UNIVERSITY OF MICHIGAN

JOINT INSTITUTE

交大密西根学院

Bipolar Junction Transistor.

BJT and BJT Circuit

Ve311 Electronic Circuits (Fall 2020)

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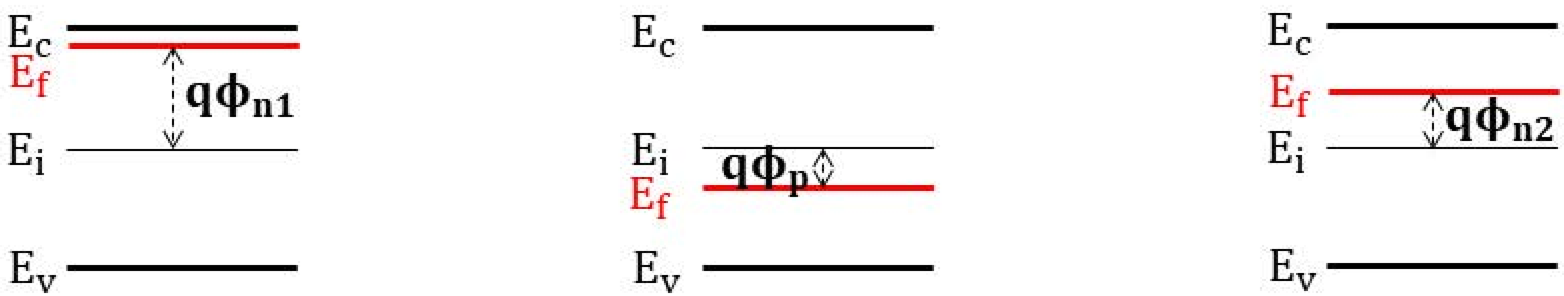
BJT (Before Contact)

Emitter	Base	Collector
n-type	p-type	n-type



P concentration

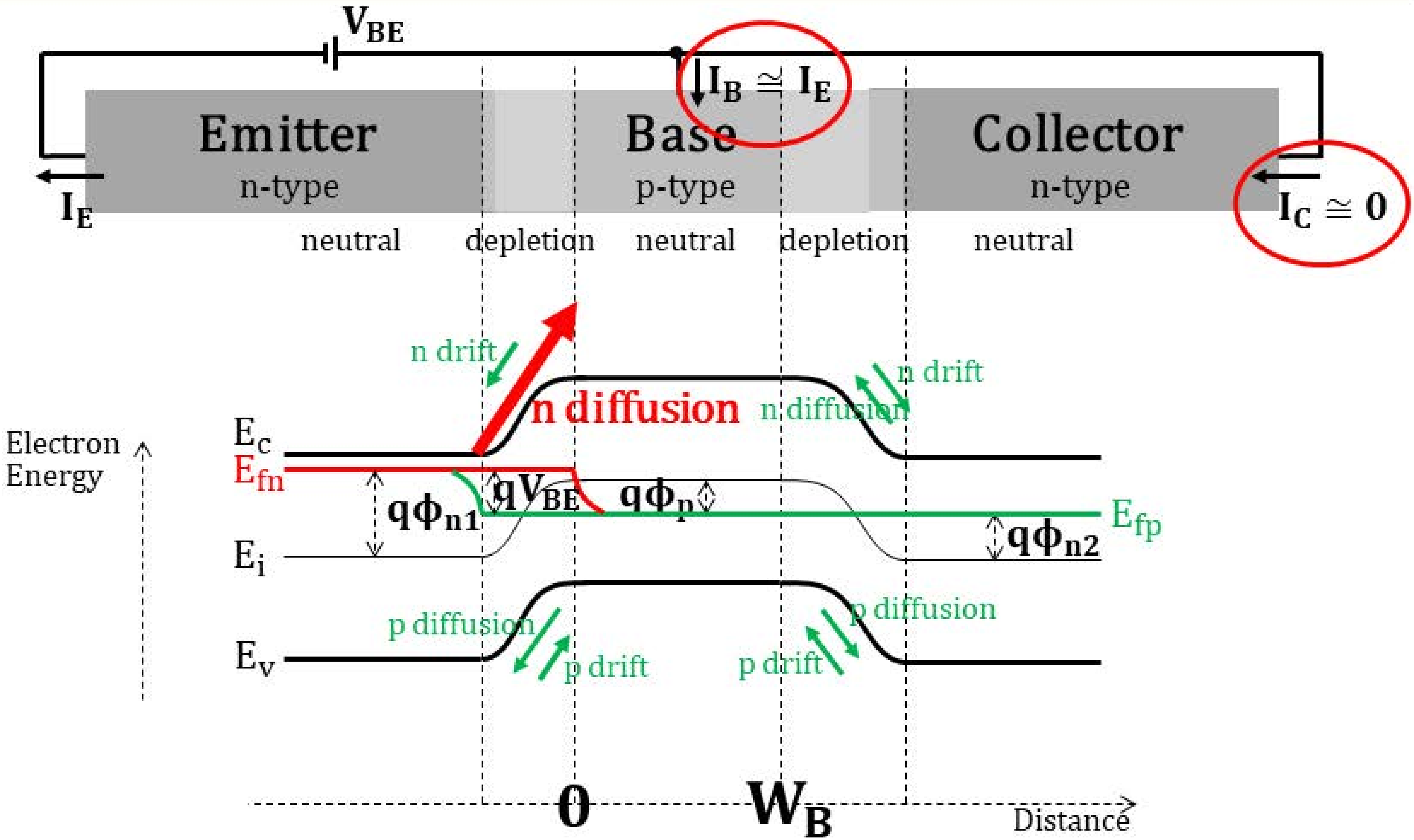
B concentration.

