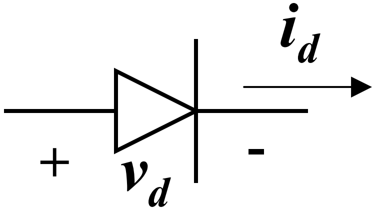
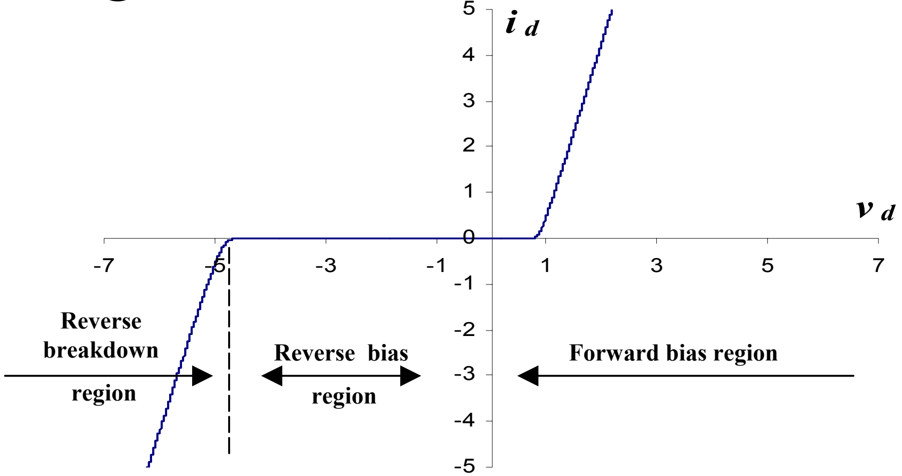
Review of Electronic I

Lesson #2
Solid State Circuitry
Diodes & Transistors
Chapter 3

Diodes

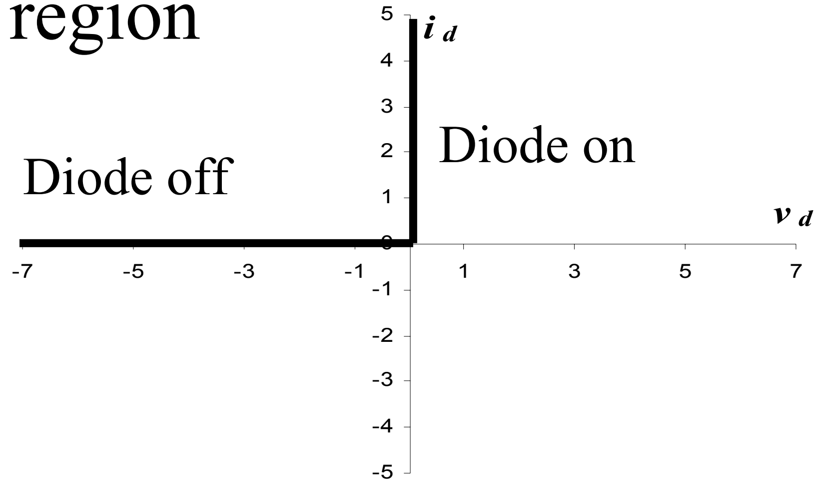
- Typical Diode VI Characteristics
  - Forward Bias Region
  - Reverse Bias Region
  - Reverse Breakdown Region





Ideal Diode

- Basically, a switch
  - Forward Bias: any current allowed, diode on
  - Reverse Bias: zero current, diode off
  - No reverse breakdown region



How Do We Use Diodes

- Rectifier circuits
  - Half-wave: only one (positive or negative) side of a waveform is passed
  - Full-wave: waveform is made single sided
  - Power Regulation
- Wave Shaping
  - Clipping Circuits: waveforms are limited in amplitude
  - Clamping Circuits: the extreme values of a waveform is clamped to a set value
- Logic Circuits
  - AND and OR gates

