Spring 2019 Purdue University

ECE 255: L10

Bipolar Junction Transistors (BJTs)

(Sedra and Smith, 7^{th} Ed., Sec. 6.1)

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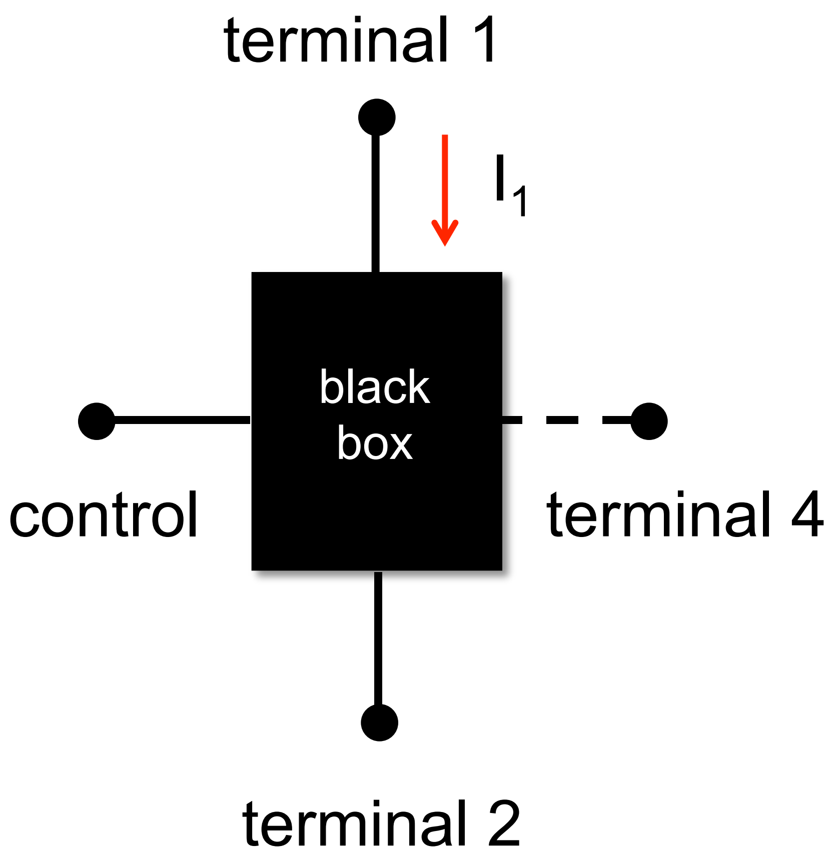
PURDUE UNIVERSITY

BJT's

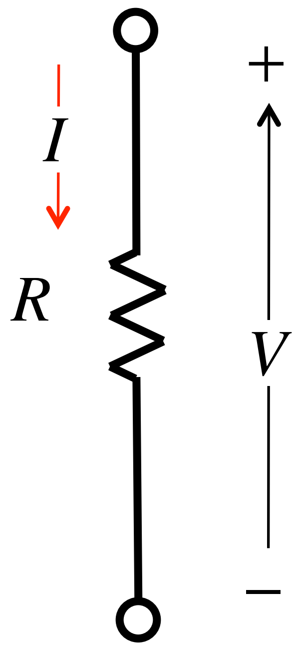
1) Transistors
2) PN junction review
3) BJT structures
4) Energy band treatment
5) BJT IV: active region
6) BJT IV: saturation region

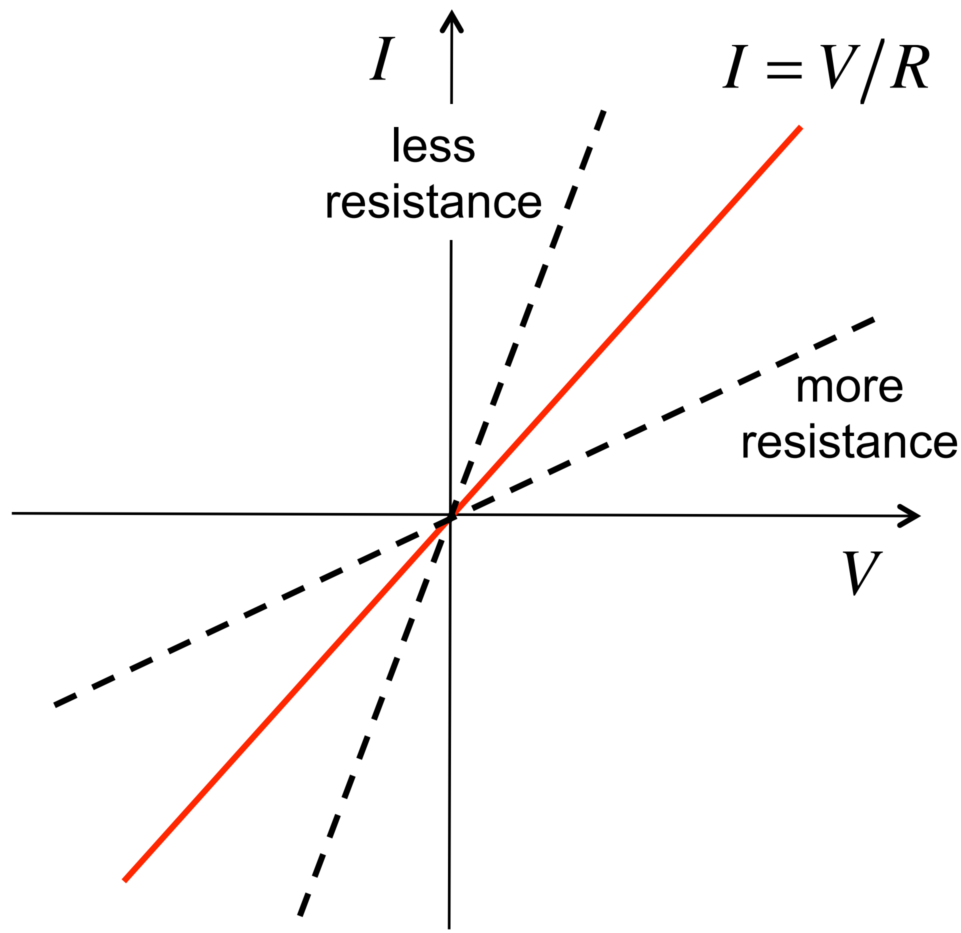
Transistor as a "black box"



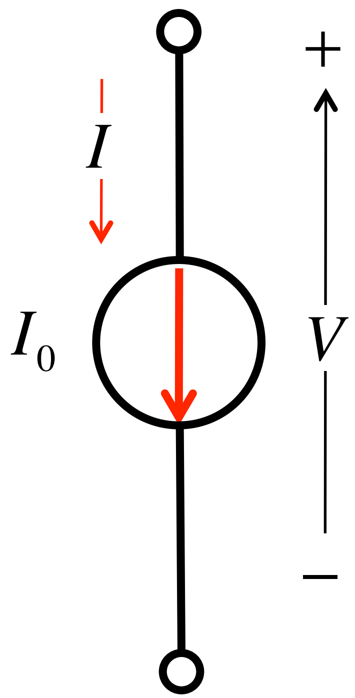
A small current (or voltage) on the control terminal controls a much larger current through two other terminals.

IV characteristics: resistor

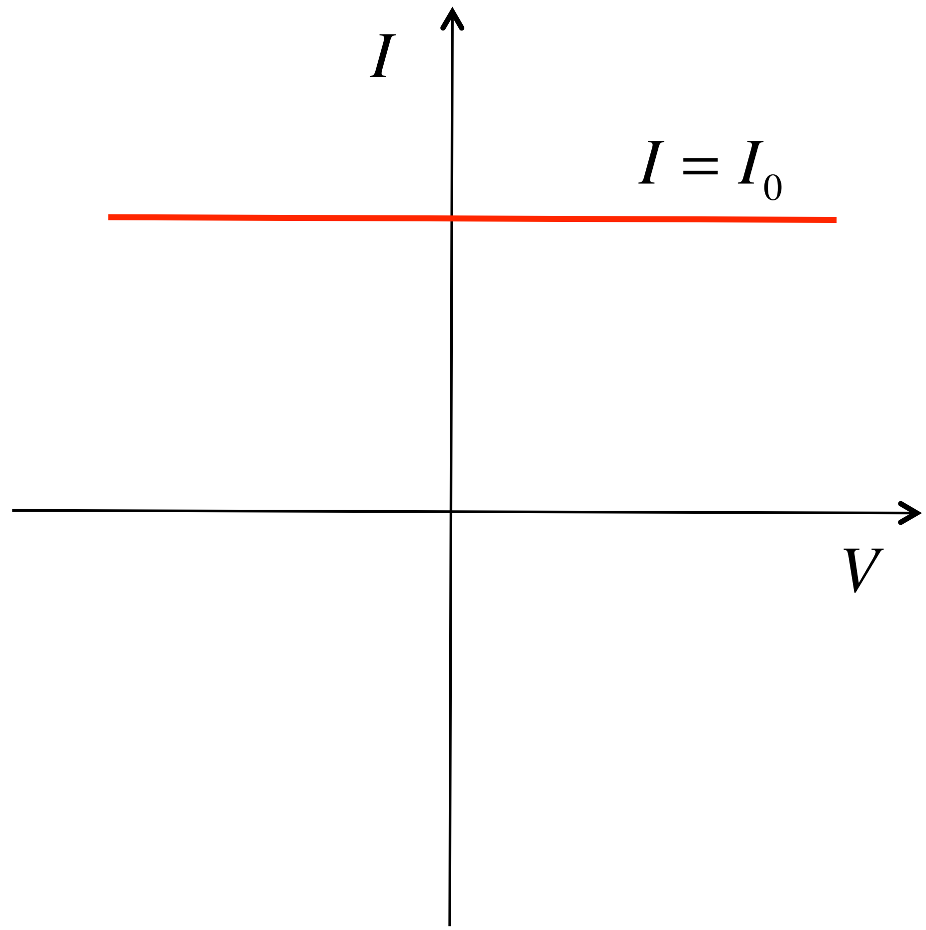




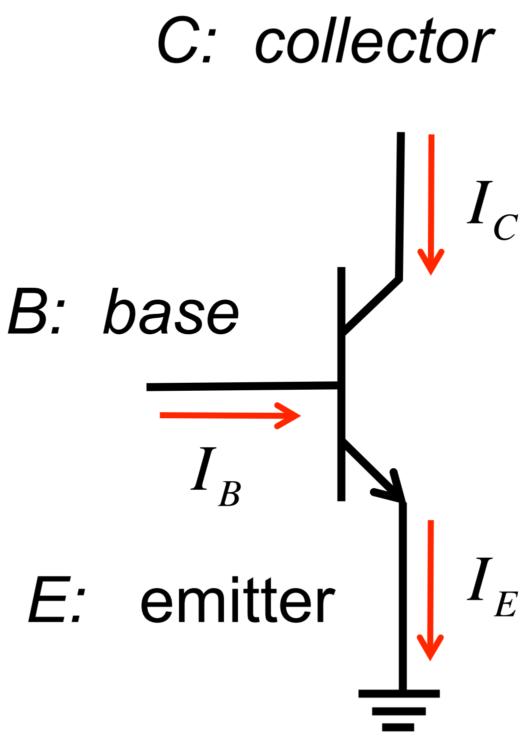
IV characteristics: ideal current source



