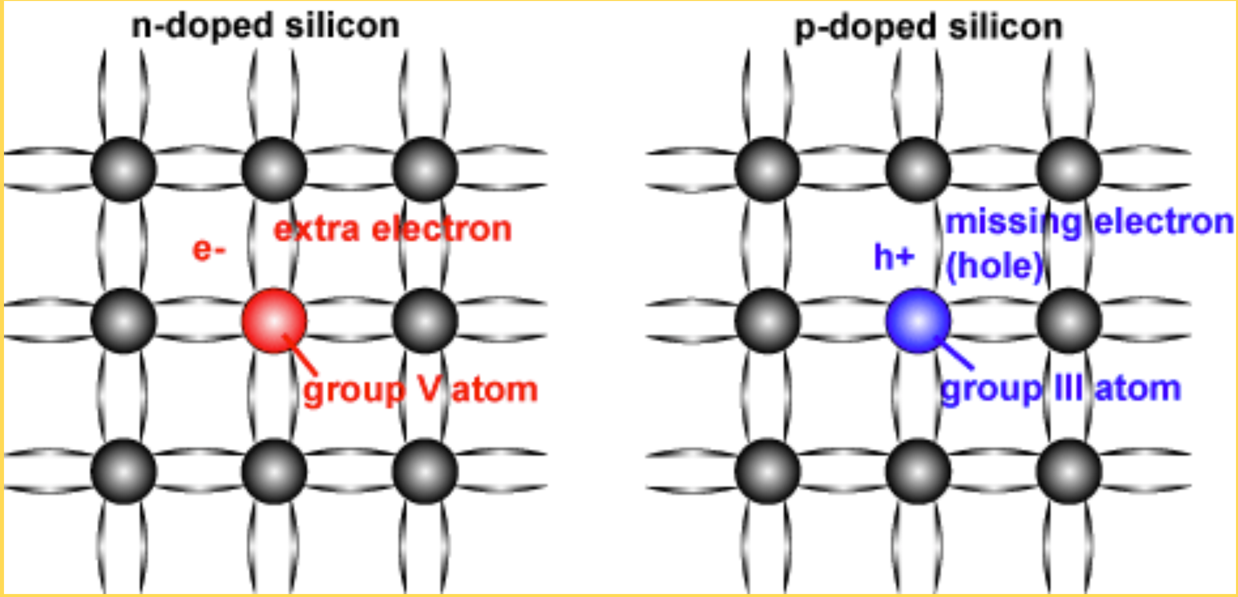


IMAGE SOURCE: http://www.globalspec.com/learnmore/passive_discrete_devices/diodes/general_purpose_diodes

DONOR
(gives an electron;
net positive in crystal)

ACCEPTOR
(takes an electron;
net negative in crystal)

WHY? EXTRA PROTON!

NOTE: due to thermal energy, there are also a few holes in n-type material, and electrons in p-type material. They are called MINORITY CARRIERS.

Doping Summary

- Adding special impurities to an intrinsic semiconductor
  - P-type
    - Add Group III element (lacking one electron ⇒ extra hole)
    - Immobilized impurity becomes negative when electron arrives
    - Increases hole density (orders of magnitude higher)
  - N-type:
    - Add Group V element ⇒ extra electron
    - Immobilized impurity becomes positive when electron leaves
    - Increases electron density (orders of magnitude higher)

Doping Concentrations

LOG
SCALE

10^{22}: # Si atoms/cm^3

10^{20}

10^{15} — 10^{15}: light doping: impurity atoms (majority carriers)/cm^3

10^{10} — 10^{10}: n_i (# naturally-occurring electrons and holes, also # recombinations/cm^3 in intrinsic or pure Si @ room temperature)

10^5 — 10^5: # minority carriers/cm^3

Doping Has Large Impact

(doping 1 part in 10^7):

Intrinsic resistivity of Silicon (ρ_i): 2300 Ω – m

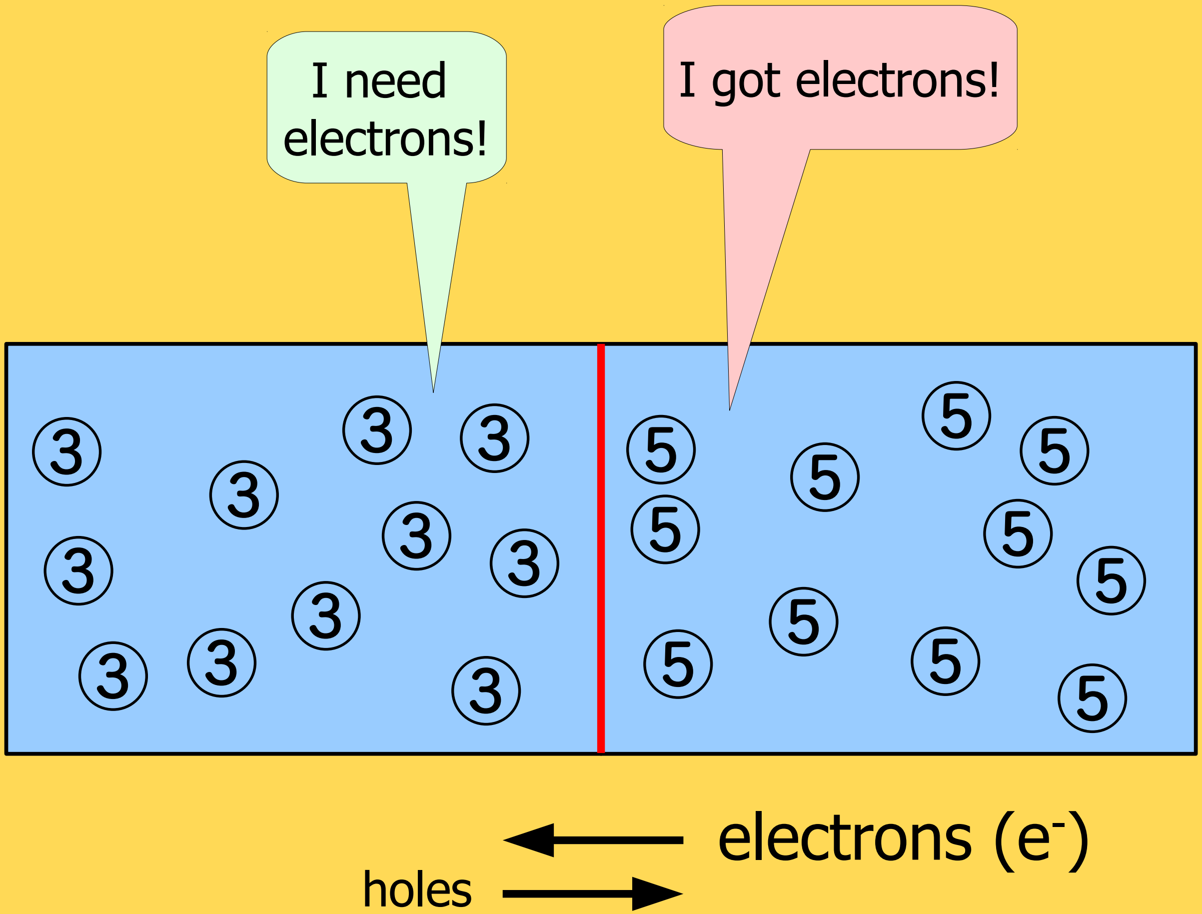
Doped resistivity of Silicon (ρ_p): 0.026 Ω – m

~ 5 orders of magnitude!