Basic Semiconductor Electronics

- Atomic Structure of Valence-4 elements like Carbon, Silicon, Germanium, etc.
  - have 4 valence electrons in its outer atomic shell
  - these atoms form covalent bonds with 4 other atoms in a lattice
- When the energy levels of these electrons are raised several of these bonds may become randomly broken and a free electron is created
  - as a result these electrons are free to move about in the material similar to electron conduction occurs in a metal
  - in addition to the free electron, a negative particle, a "hole" which is a positive "particle" is created which also moves freely within the material.
- As electrons and holes move through the material, they may encounter each other and recombine and, thereby, become electrically neutral
- This type of material is called an intrinsic semiconductor

Doped Semiconductor Material

- If we incorporate a small impurity of five or three valence band materials into a 4 valence band lattice, we have created an extrinsic semiconductor which is doped with an impurity
- n-type semiconductor
  - Doping with five valence material (e.g. Arsenic) to create additional free (donor) electrons and a static positive charged ion in the core lattice
  - Majority carriers are electrons; minority carriers are holes
  - The concentration of electrons in a n-type semiconductor = concentration of the donor electrons + the concentration of free holes (which is the same as the number of electrons which have randomly broken their valence bonds)
- p-type semiconductor
  - Doping with three valence material (e.g., Gallium) to create additional free (donor) holes and a static negative charged ion in the core lattice
  - Majority carriers are holes; minority carriers are electrons
  - The concentration of holes in a p-type semiconductor = concentration of the donor holes + the concentration of free electrons (which is the same as the number of holes which have randomly broken their valence bonds)

PN Junction

- When a p-type semiconductor is fused with a n-type, the following occurs at the junction.
  - Because the concentration of electrons is greater on n-type side, holes from the p-type diffuse across the junction to the n-type side
  - Likewise electrons diffuse across the junction from the n-type to the p-type material
  - These carriers recombine and what remains are the negatively charged ions on the p-type side and positively charged ion on the n-type side.
- The ions which are tied to the lattice form an electric field which prohibits the flow of carriers across the junction.
  - The area where these ions and their associated electric field are situated is called the depletion region since it is depleted of holes and electrons
  - The electric field which prohibits the flow of carriers is called the barrier potential

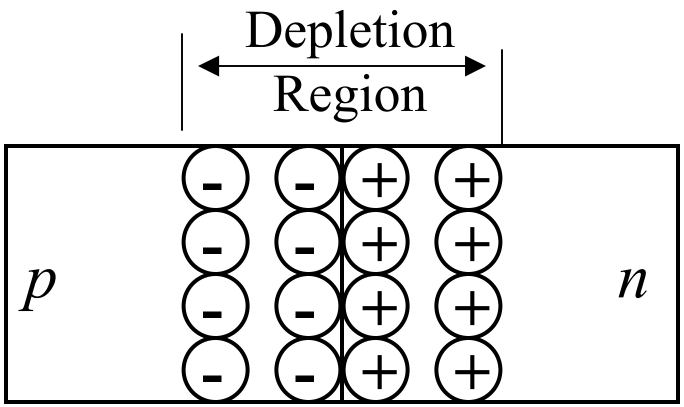
Reverse Bias PN Junction

- When an external voltage is a applied to a PN junction such that the n-type is more positive than the p-type, then we say that the PN junction is reverse-biased and the following happens:
  - The external voltage creates an electric field which enhances the barrier potential and the depletion region becomes wider since the majority carriers are pulled away from the junction (e.g., the electrons in the n-type material are attracted away from the junction by the positive voltage).
  - However, this applied field supports the flow of minority carriers across the junction (e.g., the holes in the n-type material are attracted across the junction by the enhanced electric field of the widened depletion region) and when they cross the junction they become majority carriers (e.g., the minority carrier n-type holes now become majority carriers once they cross the junction to the p-type) and are attracted away from the junction as described above.
  - Since the flow across the junction is due to minority carriers the current flow is small (this is sometimes called the reverse-based leakage current).

