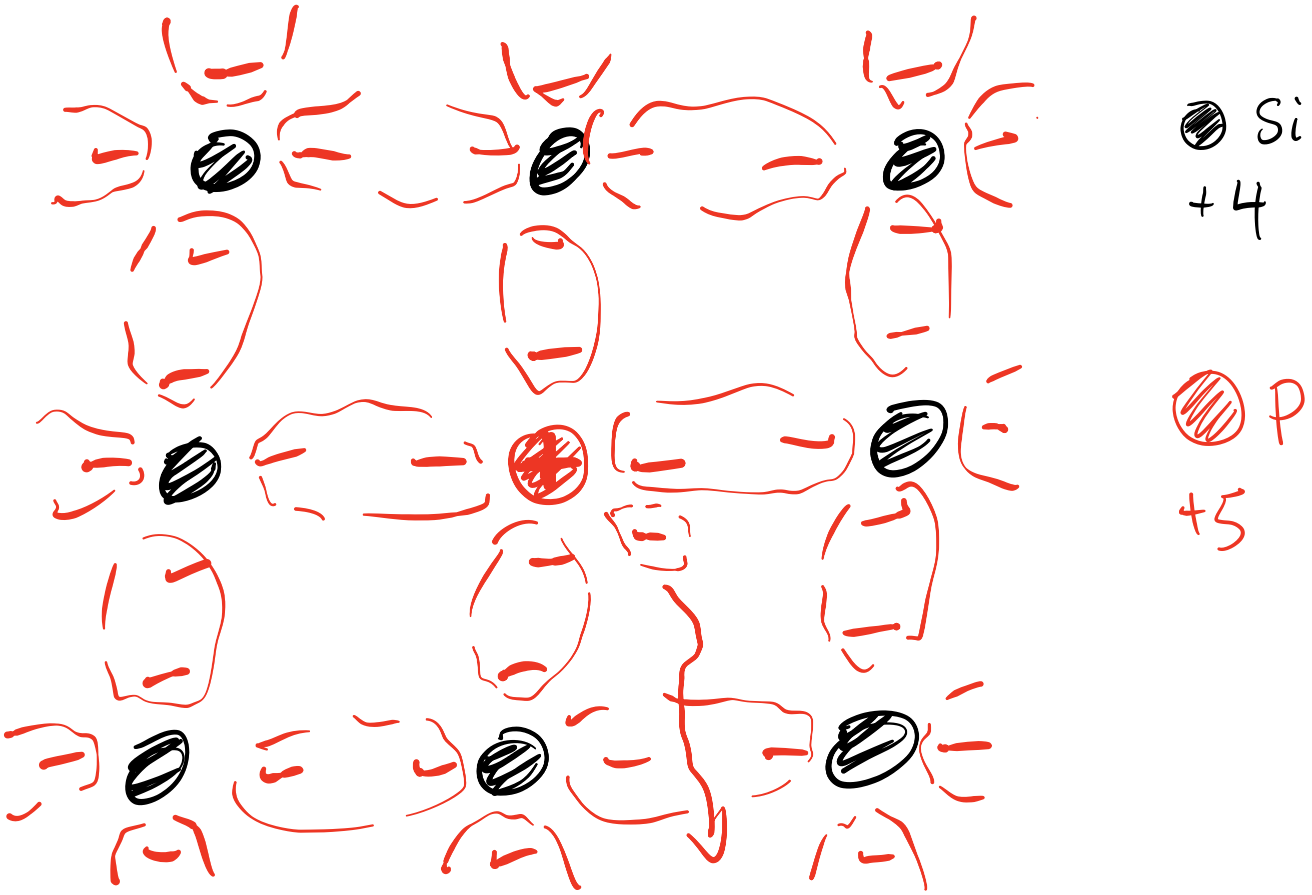
PHYS 231 - Nov. 27, 2023

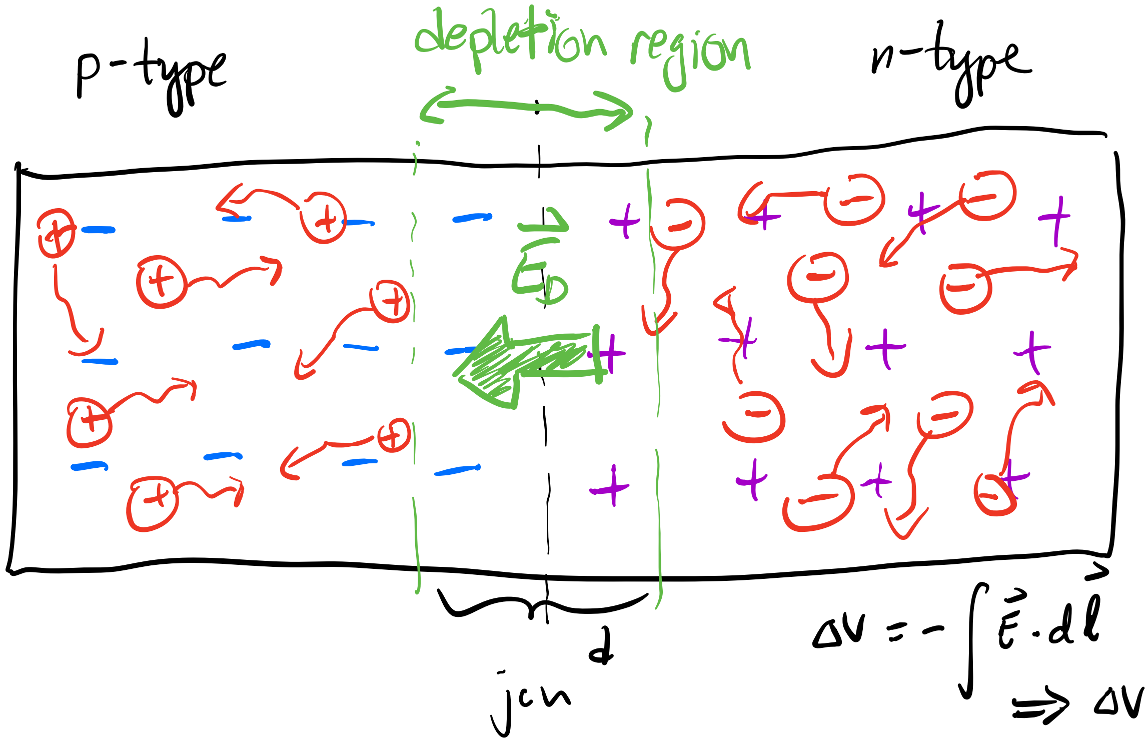
n-type doping ⇒ 5 valence electrons



p-type doping ⇒ 3 valence electrons.

A single p-n jcn produce a <u>diode</u>.

We will see that diodes act as one-valves for charge. They pass current in one dir'n, but not the other.



$$\Delta V = -\int \vec{E}\cdot d\vec{l}$$

$$\Rightarrow \Delta V = -Ed$$

− fixed negative ion

+ fixed pos. ion

⊕ mobile holes.

Near the jcn, mobile holes & electrons recombine leading to a region near the jcn that has an absence of mobile charges ⇒ "depletion region"

The fixed ions create a pos. region & a neg. region on either side of the jcn.

⇒ Electric field pts from pos. side to the negative side $\vec{E}_D$

$\vec{E}_D$ prevents further migration of mobile charges across the jcn.

Consider the electron current in our isolated diode.