$$n \cong N_{d1} = n_i e^{\frac{q\phi_{n1}}{kT}} \qquad p \cong N_a = n_i e^{\frac{q\phi_p}{kT}} \qquad n \cong N_{d2} = n_i e^{\frac{q\phi_{n2}}{kT}}$$

$$p \cong \frac{{n_i}^2}{N_{d1}} = n_i e^{\frac{-q\phi_{n1}}{kT}} \qquad n \cong \frac{{n_i}^2}{N_a} = n_i e^{\frac{-q\phi_p}{kT}} \qquad p \cong \frac{{n_i}^2}{N_{d2}} = n_i e^{\frac{-q\phi_{n2}}{kT}}$$

$$\boxed{N_{d1} \gg N_a}$$

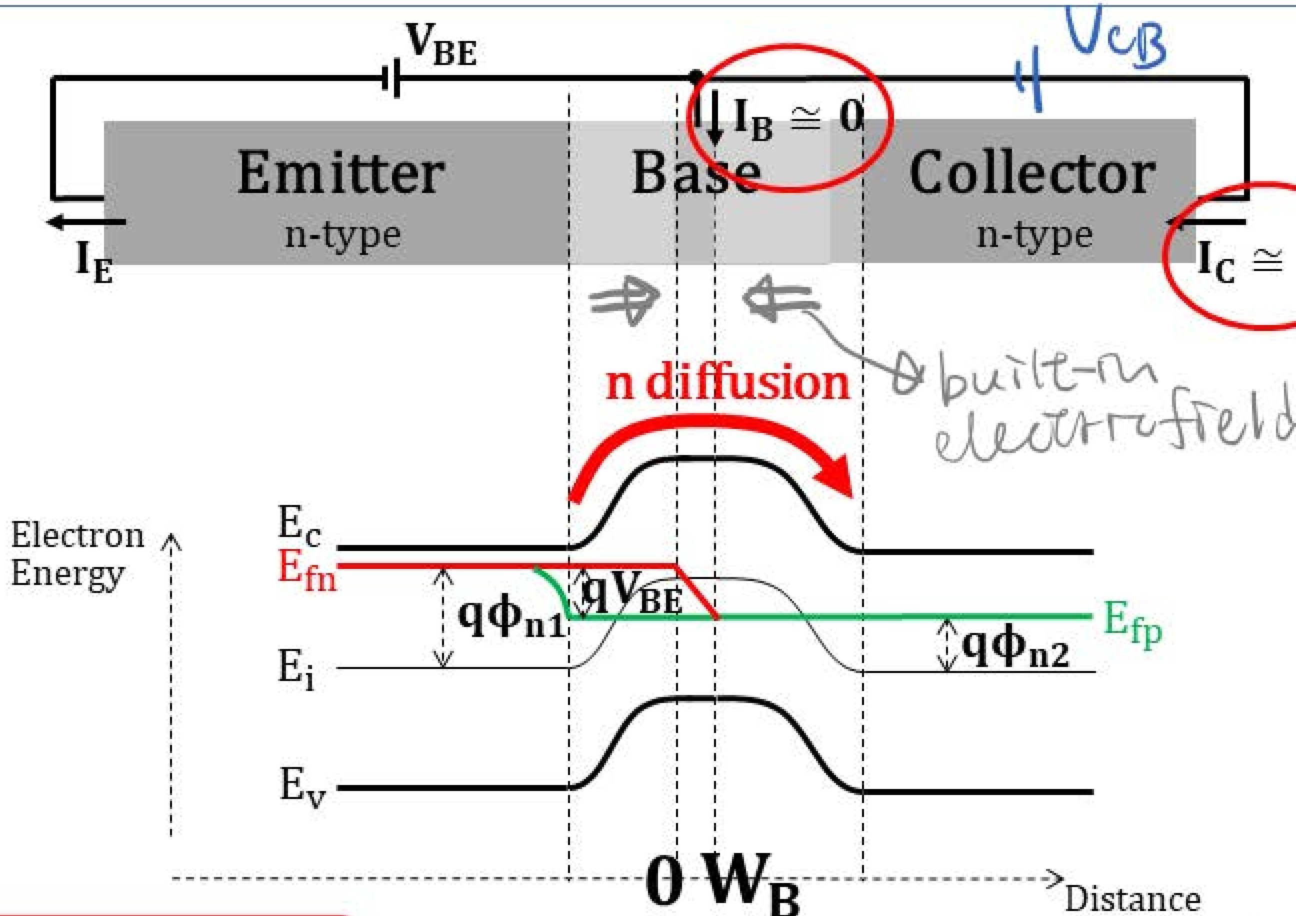
$V_{BE} > 0$ and $V_{CB} = 0$ (W_B long)



$$\boxed{N_{d1} \gg N_a}$$

The n (electron) diffusion is much larger than the p (hole) diffusion at the Base-Emitter junction.