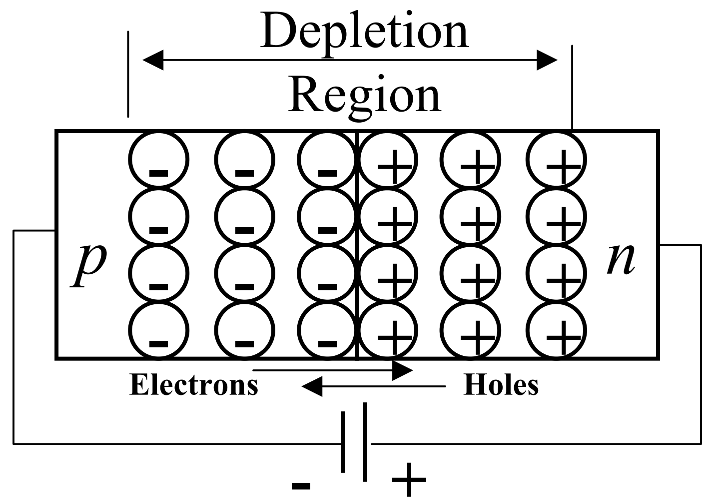
Forward Bias PN Junction

- When an external voltage is a applied to a PN junction such that the n-type is more negative than the p-type, then we say that the PN junction is forward-biased and the following happens:
  - The external voltage creates an electric field which opposes the barrier potential and the depletion region becomes smaller provided it is larger than the voltage barrier of the depletion region (typically, a few tenths of a volt)
  - This allows for the further flow of majority carriers across the junction
  - As the majority carriers cross the junction, the become minority carriers and then recombine the majority carriers on the other side
  - Since the flow across the junction is due to majority carriers the current flow is large.