① Free e^- in n-region w/ sufficient thermal energy overcome potential energy barrier & cross the depletion region.

$$I_L = A e^{-\underbrace{eV_D}_{\text{pot. energy barrier}}/\underbrace{k_B T}_{\text{thermal energy}}} \approx 10^{-10} - 10^{-12} A$$

$$V_D \simeq \mathcal{E}_D d$$

-called the Boltzmann dist'n

(200 & 245)

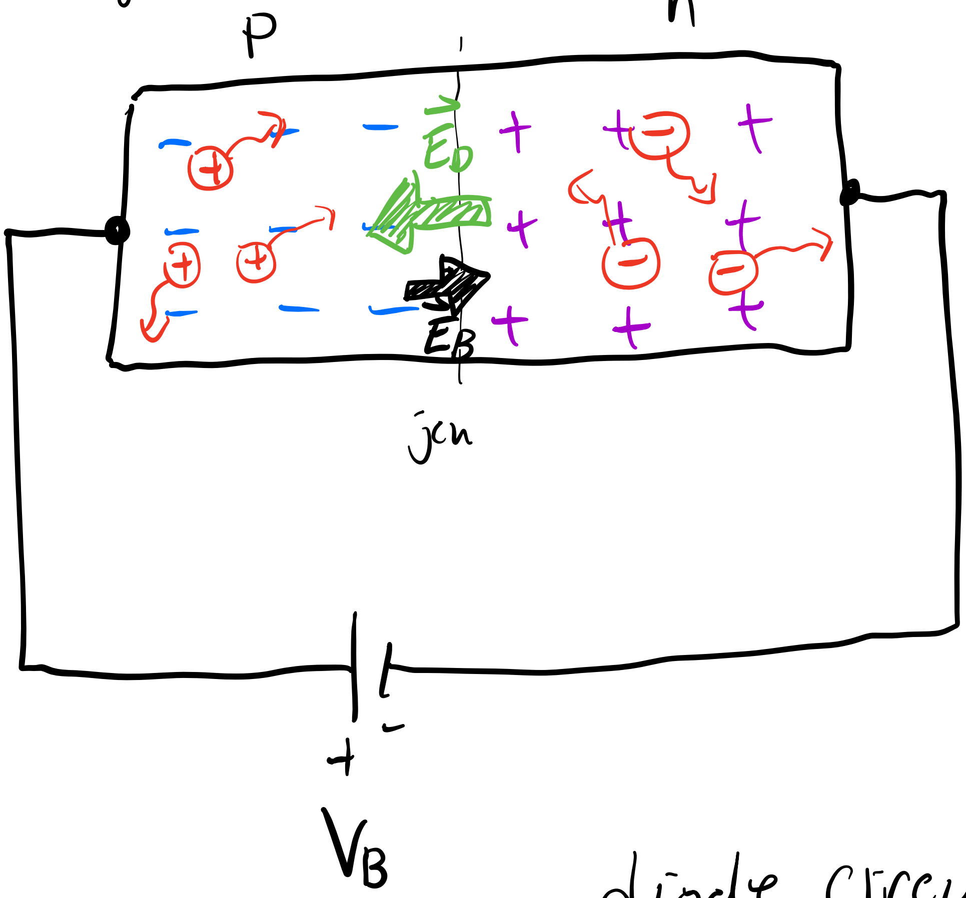
② Minority e^- in $\underline{p}$-region swept across the jcn due to $\mathcal{E}_D$. This creates an e^- current I_R to the right.

In equil., net current must the zero.

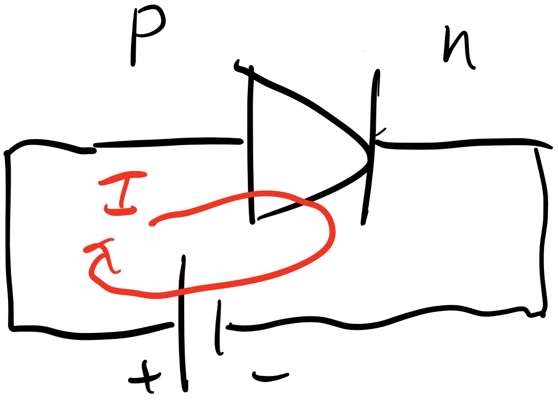
$$\therefore \quad I_{net} = I_R + I_L = 0$$

$$\Rightarrow I_R = -I_L = -Ae^{-eV_D/k_BT}$$

Next, let's connect a battery across our diode. Connect pos. terminal to p-region & neg. terminal to n-region.



diode circuit symbol



The battery establishes a second electric field the oppose $\vec{E}_D$.

