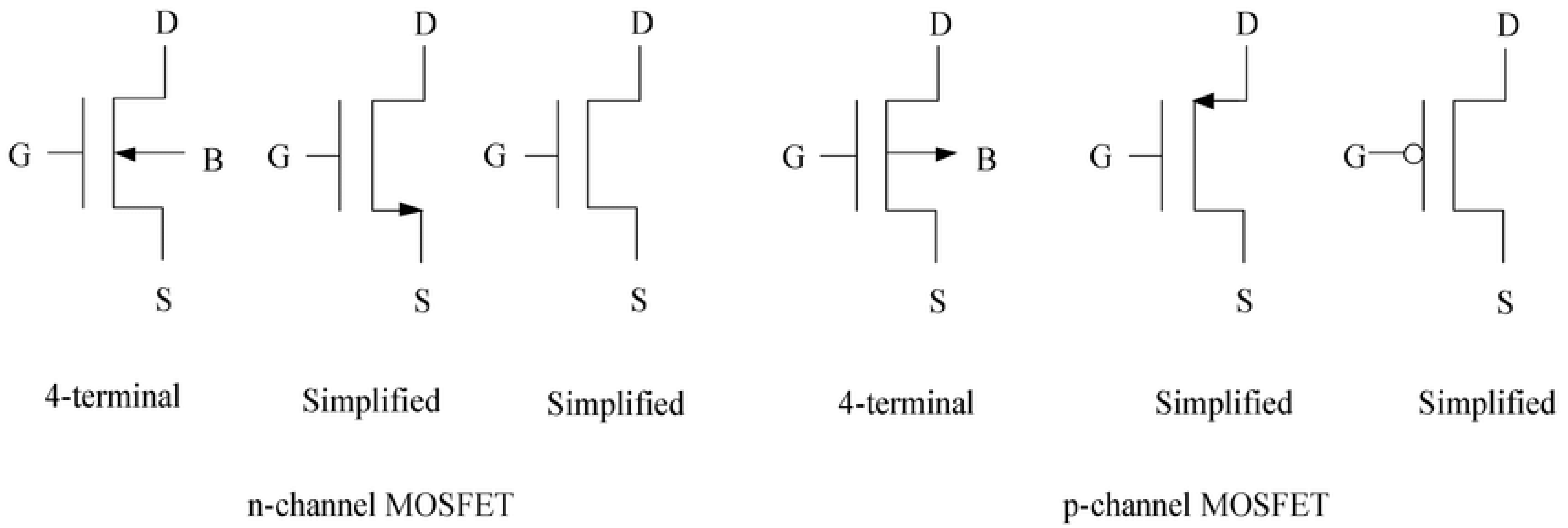
Fundamentals of Electronics

ECE 101

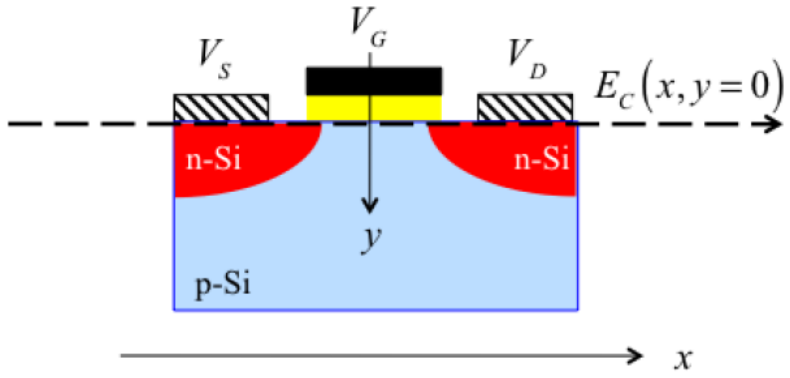
MOSFET (Metal–Oxide–Semiconductor Field-Effect Transistor)

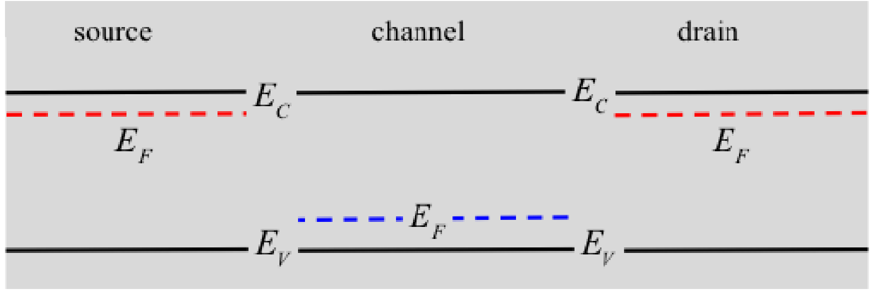
N-Channel MOSFETs use electron flow as the charge carrier. P-Channel MOSFETs use hole flow as the charge carrier, which has less mobility than electron flow.