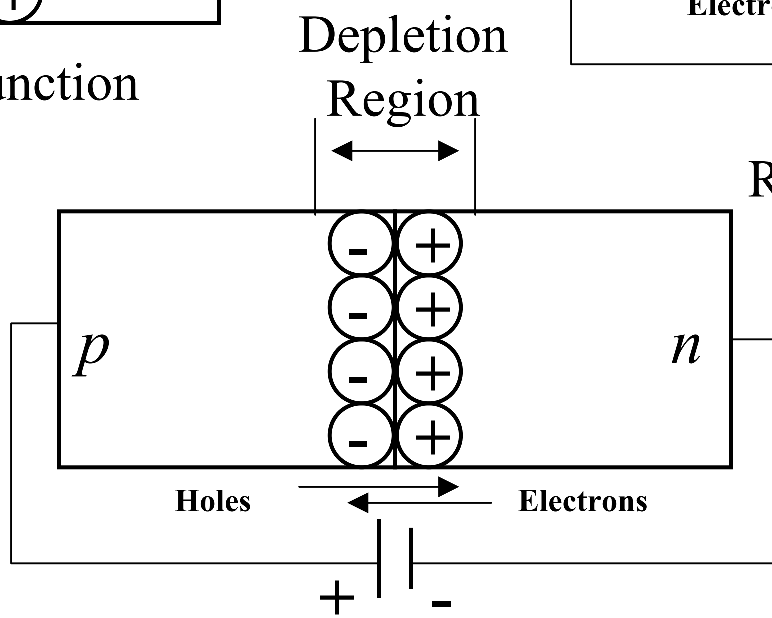
PN Junctions Summarized



Unbiased PN Junction

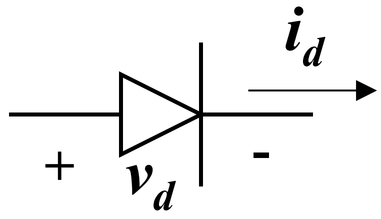


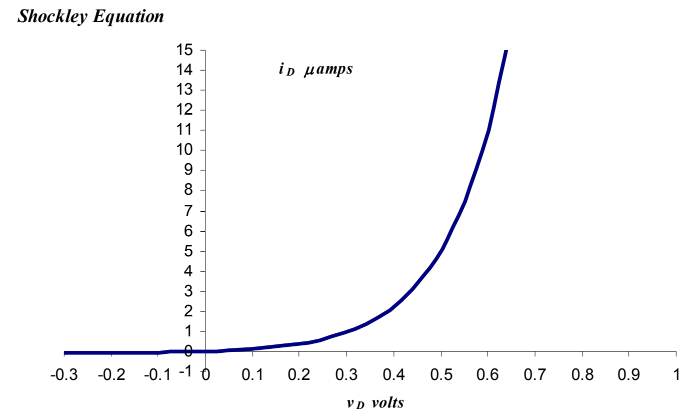
Reverse-biased PN Junction



Forward-biased PN Junction

PN Junctions - Shockley Equation





$i_D = I_S(e^{\frac{v_D}{V_T}} - 1)$ where i_D and v_D are the diode current and voltage,

I_S is called the reverse bias saturation current,

and V_T is the called the thermal voltage and is

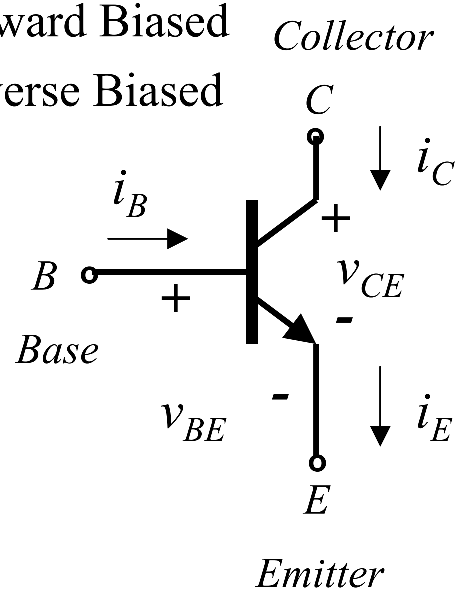
$V_T = \frac{kT}{q}$ where k is the boltzman constant, 1.38×10^{-23} Joule/$^\circ$Kelvin,

T is the temperature of the junction in degrees Kelvin,

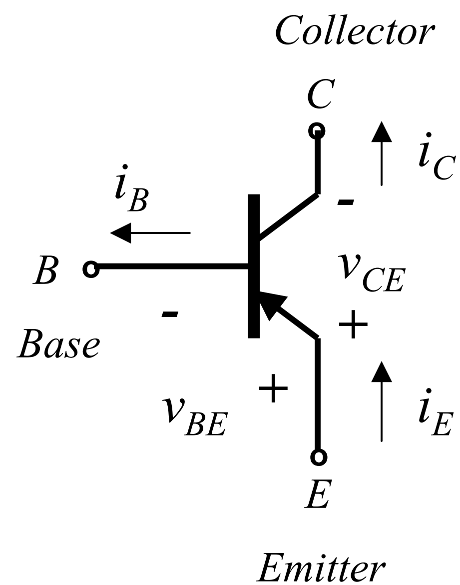
and q is the magnitude of electric charge of an electron, 1.60×10^{-19} coulombs

Bipolar Junction Transistors

- Two junctions *npn* or *pnp*
  - Collector-Base and Emitter-Base
- Biasing
  - v_{BE} Forward Biased
  - v_{CB} Reverse Biased