The external battery can be used to overcome $\vec{E}_D$ s.t. majority charges cross jcn & conduct electricity (only when p-side is higher potential than n-side).

Now $I_{net} = I_L + I_R$ becomes:

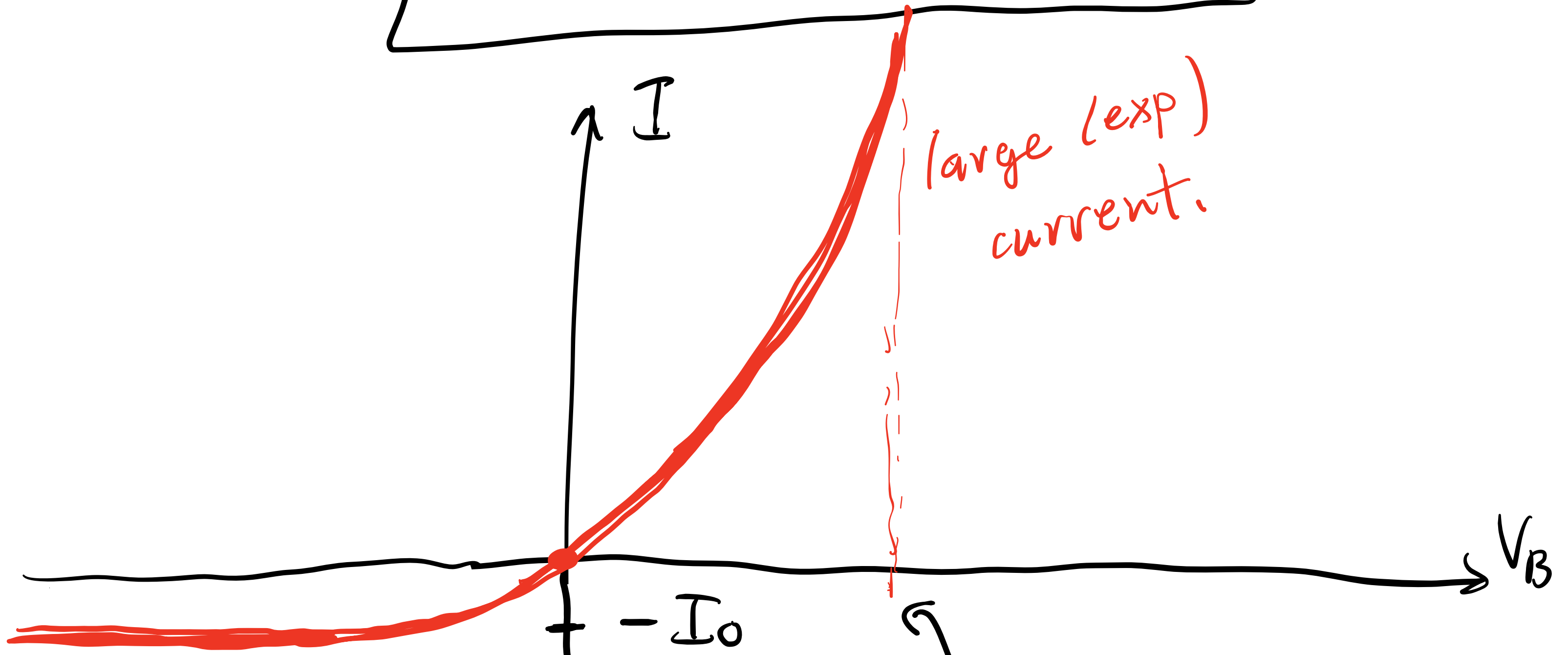
$$I_{net} = \underbrace{Ae^{-e(V_D - V_B)/k_BT}}_{I_L} - \underbrace{Ae^{-eV_D/k_BT}}_{I_R \text{ (stays the same)}}$$

