Bipolar Junction Transistors

Recall key features of p-n junctions: {Key Lectures}

- Injection of minority carriers (forward bias)
- Variation of depletion width (reverse bias)

Now consider 3-terminal device: transistor

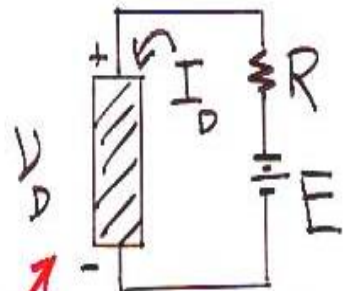
→ use for and

e^- and h^+ action both important:

Bipolar junction transistor

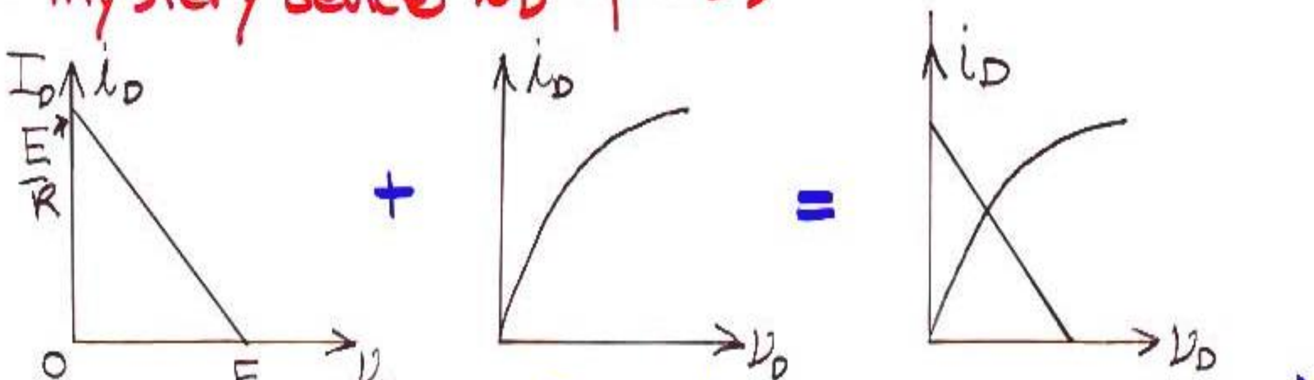
Start with ampl**ific**ation (get a feeling for it)

2-Terminal device circuit looks like:



loop equation: $E = i_D R + v_D$

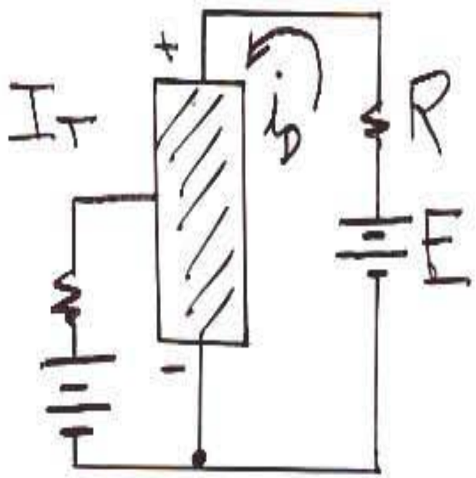
mystery device $i_D = f(v_D)$



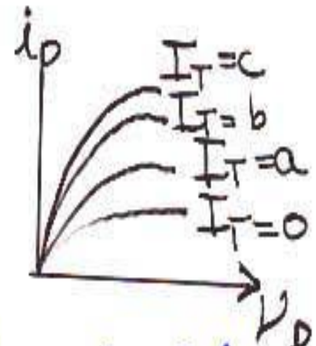
2 equations, 2 unknowns (i_D, v_D)

Now change to 3-terminal device

→ change $i_D = f(v_D)$ in controlled way



and



family of $f(v_D)$ curves

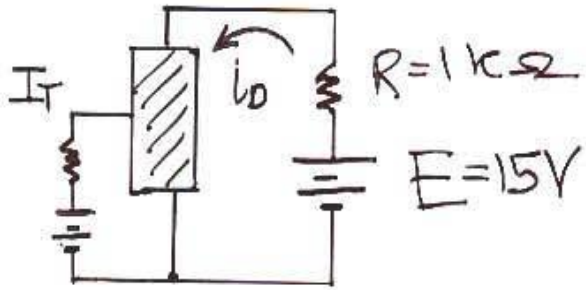
Terminology:

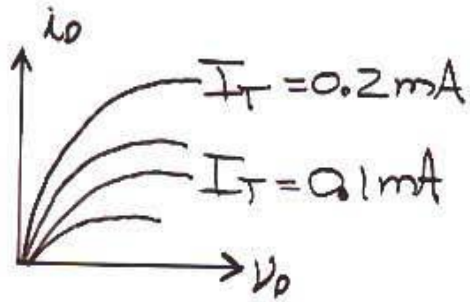
i_D = Total Current

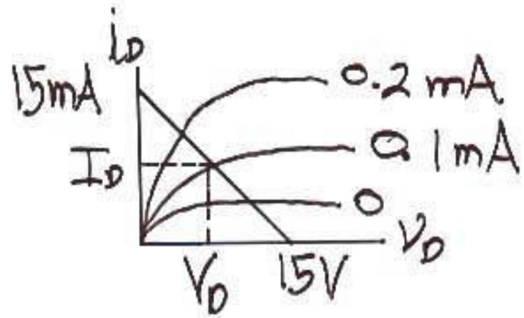
I_D = d-c current

i_d = a-c current

Put in values







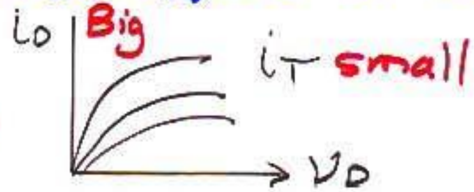
Now I_D and V_D depend on I_T

Amplification: Change I_T by small amount (e.g., 0.05mA)
Get big change in I_D (e.g., 2mA)

2.00/0.05 = 40 x factor

Switching: change I_T so $i_D = 0$ or $i_D = E/R$

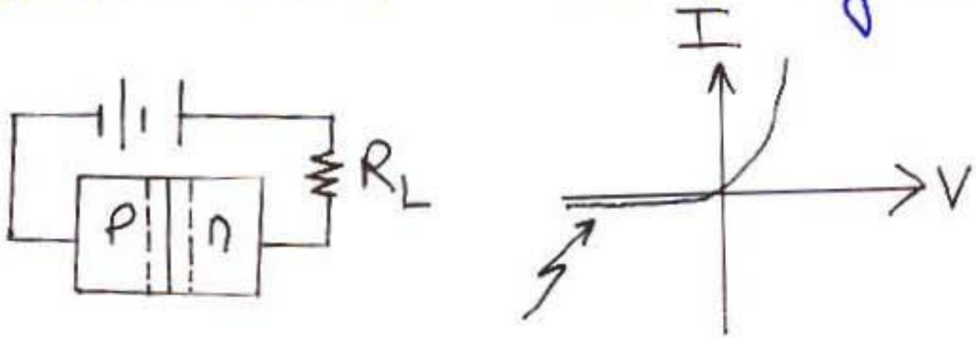
okay, but how come



???

BJT Operation

To see how 3rd terminal changes $i_0(V_0)$, consider reverse-biased p-n junction:



→ I_0 depends on rate of electron-hole pair creation within a diffusion length of the junction,
(not on how fast field sweeps carriers through).

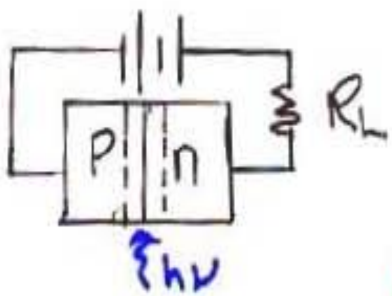
Big Deal

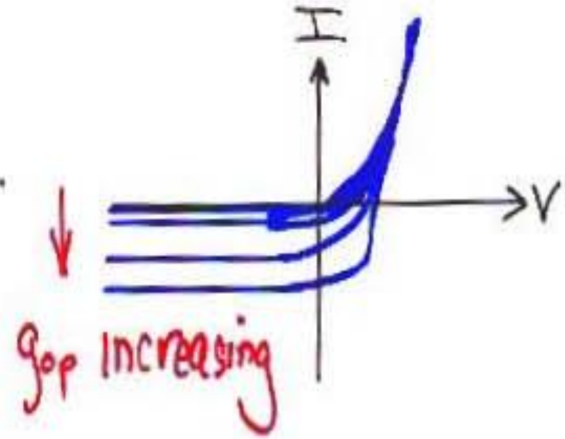
So what happens if we inject more electron-hole pairs?