npn

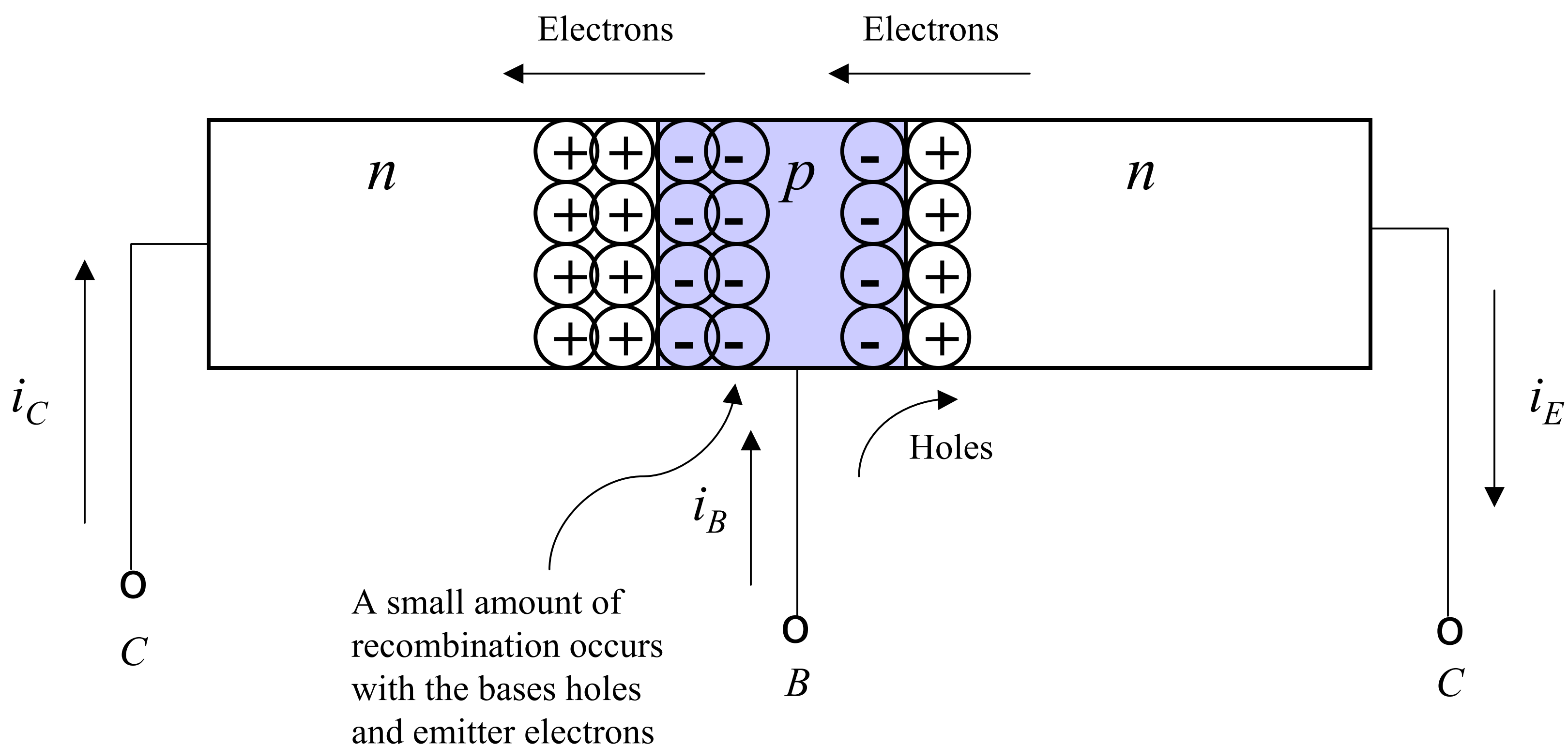


pnp

npn (pnp) BJT Semiconductor

- Physical characteristics:
  - Base is narrower than the emitter
  - Emitter is doped more than the base
    - Free electron (hole) concentration in the emitter greater than the hole (electron) concentration in base
- Base-emitter junction is forward biased
  - There is a flow of electrons (holes) from the emitter to base and holes (electrons) from the base to emitter; however since the concentration of emitter electrons (holes) are greater than the base holes (electrons), this current is primarily made of electrons (holes)
  - These emitter electrons (holes) become minority carriers in the base; however, since the base is narrow very little electron-hole recombination occurs in the base and these electrons (holes) are drawn towards the collector-base junction
- Collector-base junction is reverse biased
  - When these emitter electrons (holes) reach the collector-base junction, they are pulled across the junction into the collector by the electric field due to the depletion region ions.
  - The ratio of the electrons (holes) reaching the collector to the electrons (holes) provided by the emitter is know as α.

npn BJT



Electrons
Electrons
n
p
n
i_C
i_E
i_B
Holes
C
B
C
A small amount of recombination occurs with the bases holes and emitter electrons