$$= \underbrace{Ae^{-eV_D/k_BT}}\left(e^{eV_B/k_BT} - 1\right)$$

$$\equiv I_0 \sim 10^{-10} - 10^{-12} A$$

∴ Diode current is

$$\boxed{I = I_0\left(e^{eV_B/k_BT} - 1\right)}$$



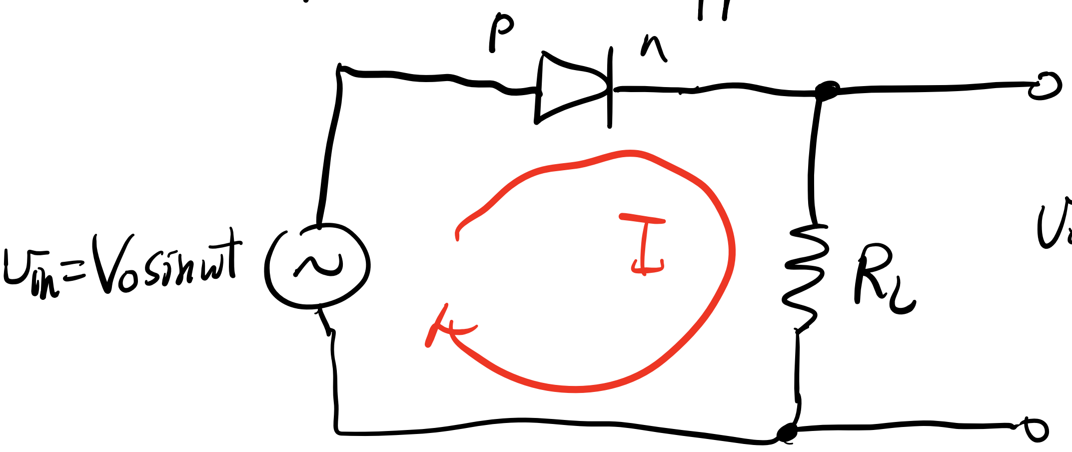
nearly zero

"diode turn-on voltage"

