ELEN E3106/4106 Lecture 15

Introduction to BJTs

Outline

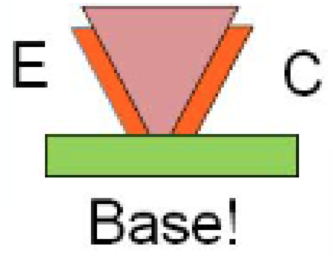
- Qualitative overview
- Theory of operation
- Energy band diagrams
- Electrostatics in Equilibrium

Assignments:
Reading: Streetman and Banerjee §7.1-7.2
Exam 2 this Tuesday Oct. 28th during class

BJT Intro

- B________ J_____________ T__________
  - Bipolar: both ___ and _____ involved
  - Junction: p-n junctions are critical to its operation!





1947
Invention of the 1st transistor (Ge point contact)
Shockley, Bardeen, Brattain
Bell Labs

What do transistors do?

1. **Amplification:** a _______ signal (I or V, terminal #2) can ______________(usually I, flowing between terminal #1 and #3)
   - Think of a ___________ controlling the amount of _________ through a giant hose!
2. **Switching:** the transistor can be turned __________

- Two main types of transistors studied in E3106/4106:

  1) BJT: small input current (faucet) controls large output current (hose) e.g. ____________________

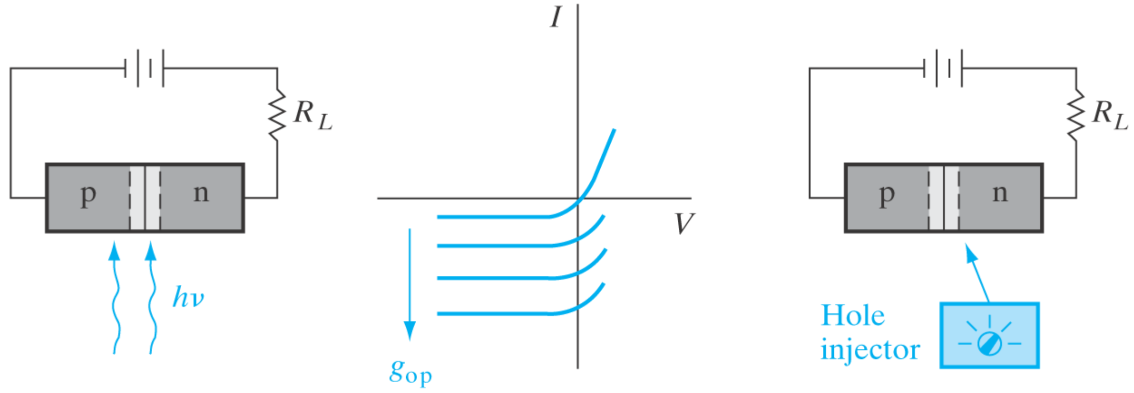
  2) Next unit: Field effect transistors (FET): small input voltage (faucet) controls large output current (hose) e.g. ____________________

Sources: E. Pop ECE 340 Slides

BJT Advantages and Recap of p-n Diode

- Disadvantage: Current-controlled current sources always have some current flowing (___________________)
  - Limits ______________ per chip
  - This is where FETs have an advantage
- BJTs have gradually been replaced by CMOS in the past 30 years, especially for high-speed logic
- But, BJTs are better for have __________