Symbols

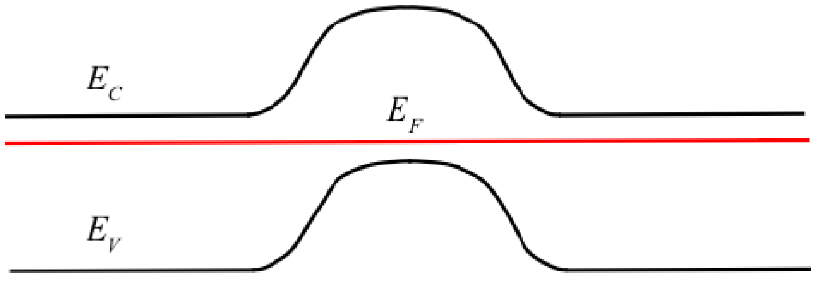


MOSFET Band Diagram





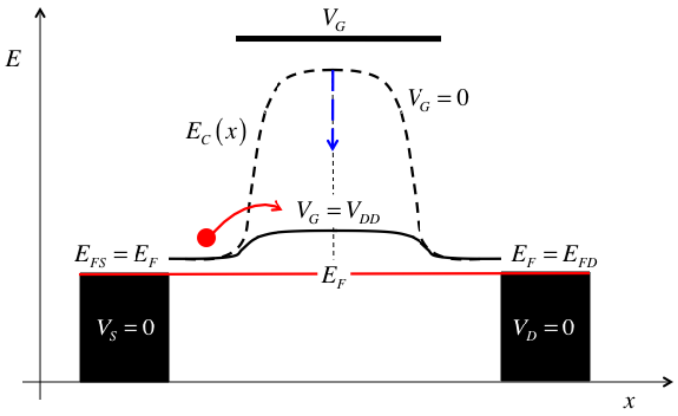
Most transistors operate by controlling the height of an energy barrier with an applied voltage.



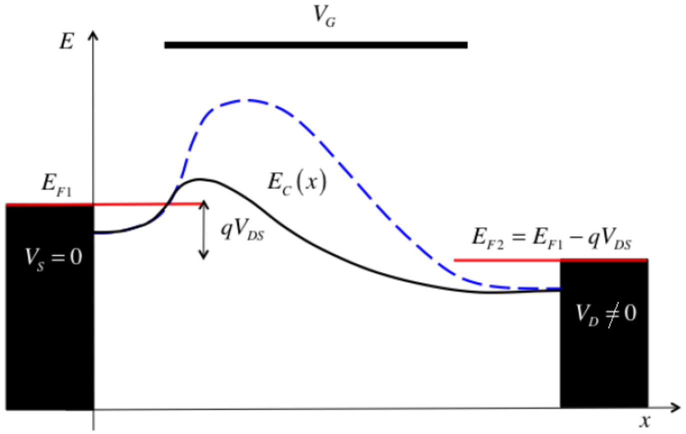
N-channel MOSFET

Note: that there is a potential energy barrier that separates electrons in the source from electrons in the drain.