Carriers

	N-type	P-type
Electrons	MAJORITY	minority
Holes	minority	MAJORITY

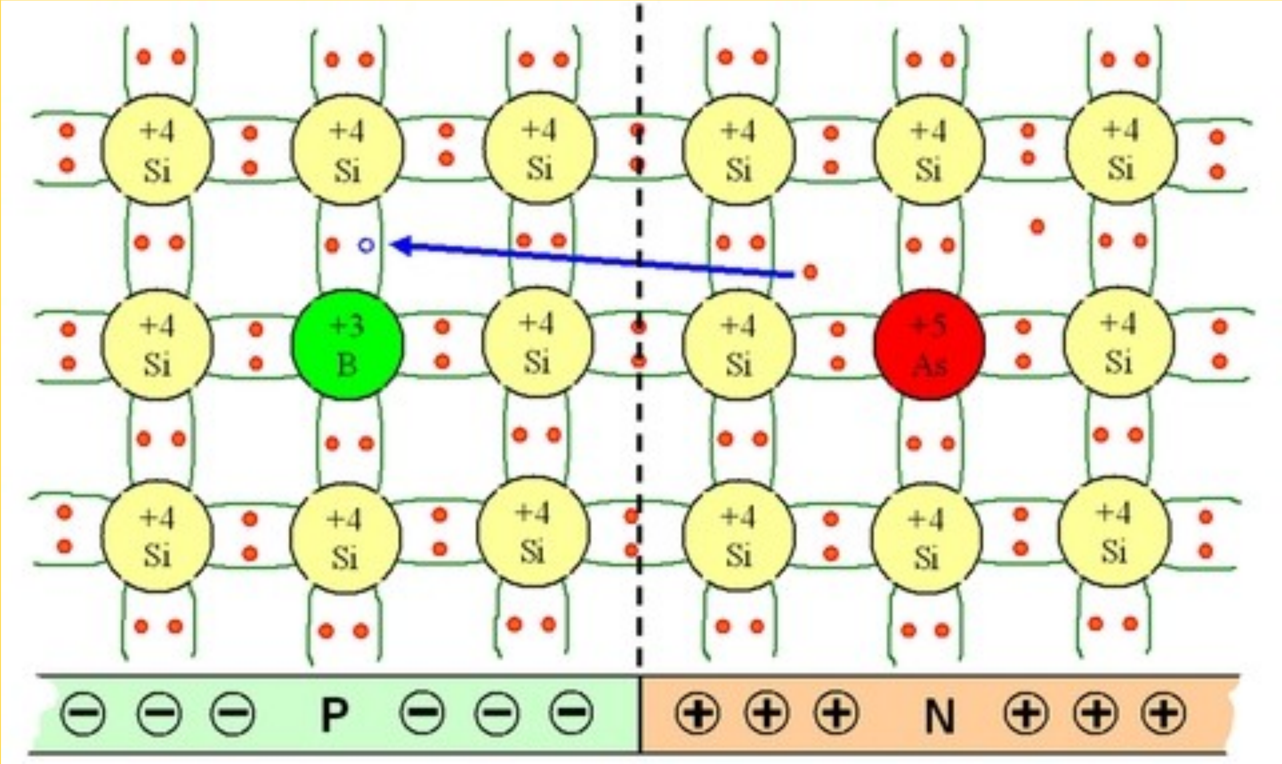
P-N Junction Marketing



Thermal energy causes <u>diffusion</u> (think gas laws).

So why don't we end up with an even distribution of electrons in the entire device?

Migration



SOURCE:http://www.optique-ingenieur.org/en/courses/OPI_ang_M05_C02/co/Contenu_05.html