We've already studied this!
→ Use

Consider first.

Consider first, optical injection:-

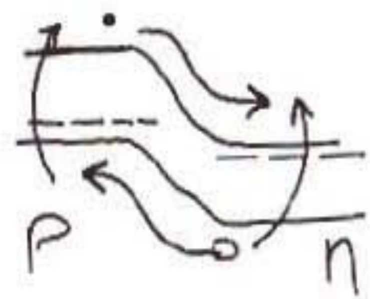




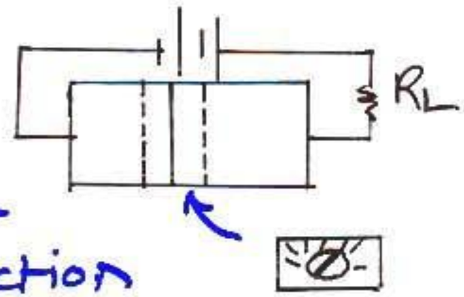
h^+ sweep from $n \rightarrow p$

e^- sweep from $p \rightarrow n$

and reverse current increases.

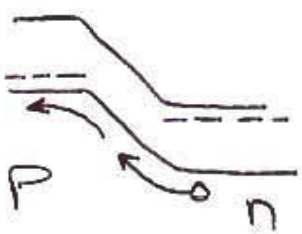


But same thing if different kind of hole injector:

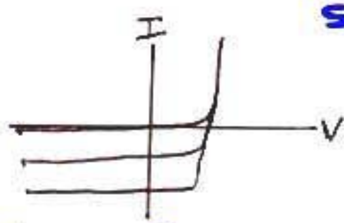


Behaves similar to optical injection

How? Inject holes into n-side



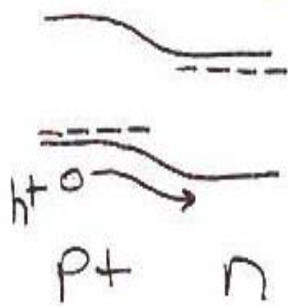
h^+ sweep $n \rightarrow p$
so more I_0

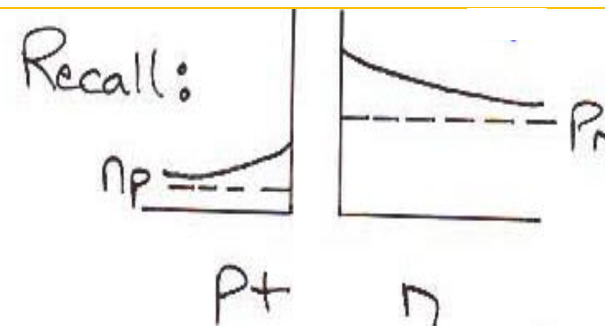


$I \sim$ independent of bias V.
Also, current $\sim$ independent of R_L.

What's a good hole injector?

→ A





p+ side is a supplier of holes =

(majority carrier)

So now add the p^+-n junction
(the one we want to forward-bias)

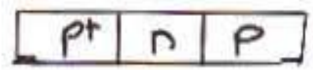
to the n-side of the p-n junction
(the one we want to reverse-bias)

Looks like this:

p^+ n p

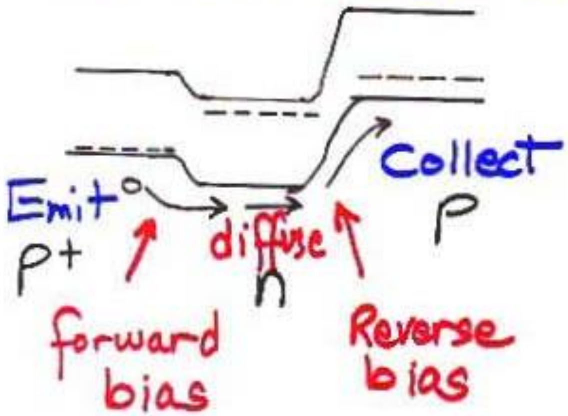
"emitter" side

"collector" side



Equilibrium
(no bias)

Forward-bias "emitter" to emit holes.
Reverse-bias "collector" to collect holes.