Application of a positive voltage

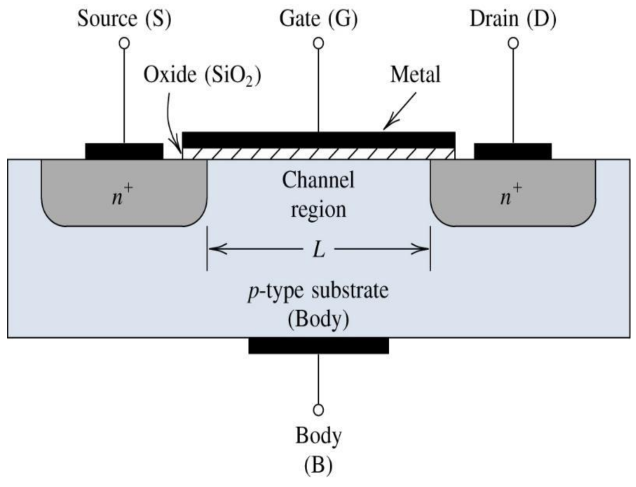


Gate voltage



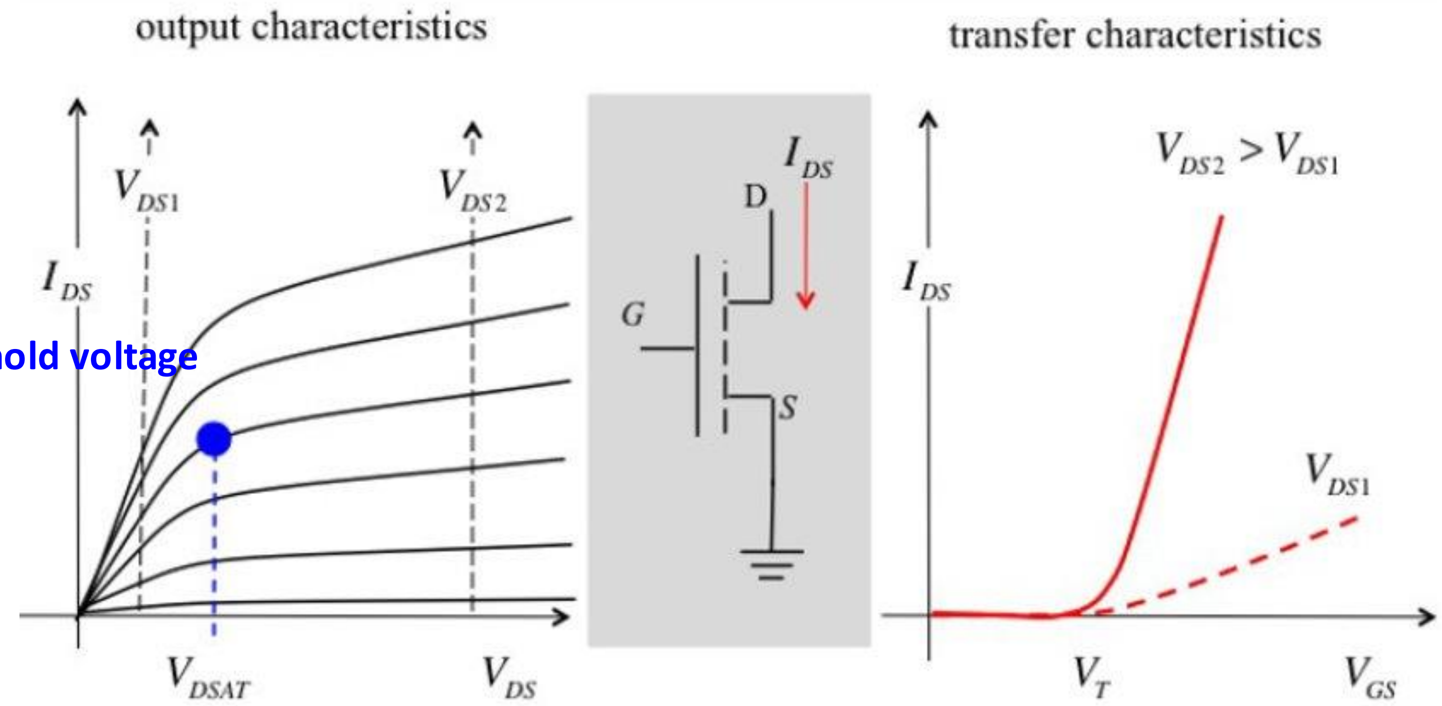
Drain voltage

MOSFET Characteristics



(b)

