Lecture (06) Bipolar Junction Transistor

By:

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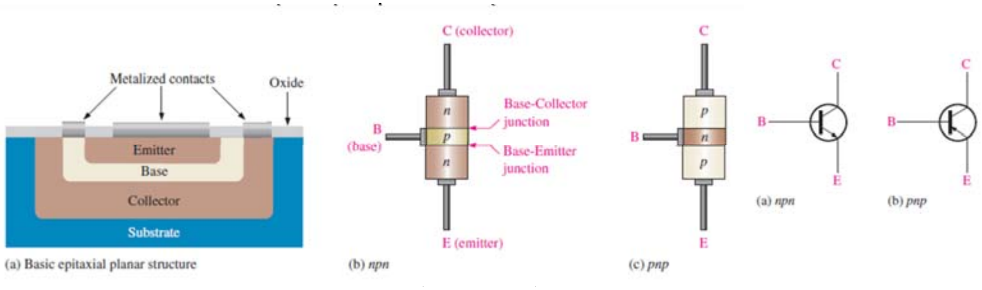
Agenda

- BJT structure
- BJT operation
- BJT characteristics

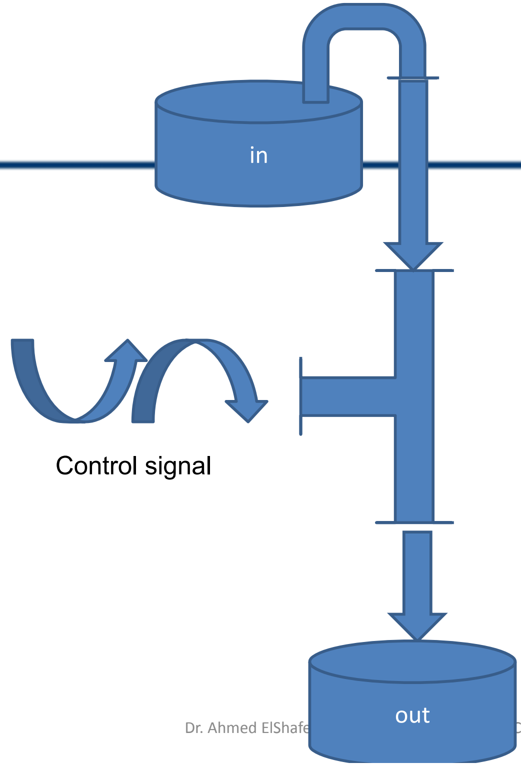
BJT structure

- The **BJT** is constructed with three doped semiconductor regions
- One type consists of two *n* regions separated by a *p* region (*npn*), and the other type consists of two *p* regions separated by an *n* region (*pnp*).
- The term **bipolar** refers to the use of both holes and electrons



(a) Basic epitaxial planar structure (b) *npn* (c) *pnp* (a) *npn* (b) *pnp*

- In order for a BJT to operate properly as an amplifier, the two *pn* junctions must be correctly biased with external dc voltages.
- In this section, we mainly use the *npn* transistor for illustration.
- The operation of the *pnp* is the same as for the *npn* except that the roles of the electrons and holes, the bias voltage polarities, and the current directions are all reversed.



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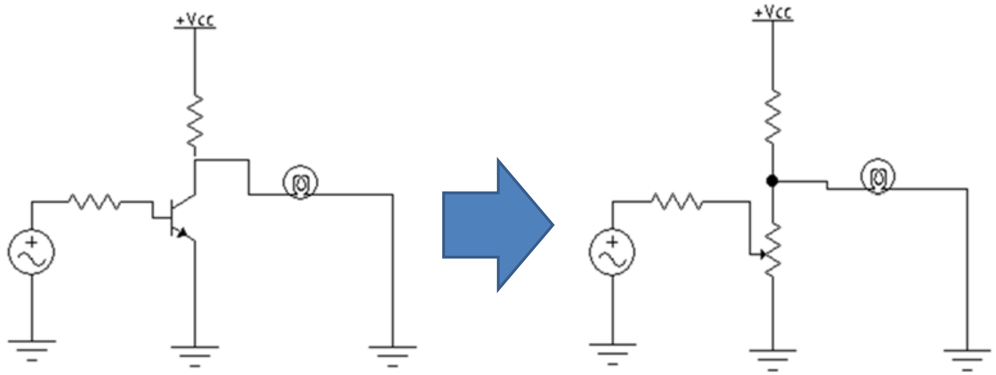
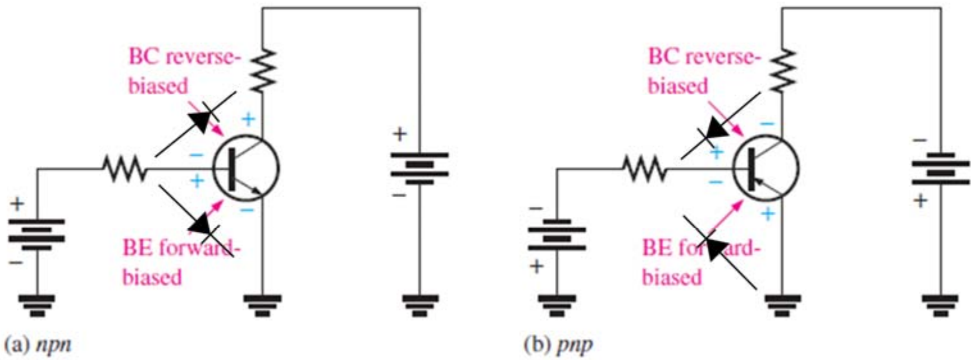