and _______
  - Better for ___________ circuits

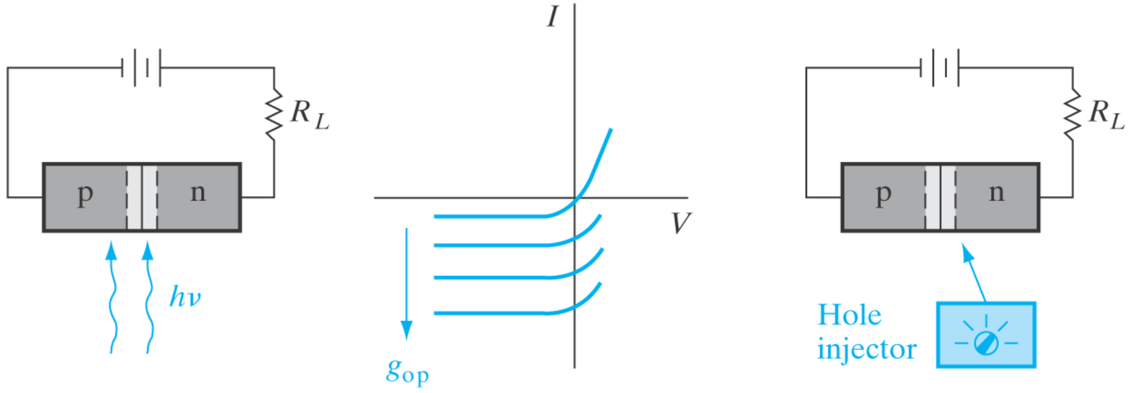


- p-n diode with the lights on
  - Recall: In RB, the current with the lights off was *small (______)*
- When light is on, it creates EHPs in the ______. Assuming L.L. injection, minority carriers are easily ___________ by the E-field and injected into the other side, modulating the current.

Sources: ECE 340 Slides, Textbook

BJT Principle of Operation

- Takeaway of RB p-n diode under illumination: we can __________ the reverse current through the diode by __________ the rate of EHP generation!
- Question: Is it possible to inject ________________ into the neighborhood of the junction electrically instead of optically?
- ______! Consider a "hole injection device
- If we can inject _____ into n side, current will resemble optical generation effects
    - Current from n to p will depend on rate of injection and **not** _________



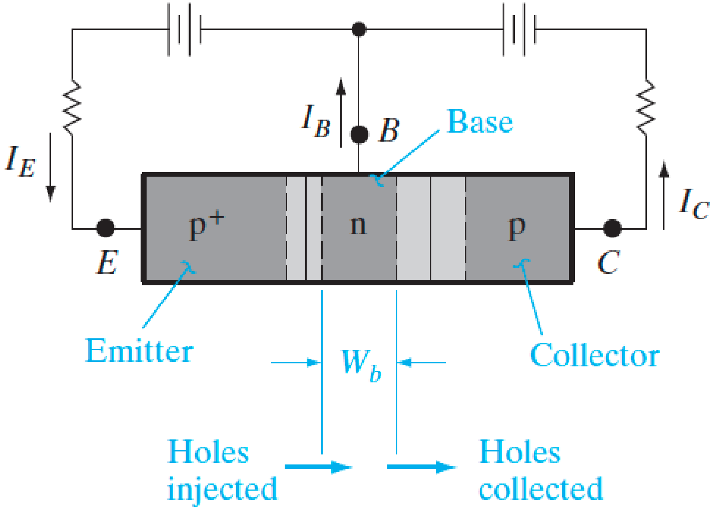
- What happens to the current if we increase the external load, R_L?

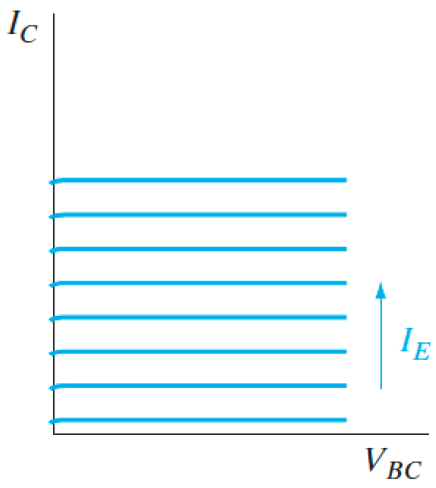
Sources: ECE 340 Slides, Textbook

BJT Principle of Operation

- What would be a convenient hole injection device?
  - A _____ p⁺-n junction!
  - Recall: current due primarily to ____ injected from p+ side into the n material
- If we make the _______ of the RB p-n junction the same as the n-side of the FB p⁺-n junction, we have a ________ BJT!
  - A BJT is basically ______________ p-n junctions