$V_{BE} > 0$ and $V_{CB} = 0$ (W_B very short)



$$I_E = I_C + I_B$$

$$\frac{I_C}{I_E} = \alpha$$

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

$N_{d1} \gg N_a$

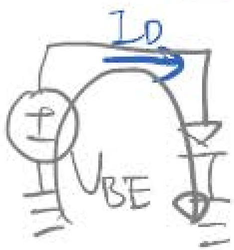
The n (electron) diffusion is much larger than the p (hole) diffusion at the Base-Emitter junction.

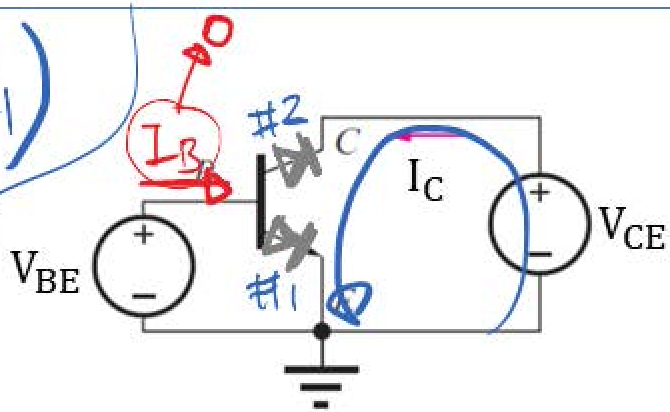
W_B very short

Nearly all the n (electron) diffusion from the Base-Emitter junction pass through the Base, enter into the depletion region of the Base-Collector junction, and are swept to the Collector side by the built-in electric field.

Summary

$I_D = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)$





$$V_{CE} \geq V_{BE}$$
$$\Rightarrow \textbf{Forward} - \textbf{Active}$$

* junction #1 → forward bias
* junction #2 → zero or reverse bias

Ideal case

$$\mathbf{I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)}$$

$$\boldsymbol{\alpha} = \frac{\mathbf{I_C}}{\mathbf{I_E}} \cong \mathbf{1}$$

$$\boldsymbol{\beta} = \frac{\mathbf{I_C}}{\mathbf{I_B}} = \frac{\boldsymbol{\alpha}}{\mathbf{1} - \boldsymbol{\alpha}}$$

$I_C + I_B = I_E$

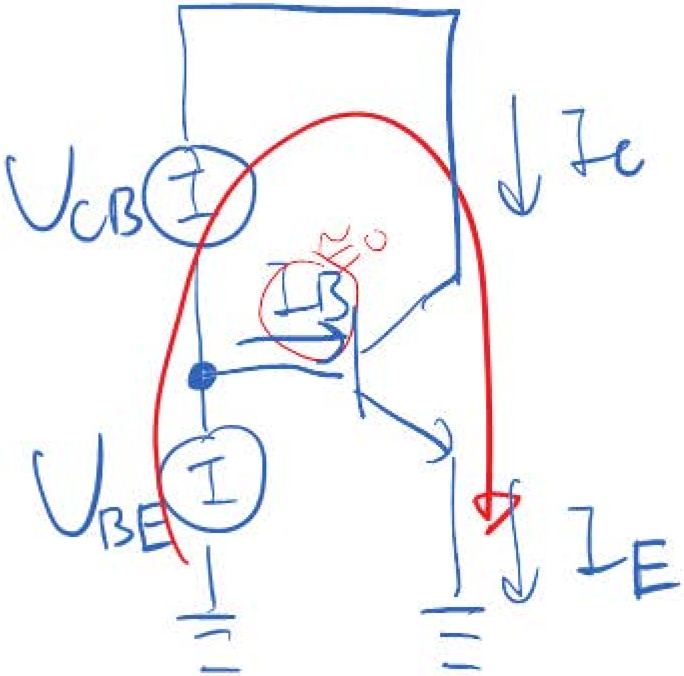
$$\mathbf{I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)}$$

$$\boldsymbol{\alpha} = \frac{\mathbf{I_C}}{\mathbf{I_E}} = \mathbf{1}$$

$$\boldsymbol{\beta} = \frac{\mathbf{I_C}}{\mathbf{I_B}} = \infty$$

I_B → 0

I_S is a constant in the spice model.