"on"

Holes flow from emitter to collector.

Can turn off this transistor by reverse-biasing emitter.

"off"
No holes injected

PNP Transistor!

Terminology

p^+ region = "emitter" (source of majority carriers — holes)

n region = "base"

p region = "collector" (collects majority carriers — holes)

For good pnp transistors,

a) inject almost all holes at emitter

and

b) collect almost all holes at collector

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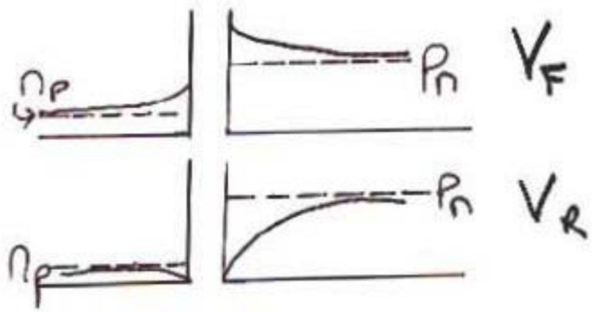
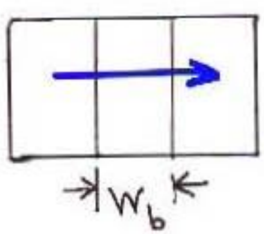
For (a), dope base lightly so holes dominate:

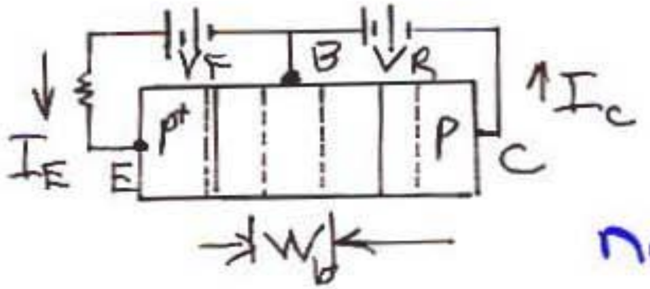


For (b), Make $L_p \gg W_b$



Minimize

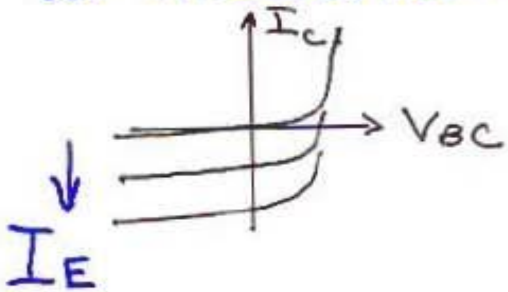
Now let's look at the magnitudes and directions of the currents.



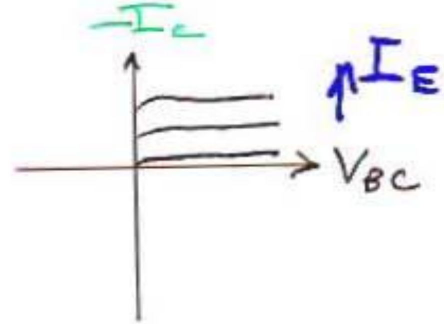
neutral base region

"on" state biasing of "common-base" configuration

Can bias forward EB and reverse-bias BC at the same time!



Flip:



I_E acts to increase reverse current of BC diode.

