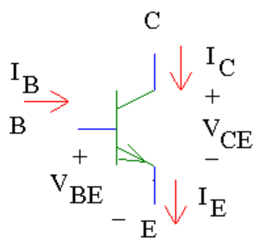
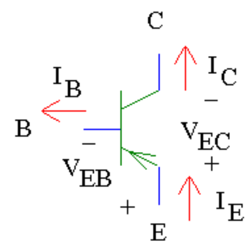
DC Bipolar Transistor Models - Jaeger

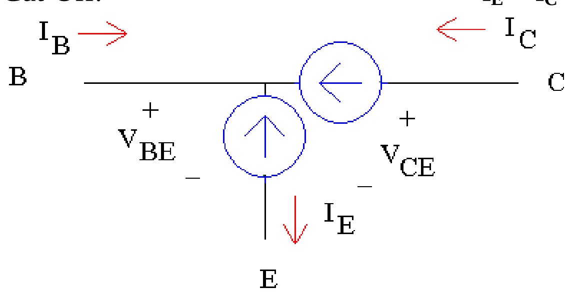
n-p-n

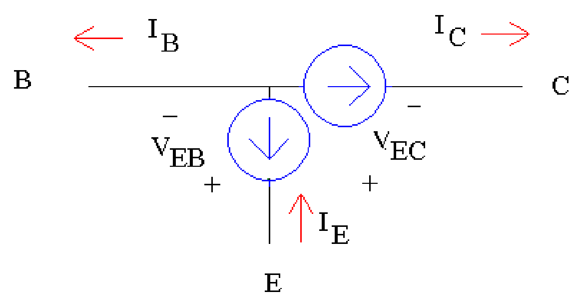


p-n-p



Cut-Off: $I_E \approx I_C \approx I_B \approx 0$mA

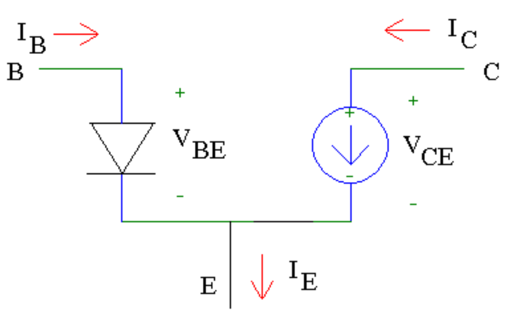


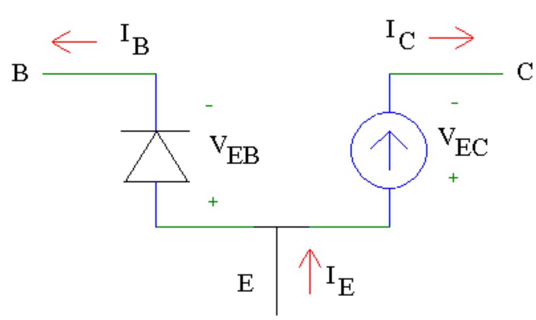


$V_{\mathbf{BE}} < -4kT/q$ $V_{\mathbf{BC}} < -4kT/q$ $V_{\mathbf{EB}} < -4kT/q$ $V_{\mathbf{CB}} < -4kT/q$

$I_C = I_S/\beta_R$ $I_E = -I_S/\beta_F$ $I_B = -I_S/\beta_F - I_S/\beta_R$

Forward Active:





$V_{\mathbf{BE}} = (q/kT)\ln I_S$

$V_{\mathbf{BE}} > 4kT/q$

$I_{\mathbf{B}} = (I_S/\beta_F)[\exp(V_{\mathbf{BE}}/V_T) - 1] - (I_S/\beta_R)$

$I_{\mathbf{B}} \approx (I_S/\beta_F)\exp(V_{\mathbf{BE}}/V_T)$

$I_{\mathbf{C}} = I_S[\exp(V_{\mathbf{BE}}/V_T) + 1/\beta_R]$

$I_{\mathbf{C}} \approx I_S \exp(V_{\mathbf{BE}}/V_T)$

$I_{\mathbf{E}} = I_S[(1/\alpha_F)(\exp(V_{\mathbf{BE}}/V_T) + 1/\beta_R]$

$I_{\mathbf{E}} \approx (I_S/\alpha_F)\exp(V_{\mathbf{BE}}/V_T)$

$V_{\mathbf{EB}} = (q/kT)\ln I_S$

$V_{\mathbf{EB}} > 4kT/q$

$I_{\mathbf{B}} = (I_S/\beta_F)[\exp(V_{\mathbf{EB}}/V_T) - 1] - (I_S/\beta_R)$

$I_{\mathbf{B}} \approx (I_S/\beta_F)\exp(V_{\mathbf{EB}}/V_T)$

$I_{\mathbf{C}} = I_S[\exp(V_{\mathbf{EB}}/V_T) + 1/\beta_R]$

$I_{\mathbf{C}} \approx I_S \exp(V_{\mathbf{EB}}/V_T)$

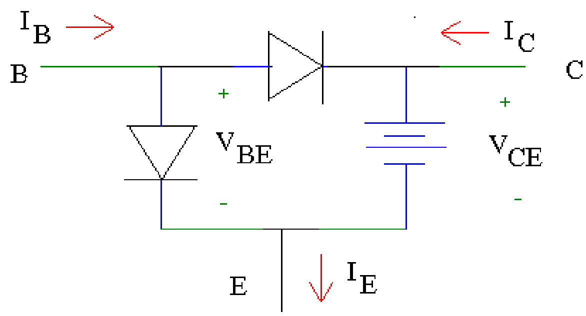
$I_{\mathbf{E}} = I_S[(1/\alpha_F)(\exp(V_{\mathbf{EB}}/V_T) + 1/\beta_R]$

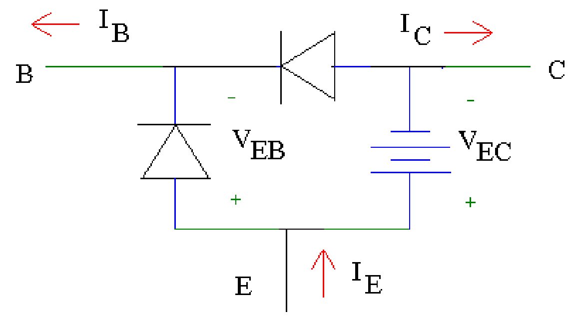
$I_{\mathbf{E}} \approx (I_S/\alpha_F)\exp(V_{\mathbf{EB}}/V_T)$

Saturation: $I_B = (I_S/\beta_F)\exp(V_{BE}/V_T) + (I_S/\beta_R)\exp(V_{CE}/V_T) \approx (I_S/\beta_F)\exp(V_{BE}/V_T)$

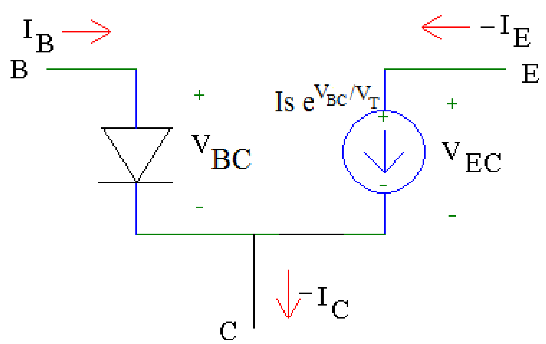
$$I_C = I_S[\exp(V_{BE}/V_T) + 1/\beta_R] \approx I_S \exp(V_{BE}/V_T)$$