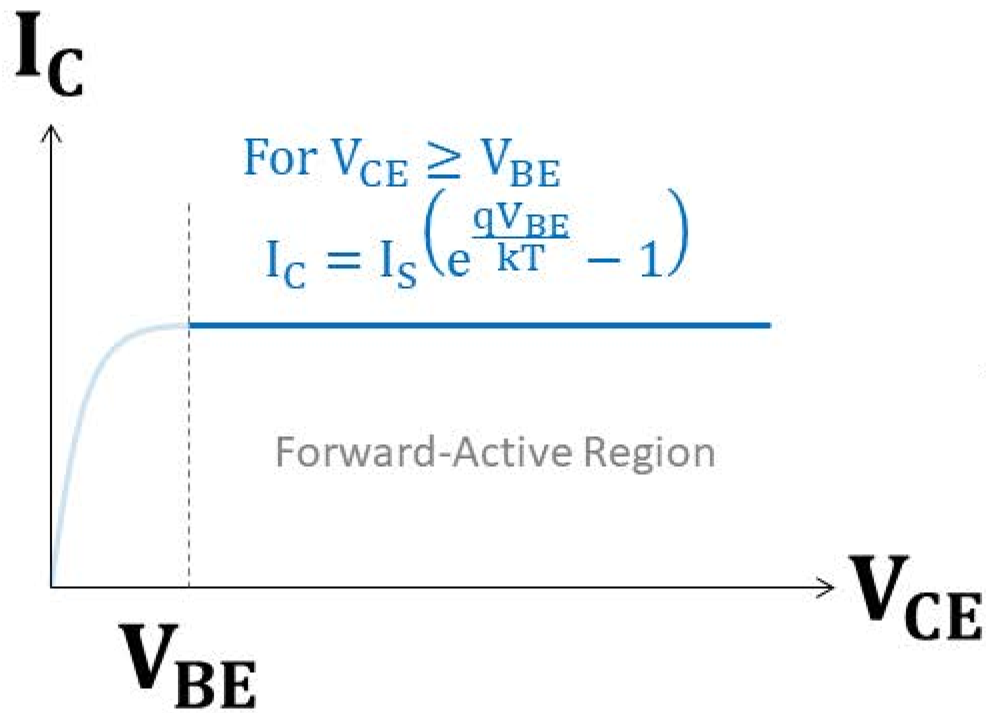
$V_{CB} \geq 0$

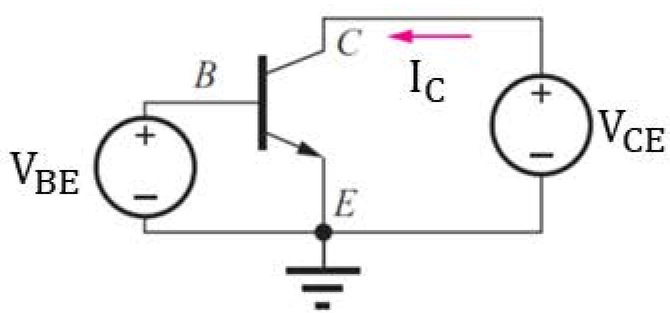
forward-active region

I_C vs V_{CE} and I_C vs V_{BE} in Forward-Active Region

I_C vs V_{CE} (not considering Early Effect)