Biasing

base-emitter (BE) junction is forward-biased

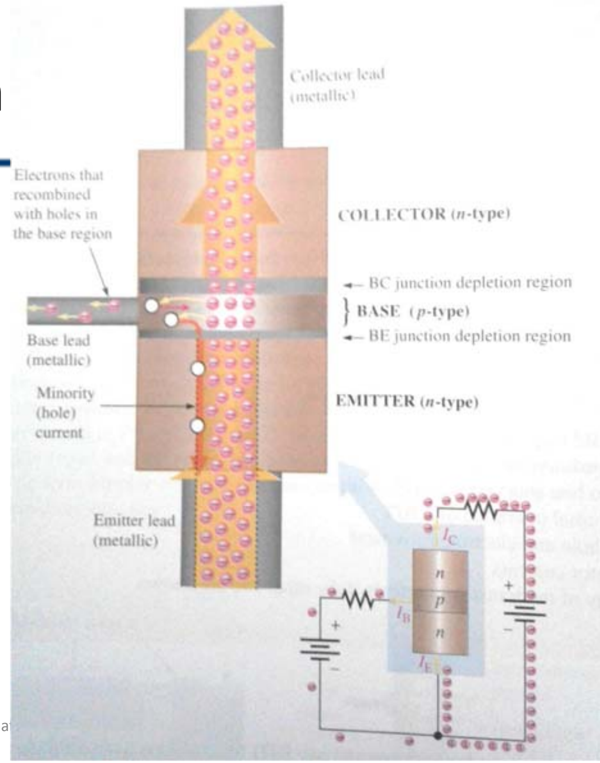
base-collector (BC) junction is reverse-biased