An Electric Field Builds Up

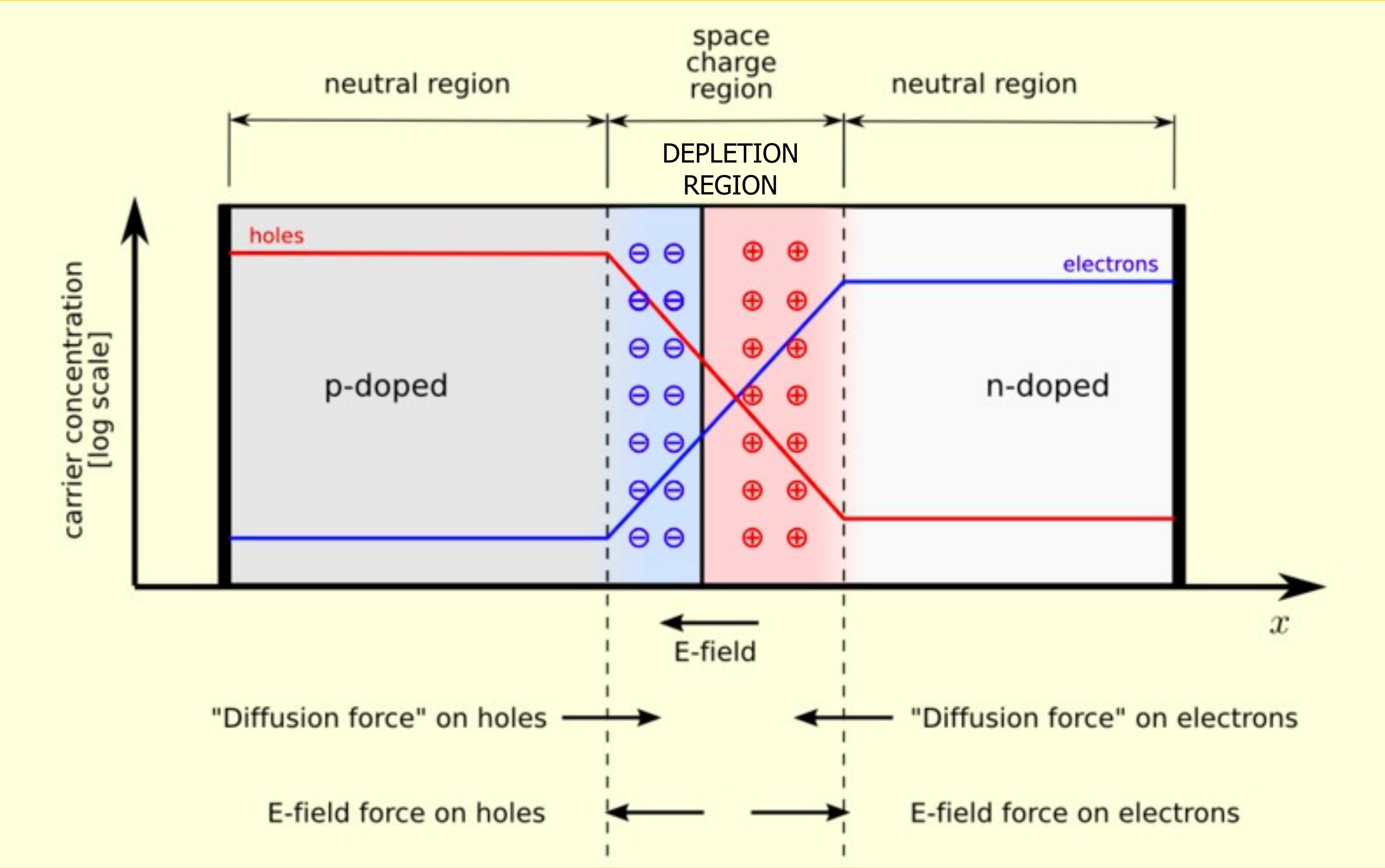
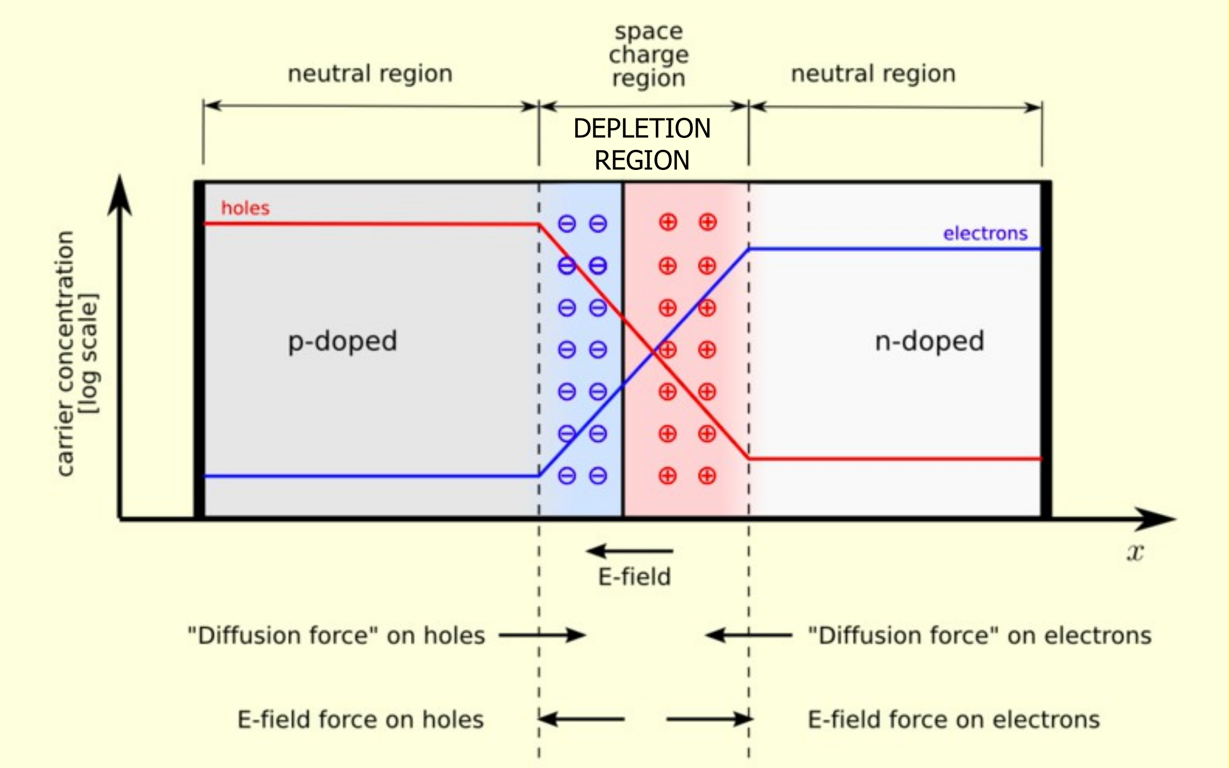


Image Source: Wikipedia

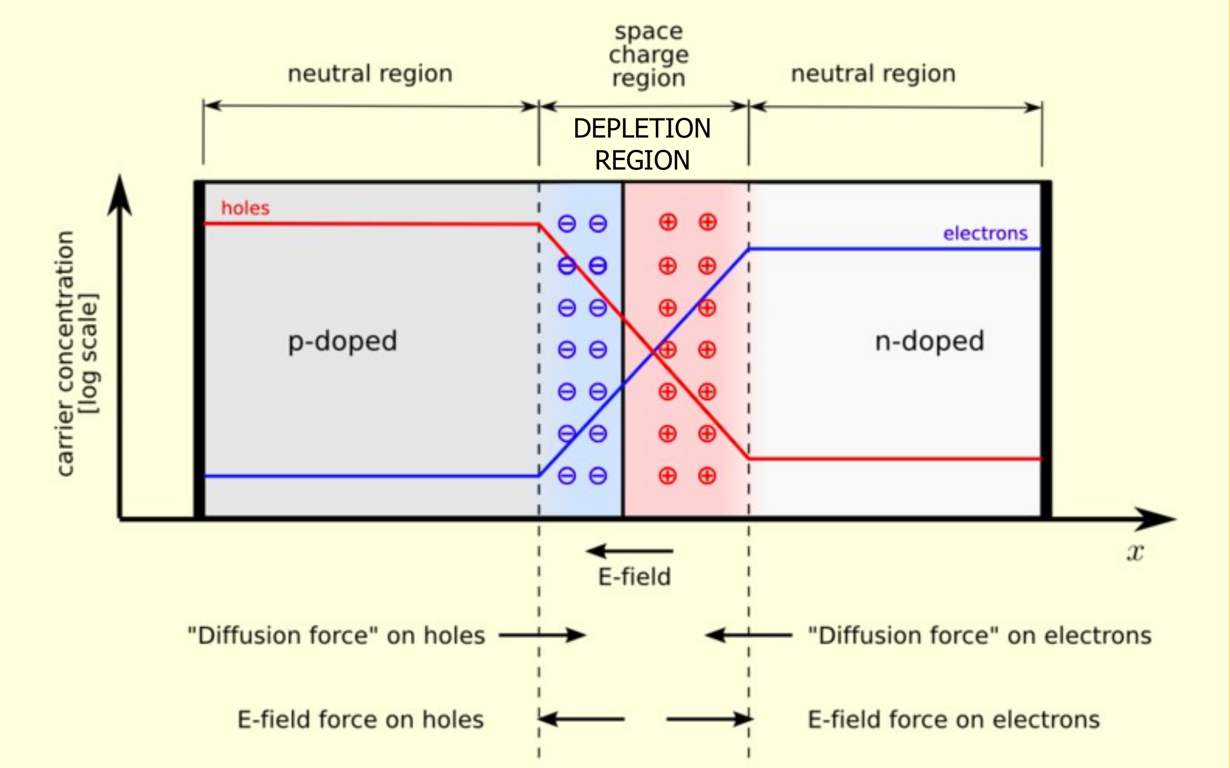
P-N Junction (Equilibrium)

- You get spontaneous diffusion
  - "Grass is greener" effect attracts carriers across P-N junction.
  - Recombination of carriers causes depletion region where carriers have migrated away