At given V_{BE}, DC *s*weep V_{CE}



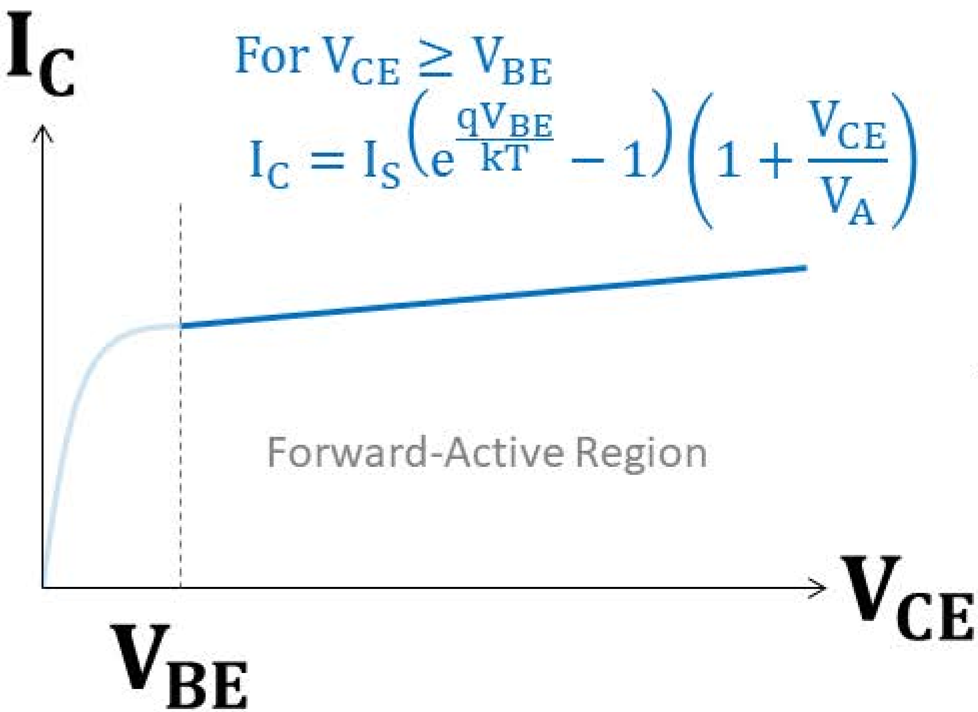


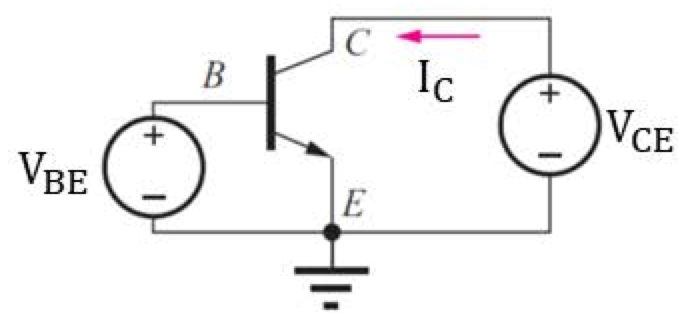
I_C vs V_{CE} (considering Early Effect)

At given $\mathbf{V_{BE}}$, DC *s*weep $\mathbf{V_{CE}}$

For $V_{CE} \geq V_{BE}$

$$I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$





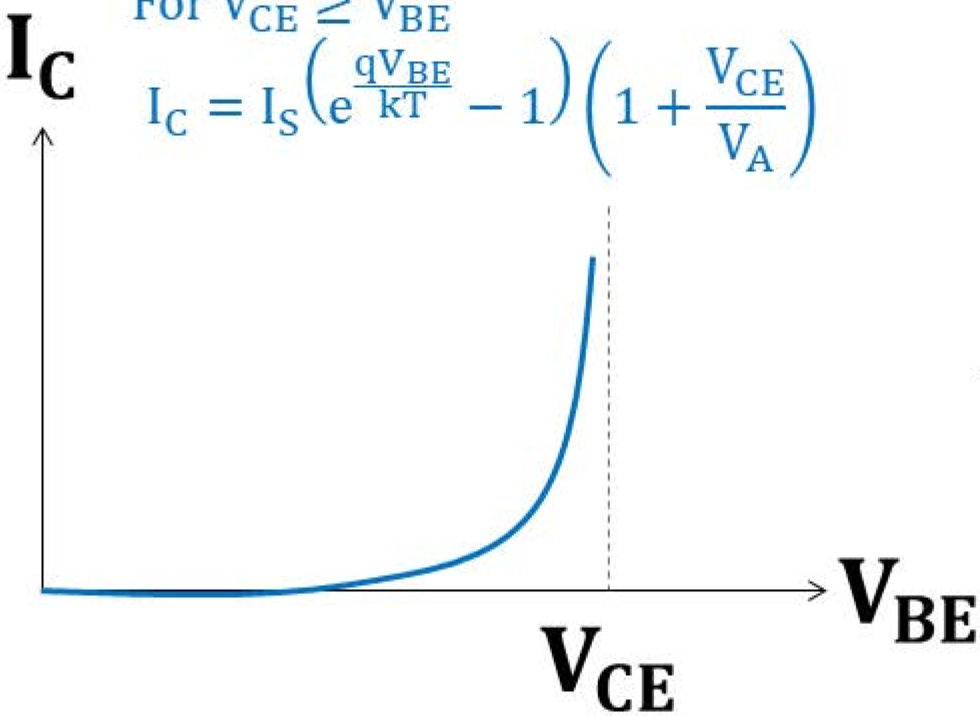
V_A is a constant in the spice model.

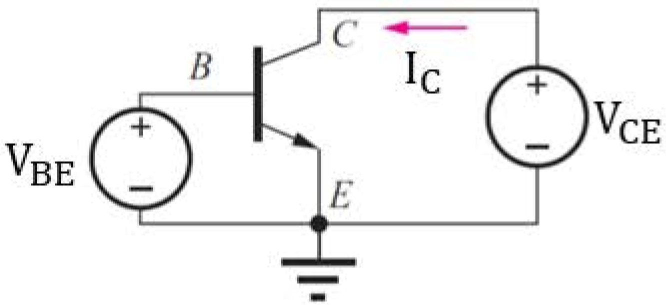
I_C vs V_{BE}

At given $\mathbf{V_{CE}}$, DC *s*weep $\mathbf{V_{BE}}$

For $V_{CE} \geq V_{BE}$

$$I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$



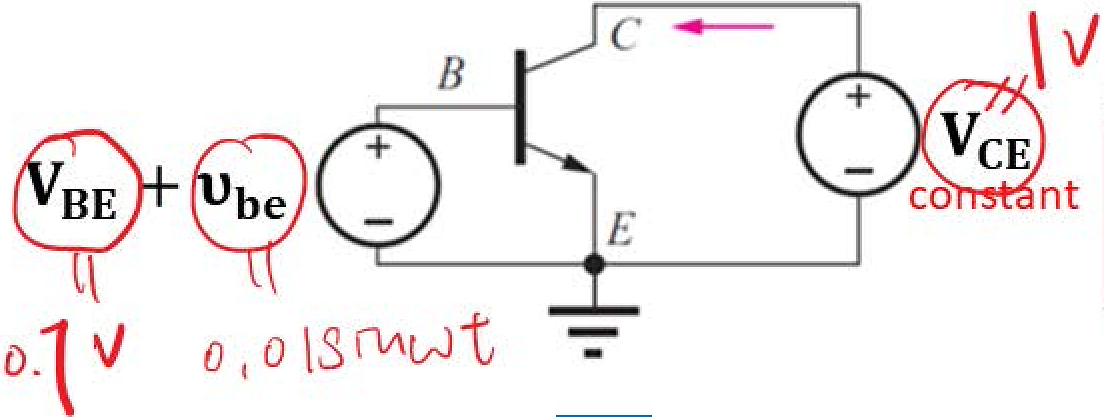


Small-Signal Model

Hybrid-π Model (how to get gm and r_π)