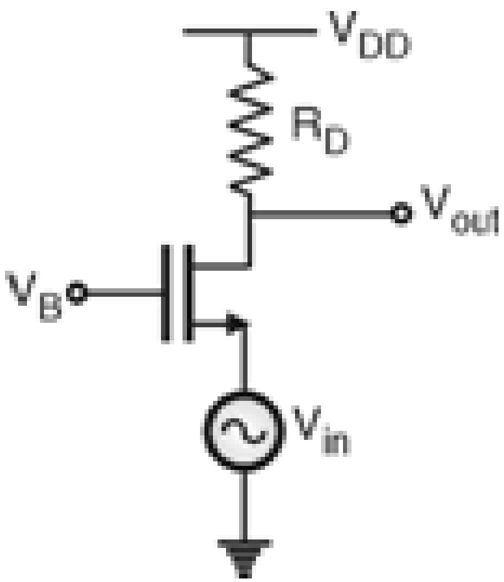
Threshold voltage



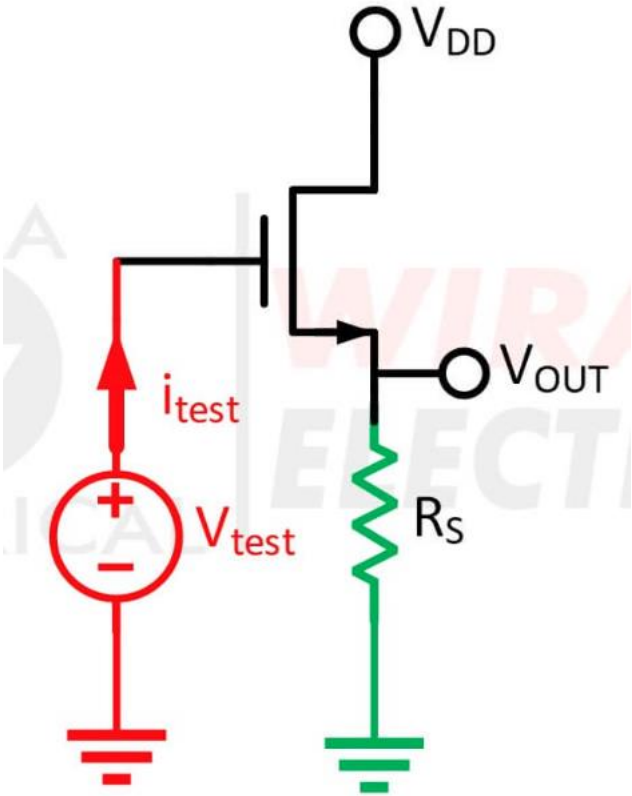
Output Characteristics

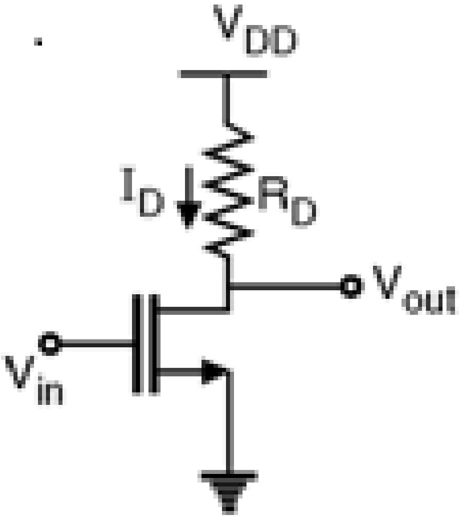
Transfer Characteristics

MOSFET Circuits



Common gate amplifier

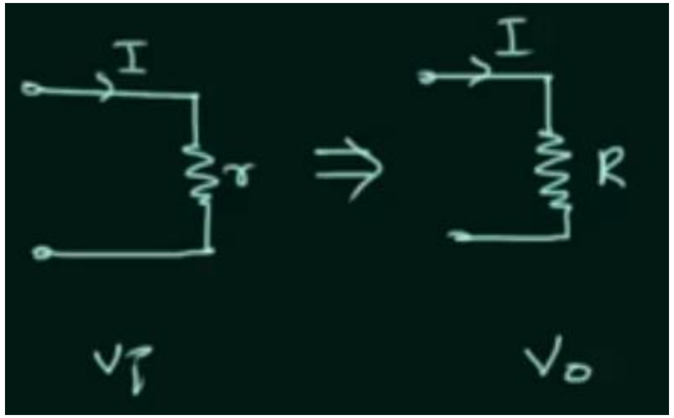




CS stage with resistive load

N-Channel

The transistor action - 1



$V_i = I \times r$ $\qquad$ $V_o = I \times R$

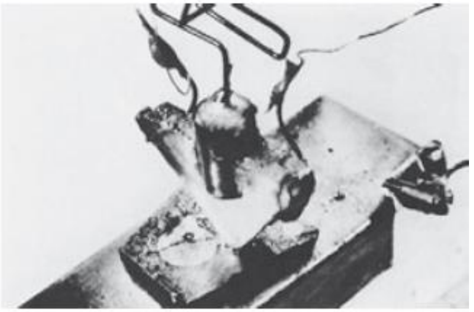
$V_i < V_o$ (amplification)

Active mode

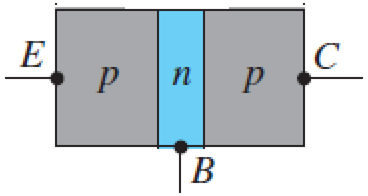
$J_1 \rightarrow$ f.b. $\quad$ Res = 0

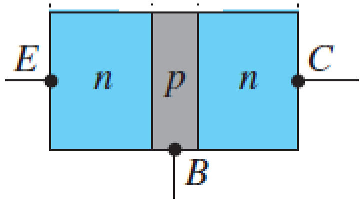
$J_2 \rightarrow$ r.b. $\quad$ Res = ∞

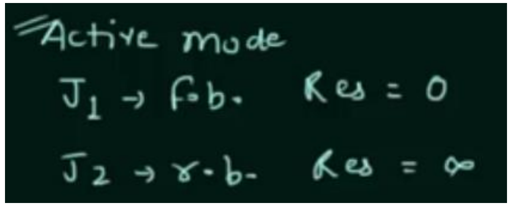
<u>Bipolar</u> <u>Junction</u> Transistor (BJT)