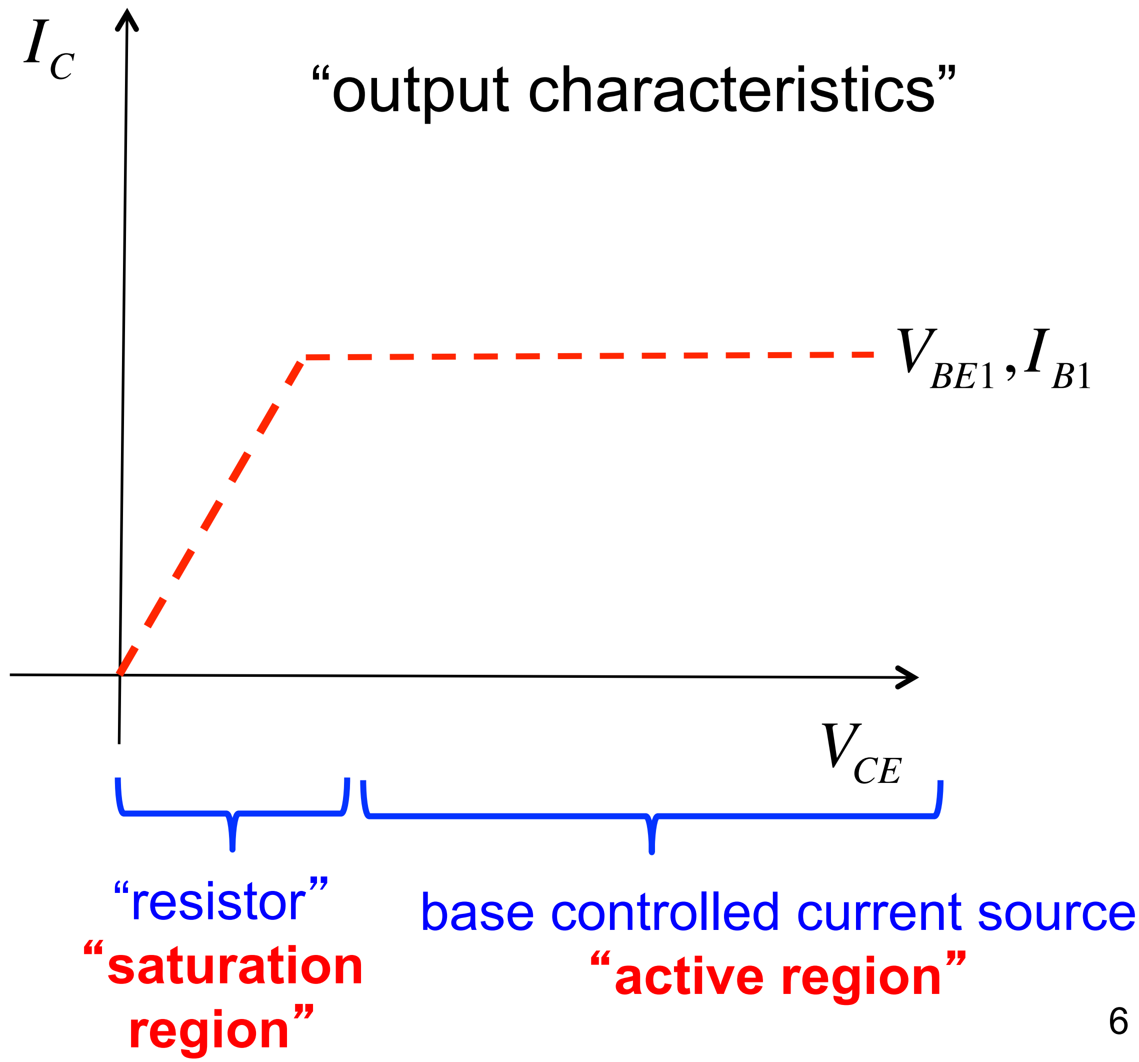
$$I = I_0$$



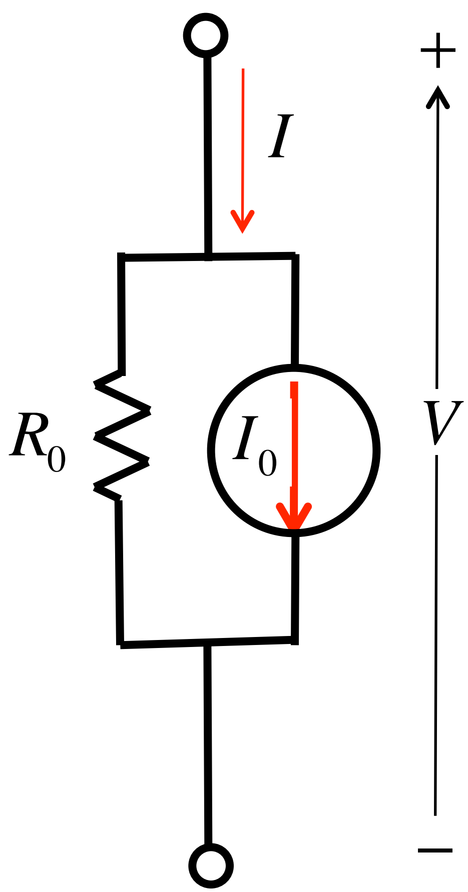
IV characteristics: transistors

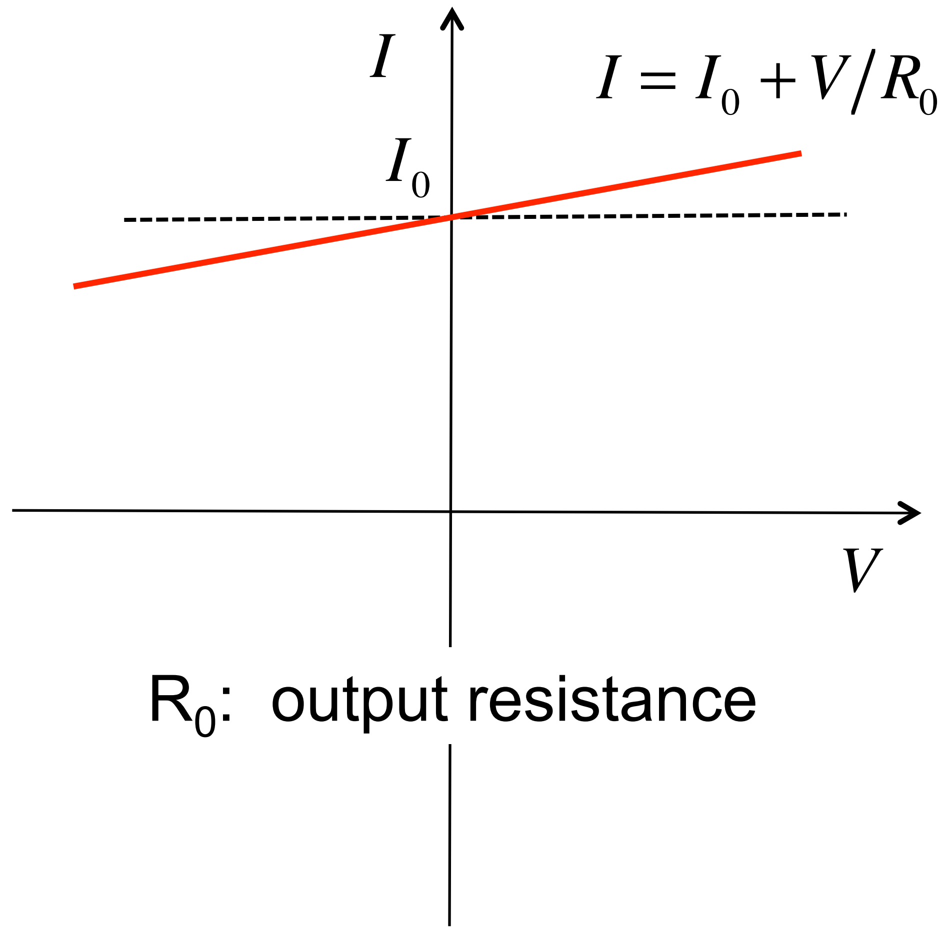


NPN BJT



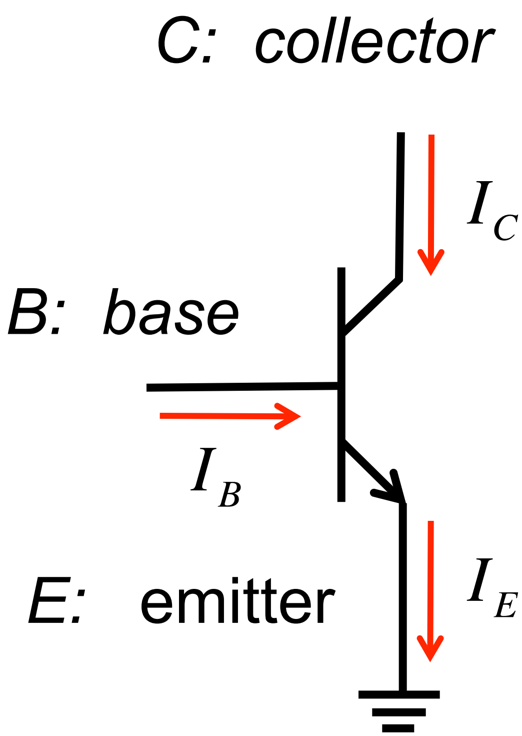
IV characteristics: real current sources

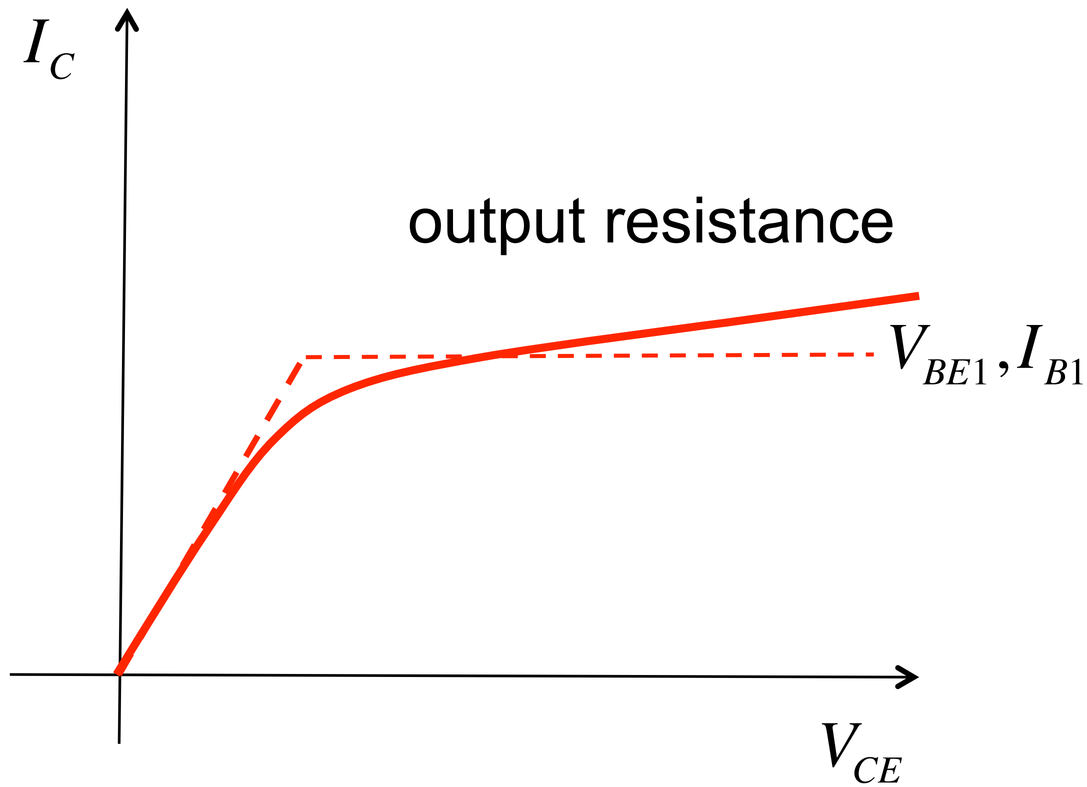




R_0: output resistance

IV characteristics: transistors



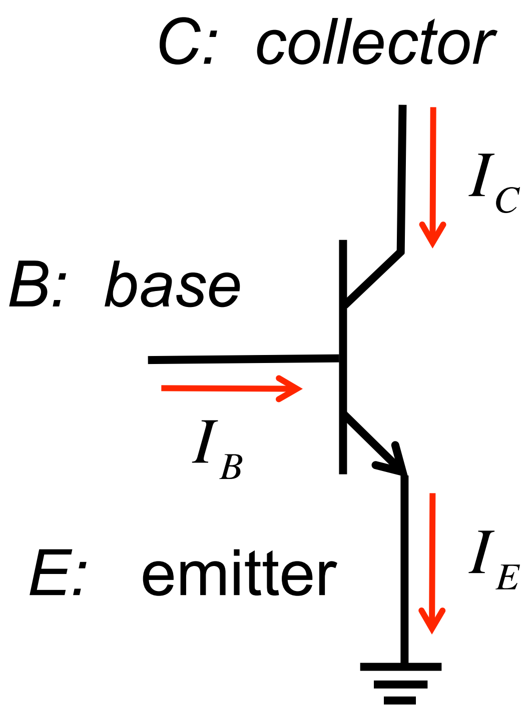


NPN BJT

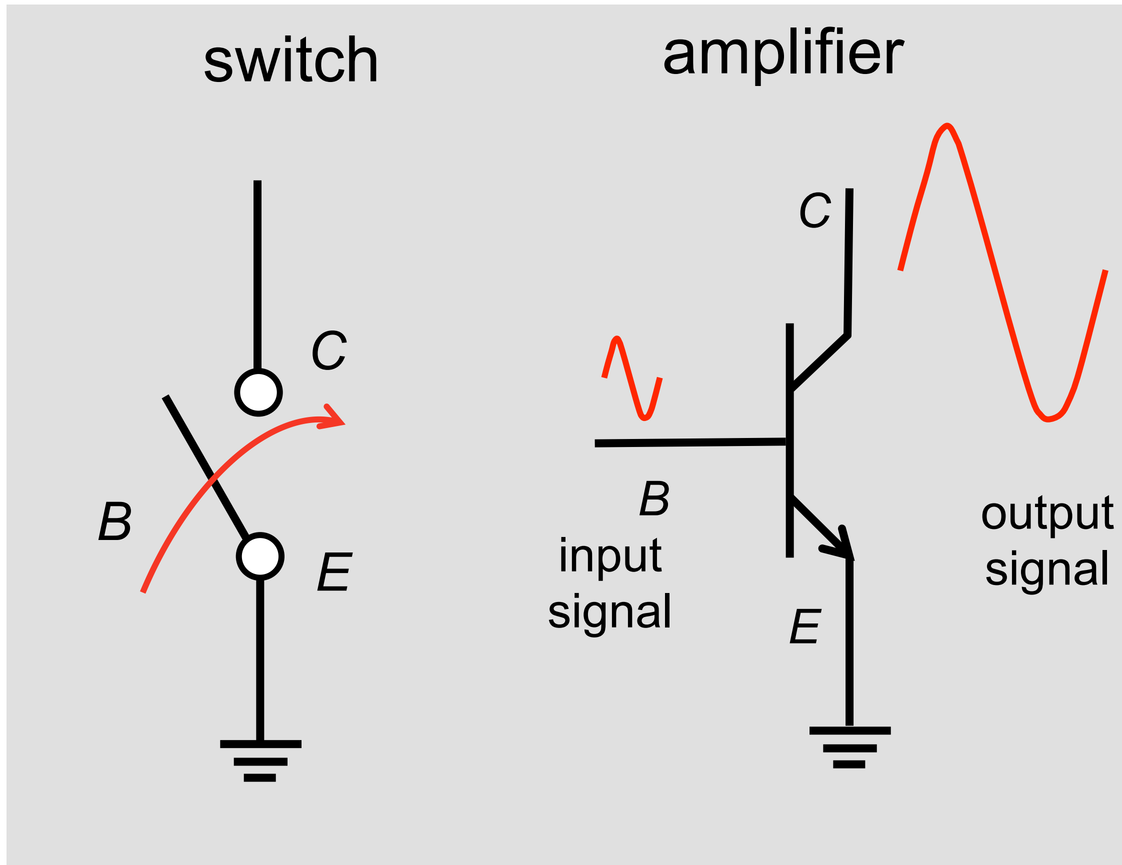
"output characteristics"