Common base **configuration: base electrode B is common to the emitter and collector circuits.**

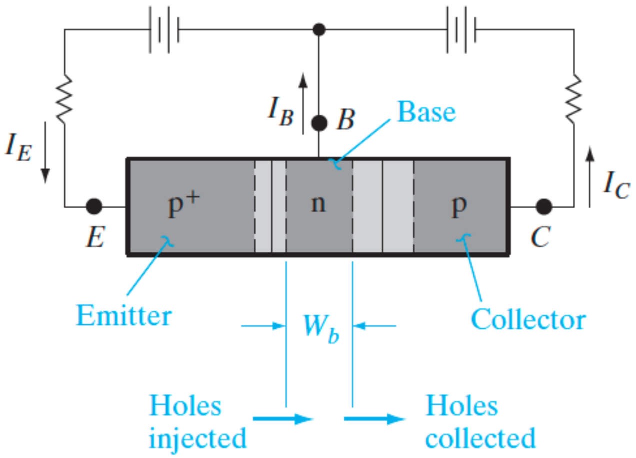


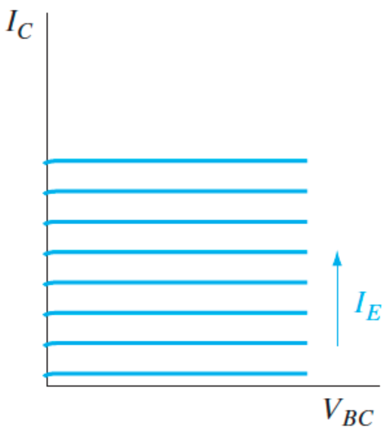


pnp BJT with FB emitter and RB collector and the I-V characteristics of the RB n-p junction (collector) as a function of emitter current.

Sources: ECE 340 Slides, Textbook

BJT Requirements for Efficient Hole Collection

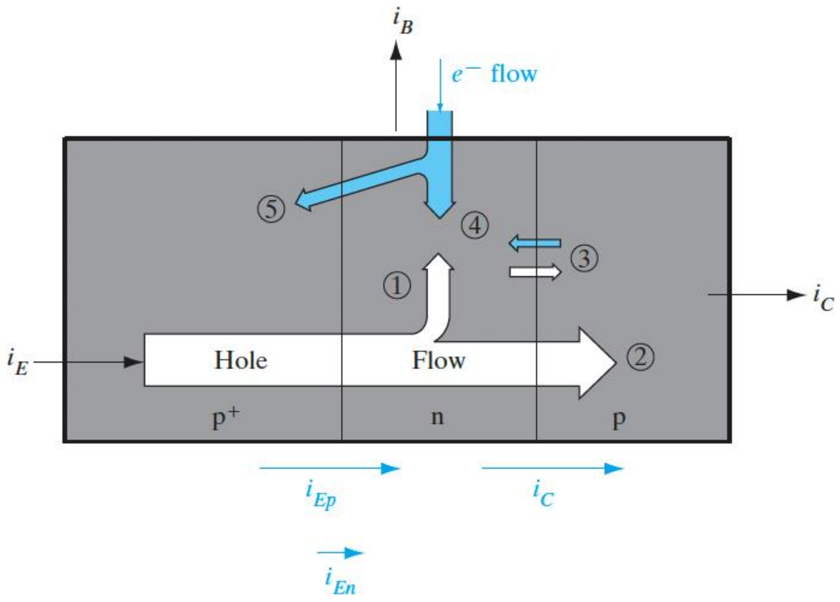




- __________ (_______ junction) injects h+ into RB base-collector
- Requirement: For __________ to collect most holes, the n base region ____ must be ________ compared to the hole diffusion length so carriers don't ________ before reaching collector! $W_b \ll$ ____ (we called this a __________ diode!)
  - Recall: $L_p = \sqrt{D_p \tau_p}$
- If so, when BJT is biased ______ then almost all injected holes are collected:
- $I_E \approx$ ____ are the "large" currents here (water passing through the hose)