The first transistor

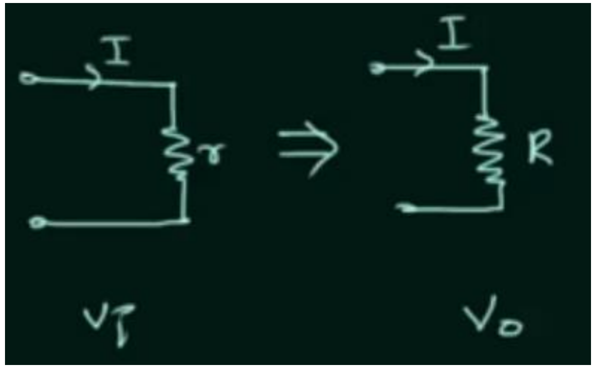


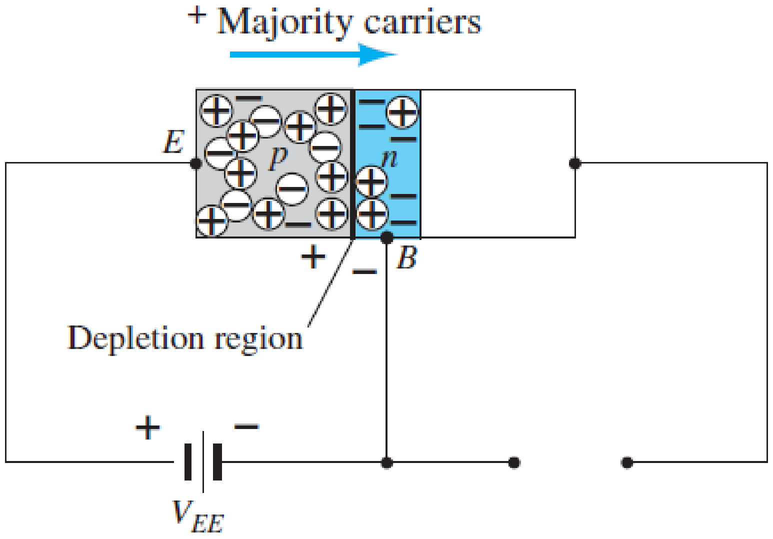


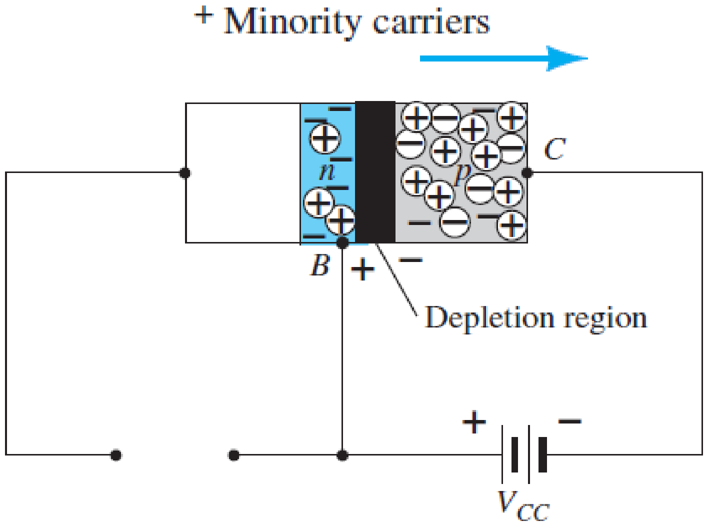


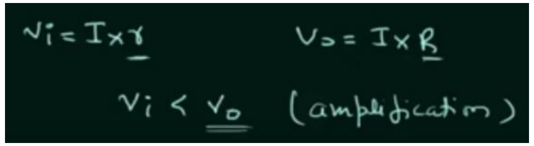
Basic mechanism

One p-n junction is forward biased,
the other one is reverse biased.

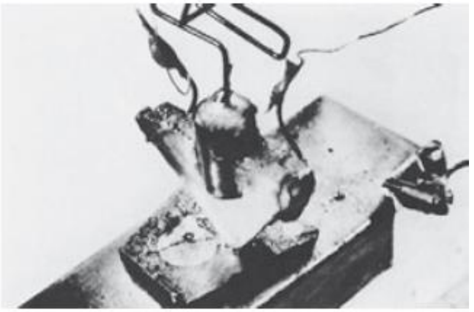








Bipolar Junction Transistor (BJT)



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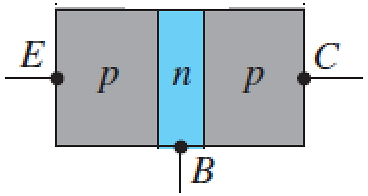

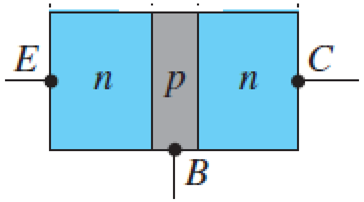

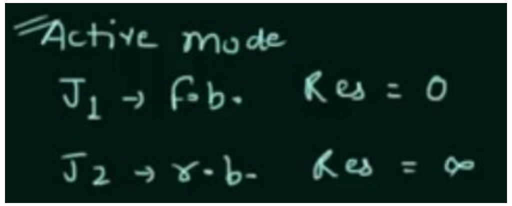

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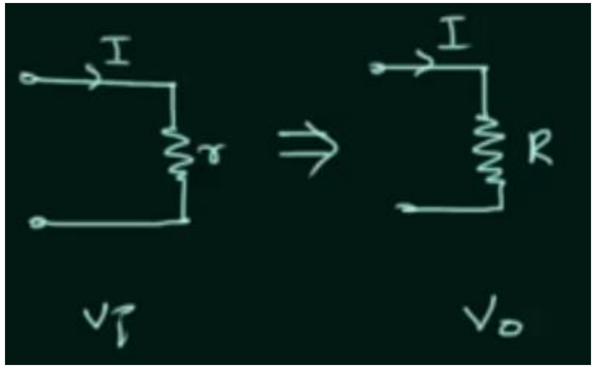
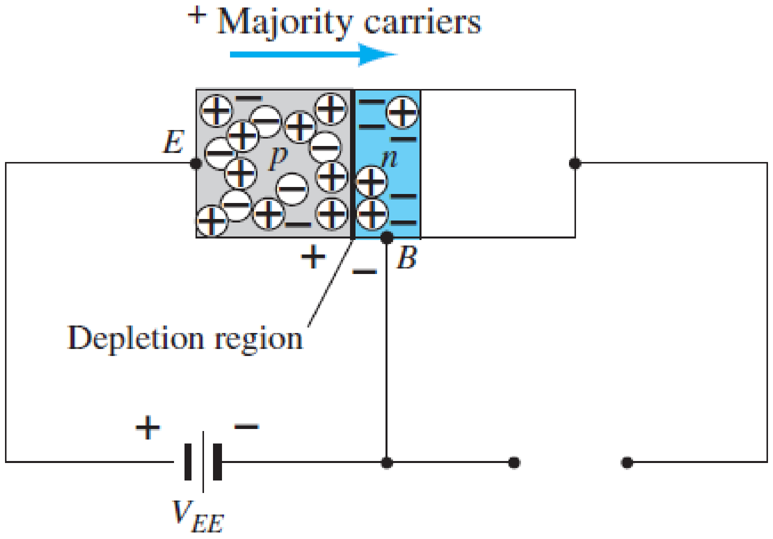
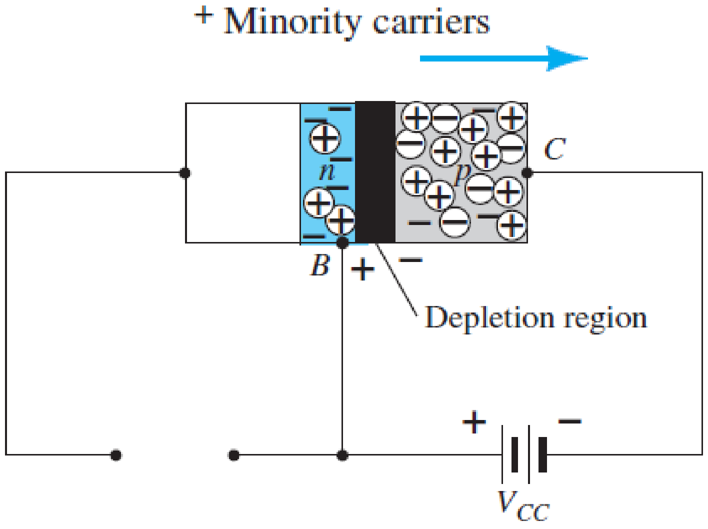
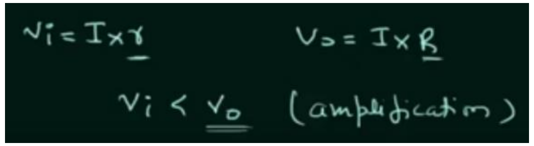
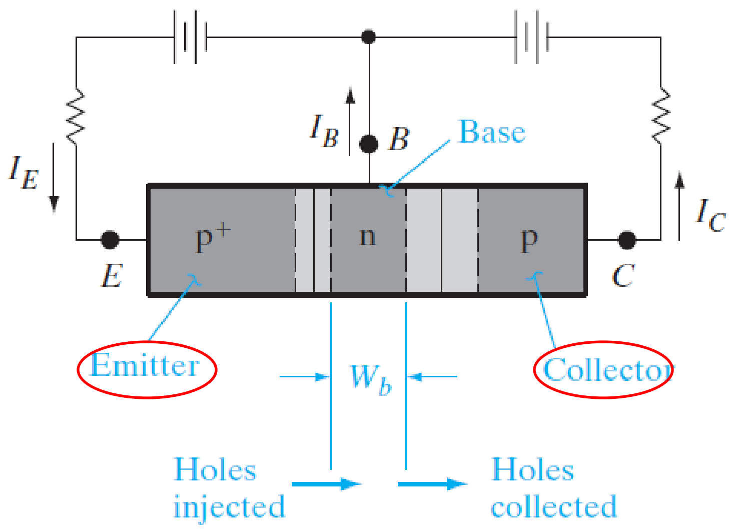