Applications of BJT's

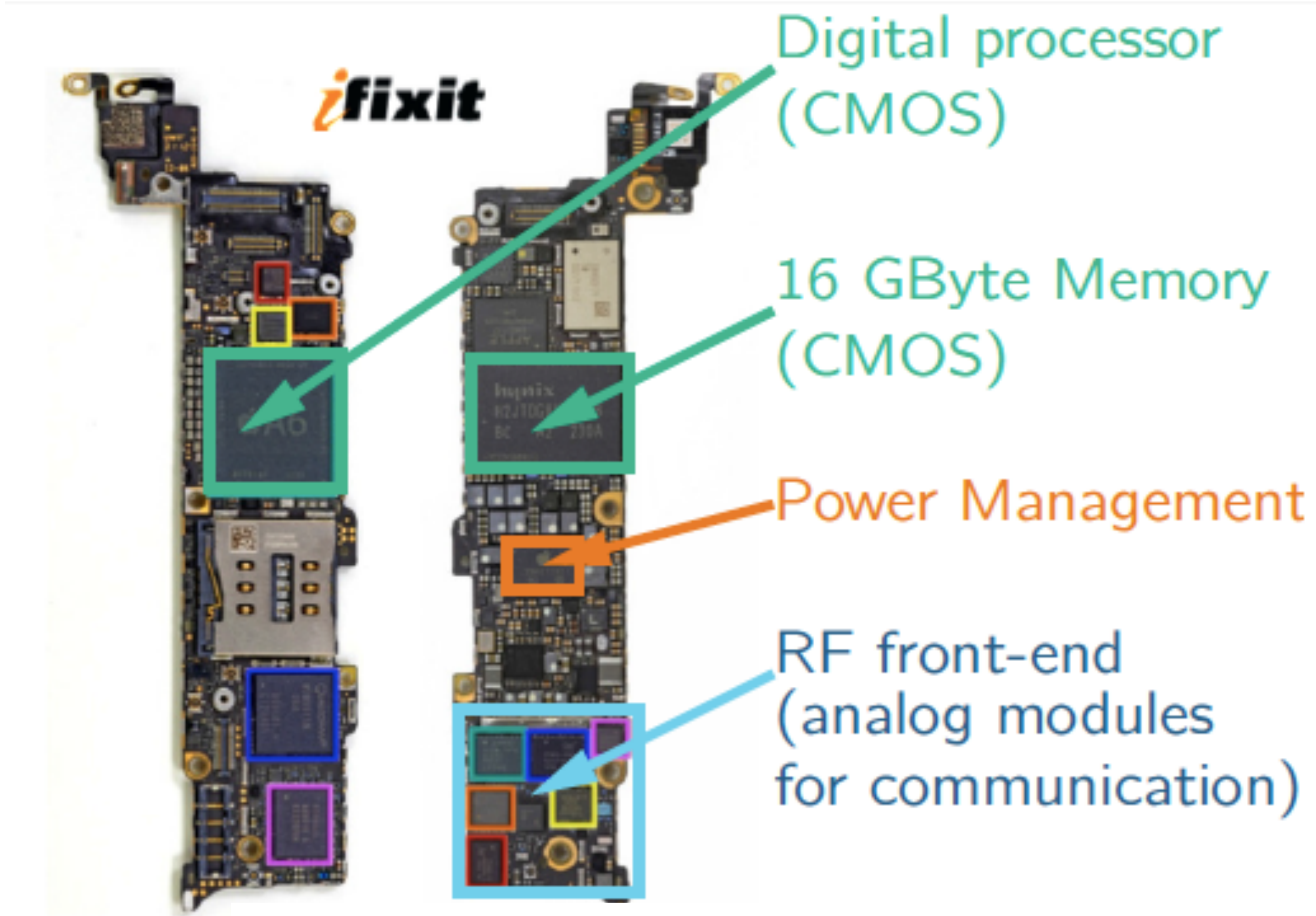
symbol



NPN BJT



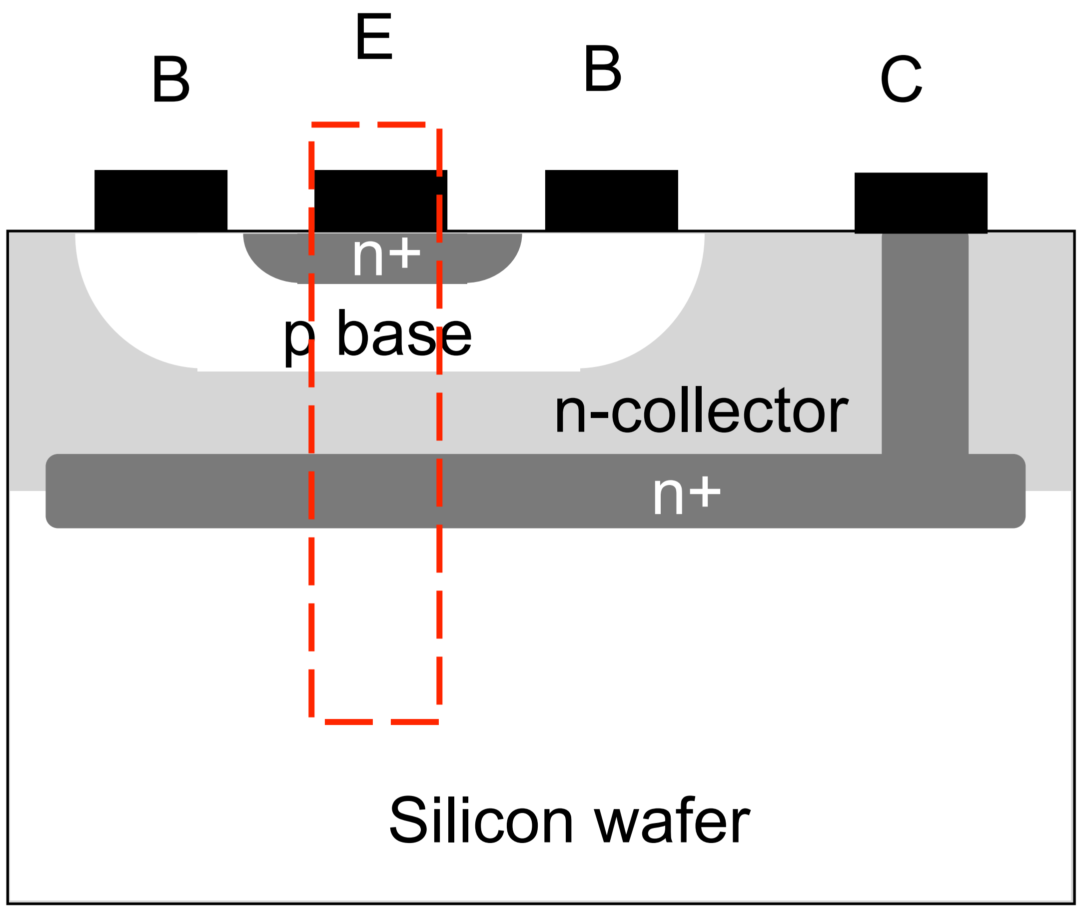
HBTs



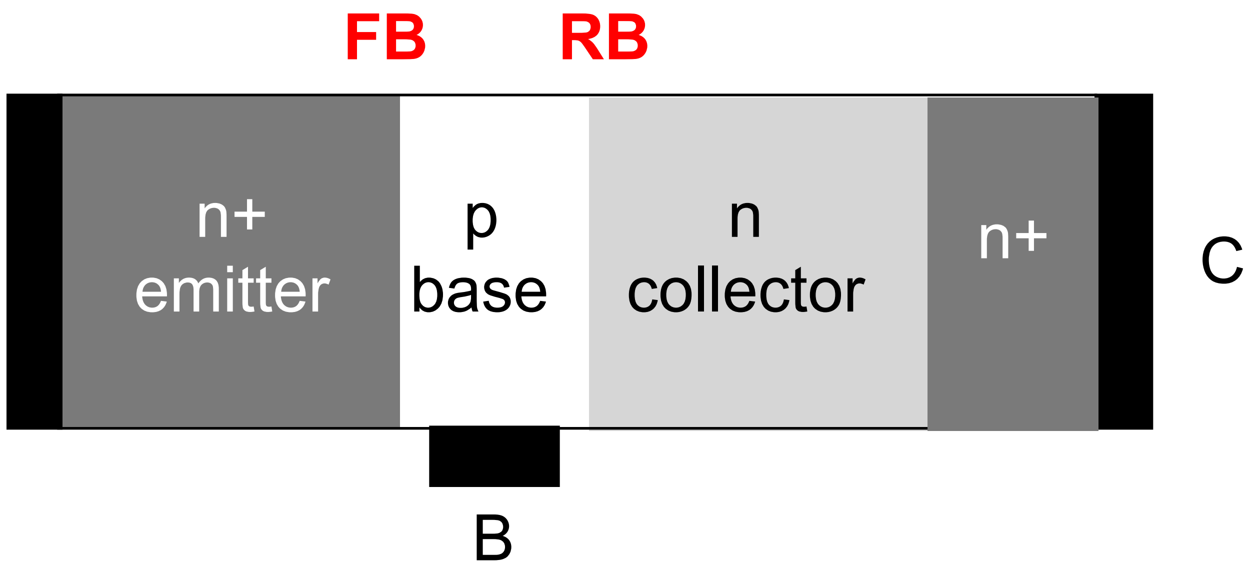
Circuit board of an iPhone 5

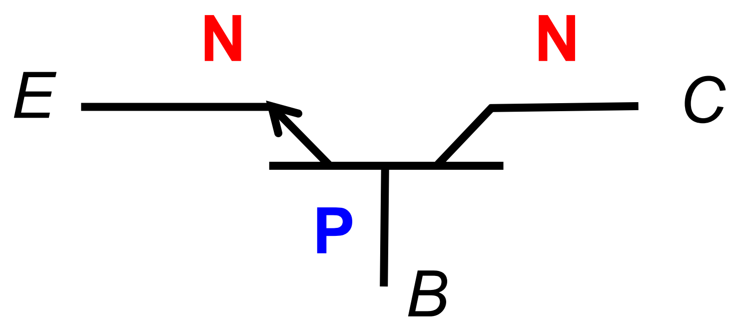
Lundstrom: 2019

Double diffused BJT



NPN BJT operation: active region

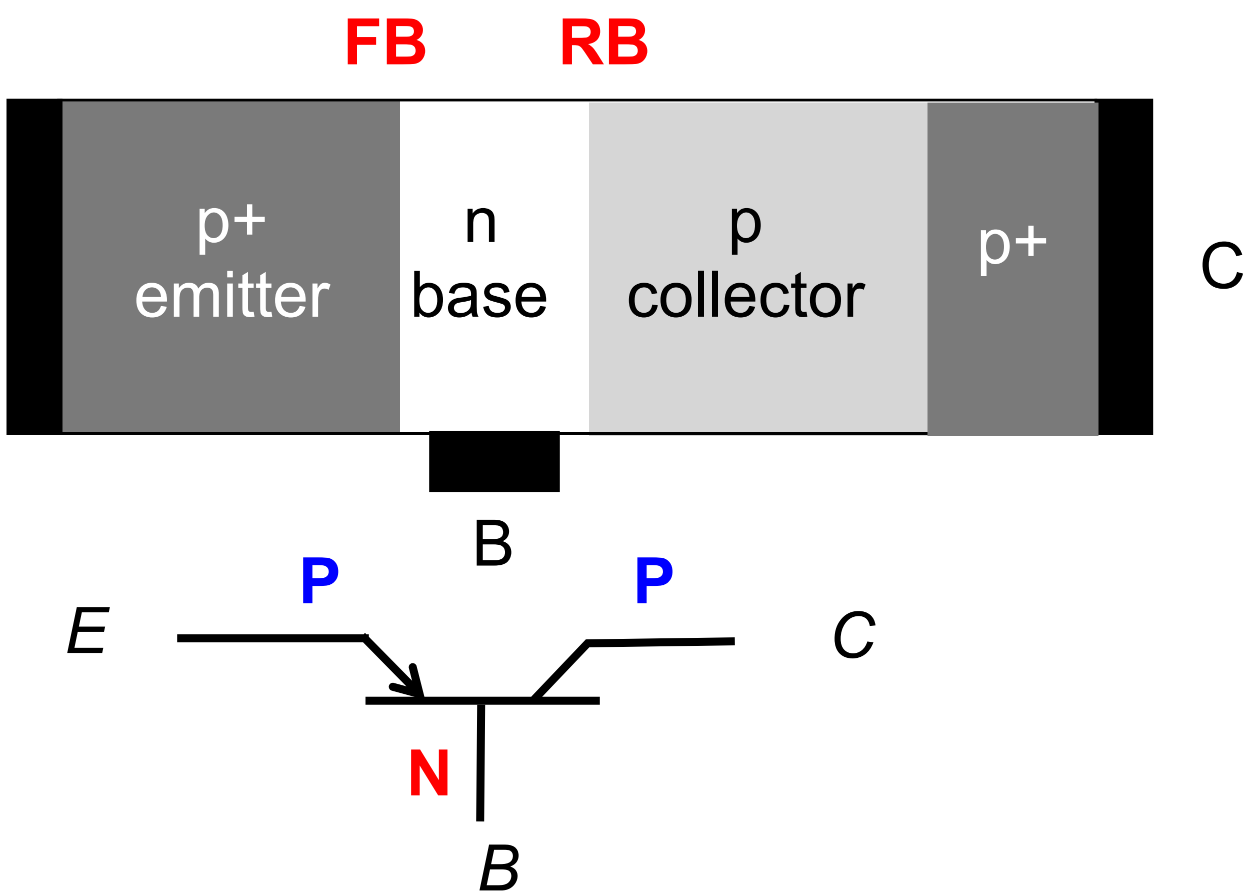




circuit symbol

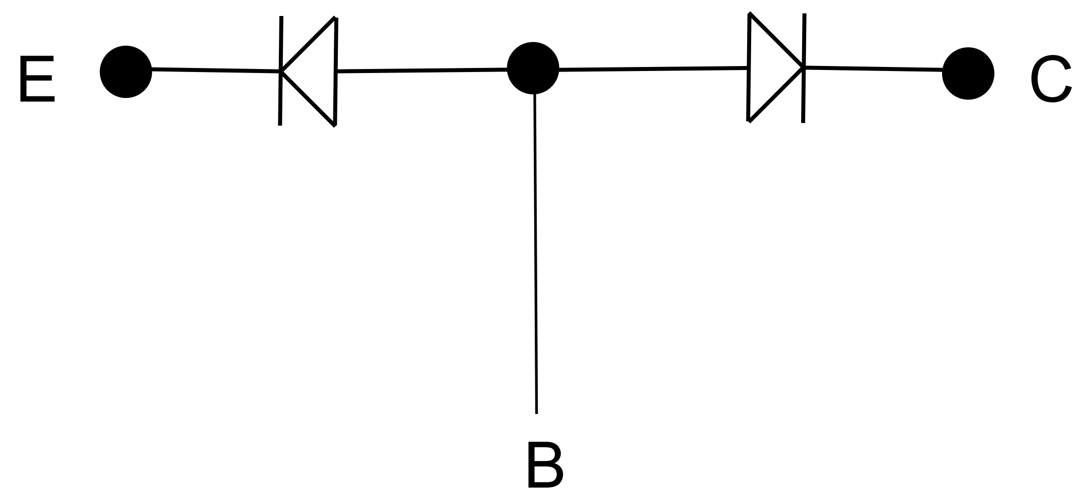
To understand this device, we just need to understand PN junctions.

PNP BJT operation: active region