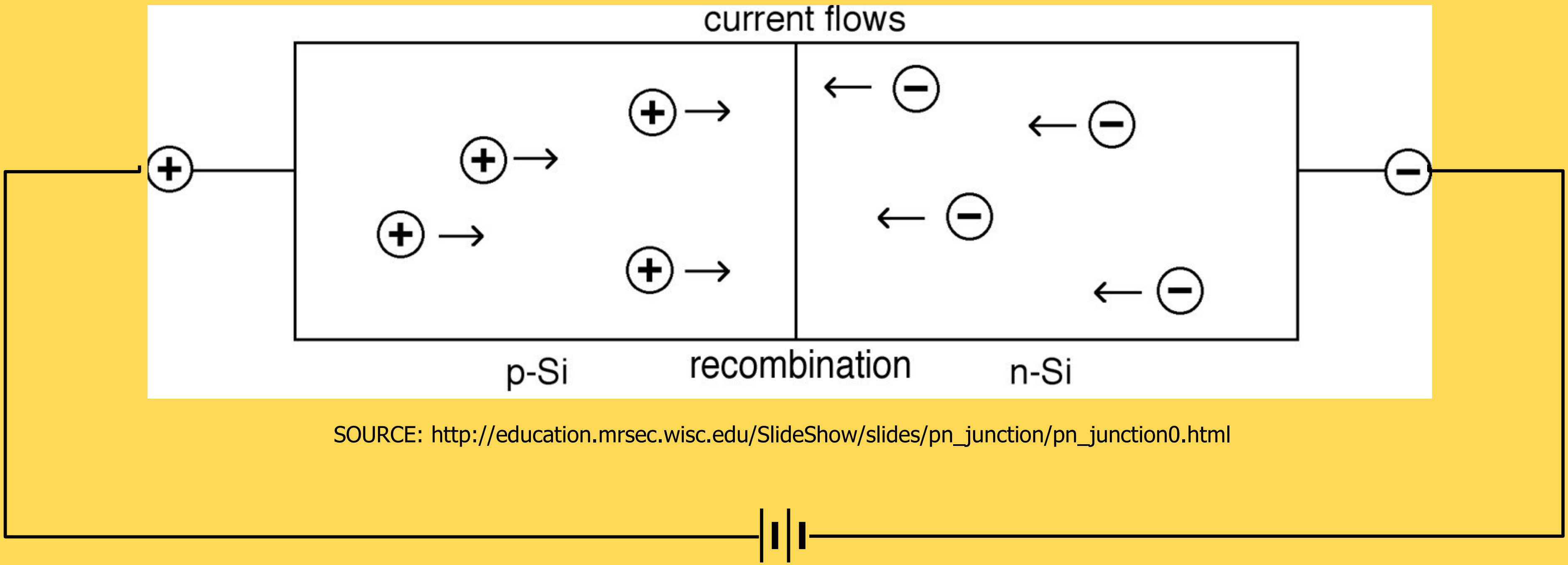
P-N Junction (Equilibrium)

- You get spontaneous diffusion
  - But diffusion stops when field created by immobile impurities opposes further carrier movement.
  - You essentially have a charged capacitor at the junction (very important in EE115A&B).
  - Built-in voltage: $V_{bi} \approx 0.9$ V



P-N Junction Forward Bias

- Apply a voltage to the ends of the P-N junction.
  - +V to P-type & -V to N-type: WE GET CURRENT!



SOURCE: http://education.mrsec.wisc.edu/SlideShow/slides/pn_junction/pn_junction0.html

P-N Junction Forward Bias

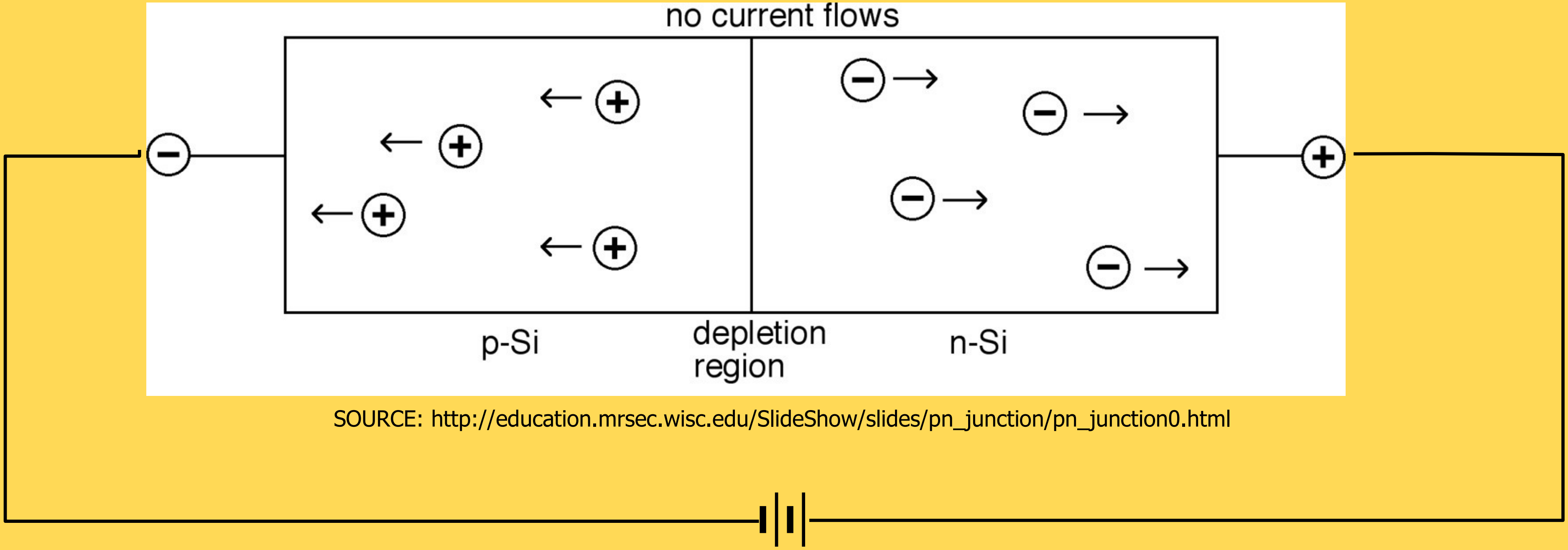
- +V at P-type repels holes toward junction.
- –V at N-type repels electrons toward junction.
- Both <u>narrow</u> the depletion region.
- Once the electrons are in the P-type material, they recombine with holes in the depletion region, lowering the E-field force.
- When the forward bias voltage is high enough, the E-field force is overcome, the resistance to carrier diffusion is greatly reduced, and <u>**current flows freely**</u>.

Favorite Question

- When forward-biased, we have holes moving and electrons moving. How do we combine the two?
  - (a) They cancel each other out.
  - (b) The holes don't count; it's all about electron flow.
  - (c) Since we are talking conventional current, the electrons don't count; it's all about the hole flow.
  - (d) They add.
- Answer: (d)

P-N Junction Reverse Bias

- Apply a voltage to the ends of the P-N junction.
  - –V to P-type & +V to N-type: NO CURRENT!



