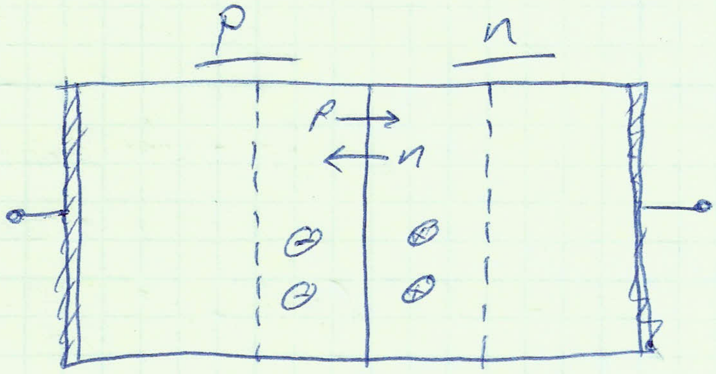
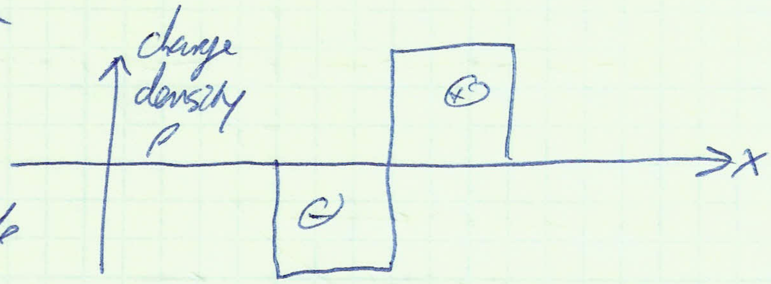
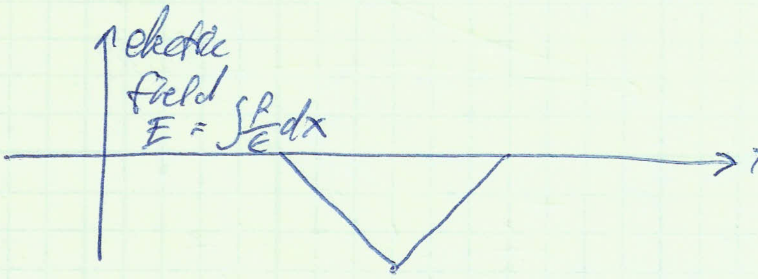
The Junction Diode



- holes diffuse to n-side
- electrons diffuse to p-side
- these minority carriers recombine, and deplete the majority carriers in a narrow (~0.5μm) region called "<u>depletion region</u>"



- width is related to dopant density in each side
- charge density creates electric field in depletion region, and built-in voltage

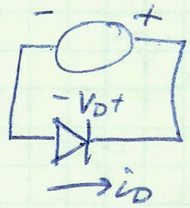


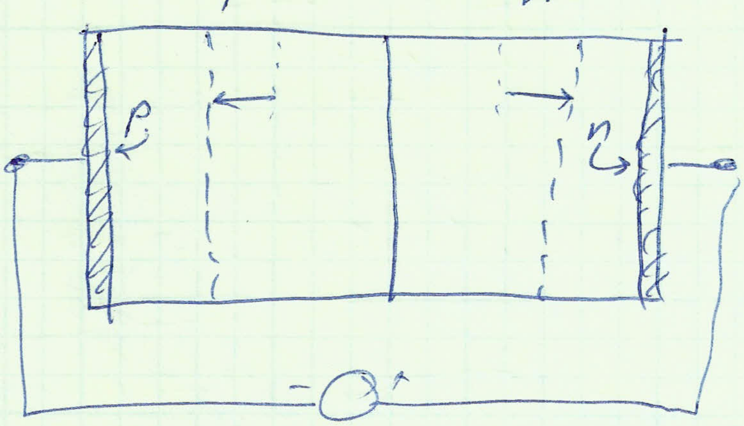
- Charge is <u>not</u> due to presence of diffused minority carriers (which have recombined) but due to "<u>uncovered</u>" ions that are exposed

- this cannot be used as a battery or voltage source.
  - if attached to a load with no other sources, there will be other voltage drops such as across the contacts, so no current will flow

I-V characteristics of Diodes

- Reverse Bias

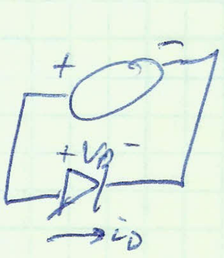




- some majority carriers flow to the terminals
- p-side becomes more negatively charged, n-side becomes more positively charged
- width of depletion region becomes <u>wider</u>
- potential barrier becomes <u>higher</u>

- no <u>majority</u> carriers can cross the depletion region
- a small current will flow due to <u>minority carriers</u>
  - called "<u>saturation current</u>", typically ~10^{-9}A (nA)
  - $i_D = -I_s$
  - I_s is temperature dependent - related to thermal electron-hole pair production
  - I_s doubles every ~7°C in temperature