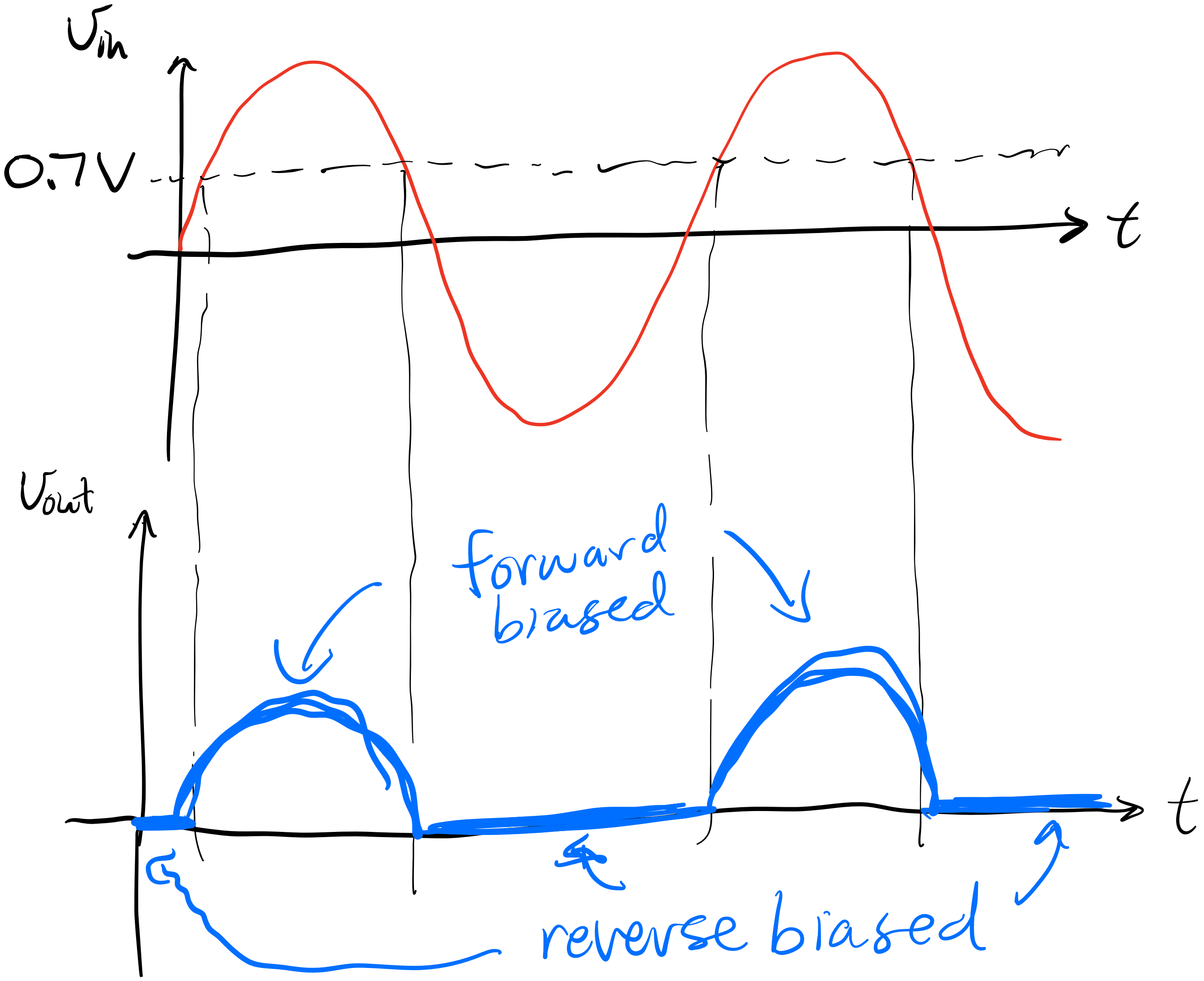
For Si diodes $\underbrace{\sim 0.6 \text{ or } 0.7\,V.}_{\simeq V_D = E_D d}$

Often approx diode I-V characteristic as:

Simple Diode application



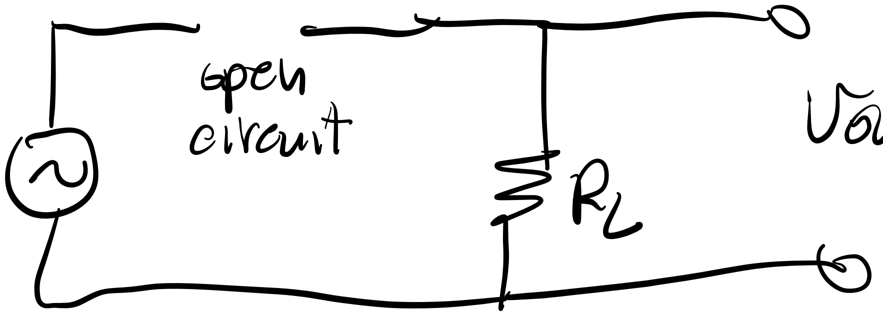
$V_{out} = IR_L$



When $v_{in} < 0.7\,V$, $I = 0$

$\therefore \; v_{out} = IR_L = 0.$

Equivalent circuit when $v_{in} < 0.7\,V$



$v_{out} = 0$

$I = 0.$

When voltage across diode is $V_p - V_n < 0.7V$, the diode is "reversed biased" & $I = 0$.