This condition is called *forward-reverse bias*

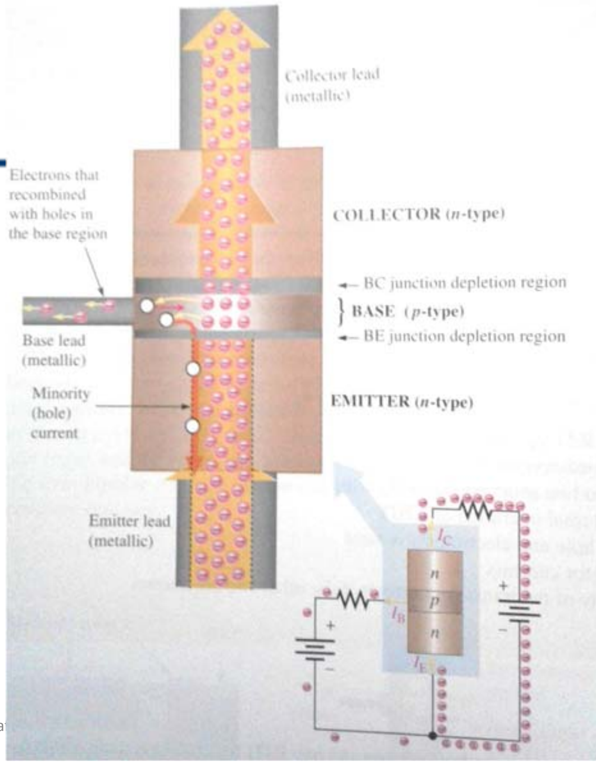


BJT **Operation**

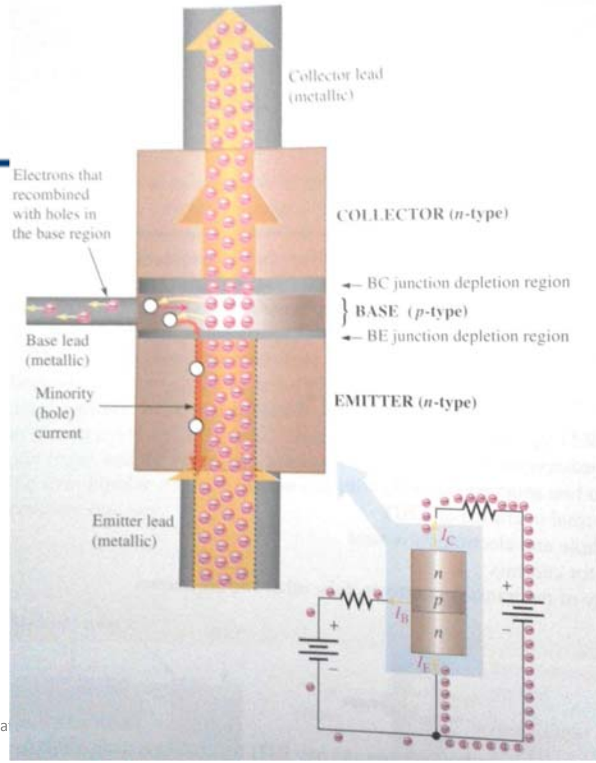
- CE battery +ve terminal attract electrons from the collector N-region.
- Collector N-region compensate electrons depletion region, which become more and more wider.



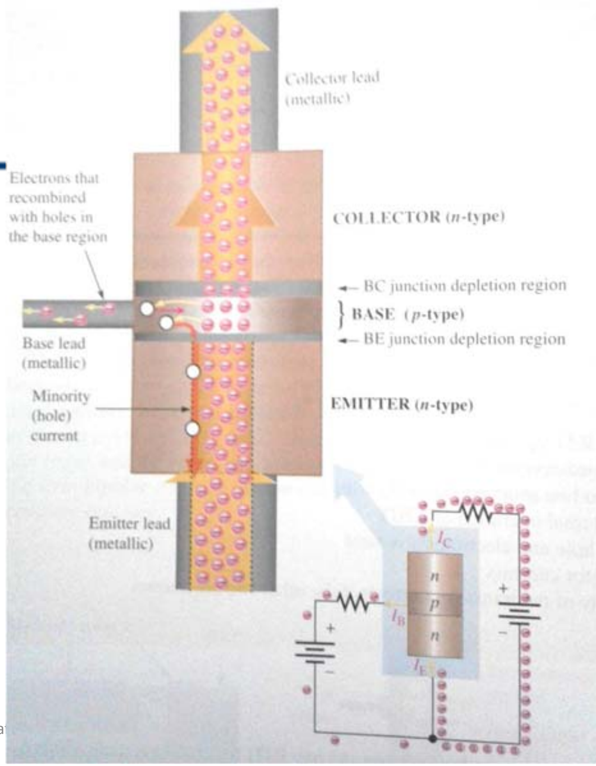
- BE battery +ve terminal start attracting the small amounts of electrons (minority carrier) from base p-type region, then starts attracting electrons from depletion region, which become thinner and thinner, then electrons start to flow from Emitter N-region



- Now base p-type now how a new electrons being transferred from CE battey –ve terminal through emitter n-type.
- Electrons stream divided between
  - Directly to BE battery +ve terminal
  - CE battery +ve terminal through emitter n-type

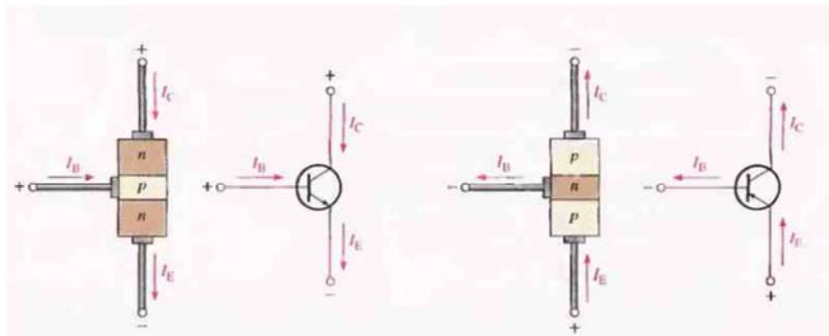


- The more +ve potential applied to base from BE battery +ve terminal, a more electrons being transferred from CE battery –ve terminal, through emitter N-region, a more electrons in turn flow to CE battery +ve terminal.