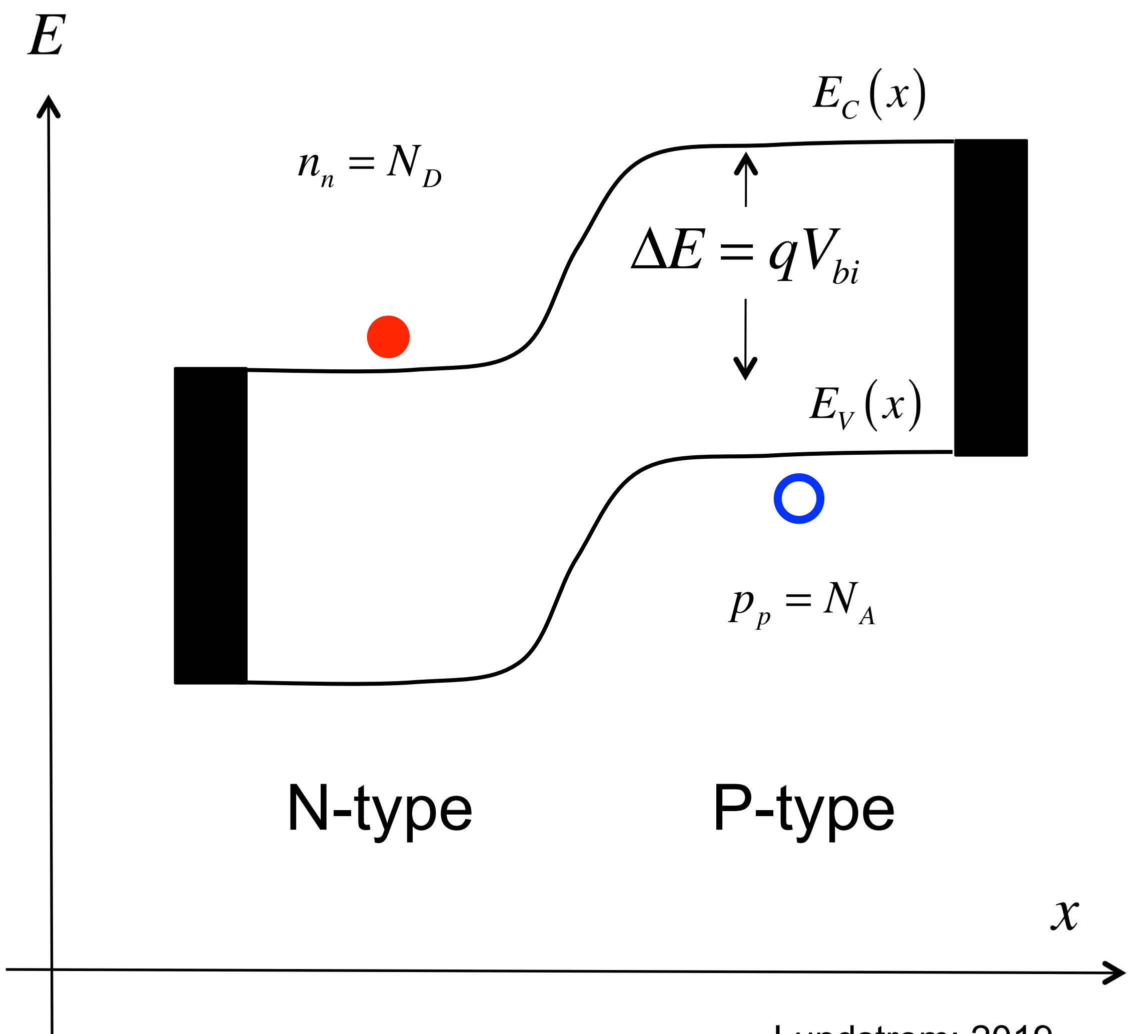


To understand this device, we just need to understand PN junctions.

This is **not** a BJT

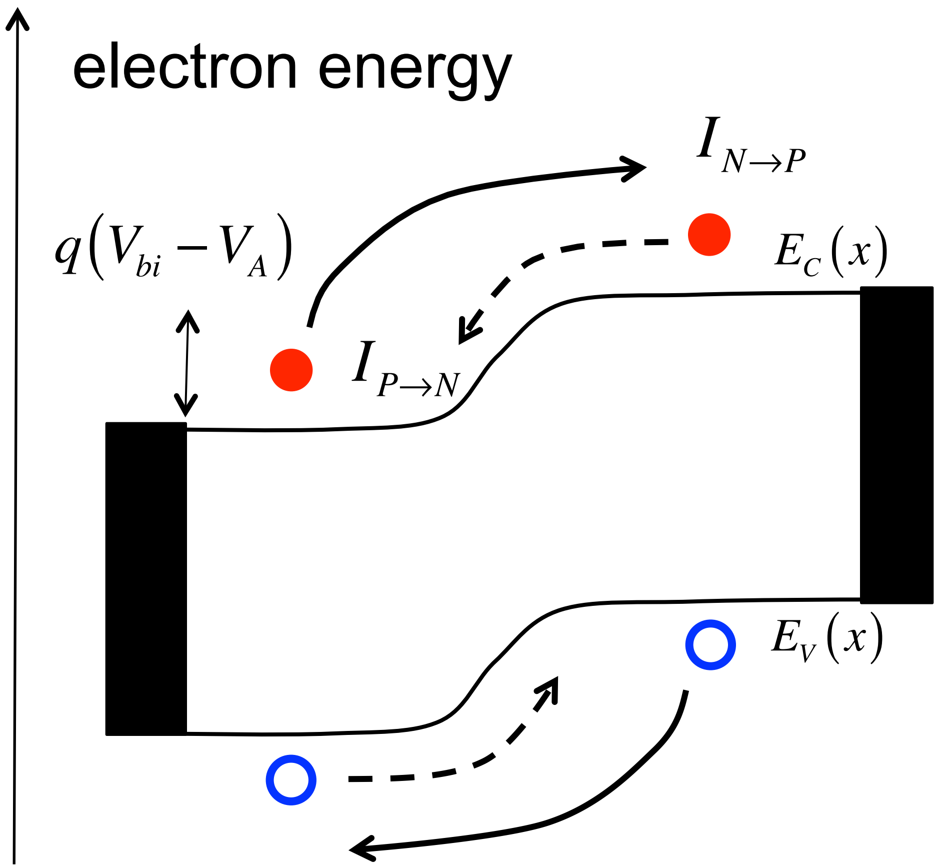


NP Junction in equilibrium



$$V_{bi} = \frac{k_B T}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

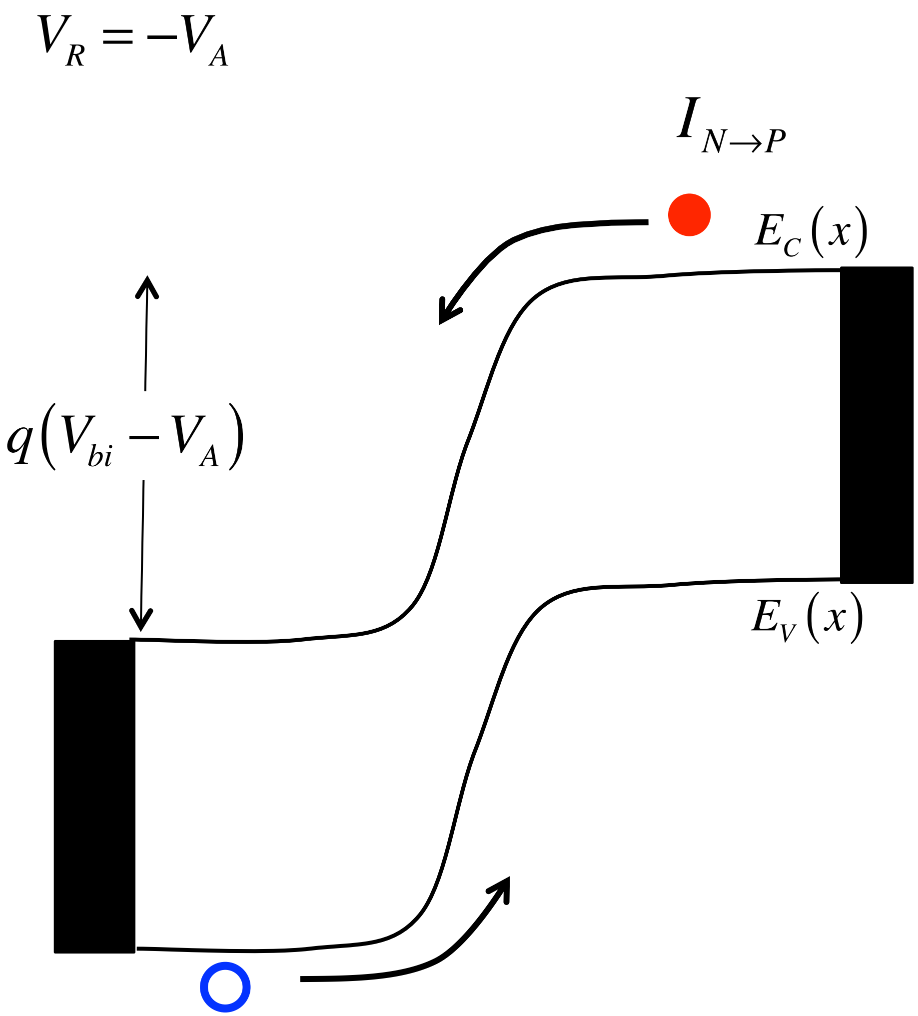
Forward biased junction



A FB junction **injects** electrons from the N-side across the junction and into the P-side.

A FB junction also **injects** holes from the P-side across the junction and into the N-side.