BJT Equations

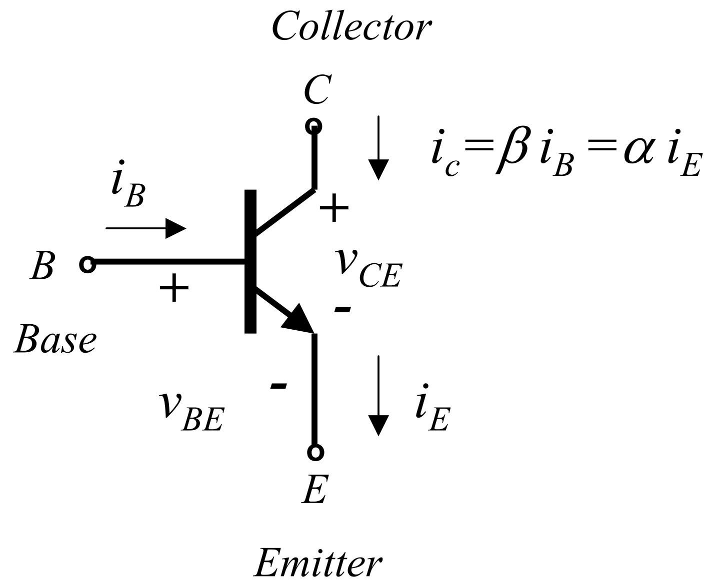
$$i_E = i_C + i_B$$

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

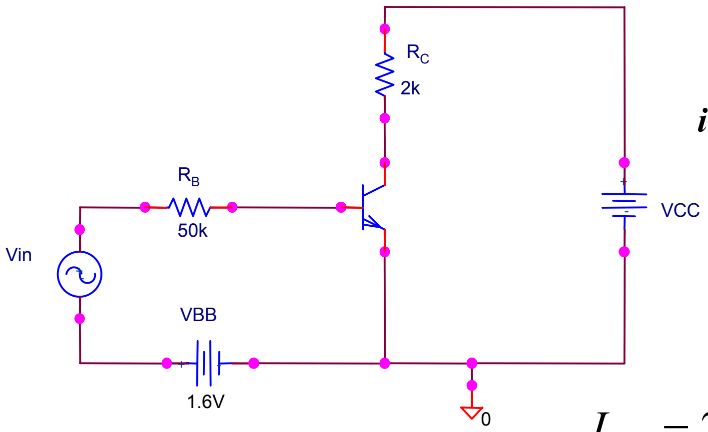
$$i_B = (1-\alpha)i_E$$

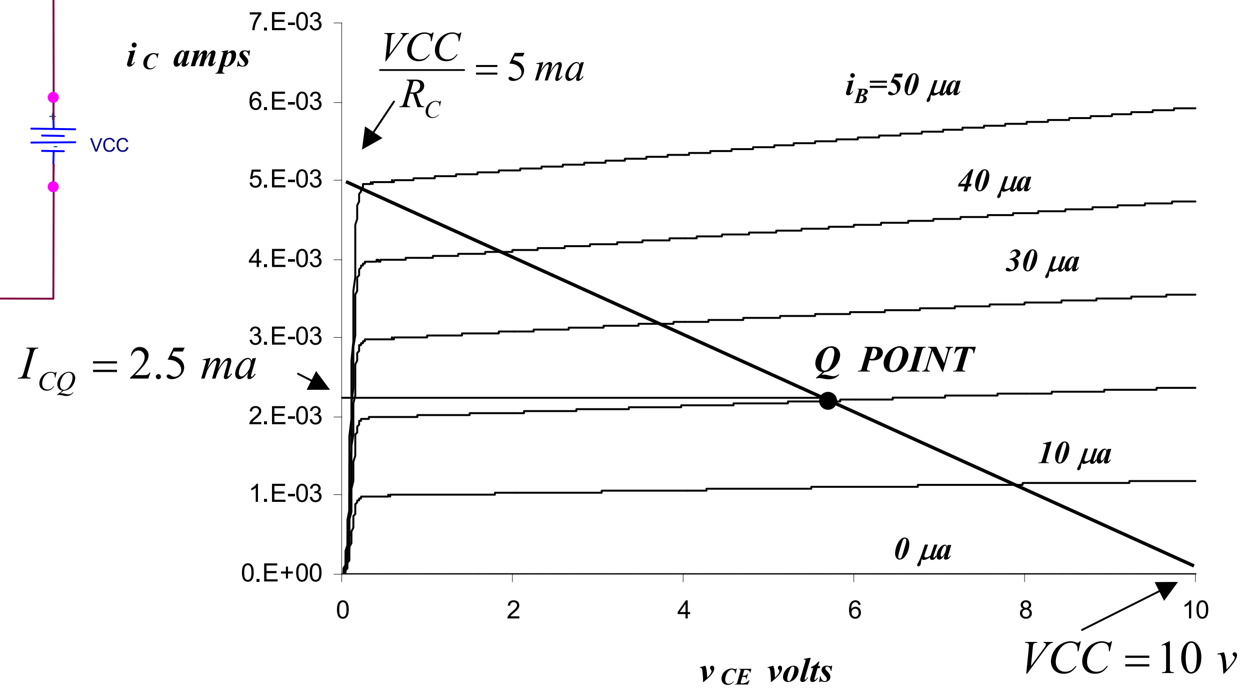
$$i_C = \frac{\alpha}{1-\alpha} i_B = \beta i_B$$