SOURCE: http://education.mrsec.wisc.edu/SlideShow/slides/pn_junction/pn_junction0.html

P-N Junction Reverse Bias

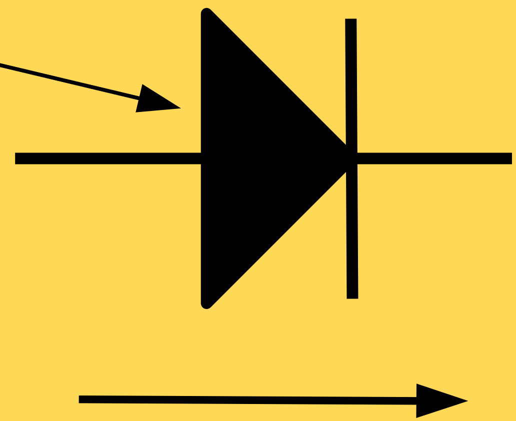
- –V at P-type attracts majority carriers (holes) away from junction.
- +V at N-type attracts majority carriers (electrons) away from junction.
- Depletion region E-field <u>widens</u>.
- Resistance increases.
- (Almost) <u>**no current flows**</u>.

P-N Junction Biasing Summary

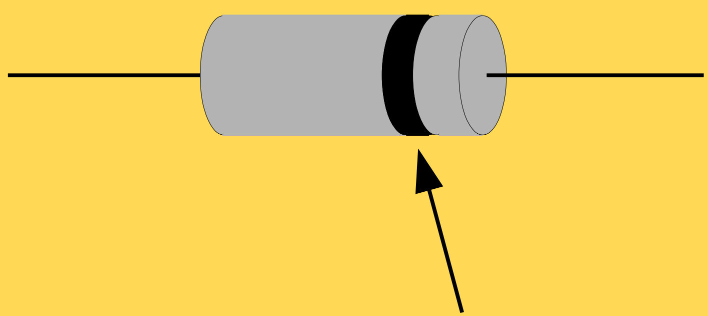
- Apply a voltage to the ends of the P-N junction.
  - +V to P-type & –V to N-type: current (forward bias)
  - –V to P-type & +V to N-type: no current (reverse bias)
- What we have here is a diode. It's a one-way valve, AKA check valve.

Diode Symbol

“Arrow” points in direction of conventional current



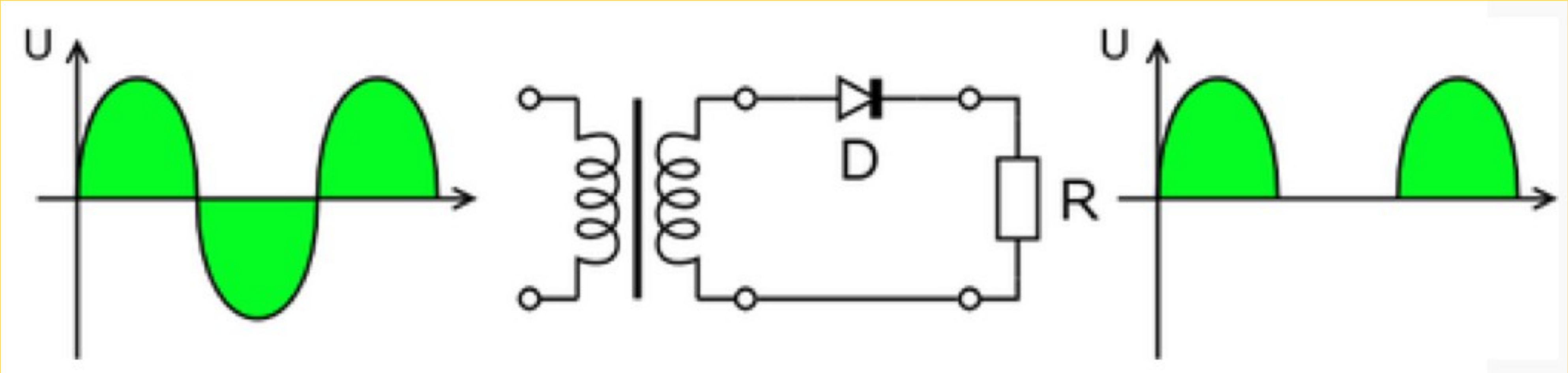
Direction of Conventional Current



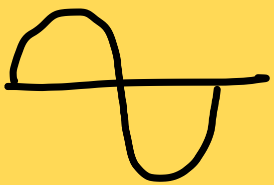
Band indicates cathode end

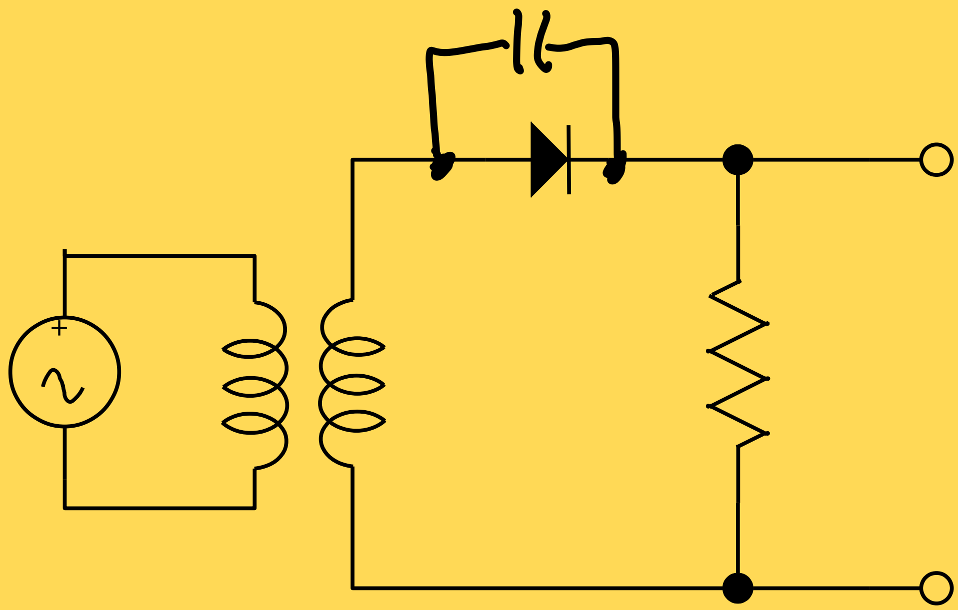
How to Use a Diode?

- In your wall wart!
- What we have in the wall: AC (sinusoidal).
- What we want for the computer: DC.
- We need to <u>rectify</u> the sine wave. Diodes do that.