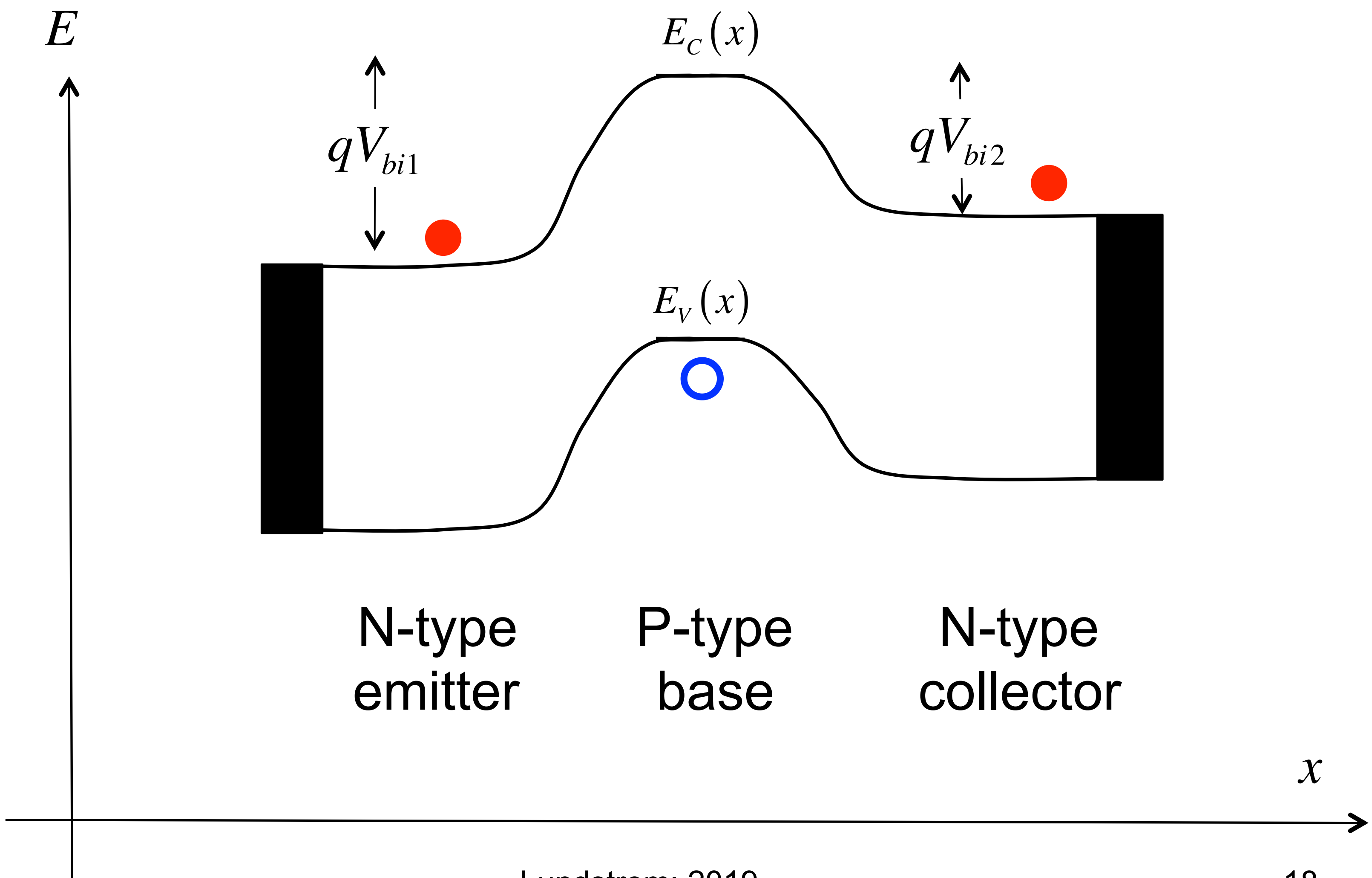
Reverse biased junction



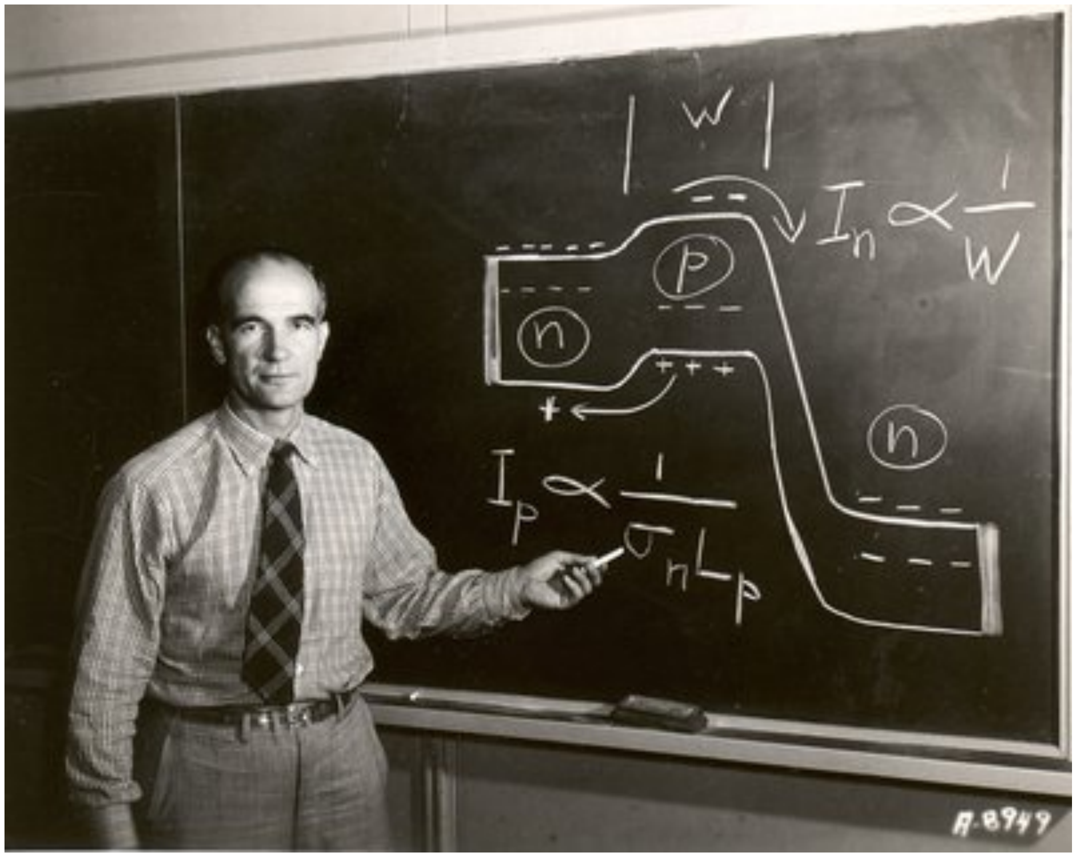
A RB junction **collects** minority carrier electrons from the P-side.

A RB junction **collects** **minority** carrier holes from the N-side.