Sources: ECE 340 Slides, Textbook

BJT Base Current



- But is there a base current ____? Why?
- Recall: base is __-type in pnp
  - Some e- in the base will _______ with injected holes
  - Some e- will be _______ from n to p+ in the FB emitter junction
  - Some _________________ e- from collector are swept into base at the RB collector junction (reduces I_B)
- Ideally, I_B is very _______ so $I_E \approx I_C$
- In properly designed BJT, $I_C = IE - I_B \; where \; I_E \approx$ ______I_B

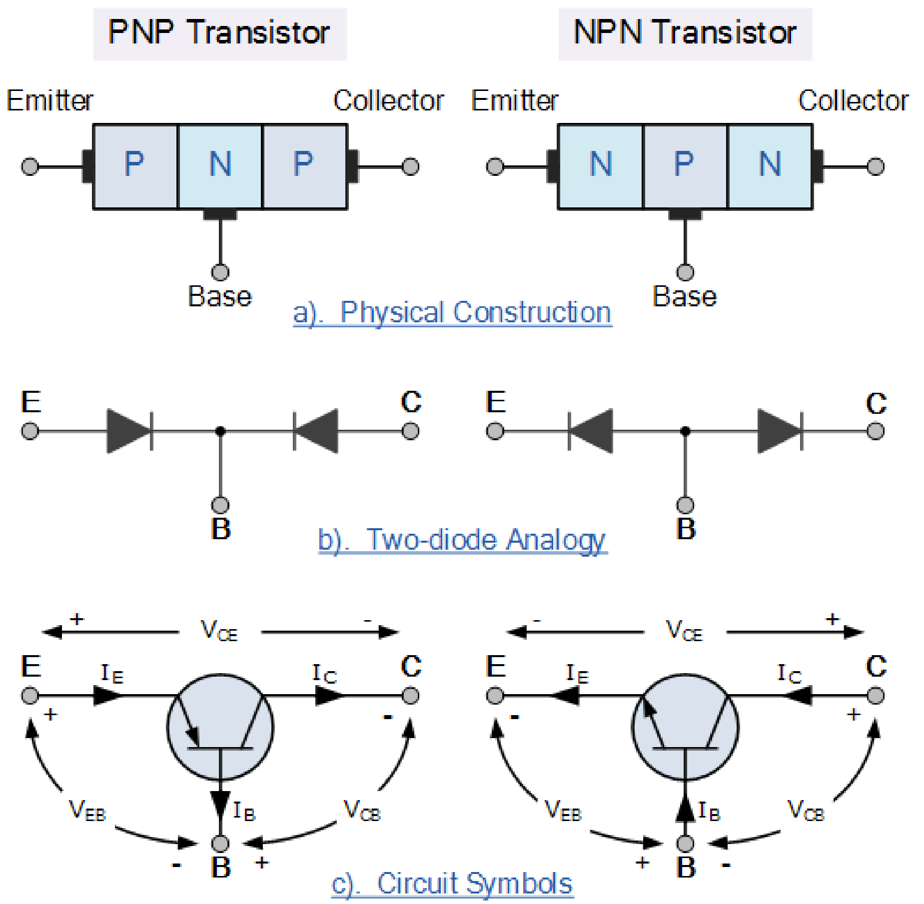
Sources: ECE 340 Slides, Textbook

BJT Symbols and Conventions

- Why does direction of arrow in symbol note?

