Bipolar Junction Transistors

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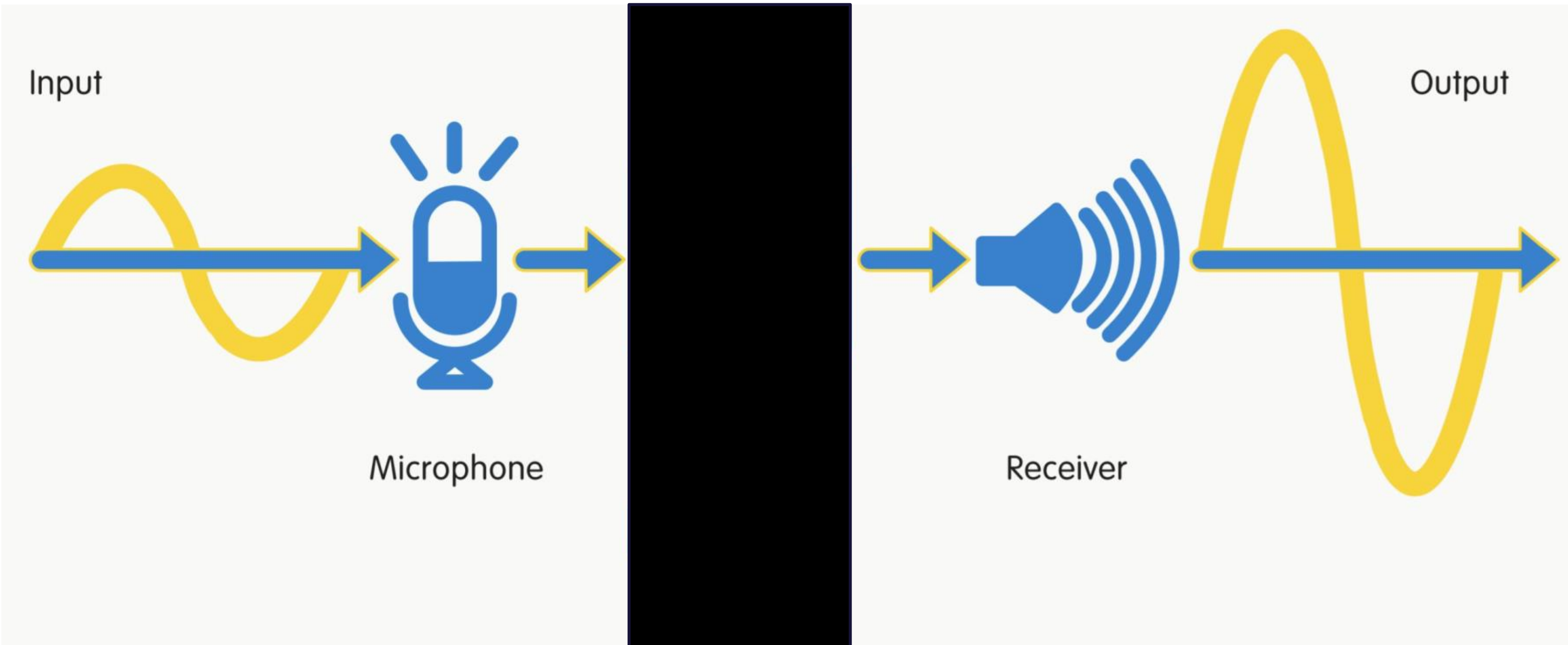