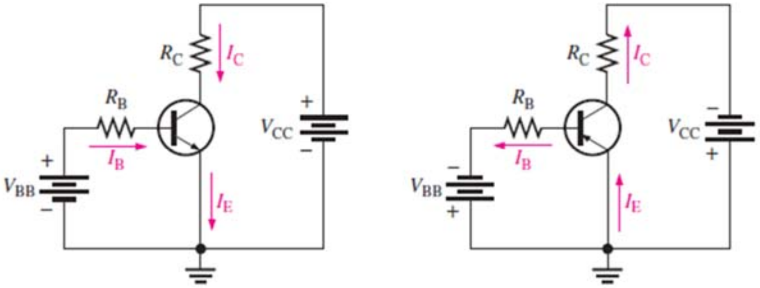
Transistor Currents

$$I_E = IB + IC$$



(a) npn (b) pnp

- VBB forward-biases the base-emitter junction,
- VCC reverse-biases the base-collector junction.
- In practice both VCC, and VBB derived from single battery with necessarily voltage divider on base terminal



(a) *npn* (b) *pnp*

- **DC Beta (β_{DC}) and DC Alpha (α_{DC})**
- DC gain called **(β_{DC})** is the ratio between IC/IB, which called h_{FE} in data sheet, range from less than 20 to 200 or higher.

$$\beta_{DC} = \frac{I_C}{I_B}$$

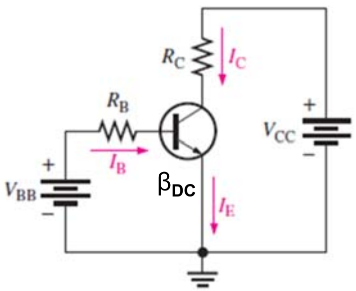
$$h_{FE} = \beta_{DC}$$

- **(α_{DC})** is the ratio between IC/IE, in range from 0.95 to 0.99 or greater

$$\alpha_{DC} = \frac{I_C}{I_E}$$

Example

Determine the dc current gain β_{DC} and the emitter current I_E for a transistor where $I_B = 50\ \mu A$ and $I_C = 3.65$ mA.

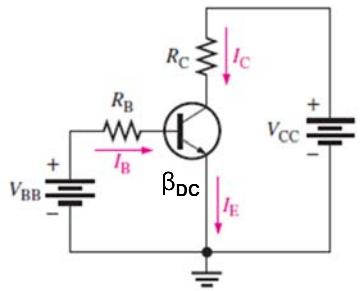


Example

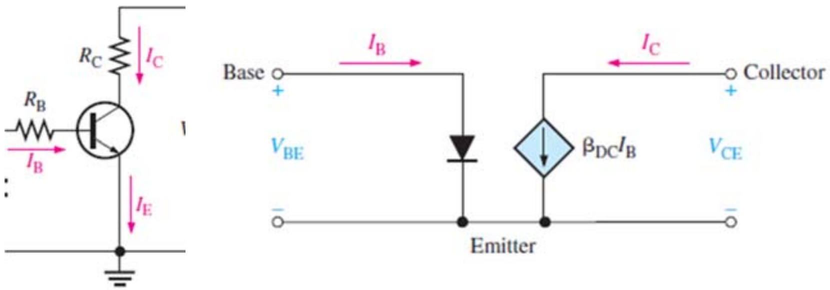
Determine the dc current gain β_{DC} and the emitter current I_E for a transistor where $I_B = 50\ \mu A$ and $I_C = 3.65$ mA.

$$\beta_{DC} = \frac{I_C}{I_B} = \frac{3.65\text{ mA}}{50\ \mu\text{A}} = \mathbf{73}$$

$$I_E = I_C + I_B = 3.65\text{ mA} + 50\ \mu\text{A} = \mathbf{3.70\ mA}$$



Transistor DC Model



BJT Circuit Analysis

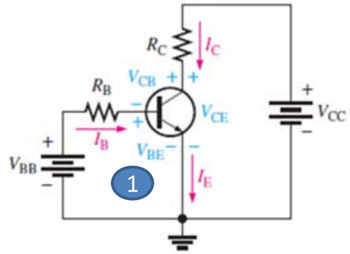
- *V*BB, forward-biases the base-emitter junction, and the collector-bias voltage source, *V*CC, reverse-biases the base-collector junction.