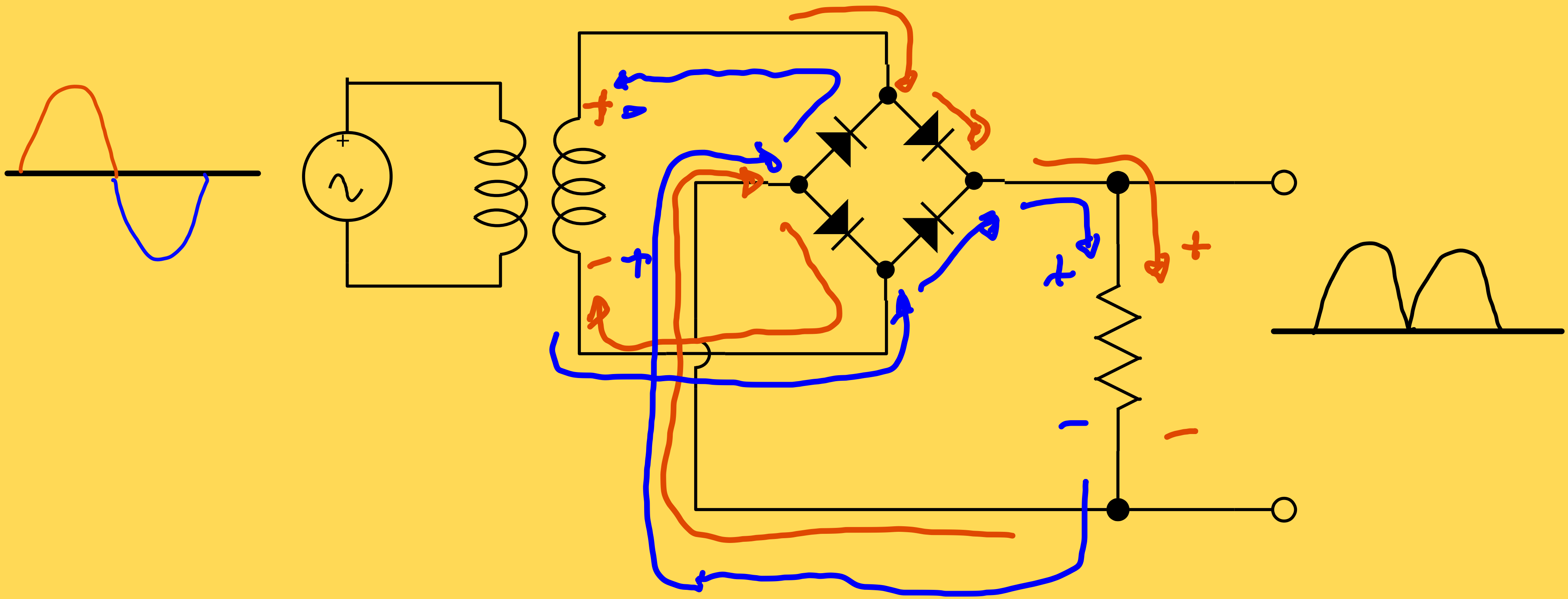


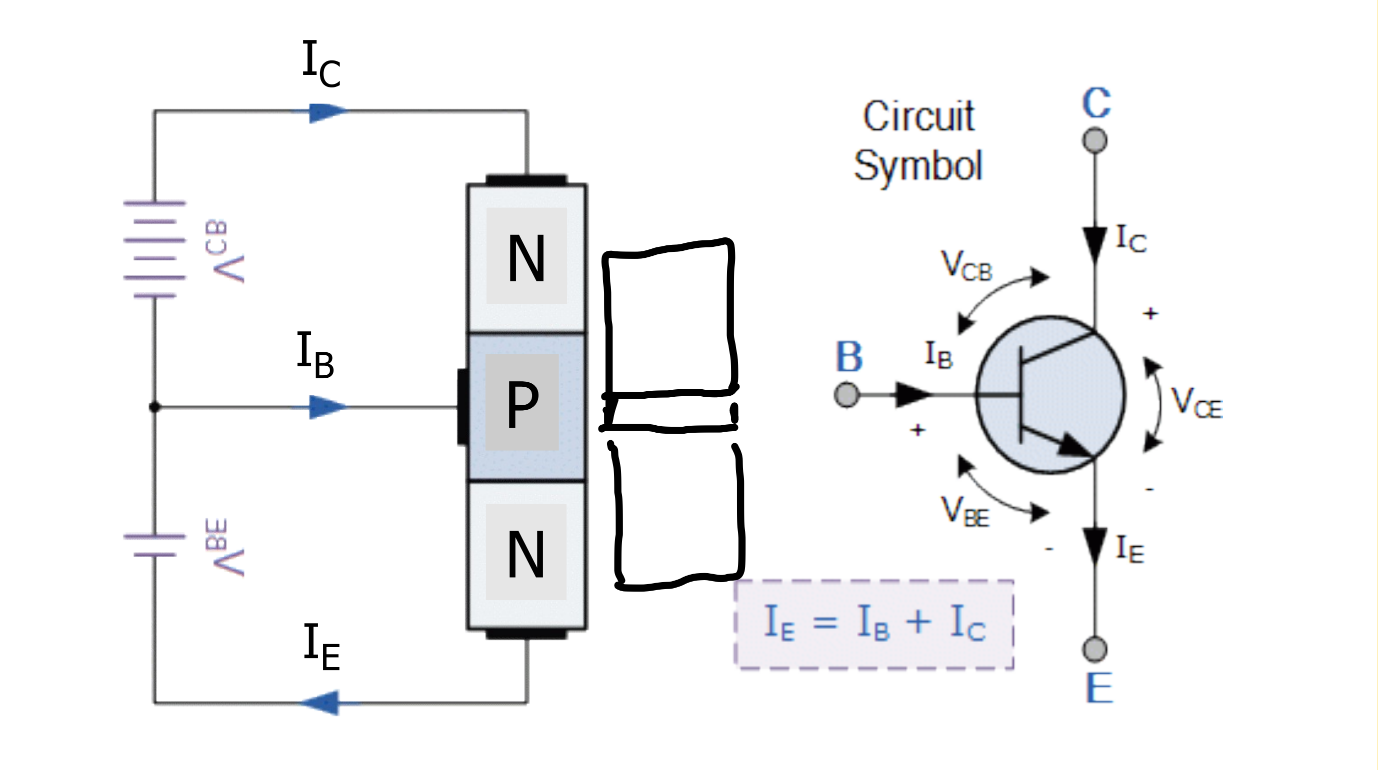
1N 4004





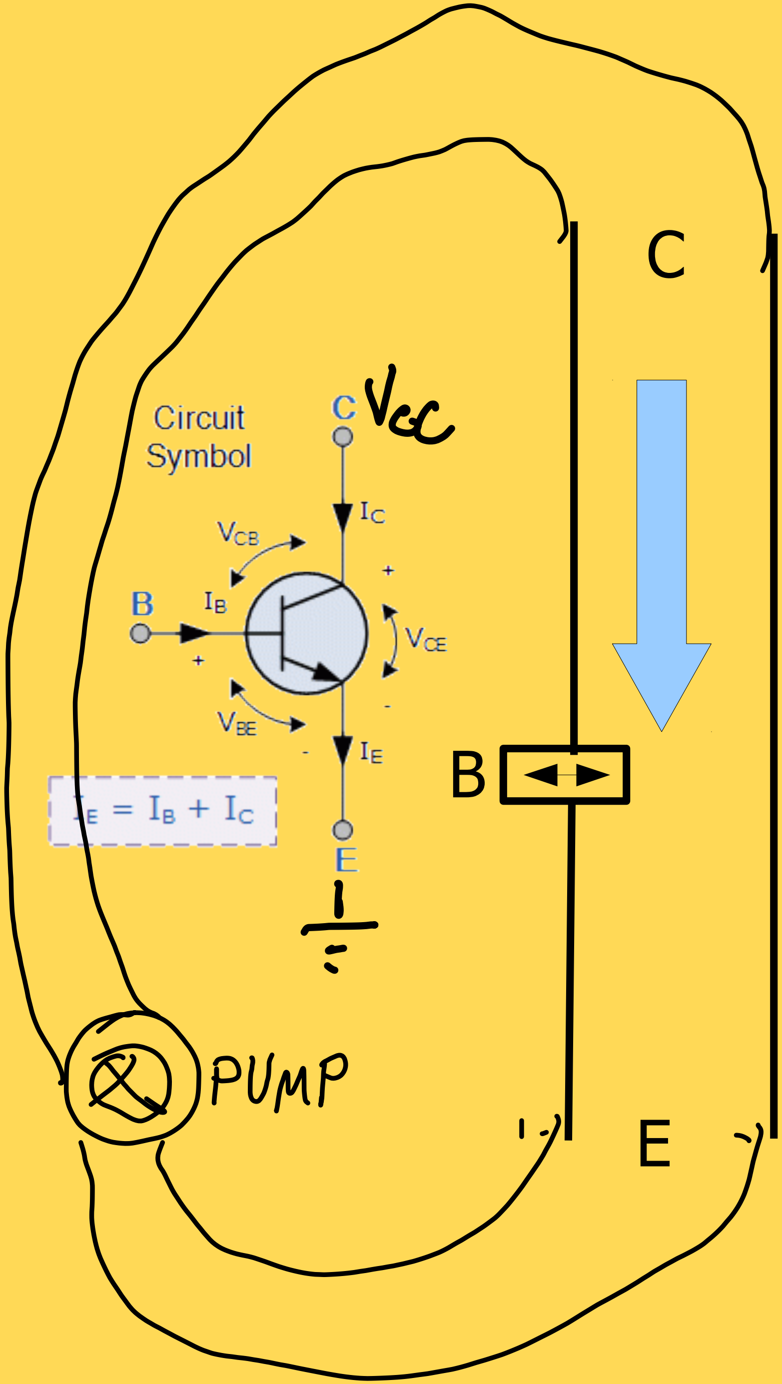
FULL-WAVE RECTIFICATION