- In pnp, current flows ______ from the emitter
- In npn, current flows ______ from the emitter

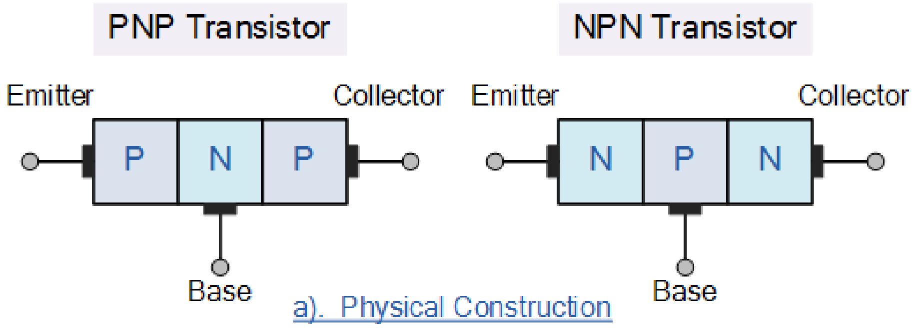
- Easier to study pnp because current flows in direction of _____
- But npn is similar, we can just reverse the roles of e- and h+ from our pnp discussion
- Which is faster? Why?



Sources: https://www.electronics-tutorials.ws/transistor/tran_1.html

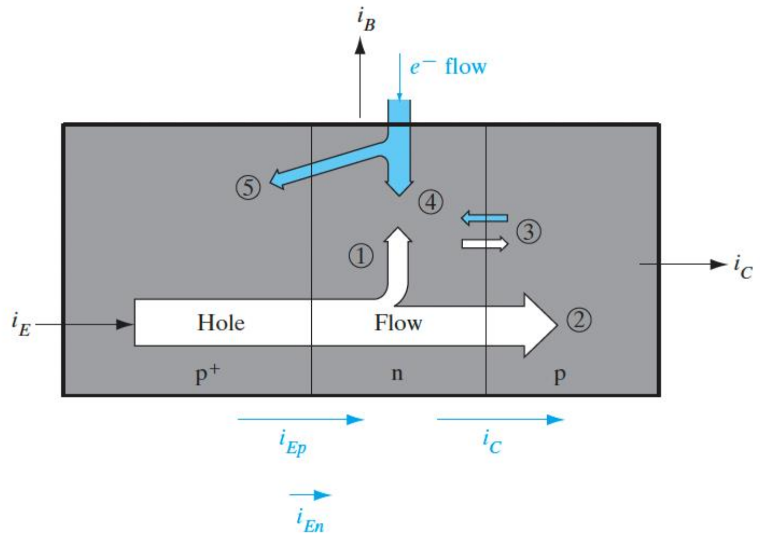
Transistor Terminals

- Terminal: Any externally available point of ________ (M-S contact)
- Recall: M-S contacts can be thought of as infinite carrier sources/sinks
- How many terminals does a transistor have?__________
- Terminal 1: brings current into the transistor
  - BJT: _______, MOSFET: _______
- Terminal 2: carriers current out
  - BJT: Collector, MOSFET: ________
- Terminal 3: acts as a handle to control the current flow (input terminal)
  - BJT: Base, MOSFET: _________



Sources: https://www.electronics-tutorials.ws/transistor/tran_1.html, Amazon

BJT Simple Analysis: Performance Parameters



- Base transport factor: $B = I_C/I_{E,majority}$
  - Fraction of h+ which make it across the _____ to ______
- Emitter injection efficiency: $\gamma = \frac{I_{E,majority}}{I_{E,majority}+I_{E,minority}}$
  - Ratio of current due to h+ to _____ current
- Current transfer ratio: $\alpha = B\gamma = \frac{BI_{E,majority}}{I_{E,majority}+I_{E,minority}} = \frac{I_C}{I_E} = \frac{B}{1+B}$
  - Represents the emitter-to-collector current ______
- Base-to-collector current ________ factor: $\beta = \frac{I_C}{I_B} = \frac{B\gamma}{1-B\gamma} = \frac{\alpha}{1-\alpha}$
- Applies to DC and small-signal AC (____________) operation
- We are assuming no ________ in the SCRs
- What have we found? I_C is controlled by _____!
- A small increase in ___ results in a much larger increase in ___. The transistor amplifies the small base current into a much larger collector current, which is why BJTs are used as current amplifiers!
- ______ is related to both the base current and the collector current but is not the controlling factor in BJT behavior. Instead, it is the sum of the two currents and is slightly larger than ___!