Physical Sources of Current

Assume forward $E \to B$ (above)

" reverse $B \to C$ (above)

" pnp transistor (above)

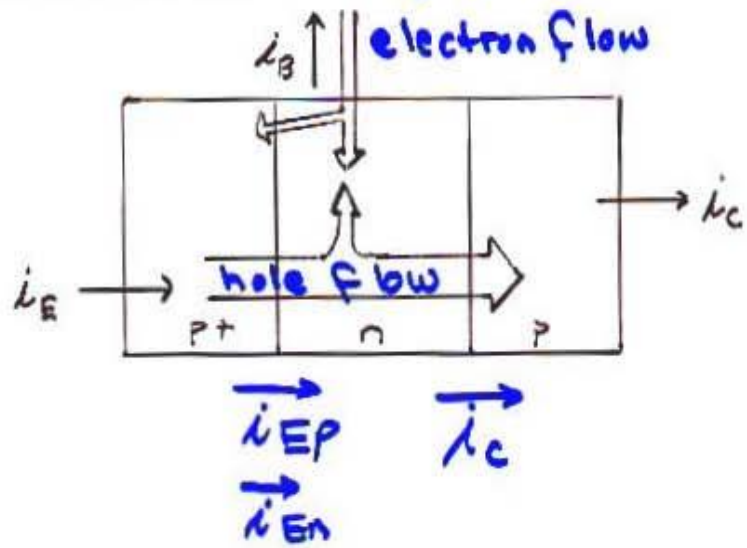
i_E Injected h^+ current from $E \to B = i_{Ep}$

" e^- " " $B \to E = i_{En}$

(back injection)

so $i_E = i_{Ep} + i_{En}$

i_E (and i_c) components:



Important!

i_c: collected h^+ current from B → C

(Neglect saturation current (h^+ and e^- both) since thermal generation in reverse bias is negligible)

i_c = emitted h^+ current from E → B

minus h^+ lost to recombination

Hopefully, is small, so treat as %.

$$i_C = B\, i_{EP}$$

B = base transport factor ≤ 1

= % that make it across.

i_B = e^- supply for recombination with injected holes in n-type base

+

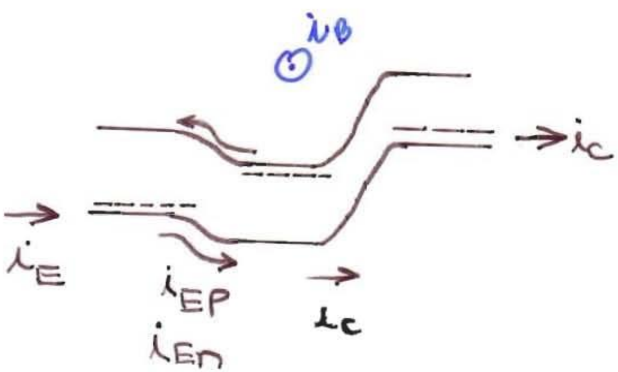
e^- supply for i_{En}

$$i_B = \underbrace{(1-B)}_{\text{fraction of injected hole current that recombines.}} i_{Ep} + i_{En}$$

For pnp BJT, i_E flows into emitter

i_C flows out of collector

i_B



For npn BJT, roles of electrons and holes are reversed.

Amplification

BJT useful since currents i_E and i_C controllable by small base current i_B.

Relate all three by important factors:

$i_C = B\, i_{EP}$ (again)

B = base transport factor ≤ 1

fraction that make it across base

Define: Emitter Injection Efficiency

$\gamma =$

fraction of i_E composed of holes

$$\gamma = \frac{i_{Ep}}{i_{Ep} + i_{En}}$$

fraction of i_E composed of holes

Ideally, $\gamma \cong 1$ and $B \simeq 1$

Relate i_C to i_E:

$$\frac{i_C}{i_E} = \boxed{}\ \boxed{} \equiv \alpha$$

Current Transfer Ratio

α close to unity – no real amplification.

(Emitter-to-Collector)

Base Current relations:

$$\frac{i_C}{i_B} = \frac{B\, i_{Ep}}{(1-B)\, i_{Ep} + i_{En}} = \frac{B\left(i_{Ep}/(i_{Ep}+i_{En})\right)}{\left[(1-B)\, i_{Ep} + i_{En}\right]/(i_{Ep}+i_{En})}$$

$$= \frac{B\left(i_{Ep}/(i_{Ep}+i_{En})\right)}{1 - B\left(i_{Ep}/(i_{Ep}+i_{En})\right)}$$

$$=$$

$$=$$

$$\equiv \beta$$

Base-to-Collector amplification Ratio
α-Factor