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

- Kirchhoff's voltage law @1

$$V_{R_B} = V_{BB} - V_{BE}$$

I_B: dc base current
I_E: dc emitter current
I_C: dc collector current
V_{BE}: dc voltage at base with respect to emitter
V_{CB}: dc voltage at collector with respect to base
V_{CE}: dc voltage at collector with respect to emitter



- Ohm's low

$$V_{R_B} = I_B R_B$$

- Substitute

$$I_B R_B = V_{BB} - V_{BE}$$

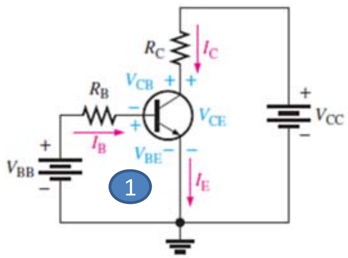
- Finally

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$$I_C = \beta\ IB$$

$$I_E = IC + IB$$

I_B: dc base current
I_E: dc emitter current
I_C: dc collector current
V_{BE}: dc voltage at base with respect to emitter
V_{CB}: dc voltage at collector with respect to base
V_{CE}: dc voltage at collector with respect to emitter



- KVL @ 2

$$-VCC + VRc + VCE = 0$$

$$V_{CE} = VCC - VRc$$

- Ohm's

$$V_{R_C} = I_C R_C$$

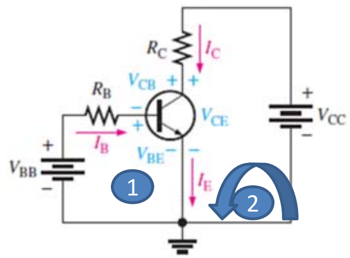
- Substitute

$$V_{CE} = V_{CC} - I_C R_C$$

- But

$$I_C = \beta_{DC} I_B.$$

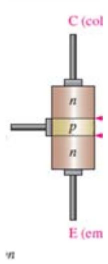
I_B: dc base current
I_E: dc emitter current
I_C: dc collector current
V_{BE}: dc voltage at base with respect to emitter
V_{CB}: dc voltage at collector with respect to base
V_{CE}: dc voltage at collector with respect to emitter



- Consider the transistor itself

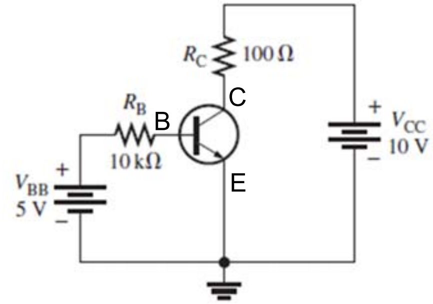
$$V_{CE} = VCB + VBE$$

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



Example 02

Determine I_B, I_C, I_E, V_{BE}, V_{CE}, and V_{CB} in the circuit of Figure 4–9. The transistor has a $\beta_{DC} = 150$.



Example 02

Determine I_B, I_C, I_E, V_{BE}, V_{CE}, and V_{CB} in the circuit of Figure 4–9. The transistor has a $\beta_{DC} = 150$.

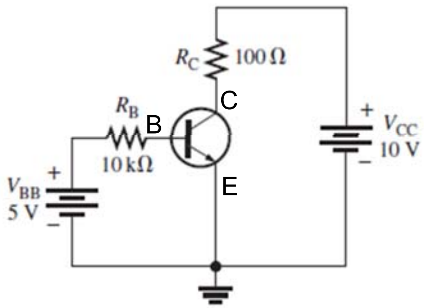
Answer

$V_{BE} \cong \mathbf{0.7\ V.}$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega} = \mathbf{430\ \mu A}$$

$$I_C = \beta_{DC} I_B = (150)(430\ \mu\text{A}) = \mathbf{64.5\ mA}$$

$$I_E = I_C + I_B = 64.5\text{ mA} + 430\ \mu\text{A} = \mathbf{64.9\ mA}$$



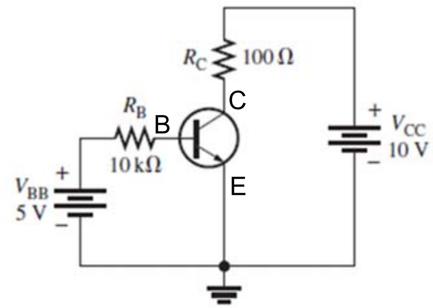
Example 02

Determine I_B, I_C, I_E, V_{BE}, V_{CE}, and V_{CB} in the circuit of Figure 4–9. The transistor has a $\beta_{DC} = 150$.