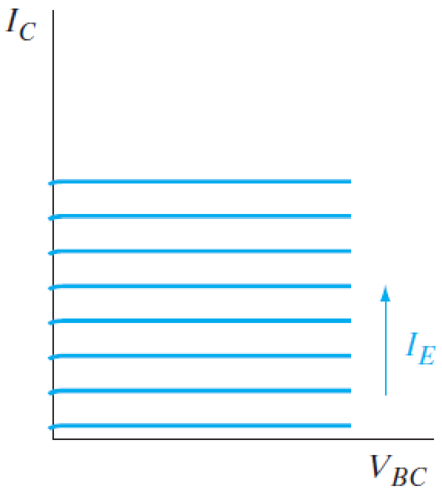






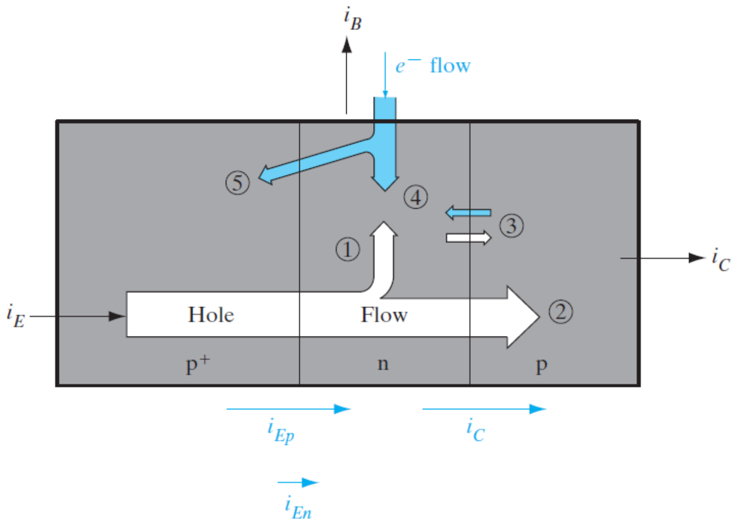
Understanding BJT IV characteristics…





- To have a good p-n-p transistor, we would prefer that <u>almost all the holes injected by the emitter into the base be collected</u>.
- Thus, the n-type base region should be narrow, and the hole lifetime t_p should be long. This requirement is summed up by specifying $W_b \ll L_p$.
- A second requirement is that the current I_E crossing the emitter junction should be composed almost entirely of holes injected into the base
  - Rather than electrons crossing from base to emitter.
  - This requirement is satisfied by doping the base region lightly compared with the emitter

Current components in BJT



Components of the base current

- Recombination of injected holes with electrons in the base, even with Wb < Lp. The electrons lost to recombination must be resupplied through the base contact.
- Some electrons will be injected from n to p in the forward-biased emitter junction, even if the emitter is heavily doped compared with the base.
- Some electrons are swept into the base at the reverse-biased collector junction due to thermal generation in the collector.