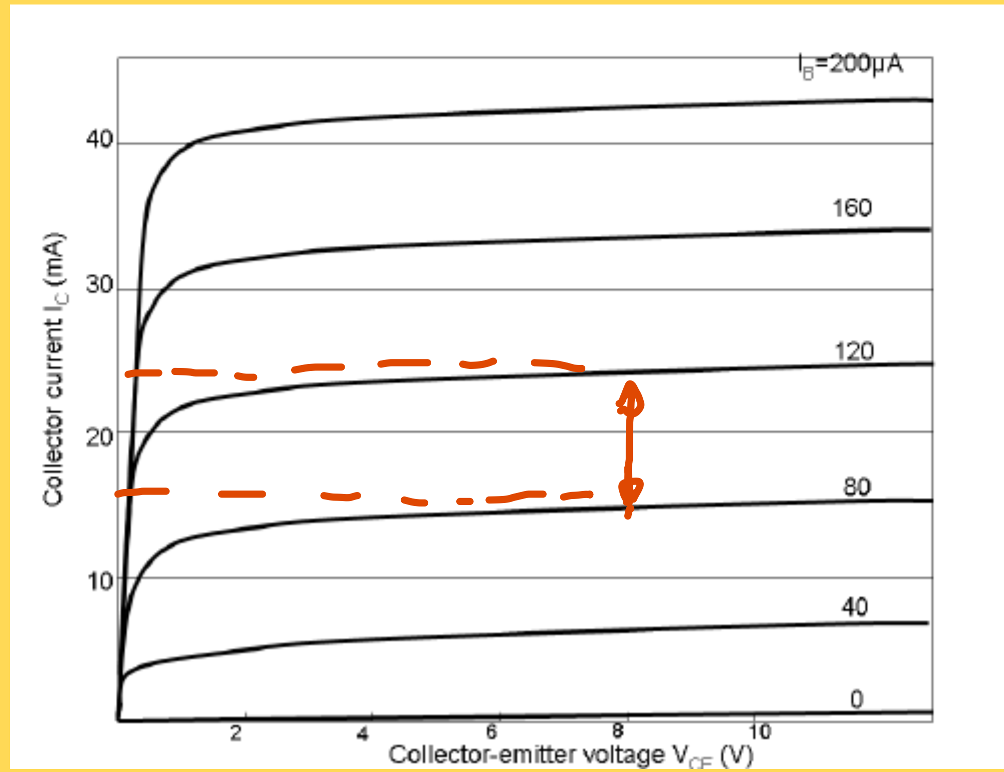




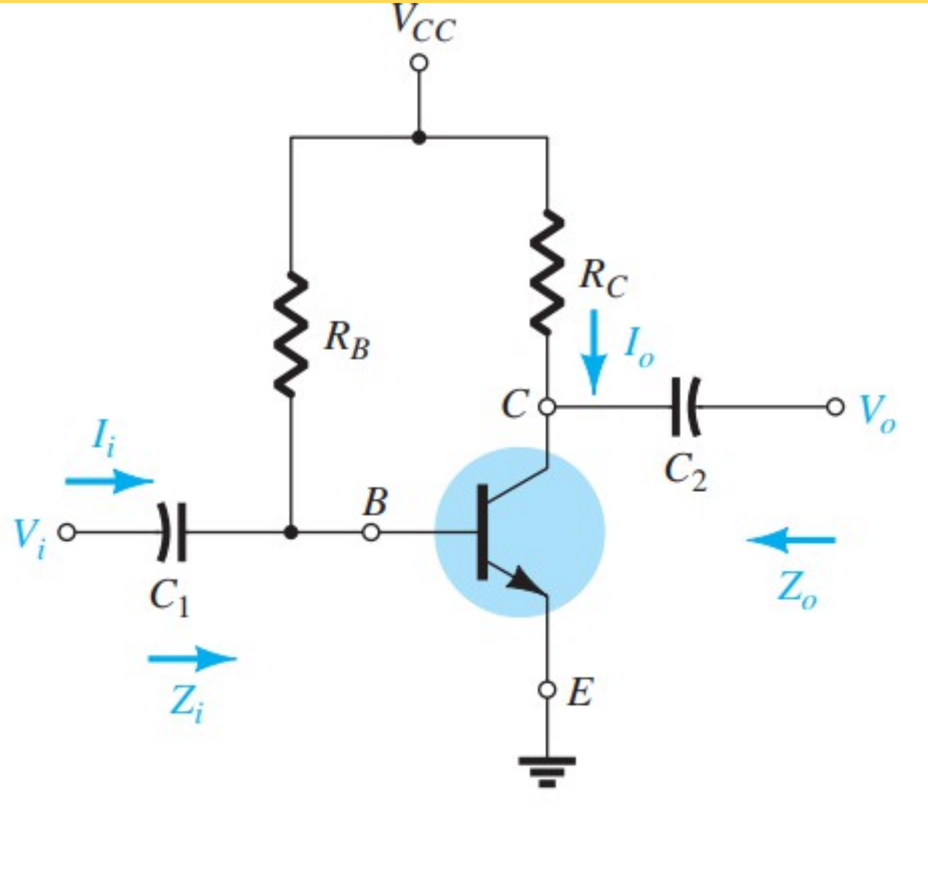
I_C
V_CB
N
I_B
P
V_BE
N
I_E
Circuit Symbol
C
I_C
V_CB
+
B
I_B
V_CE
+
-
V_BE
-
I_E
E
I_E = I_B + I_C