Answer

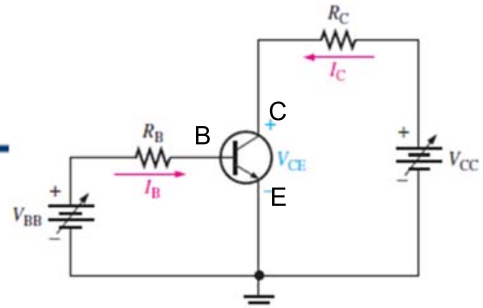
$$V_{CE} = V_{CC} - I_C R_C = 10\text{ V} - (64.5\text{ mA})(100\ \Omega) = 10\text{ V} - 6.45\text{ V} = \mathbf{3.55\ V}$$

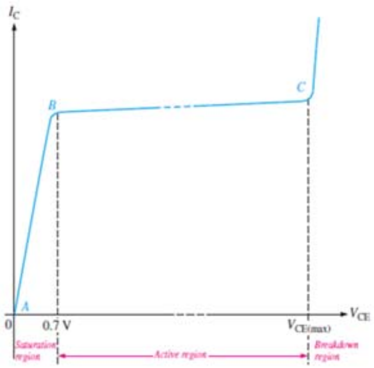
$$V_{CB} = V_{CE} - V_{BE} = 3.55\text{ V} - 0.7\text{ V} = \mathbf{2.85\ V}$$

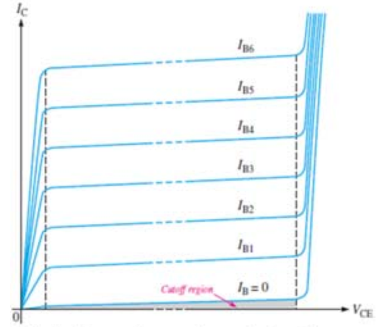


BJT **Characteristic**

Collector Characteristic Curves

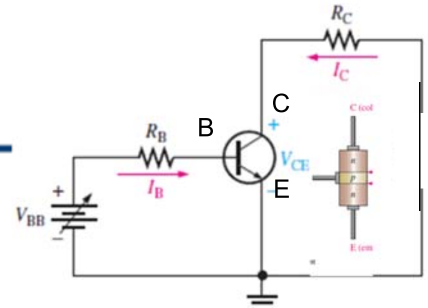






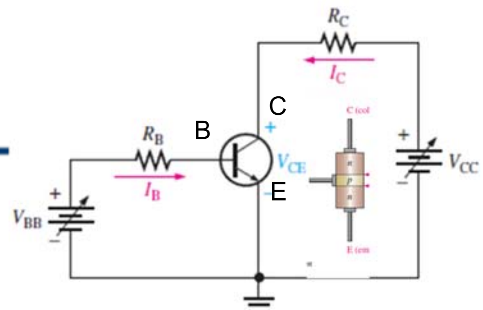
(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1} < I_{B2} < I_{B3}$, etc.)

Applying fixed VBB, increasing VCC

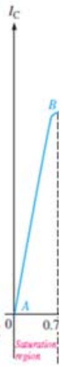


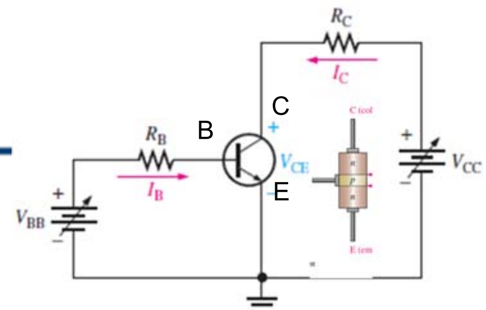
Saturation

- Assume that *V*BB is set to produce a certain value of *I*B and *V*CC is zero
- both the BE junction and the BC junction are forward-biased because the base is at approximately 0.7 V while the emitter and the collector are at 0 V.
- *I*C is zero.
- **Saturation is** both junctions are forward-biased



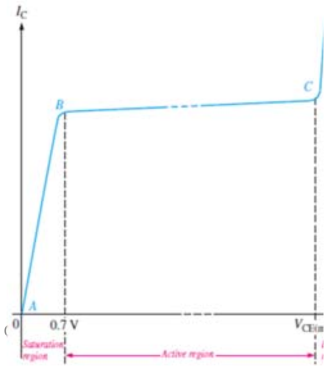
- As *V*CC is increased, *V*CE increases as the collector current increases, because *V*CE remains less than 0.7 V due to the forward-biased base-collector junction.