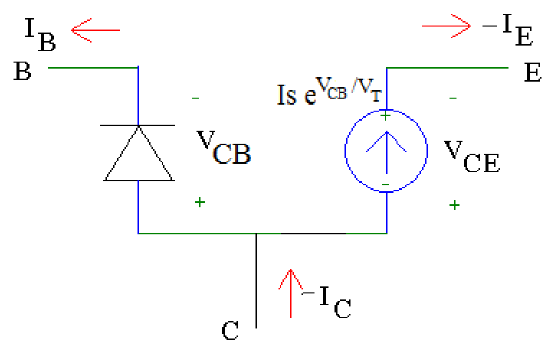
$$I_E = I_S\,[(1/\alpha_F)(\exp(V_{BE}/V_T) + 1/\beta_R] \approx (I_S/\alpha_F)\exp(V_{BE}/V_T)$$





Reverse Active: $I_E = \beta_R I_B$, $I_C = (\beta_R + 1)\, I_B$





$V_{BE} = (q/kT)\ln I_S$

$V_{BE} > 4kT/q$

$I_B = (I_S/\beta_R)[\exp(V_{BC}/V_T) - 1] - (I_S/\beta_F)$

$I_B \approx (I_S/\beta_R)\exp(V_{BC}/V_T)$

$I_C = -\,I_S\,[(1/\alpha_R)(\exp(V_{BC}/V_T) + 1/\beta_F]$

$I_C \approx -\,(I_S/\alpha_R)(\exp(V_{BC}/V_T)$

$I_E = -\,I_S[\exp(V_{BC}/V_T) + 1/\beta_F]$

$I_E \approx -\,I_S\exp(V_{BC}/V_T)$

$V_{EB} = (q/kT)\ln I_S$

$V_{EB} > 4kT/q$

$I_B = (I_S/\beta_R)[\exp(V_{CB}/V_T) - 1] - (I_S/\beta_F)$

$I_B \approx (I_S/\beta_R)\exp(V_{CB}/V_T)$

$I_C = -\,I_S\,[(1/\alpha_R)(\exp(V_{CB}/V_T) + 1/\beta_F]$

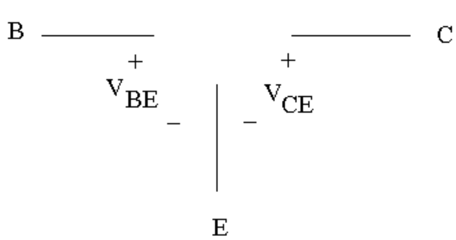
$I_C \approx -\,(I_S/\alpha_R)(\exp(V_{CB}/V_T)$

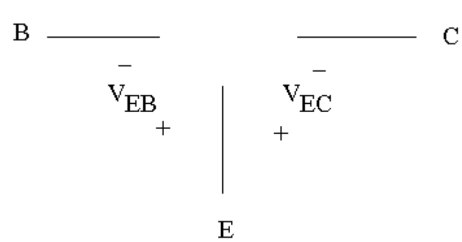
$I_E = -\,I_S[\exp(V_{CB}/V_T) + 1/\beta_F]$

$I_E \approx -\,I_S\exp(V_{CB}/V_T)$

Further Simplification of DC Bipolar Transistor Models – Jaeger

Cut-Off: $I_E = I_C = I_B = 0\text{mA}$

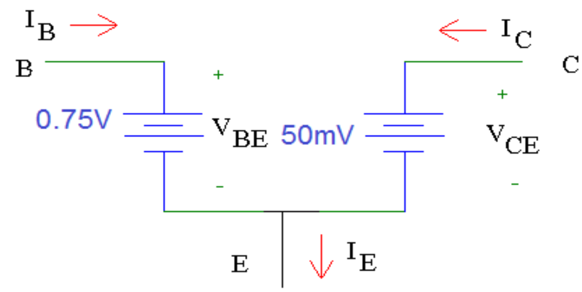




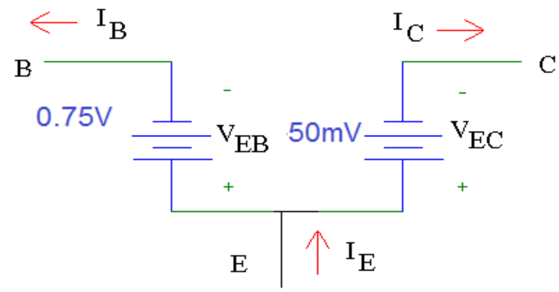
$V_{BE} < V_{on}$ (base-emitter diode)