BJT: equilibrium energy band diagram

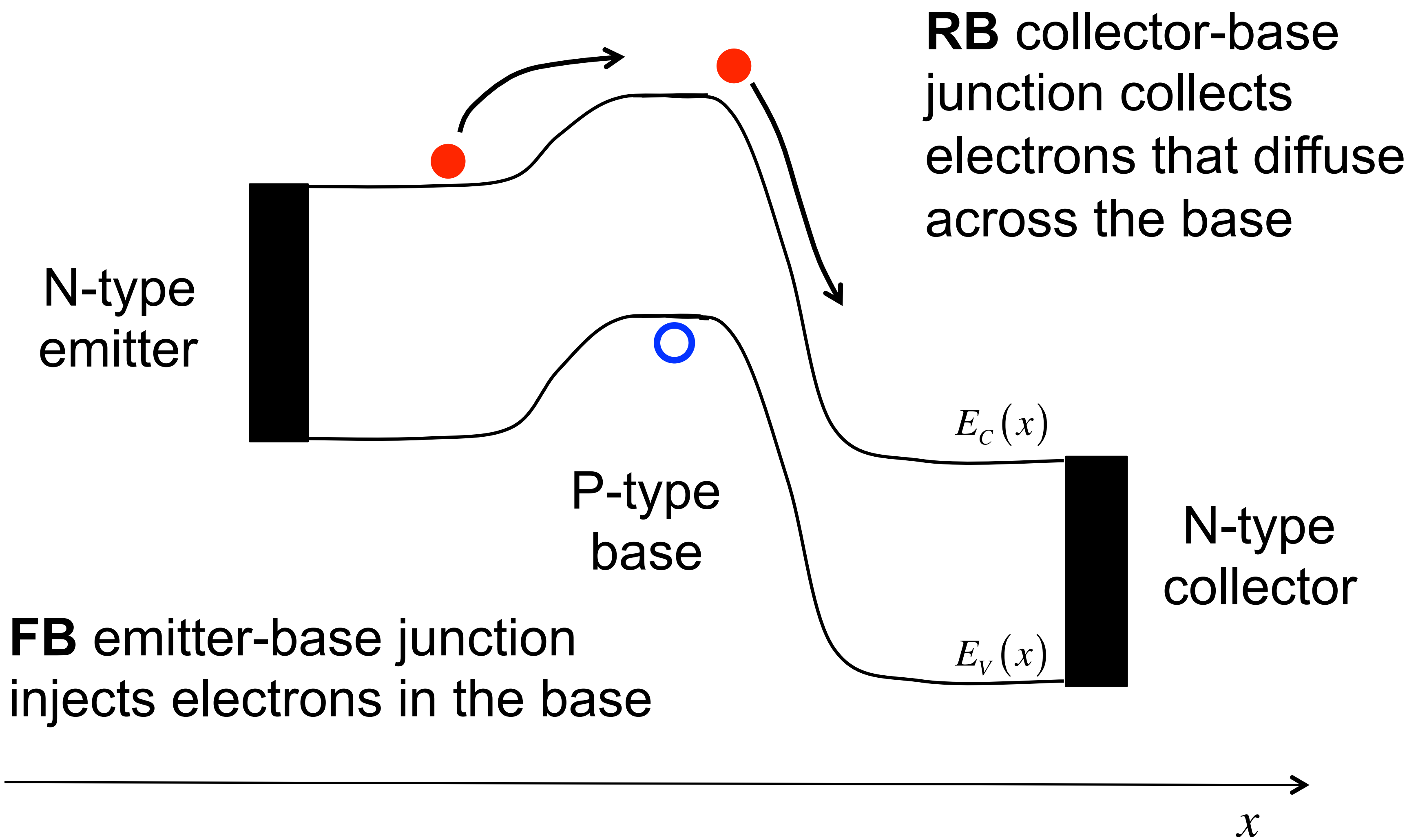


Energy band diagrams

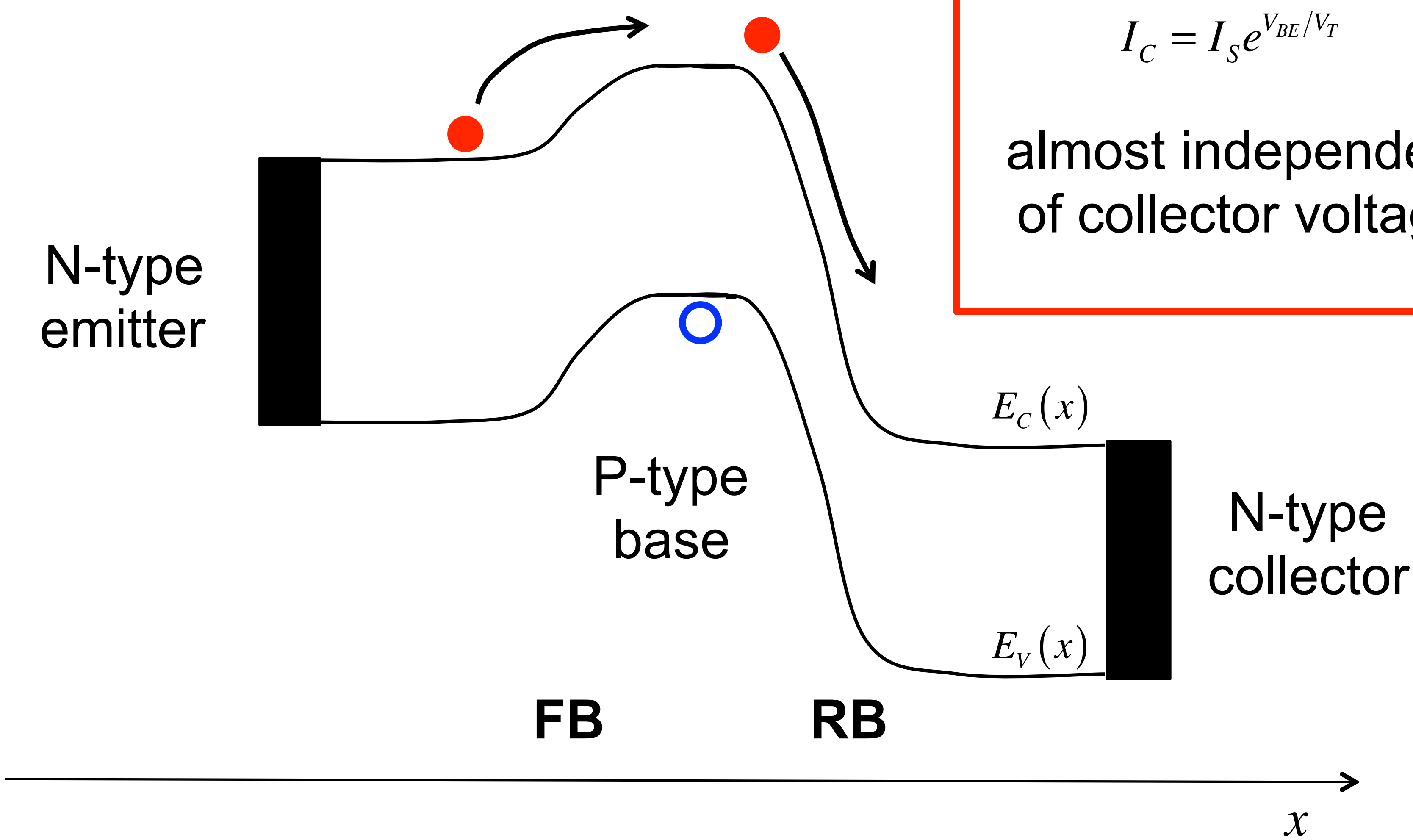


https://www.pbs.org/wgbh/americanexperience/features/silicon-timeline-silicon/

BJT: active region energy band diagram



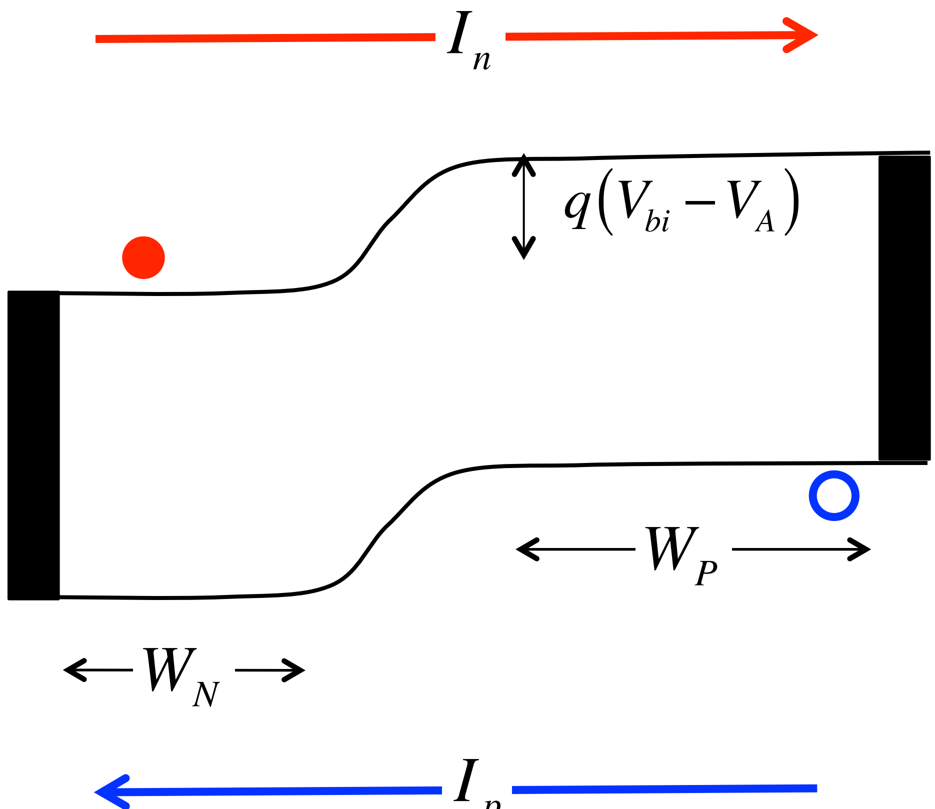
BJT: active region energy band diagram



$$I_C = I_S e^{V_{BE}/V_T}$$

almost independent of collector voltage

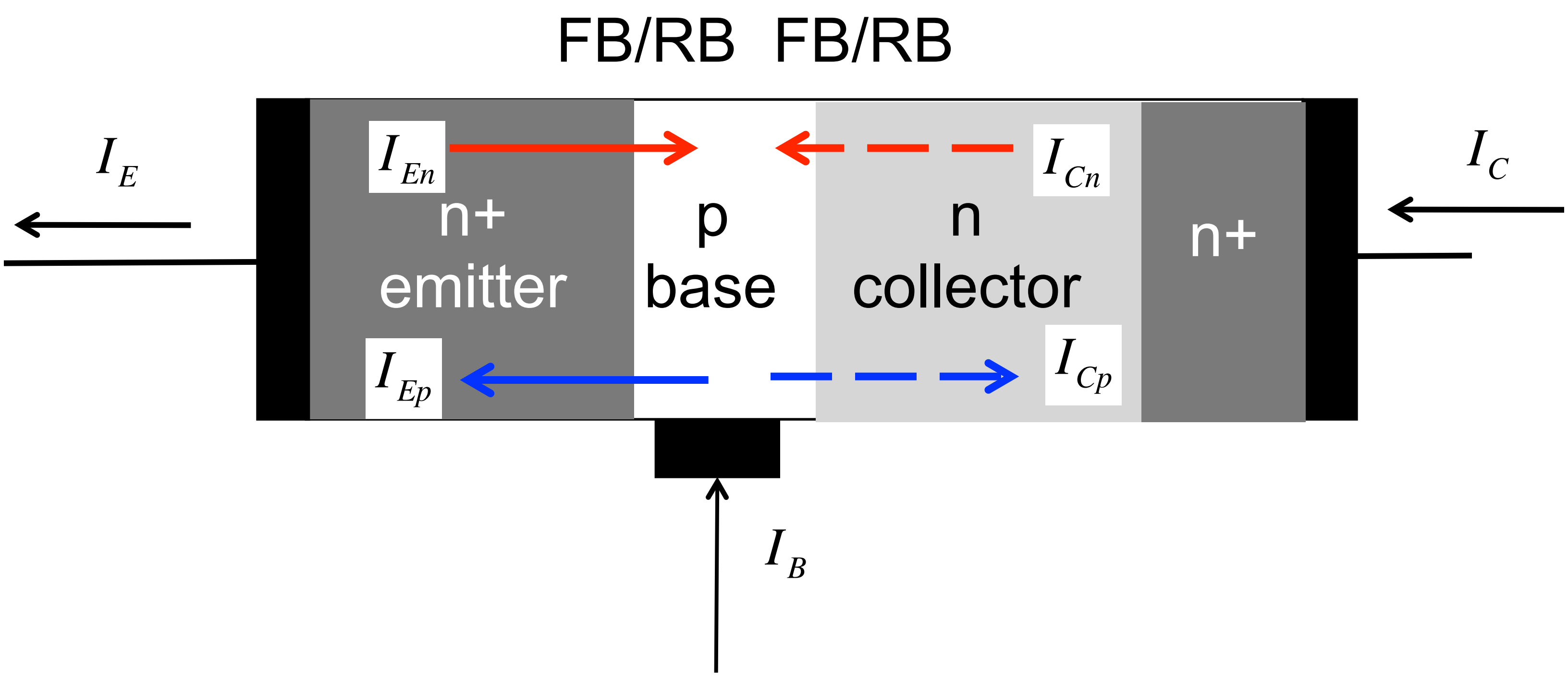
Forward biased NP junction



$$I_n \propto \frac{n_i^2}{N_A} e^{V_D/V_T}$$

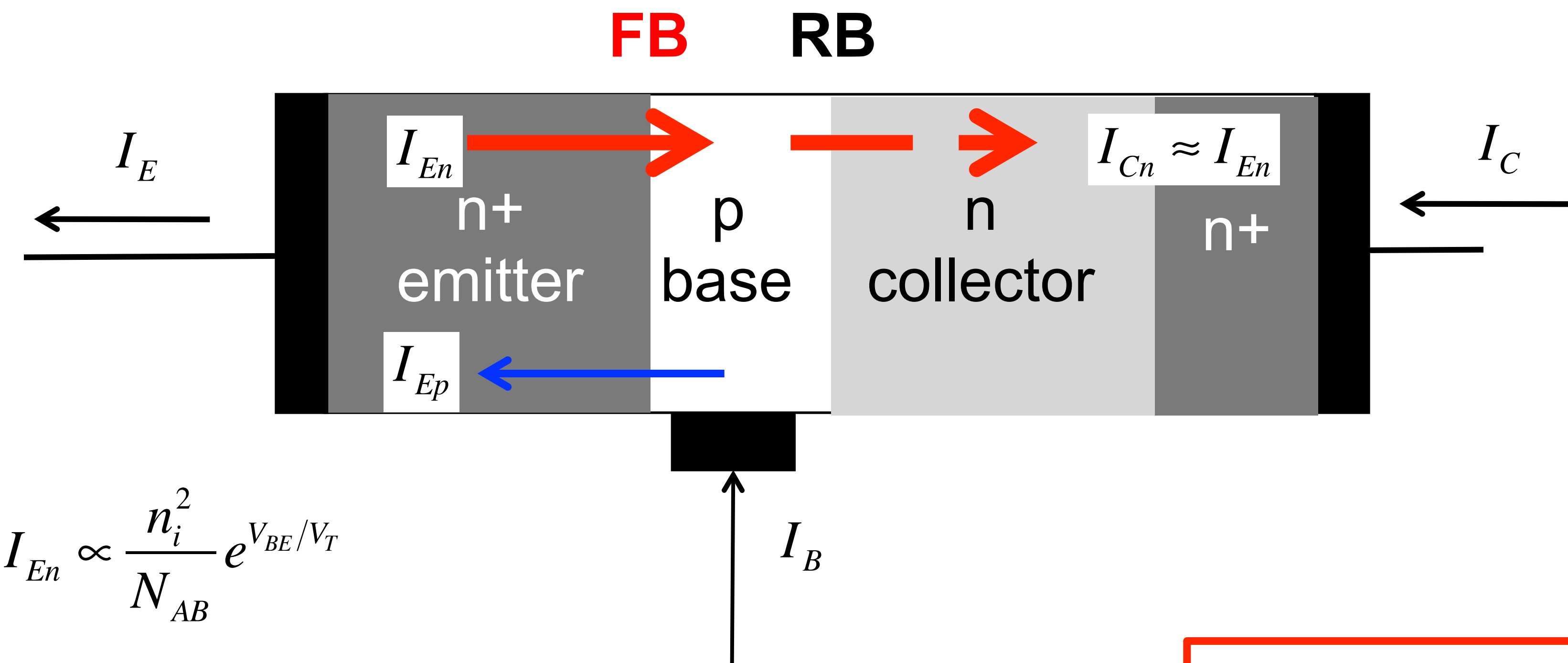
$$I_p \propto \frac{n_i^2}{N_D} e^{V_D/V_T}$$

NPN BJT operation (general)



In general, four currents, two for each junction

NPN BJT operation (active)



$$I_{En} \propto \frac{n_i^2}{N_{AB}} e^{V_{BE}/V_T}$$

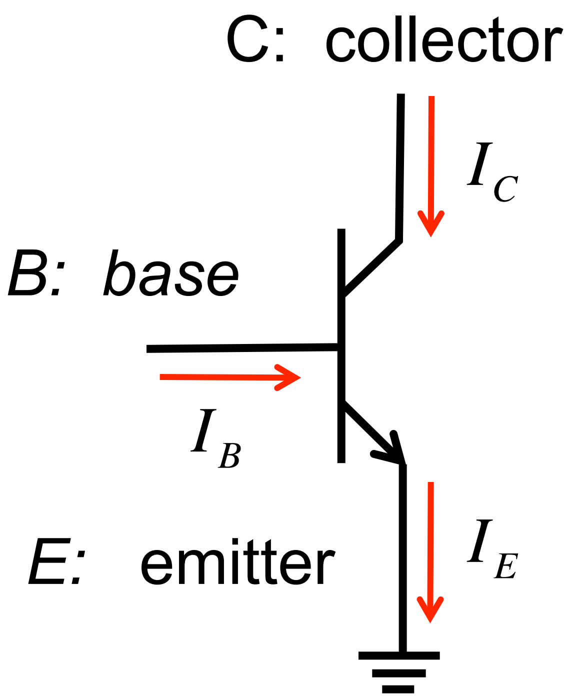
$$I_{Ep} \propto \frac{n_i^2}{N_{DE}} e^{V_{BE}/V_T}$$