Amplification with BJTs

$$i_C = Bi_{Ep}$$

- B is the fraction of injected holes which make it across the base to the collector. it is called the **base transport factor**.
- The total emitter current consists of hole component and electron component (injected from the base). The **emitter injection efficiency** is defined as:

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

- **For an ideal transistor, we would like B and γ to be unity.**
- The relation between collector and emitter currents is:

$$\frac{i_C}{i_E} = \frac{Bi_{Ep}}{i_{En} + i_{Ep}} = B\gamma \equiv \alpha$$

The product Bγ is defined as the factor α, called the current transfer ratio.

Amplification with BJTs contd…

- There is no real amplification between emitter and collector currents, since α is smaller than unity.
- On the other hand, the relation between base current and collector current is more promising.
- The base current consists of mainly two parts: **electrons recombining with holes in the base**, **electrons injected across the forward bias junction**:

$$i_B = i_{En} + (1-B)i_{Ep}$$

- The relation between collector and base current is: $\frac{i_C}{i_B} = \frac{Bi_{Ep}}{i_{En} + (1 - B)i_{Ep}} = \frac{B[i_{Ep}/(i_{En} + i_{Ep})]}{1 - B[i_{Ep}/(i_{En} + i_{Ep})]}$

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

- The factor β relating the collector current to the base current is the *base-to-collector current amplification factor.*
- Since α is near unity, it is clear that β can be large for a good transistor, and the collector current is large compared with the base current.

But, how can the collector current $\boldsymbol{i_C}$ can be controlled by variations in the small current $\boldsymbol{i_B}$?

- It can be shown from space charge neutrality arguments that $\boldsymbol{i_B}$ can indeed be used to determine the magnitude of $\boldsymbol{i_C}$.

- Since the n-type base region is electrostatically neutral between the two transition regions, the presence of excess holes in transit from emitter to collector calls for compensating excess electrons from the base contact.

- There is an important difference in the times that electrons and holes spend in the base.
- The average excess hole spends a time τ_t, defined as the transit time from the emitter to collector.
- Since the base width W_b is made small compared with L_p, this transit time is much less than the average hole lifetime τ_p in the base.

- On the other hand, an average excess electron supplied from the base contact spends τ_p seconds in the base, ensuring space charge neutrality during the lifetime of an average excess hole.
- While the average electron waits τ_p seconds for recombination, many individual holes can enter and leave the base region, each with an average transit time τ_t.
- In particular, for each electron entering from the base contact, τ_p / τ_t holes can pass from the emitter to collector while maintaining space charge neutrality.
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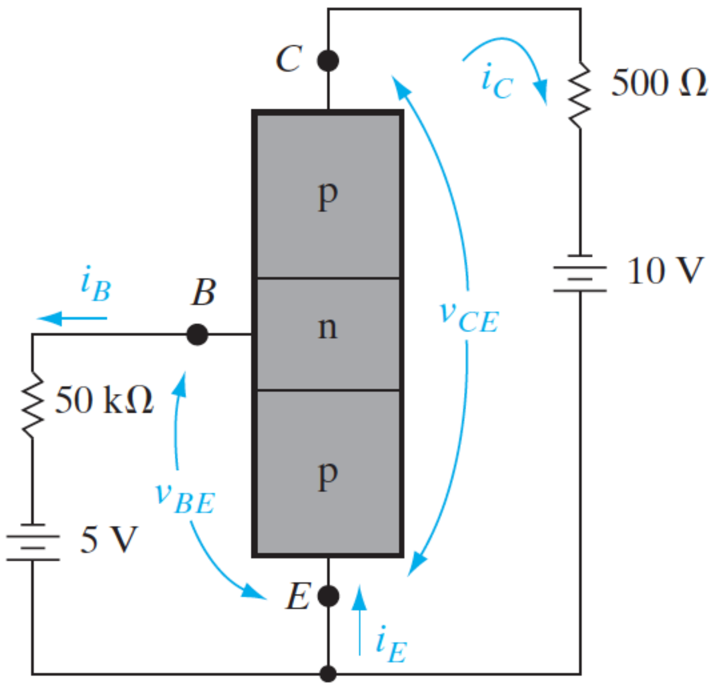
- Thus the ratio of collector current to base current is simply: $\dfrac{i_C}{i_B} = \beta = \dfrac{\tau_p}{\tau_t}$



$$\tau_p = 10\ \mu\text{s}$$

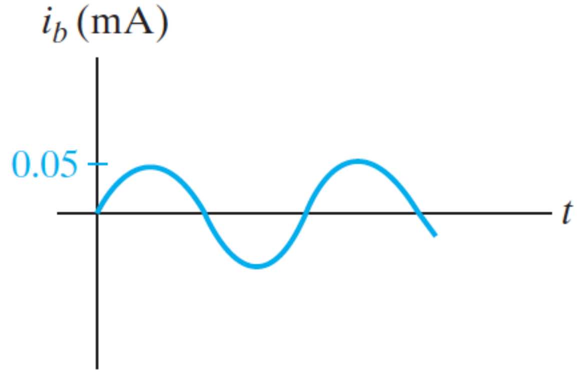
$$\tau_t = 0.1\ \mu\text{s}$$

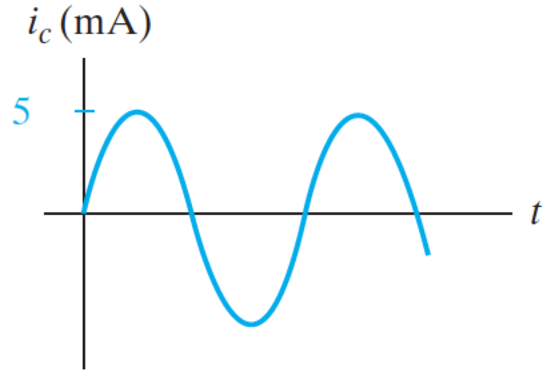
$$\frac{i_C}{i_B} = \beta = \frac{\tau_p}{\tau_t} = 100$$