Complete circuit:

$$I_c = I_C + i_c$$



$V_{CE} \geq V_{BE}$
$\Rightarrow$ Forward – Active

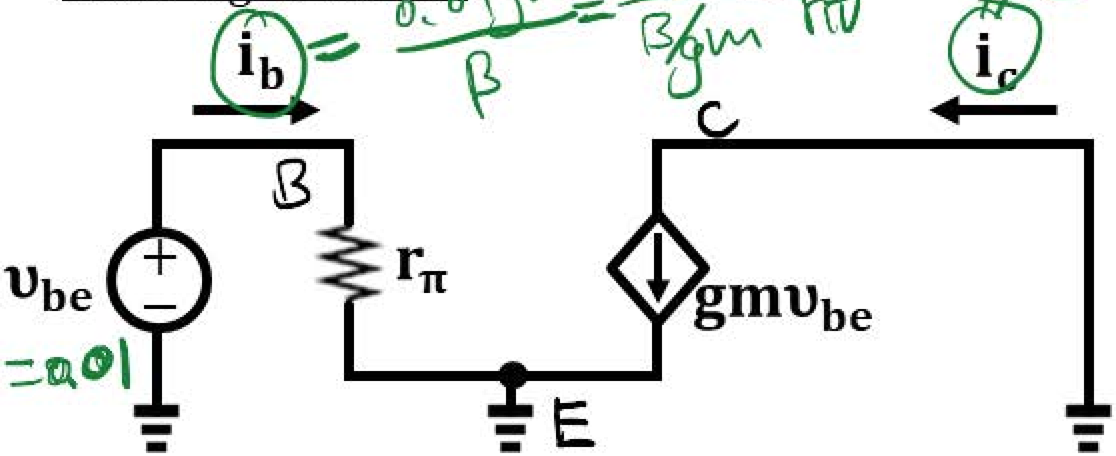
$$\boxed{I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)}$$

V_A = 100

Small-signal circuit:

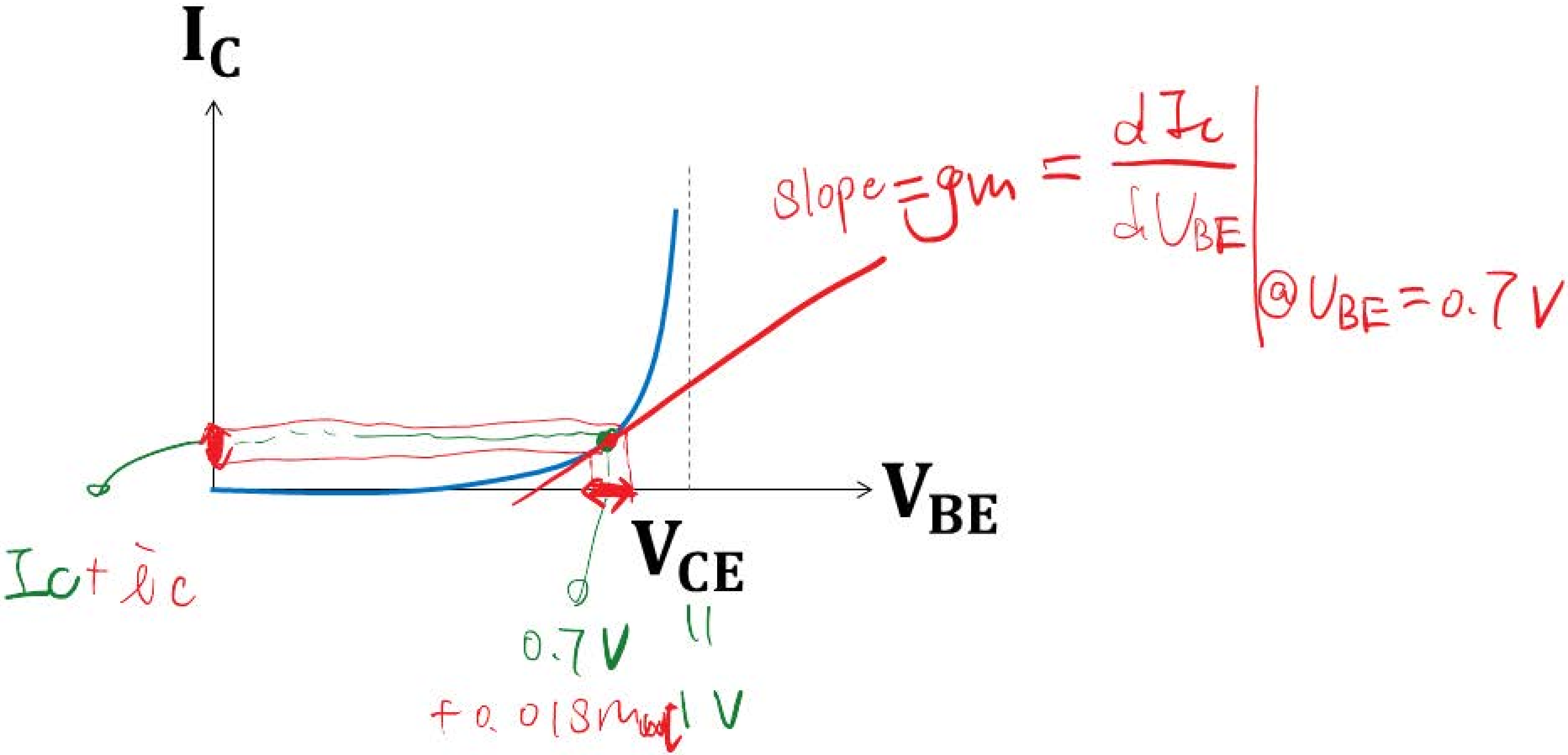
$i_b = \frac{0.01gm}{\beta} = \frac{0.01}{\beta/gm} = \frac{0.01}{r_\pi}$