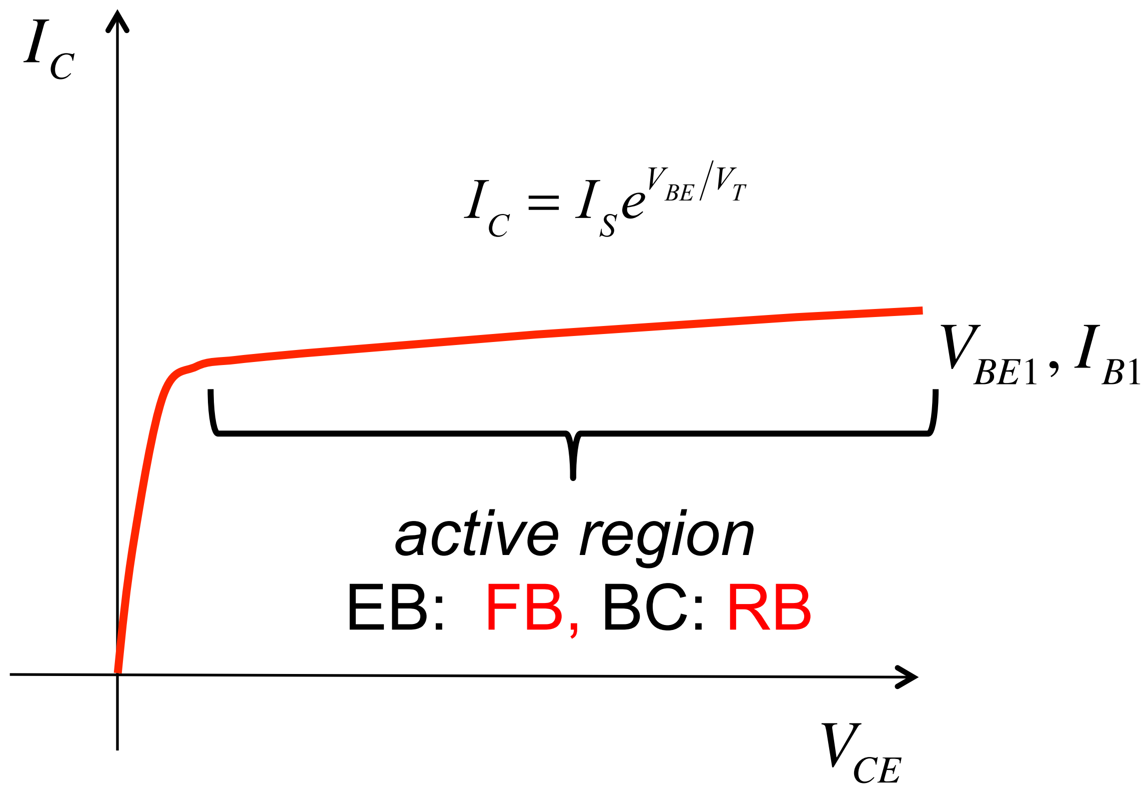
$$I_C \approx I_{En}$$

$$I_C = I_S e^{qV_{BE}/k_B T}$$

$$I_{En} >> I_{Ep} \qquad \left(N_{DE} >> N_{AB}\right)$$

BJT in active region

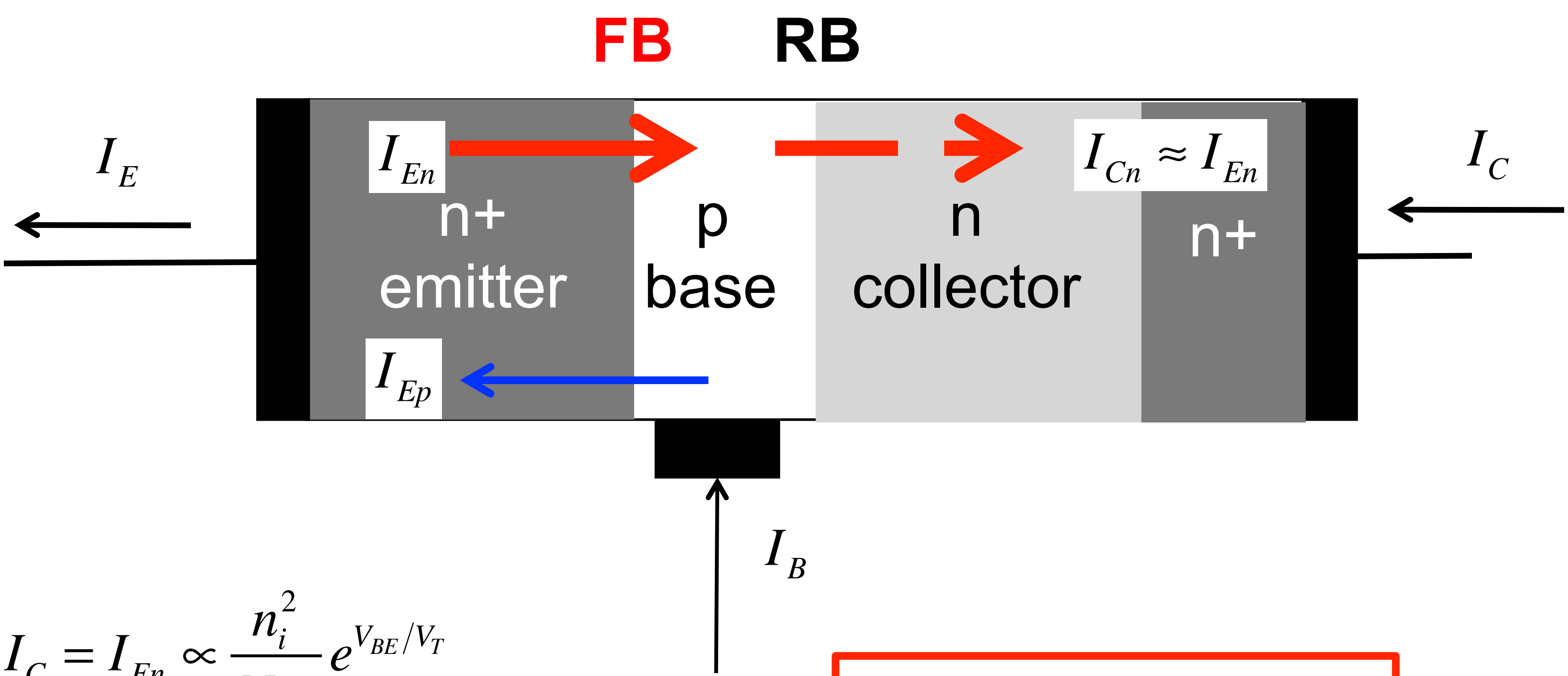




NPN BJT

Early effect: $I_C = I_S e^{V_{BE}/V_T}\left(1 + V_{CE}/V_A\right)$

Base current



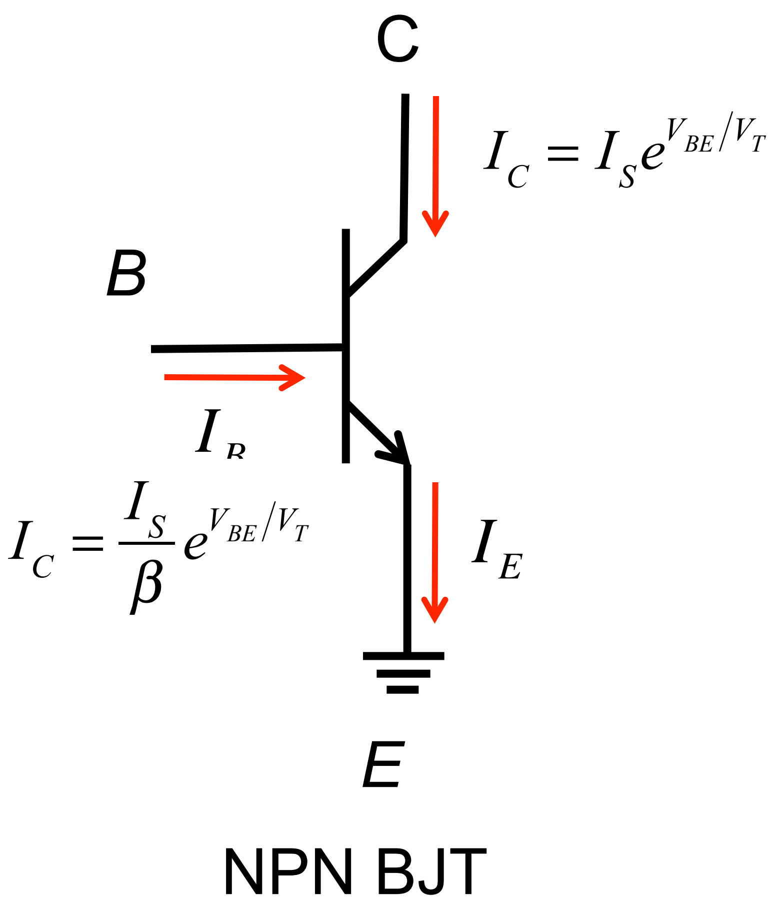
$$I_C = I_{En} \propto \frac{n_i^2}{N_{AB}} e^{V_{BE}/V_T}$$

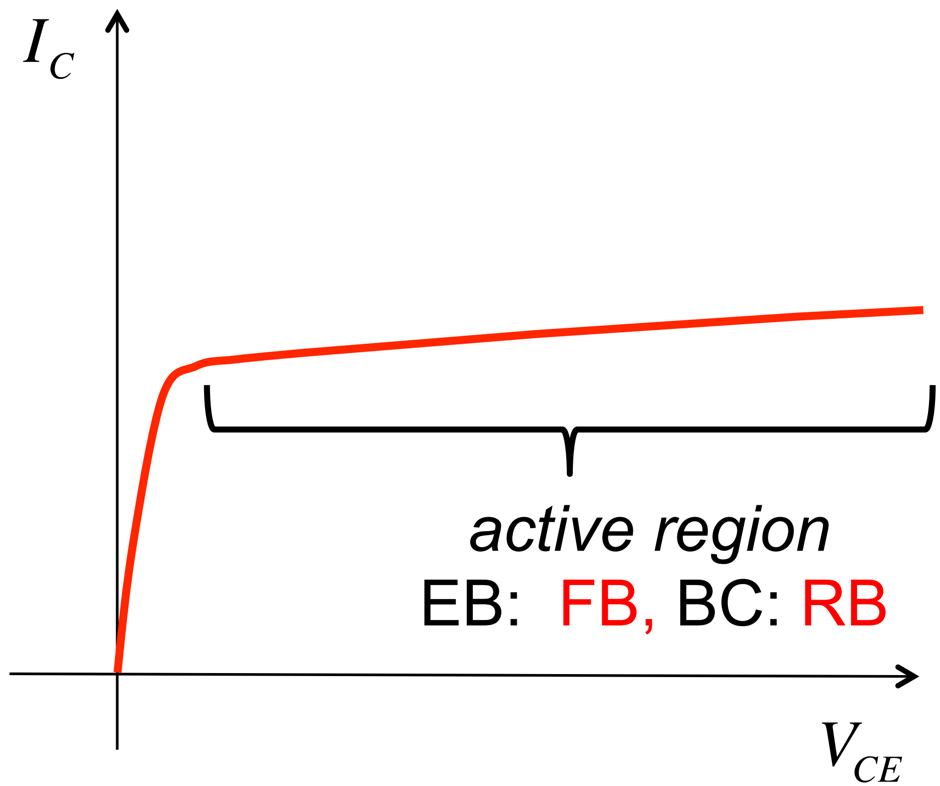
$$I_B \approx I_{Ep} \propto \frac{n_i^2}{N_{DE}} e^{V_{BE}/V_T} << I_C$$

$$I_B = \frac{I_S}{\beta} e^{V_{BE}/V_T} << I_C$$

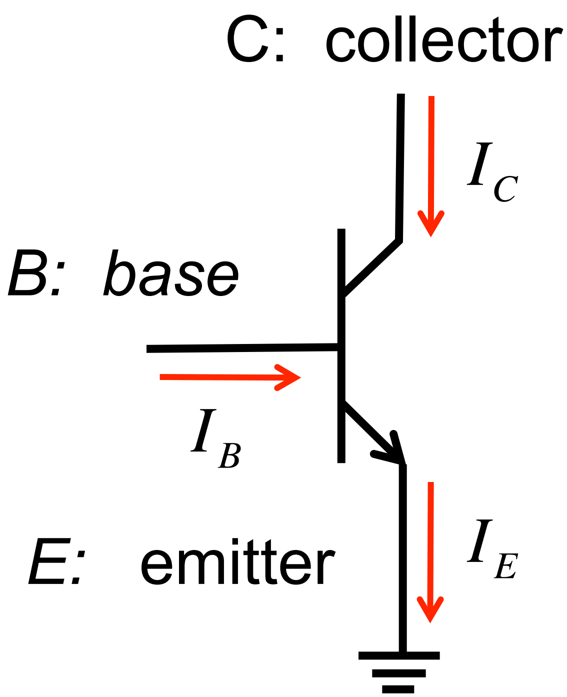
$$10 < \beta < 1000$$

BJT in active region (beta = 100)

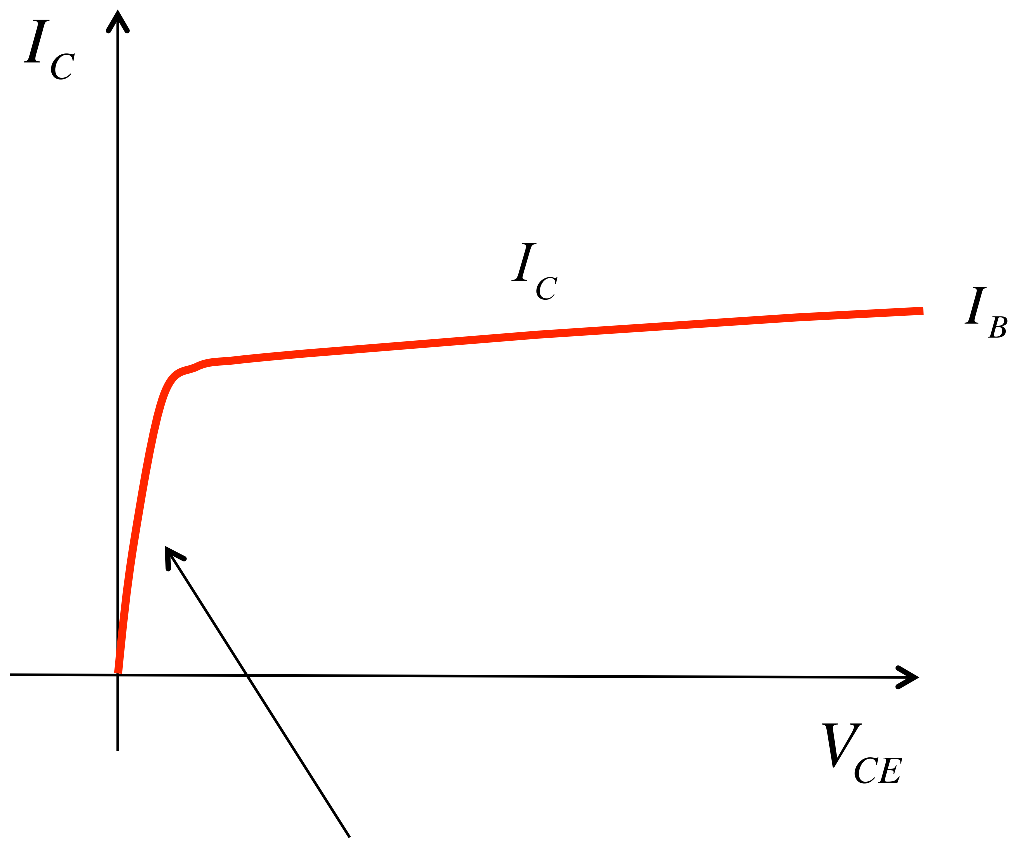




BJTs at low V_{CE}

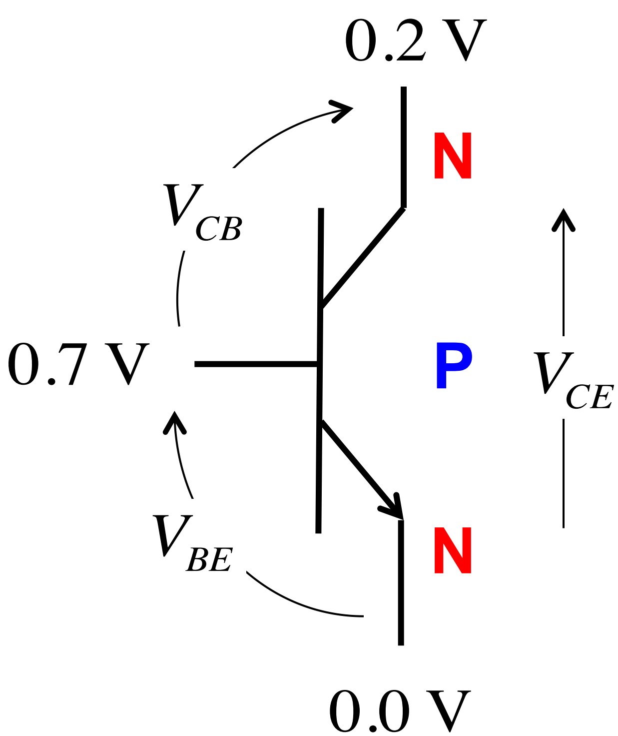


NPN BJT



What happens here (at low V_{CE})?