$V_{EB} < V_{on}$ (base-emitter diode)

Saturation: $I_C \sim I_{SC}$ $I_C < \beta_F I_B$

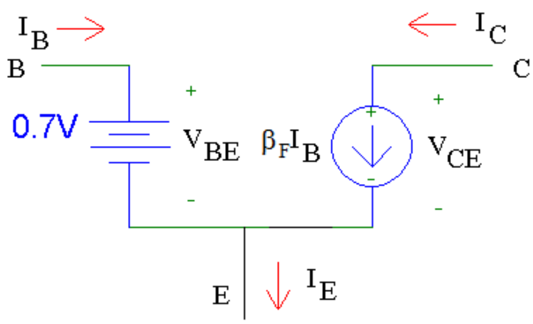


$V_{BE} = 0.75V$ $V_{CE} = 50mV$
$I_B > 0mA$

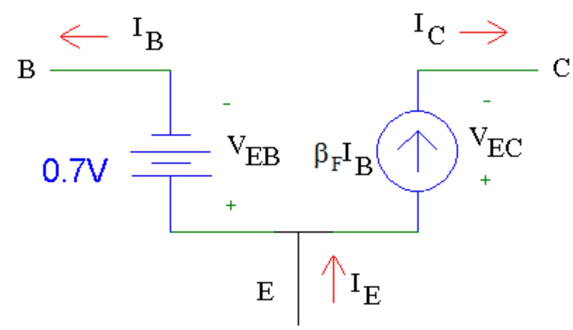


$V_{EB} = 0.75V$ $V_{CE} = 50mV$
$I_B > 0mA$

Forward Active: $I_C = \beta_F I_B$, $I_E = (\beta_F + 1) I_B$

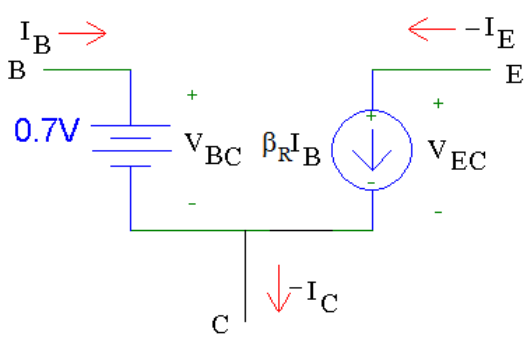


$V_{BE} = 0.7V$ $V_{CE} > 50mVV$
$I_B > 0mA$

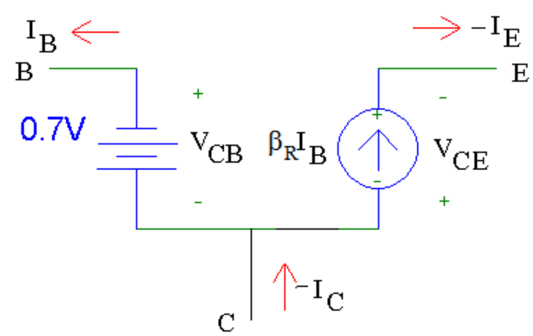


$V_{EB} = 0.7V$ $V_{EC} > 50mV$
$I_B > 0mA$

Reverse Active: $I_E = \beta_R I_B$, $I_C = (\beta_R + 1) I_B$



$V_{BC} = 0.7V$ $V_{EC} > 50mVV$
$I_B > 0mA$



$V_{CB} = 0.7V$ $V_{CE} > 50mV$
$I_B > 0mA$