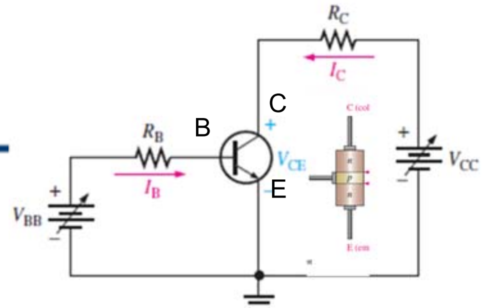
Active

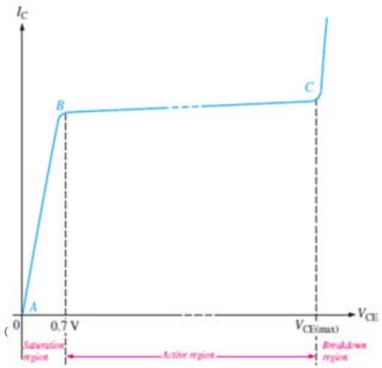
- when *V*CE exceeds 0.7 V, the base-collector junction becomes reverse-biased
- BJT become ***active**,* or **linear**, *region*
- IC levels off and remains essentially constant for a given value of *I*B as *V*CE continues to increase



breakdown

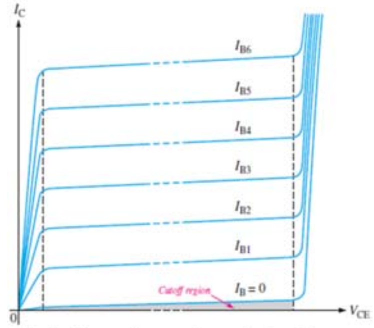
- When V_{CE} reaches a sufficiently high voltage, the reverse-biased base-collector junction goes into **breakdown**; and the collector current increases rapidly as indicated by the part of the curve to the right of point *C*





cutoff

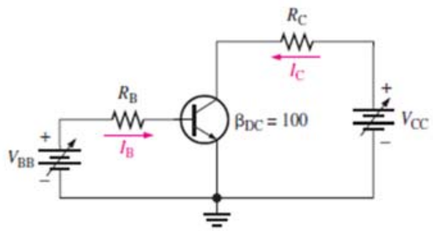
- When I_B 0, the transistor is in the **cutoff** region although there is a very small collector leakage current as indicated.
- **Cutoff** is the nonconducting state of a transistor.



(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1} < I_{B2} < I_{B3}$, etc.)

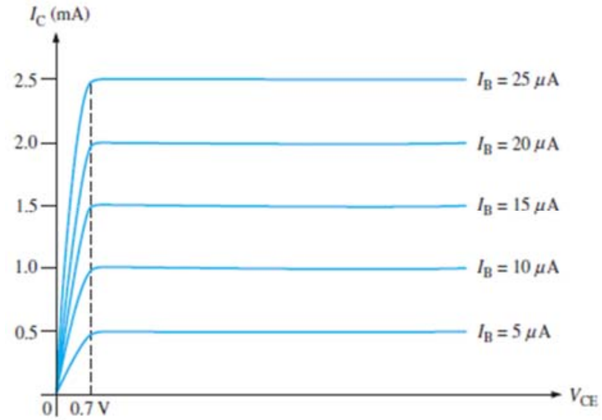
Example 03

Sketch an ideal family of collector curves for the circuit in Figure 4–11 for $I_B = 5\ \mu A$ to $25\ \mu A$ in $5\ \mu A$ increments. Assume $\beta_{DC} = 100$ and that V_{CE} does not exceed breakdown.

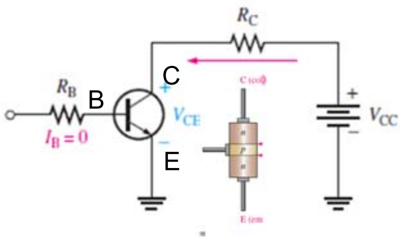


$I_C = \beta_{DC} I_B$.