Neglecting v_{BE}

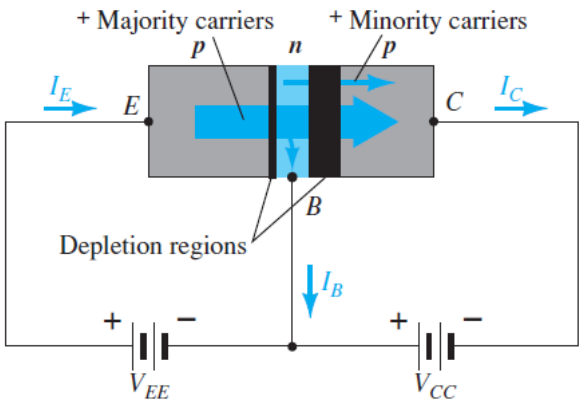
$$I_B = \frac{5\text{ V}}{50\text{ k}\Omega} = 0.1\text{ mA}$$

$$I_C = \beta I_B = 10\text{ mA}$$

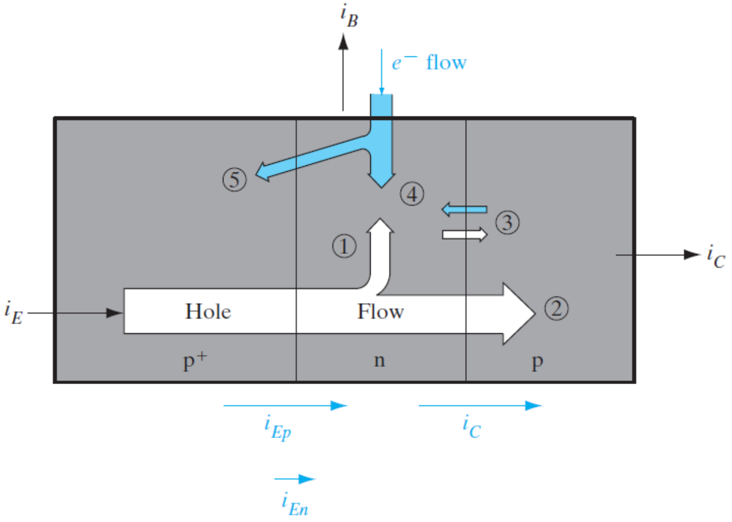


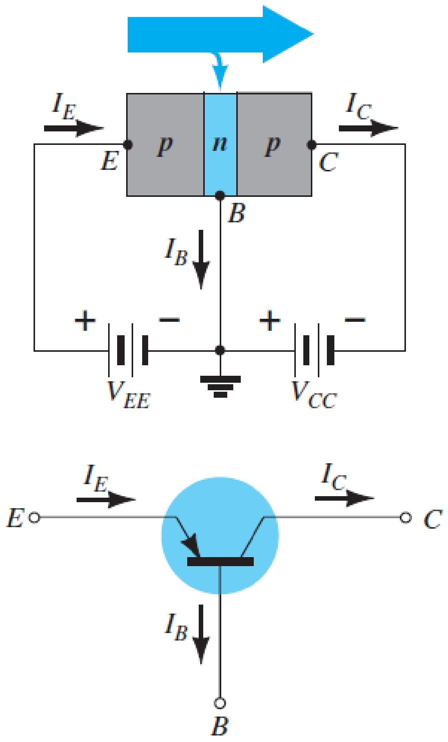


Bipolar Junction Transistor (BJT)

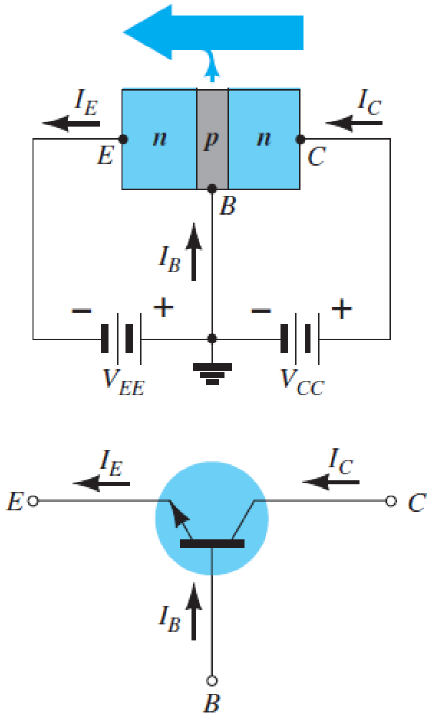


Current components in BJT





pnp transistor



npn transistor

Different regimes of operation of BJT

Active regime

Inverse active regime

Cut-off regime

Saturation regime

Thank you