- Forward Bias



- majority carriers move toward depletion region
- depletion region gets <u>narrower</u>
- potential barrier is <u>reduced</u>
- at high enough voltage, carriers can flow through the depletion region

$$i_D = I_S \left(e^{V_D/nV_T} - 1\right)$$

reverse current due to minority carriers

$V_T = kT/q \approx 26mV$ at $T = 300K$

- note at $V_D = 0$,
  $i_D = I_S(1-1) = 0$

$q = 1.6 \times 10^{-19}$ C

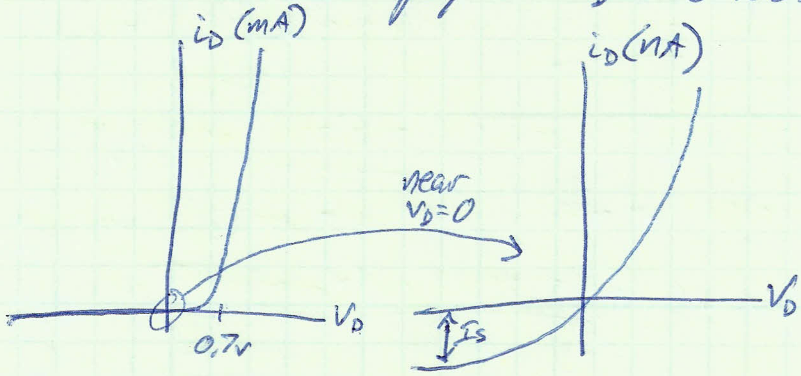
$k = 1.38 \times 10^{-23}$ J/K

n = emission coefficient

($n = 2$ for Si diodes, $1 \leq n \leq 2$ in ICs)

I_S is ~ nA range

Although I_S is very small, $e^{V_D/0.05}$ compensates, current rises sharply at $V_D = 0.6$ to $0.7V$



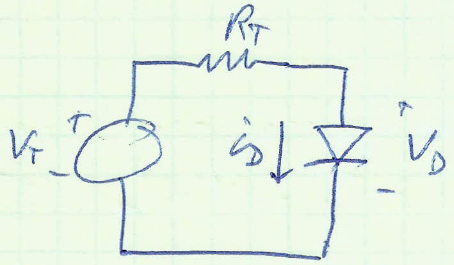
<u>Power</u> $P = i_D V_D$ is dissipated as <u>heat</u>

at high enough currents this can damage the diode

<u>Reverse Breakdown</u>

- At high enough bias voltage, minority carriers are accelerated through the depletion region
- Impact ionization can create new electron-hole pairs
- Avalanche process leads to sharp increase in current
- Can destroy the diode (except Zener diodes)

Solving Diode Circuits



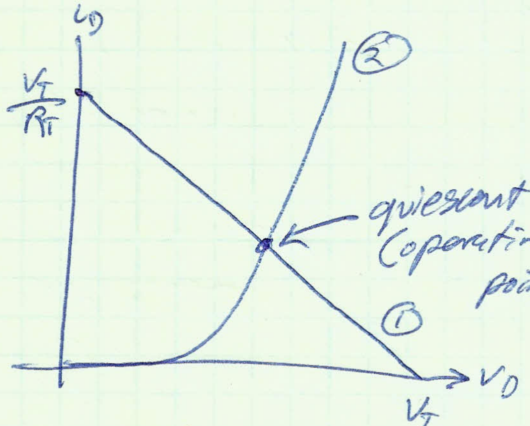
(1) $V_T = i_D R_T + V_D$

(2) $i_D = I_S (e^{V_D/nV_T} - 1)$

2 equations and 2 unknowns, but difficult to solve because nonlinear

Load Line

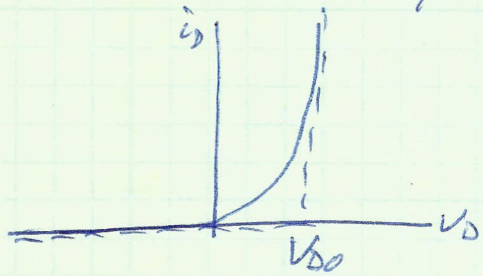
• Useful graphical solution, but does not easily give numerical result



Piecewise Linear Model

Diode ON: $V_D = V_{D0}$, $i_D \geq 0$

Diode OFF: $i_D = 0$, $V_D < V_{D0}$



V_{D0} is "cut-in" voltage, for Si $V_{D0} \approx 0.6-0.7V$

for GaAs, $V_{D0} \approx 1.7-1.9V$

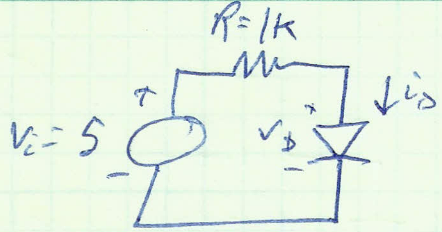
Recipe for solving:

(1) write down circuit equations, with i_D, V_D as parameters

(2) assume either ON or OFF and solve circuit

(3) check for self-consistency with values of i_D, V_D that you found

Example



$V_i = i_D R + V_D$

$5 = 10^3 i_D + V_D$

assume diode is OFF $\longrightarrow i_D = 0$

$5 = 10^3 \times 0 + V_D \longrightarrow V_D = 5V$

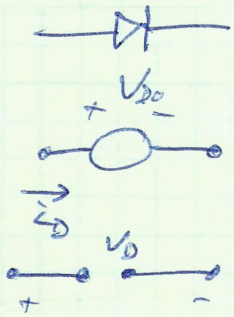
is $V_D < V_{D0}$ $(V_{D0} = 0.7v)$? NO.

assume diode is ON

$5 = 10^3 \times i_D + 0.7 \longrightarrow i_D = 4.3mA$

is $i_D \geq 0$? Yes

Diode Circuit Model



Diode ON $i_D \geq 0$

Diode OFF $V_D < V_{D0}$

- Can use the same procedure, but check for self-consistency