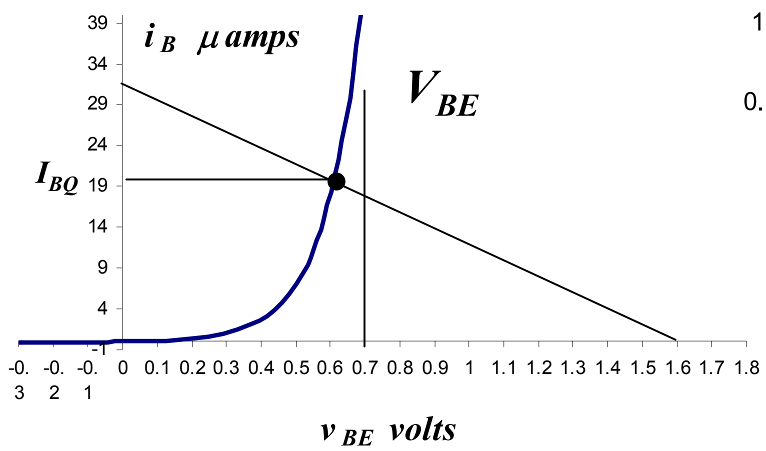
$$\beta = \frac{\alpha}{1-\alpha}$$



BJT Characteristics



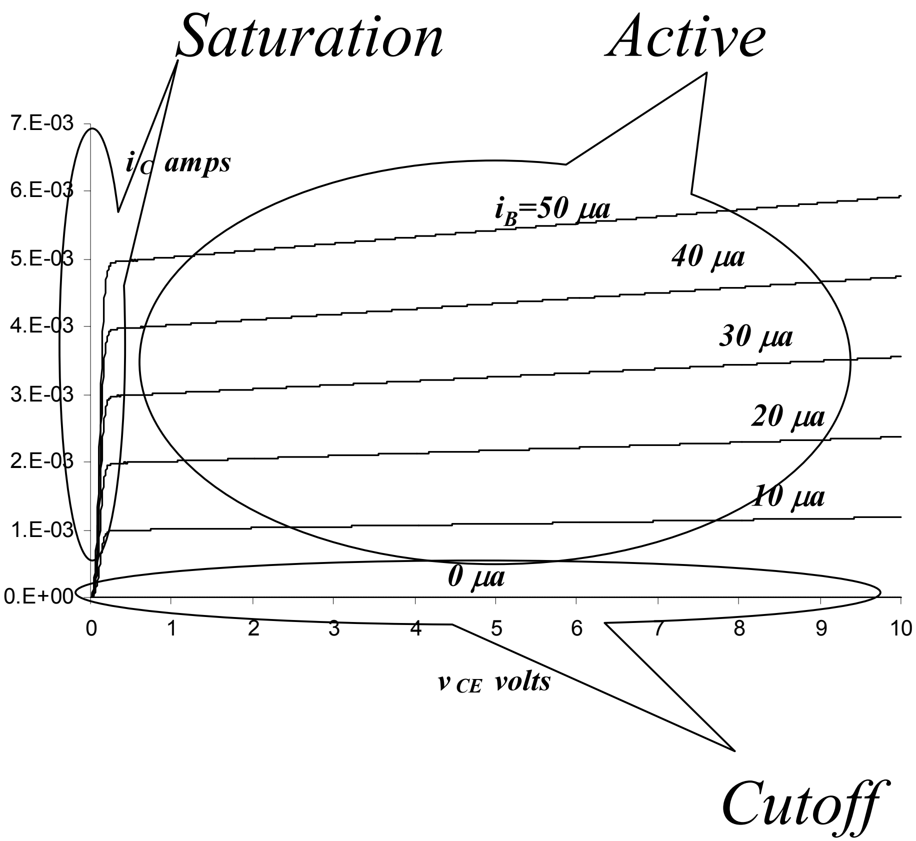




$$i_B = \frac{VBB - V_{BE} + V_{in}}{R_B}$$

$$\text{DC value of } i_B = I_{BQ} = \frac{VBB - V_{BE}}{R_B} = 20\, \mu amps$$

BJT Regions of Operation



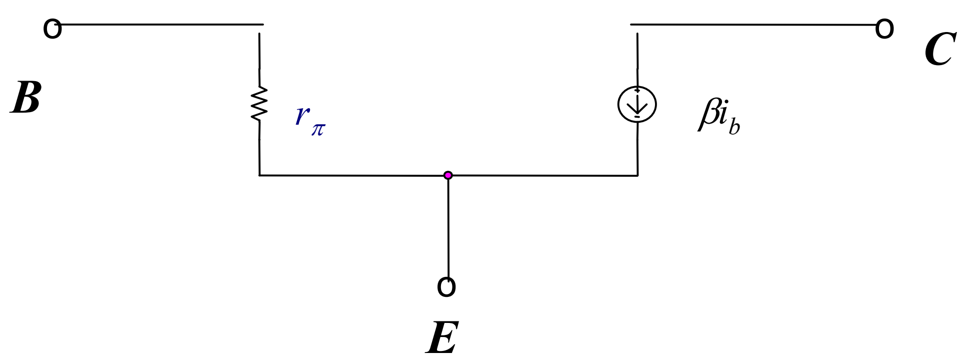
Cutoff: both junctions are reverse biased, $i_B=0$, $v_{BE}<V_{BE}$, $v_{BC}= v_{BE}-v_{CE}$, $i_C=0$, $v_{CE}=VCC$

Active: Emitter-Base junction forward biased, Collector Base junction reverse biased, $i_B>0$, $v_{BE}=V_{BE}$, $i_C=\beta i_B>0$, $v_{CE}=VCC-i_C R_L$

Saturation: both junctions are forward biased, $i_B>0$, $v_{BE}=V_{BE}$, $v_{CB}= v_{BE}-v_{CE}$, $v_{CE}\approx 0<v_{BE}$, $i_C=VCC/R_L$

Small Signal Equivalent Circuits and Parameters for the BJT

- When the AC Portion of the input is small around the Q point (<<V_T in value) then we can approximate the operation of transistor by an equivalent circuit consisting of a resistor, $r_\pi = V_T/I_{BQ}$ and a current source, βi_b, where i_b is the small signal component of the base current:



The BJT as a Digital Switch

- Operating between cutoff and saturation (i.e., bypassing the active region), the BJT acts like an inverter.
- From this behavior, logic circuits such as NOR gates can be developed

Homework

- Probs. 3.2, 3.3, 3.5, 3.15, 3.16, 3.17, 3.65, 3.73
- Probs. 4.4, 4.5, 4.8, 4.10, 4.20, 4.21, 4.22, 4.42