NPN BJT at low V_{CE}



KVL:

$$V_{BE} + V_{CB} = V_{CE}$$

Active region:

$$V_{BE} \approx 0.7 \text{ V}$$

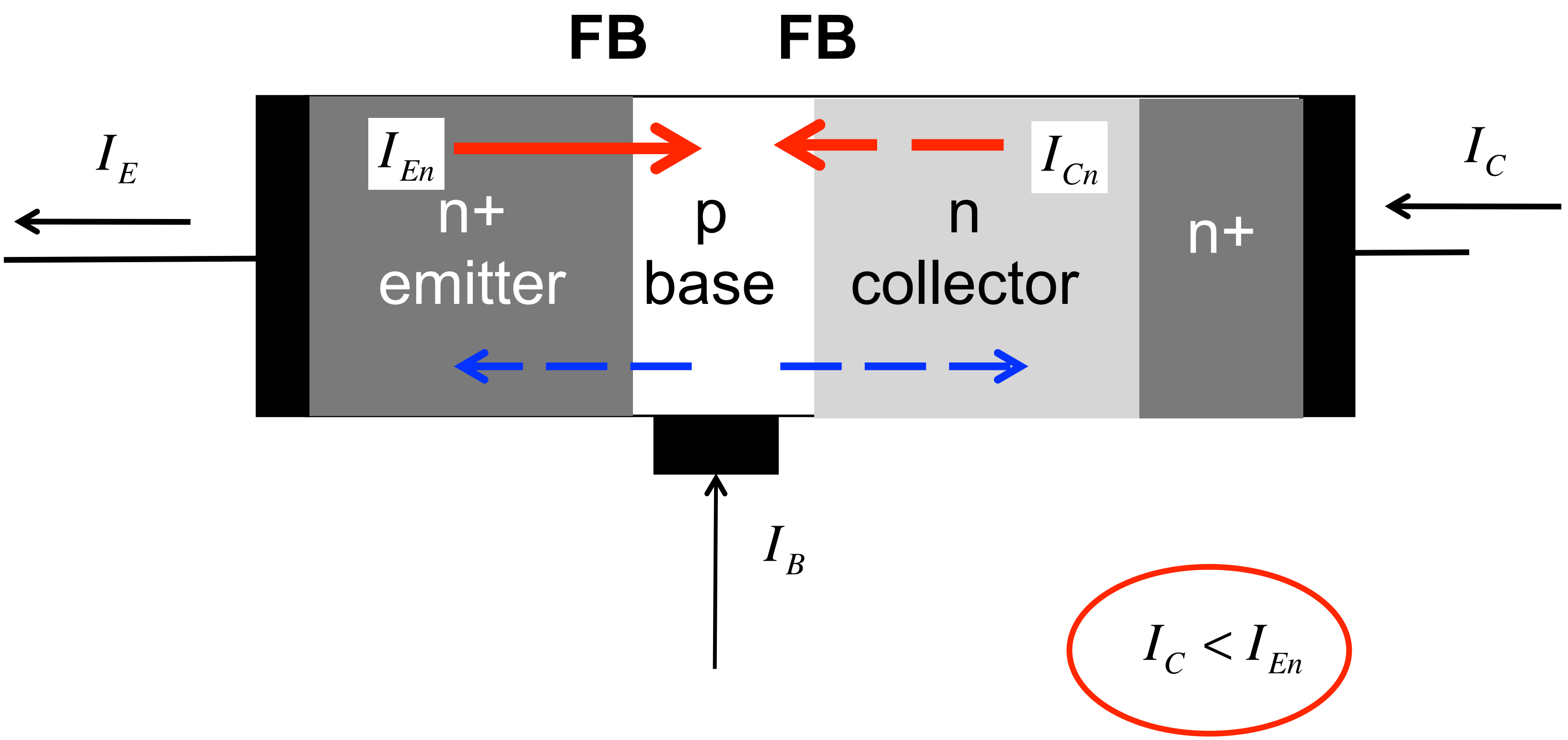
If:

$$V_{CE} < V_{BE}$$

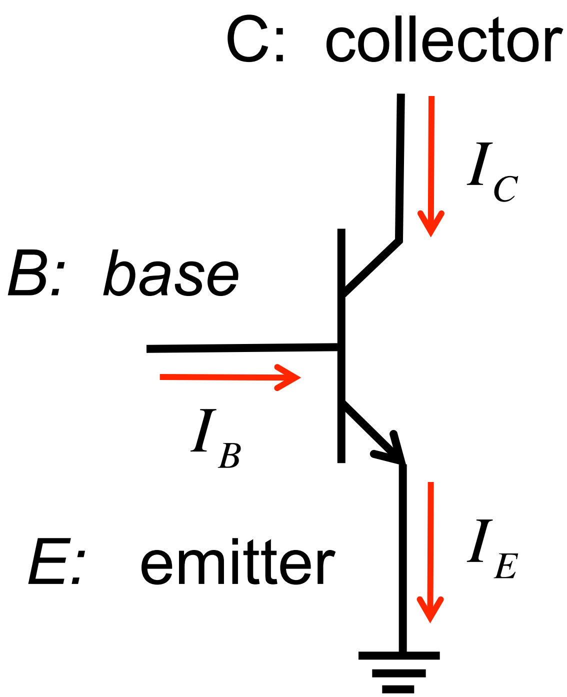
$$V_{CB} < 0$$

The base-collector junction is forward biased!

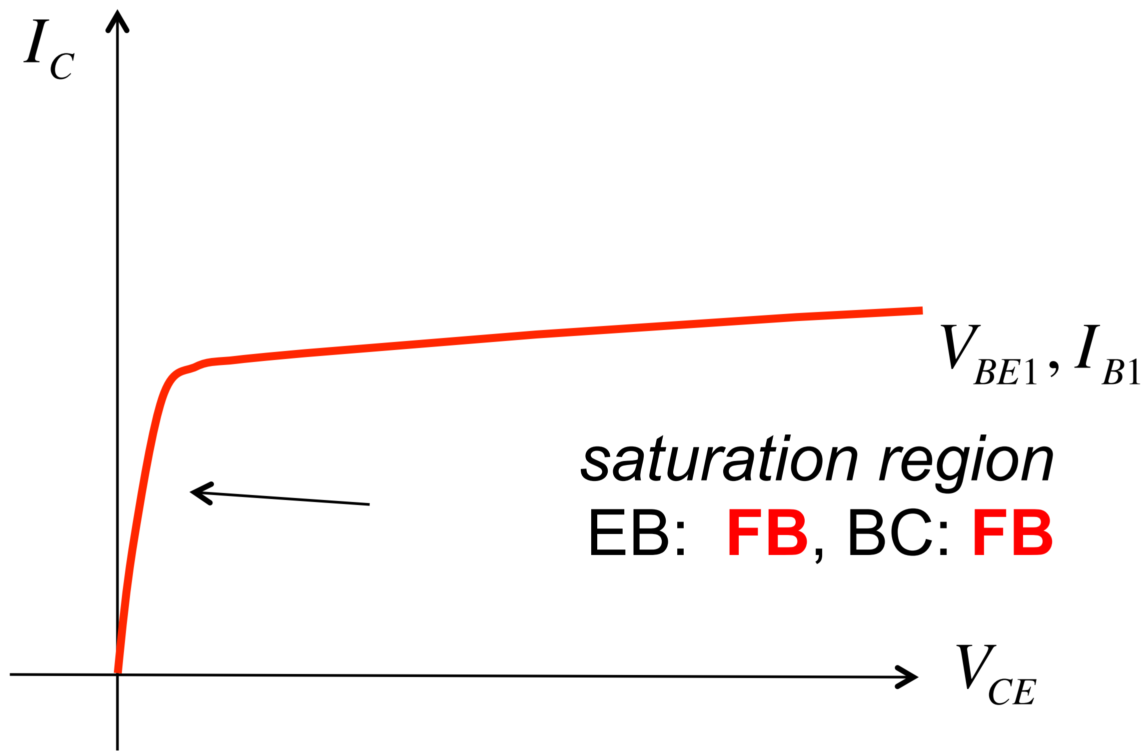
NPN BJT operation (saturation)



BJT at low V_{CE}



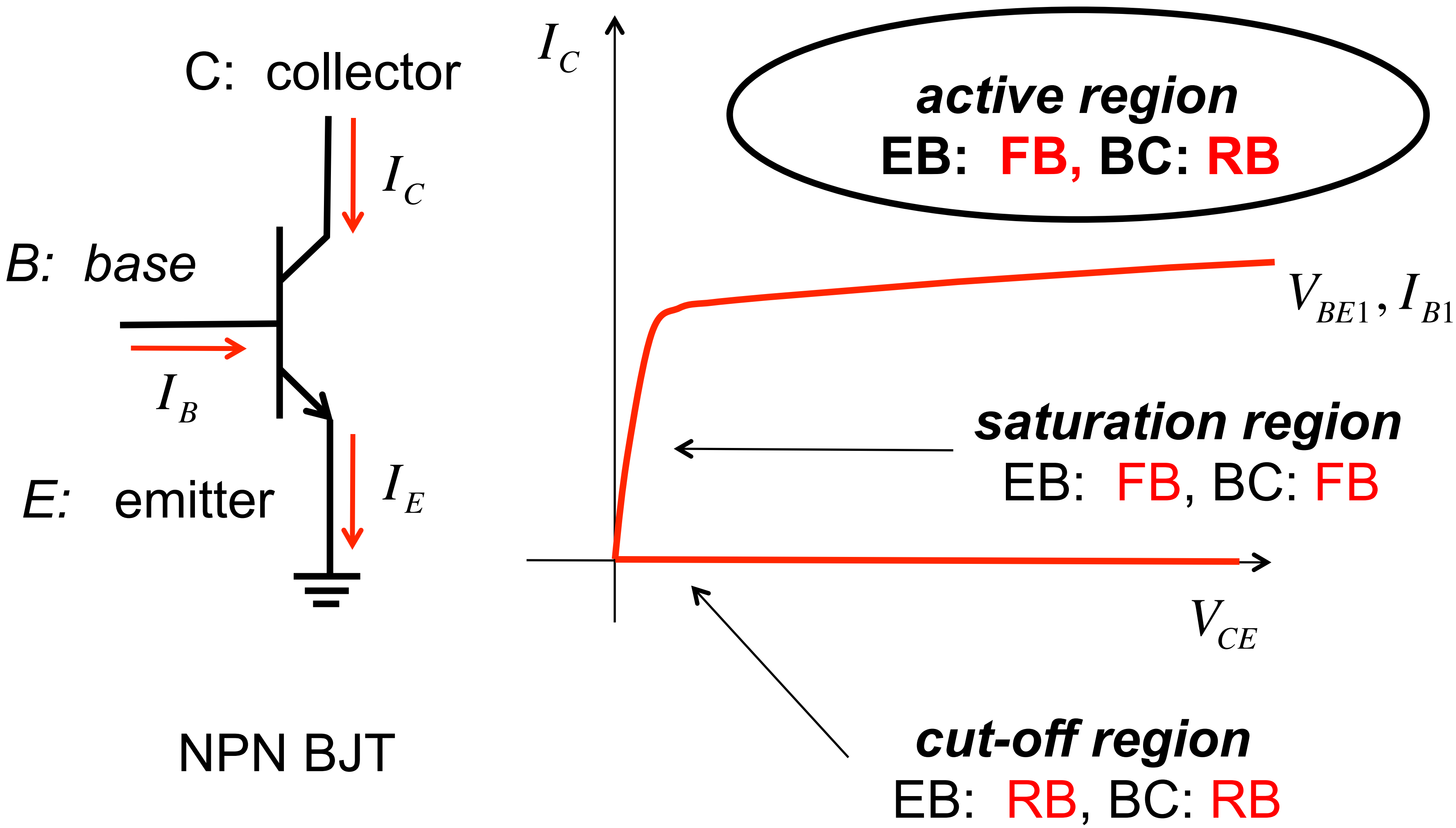
NPN BJT



$$I_C < I_S e^{qV_{BE}/k_BT}$$

$$I_B > \frac{I_C}{\beta}$$

Three regions



NPN BJT

Summary

A BJT consists of two, interacting PN junctions.

BJTs come in two flavors – NPN and PNP.

In the active region, the EB junction is forward biased and the BC junction is reverse biased.

In the active region, a small base current produces a much larger collector current.

BJT's

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