Sources: ECE 340 Slides, Textbook

BJT Band Diagram

pnp:

- In equilibrium:

- In "______" mode:
  - E-B junction: *Forward biased*
    - Recall, rate of injection α _____
  - C-B junction: *Reverse biased*

$$I = I_0(e^{qV/kT} - 1)$$

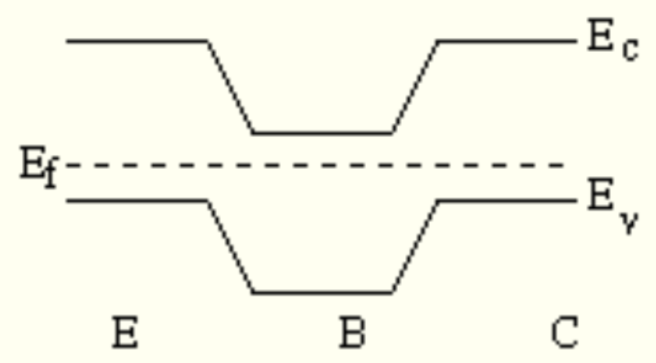


Figure A

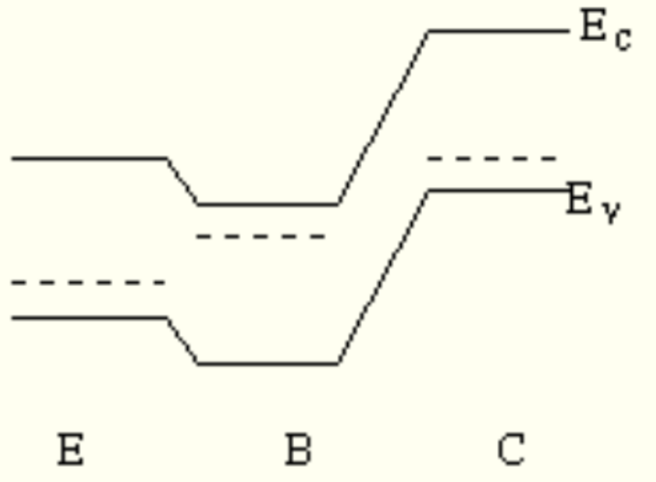
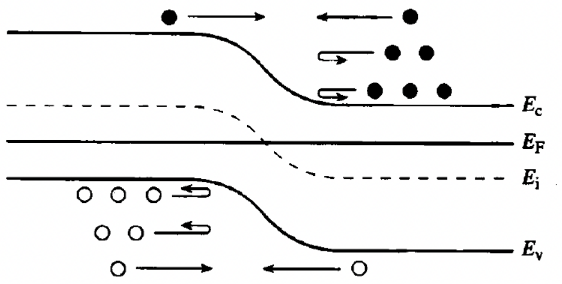
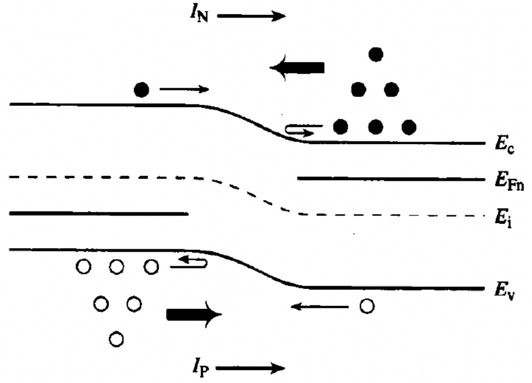
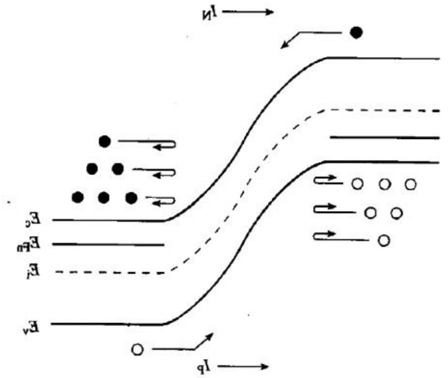