CURRENT AMPLIFIER





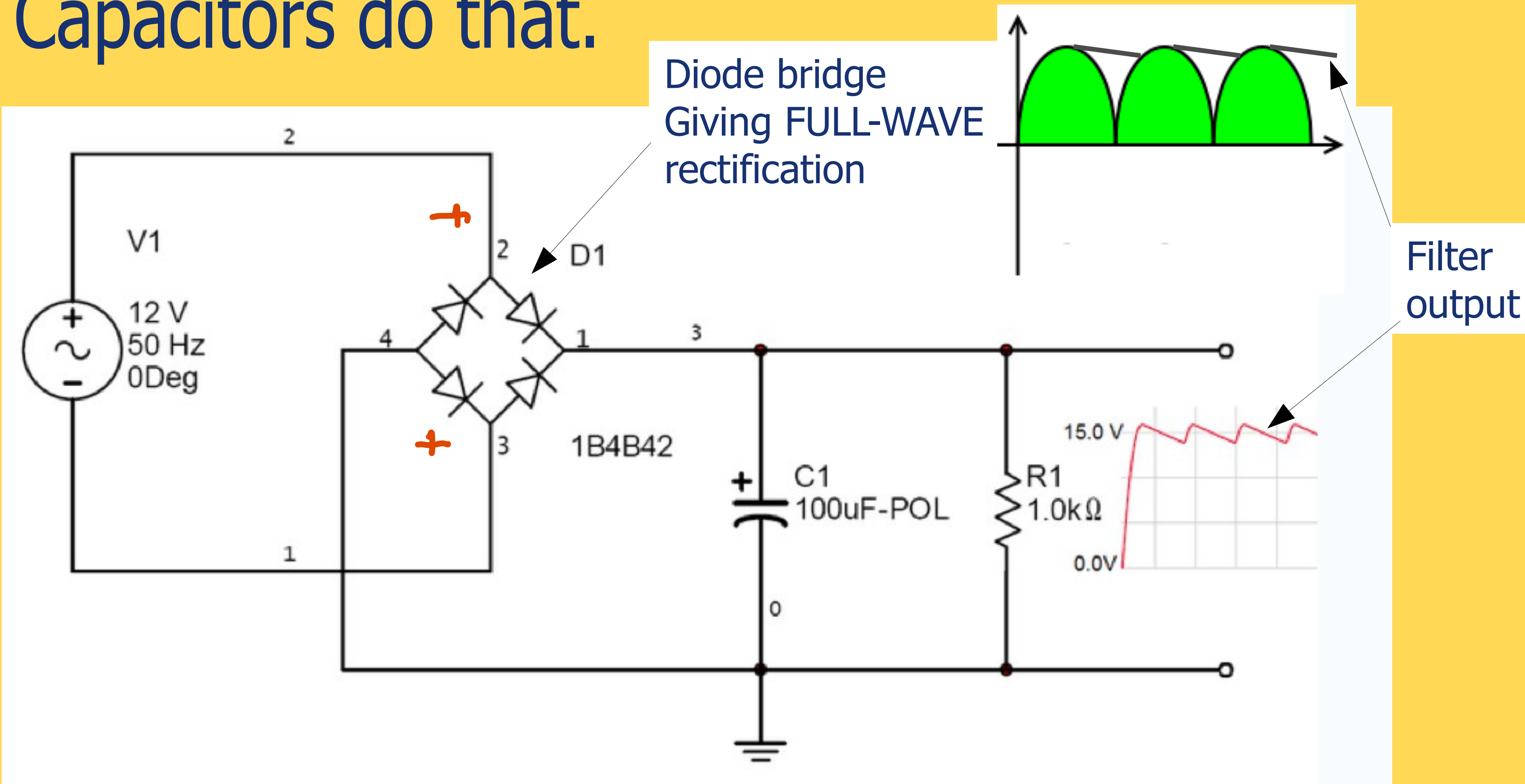
$$\text{Gain (Current)} = \frac{\Delta i_c}{\Delta i_b} = \frac{(25-15)\,\text{mA}}{(120-80)\,\mu\text{A}} = \frac{10e{-3}}{40e{-6}} = \boxed{250}$$



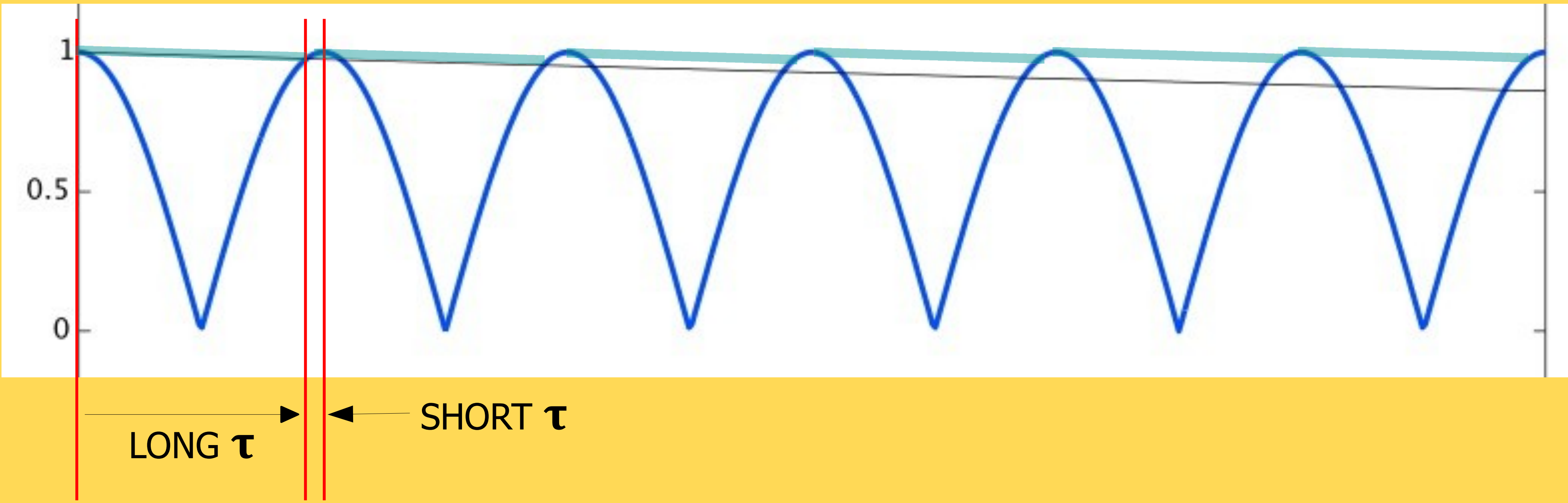
Common-emitter fixed-bias configuration.

How to Use a Diode?

- Then we need to filter the rectified sine wave. Capacitors do that.



What Should R Be?



Assume 60 Hz, fullwave rectified.

Choose LONG $\tau = 20\,\mathrm{T} = 0.167$ s

If $C = 100\,\mu$ F, then

$$R = \frac{20\,\mathrm{T}}{100\mathrm{e}\text{-}6} = 1.7\,\mathrm{K}\Omega$$