i_c = 0.01 gm



$$r_\pi = \frac{dV_{BE}}{dI_B} = \frac{1}{\frac{dI_C}{\beta dV_{BE}}} = \frac{1}{\frac{gm}{\beta}} = \frac{\beta}{gm}$$

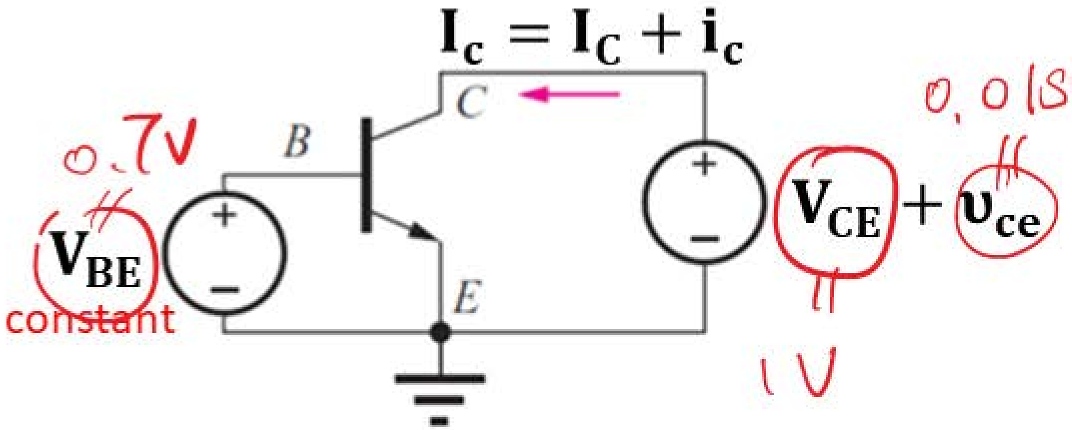
$$gm = \frac{dI_C}{dV_{BE}} \cong \frac{I_C}{kT/q}$$



$$I_C = I_S\left(e^{\frac{0.7}{0.026}} - 1\right)\left(1 + \frac{1}{V_A}\right), \quad i_c = (0.01\sin\omega t)\, g_m$$

Hybrid-π Model (how to get r_o)

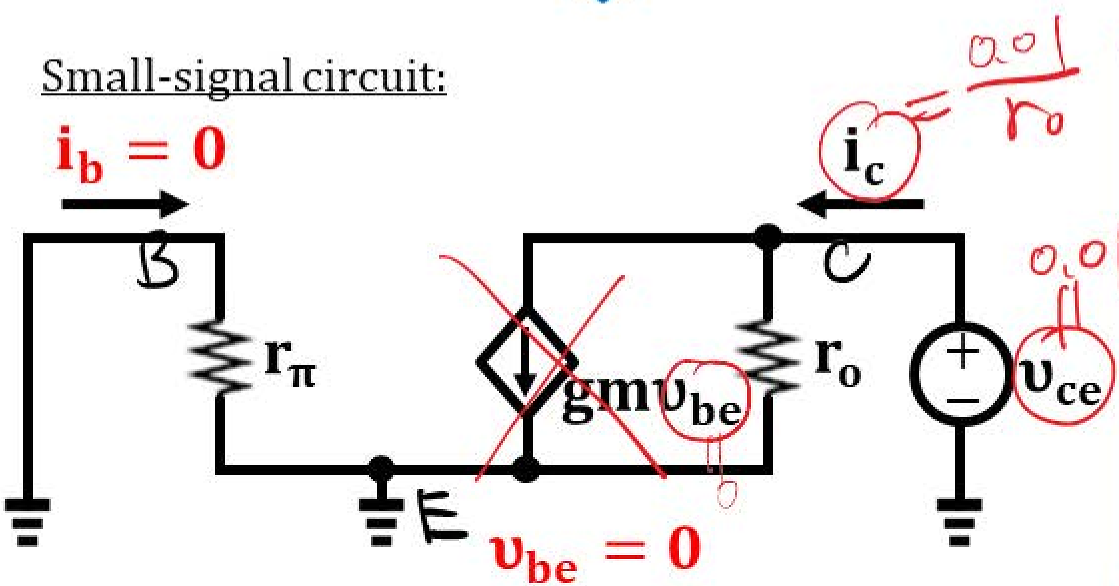
Complete circuit:



$V_{CE} \geq V_{BE}$
$\Rightarrow$ Forward – Active

$$\boxed{I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)}$$

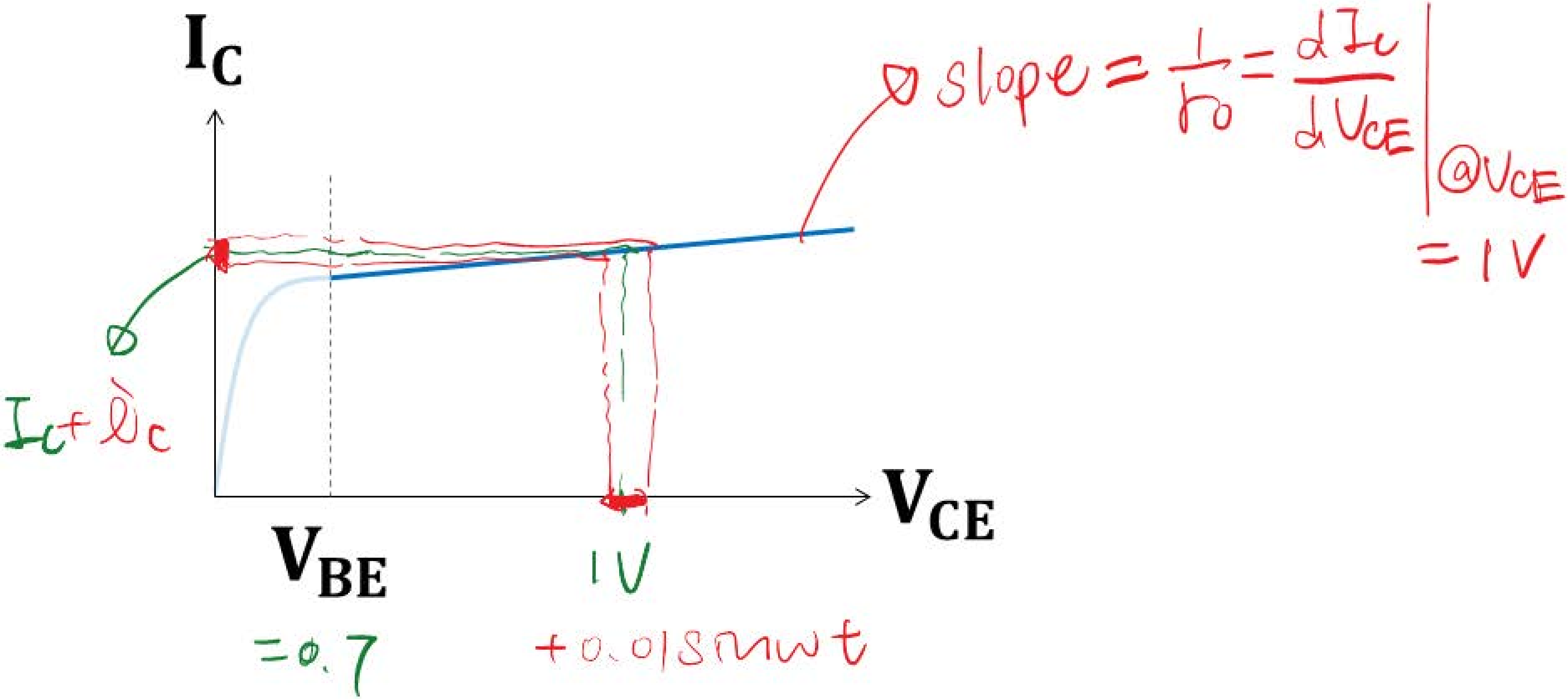
Small-signal circuit:



$$r_\pi = \frac{1}{\frac{dI_B}{dV_{BE}}} = \frac{1}{\frac{dI_C}{\beta dV_{BE}}} = \frac{1}{\frac{gm}{\beta}} = \frac{\beta}{gm}$$

$$gm = \frac{dI_C}{dV_{BE}} \cong \frac{I_C}{kT/q}$$

$$r_o = \frac{1}{\frac{dI_C}{dV_{CE}}} \cong \frac{V_A}{I_C}$$



$$I_C = I_S\left(e^{\frac{0.7}{0.026}} - 1\right)\left(1+\frac{1}{V_A}\right), \qquad i_c = \frac{0.01\sin\omega t}{r_o}$$