Figure B

Recall our equilibrium, FB, and RB diagrams for a single p-n junction:





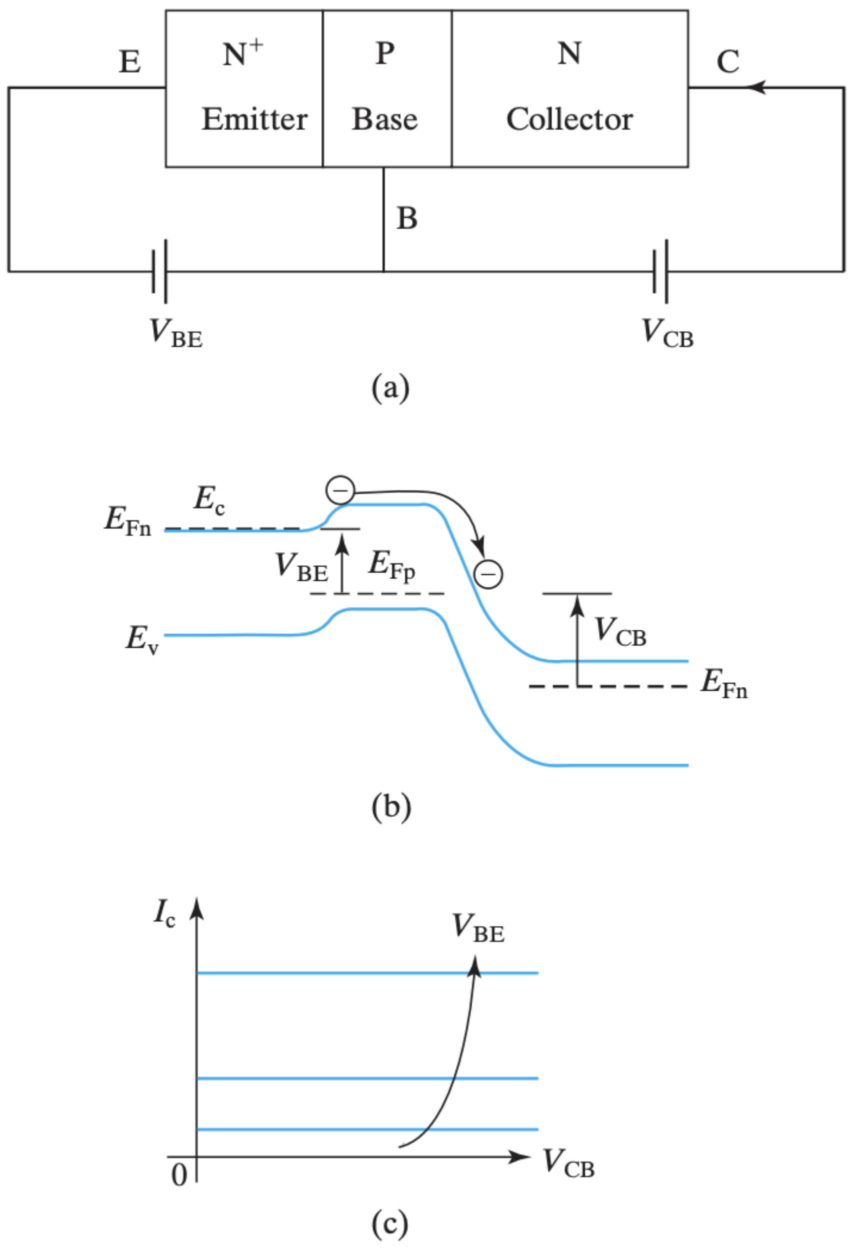


Sources: The Ohio State University

BJT Band Diagram

npn in "normal" mode:

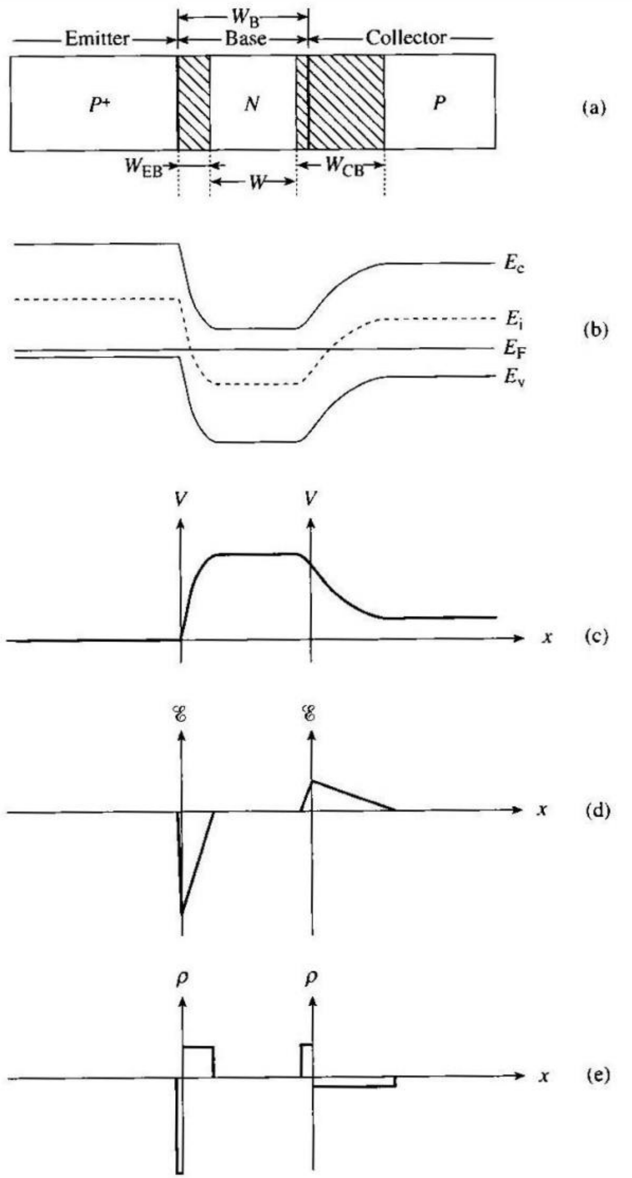
- When the base–emitter junction is FB, e- are injected into the ___________ base
- e- _____ across the narrow base to RB base–collector junction, reach edge of the ________, and get swept into the collector
- I_C is essentially independent of V_{CB}, as long as V_{CB} is ___ (or small FB)
- I_C is instead determined by rate of e- injection from the ______ (e.g. V_{BE} and _______)



Sources: ECE 340 Slides, Textbook

BJT “Big Three”

- Let’s again consider the BJT as two independent p-n junctions
- In equilibrium
    - Electrostatic potential:
    - Electric field:
    - Charge density:
- In this example, $N_{a}, \quad \gg N_{d,B} > N_{a,C}$



Sources: E. Pop ECE 340 Slides, Korea University Photonics Laboratory: http://contents.kocw.or.kr/KOCW/document/2015/korea_sejong/youjonghoon1/04.pdf