I_B	I_C
5 μA	0.5 mA
10 μA	1.0 mA
15 μA	1.5 mA
20 μA	2.0 mA
25 μA	2.5 mA

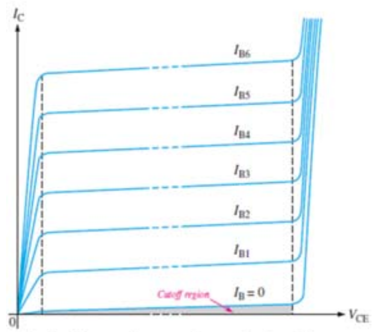


Applying fixed VCC, increasing VBB



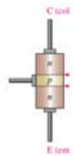
Cutoff

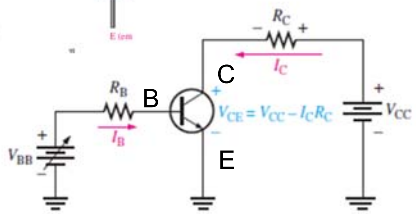
- when I_B = 0, the transistor is in the cutoff region
- I_{CEO} is extremely small, it will usually be neglected in circuit analysis
- $V_{CE} = V_{CC}$
- CEO represents collector-to-emitter with the base open.



(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1}< I_{B2}< I_{B3}$, etc.)

Applying fixed VCC, increasing VBB



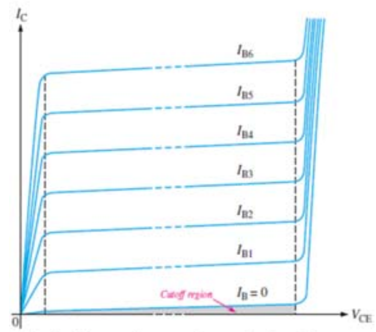


Saturation

- When the base-emitter junction becomes forward-biased and the base current is increased, the collector current also increases

  ($I_C = \beta I_B$)
- *V*CE decreases as a result of more drop across the collector resistor

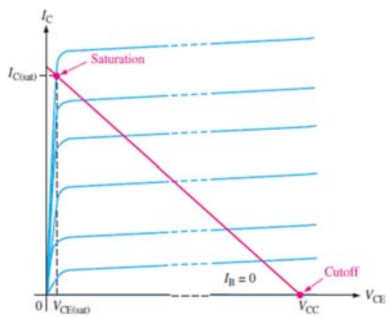
  (*V*CE = *V*CC – *I*C *R*C).
- *V*CE reaches its saturation value, *V*CE(sat),
- base-collector junction becomes forward-biased and
- At the point of saturation, the ($I_C = \beta I_B$) is no longer valid.



(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1}< I_{B2}< I_{B3}$, etc.)

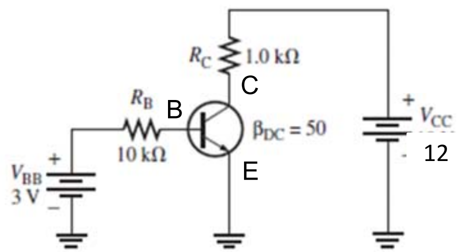
DC Load Line

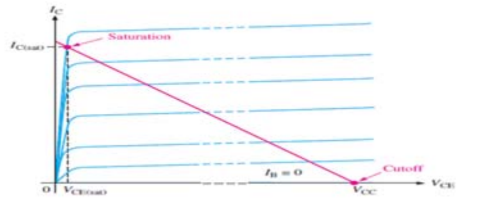
- dc load line drawn on a family of curves connecting the cutoff point and the saturation point.
- The bottom of the load line is at ideal cutoff where *I*C 0 and *V*CE *V*CC.



Example 04

Determine whether or not the transistor in Figure 4–16 is in saturation. Assume $V_{CE(sat)} = 0.2$ V.





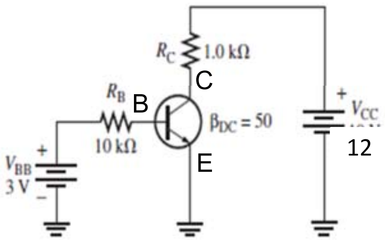
Example 04

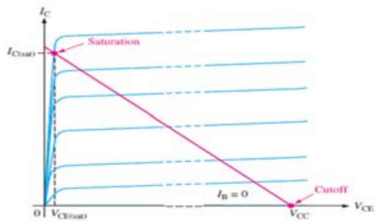
Determine whether or not the transistor in Figure 4–16 is in saturation. Assume $V_{CE(sat)} = 0.2$ V.

$$IB = \frac{3 - 0.7}{10000} = 0.23\, mA$$

$$IC = \beta\, IB = 50 \times 0.23 = 11.5\, mA$$

$$VCE = 12 - (11.5 \times 1) = 0.5\, Volt$$





VCE doesn’t reach VCEsat then **transistor is in active mode,**

More About β_{DC}

- β_{DC} is not truly constant but varies with both collector current and with temperature