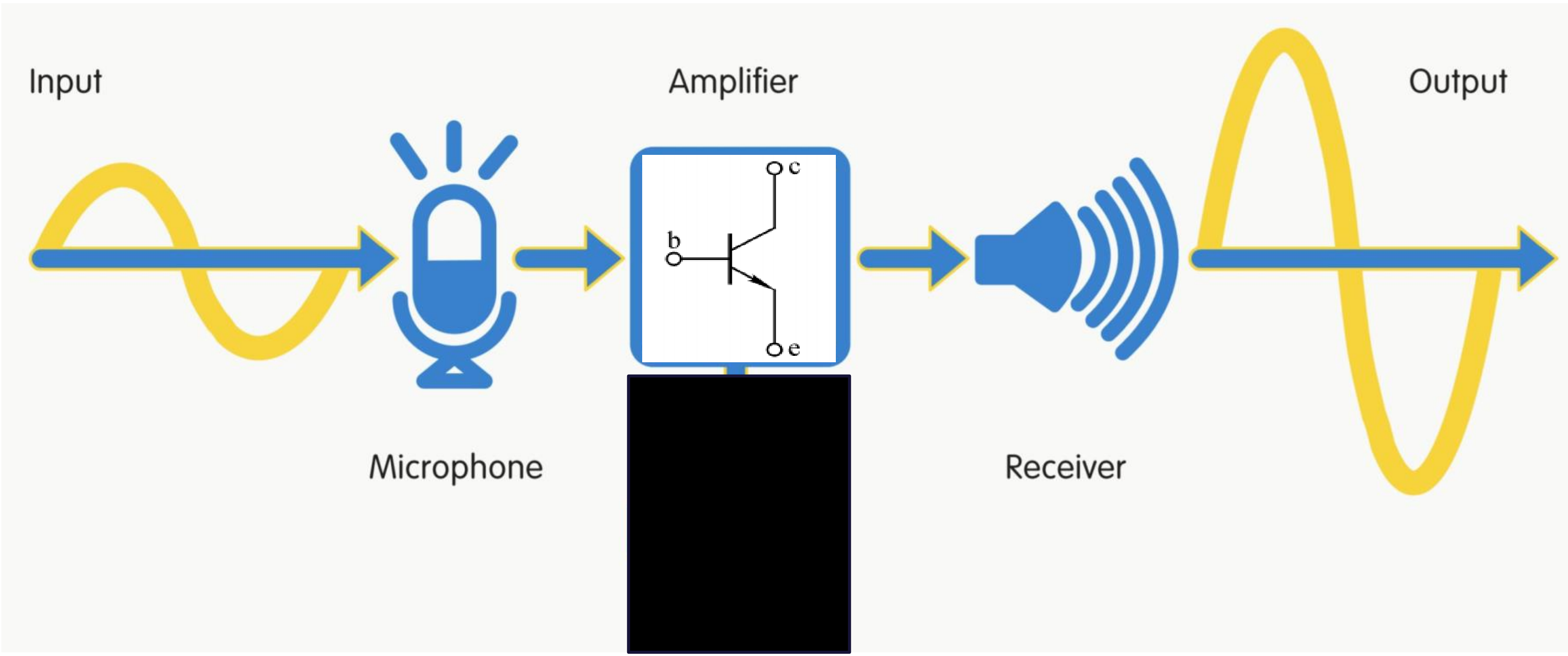
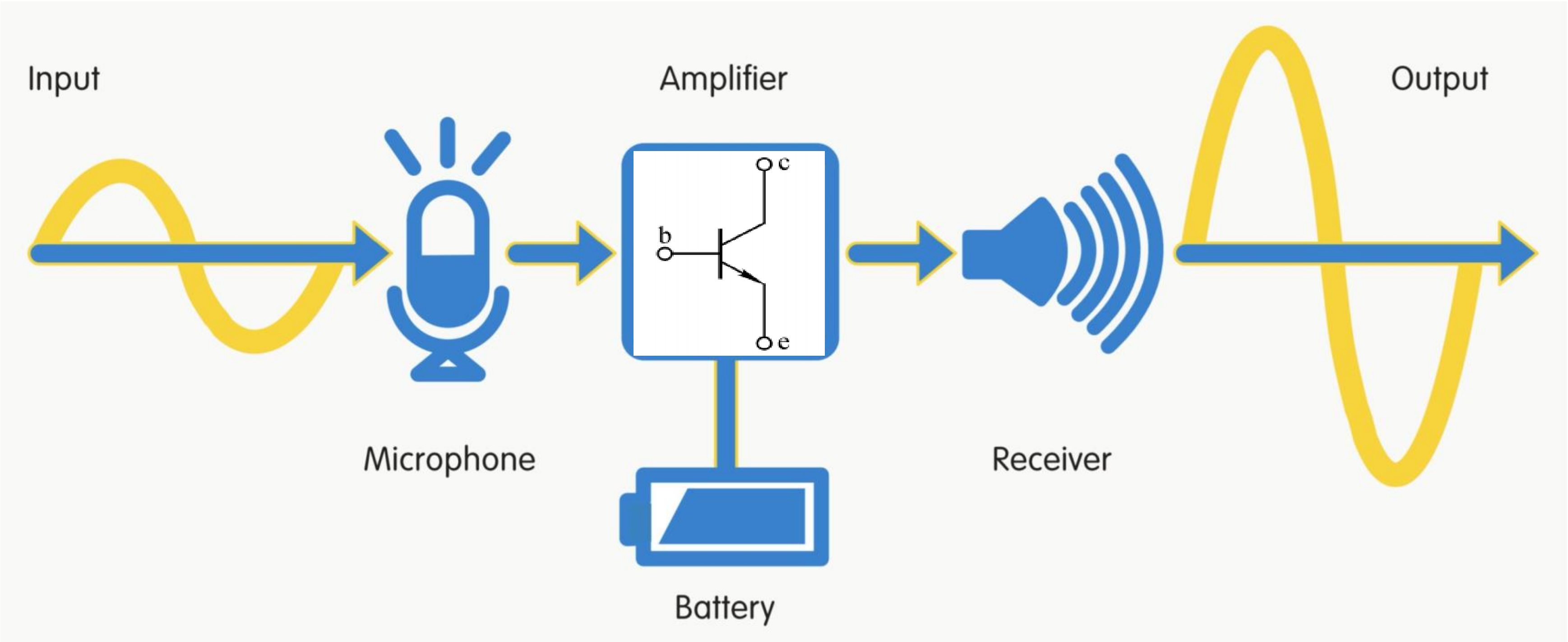
Learning objectives:

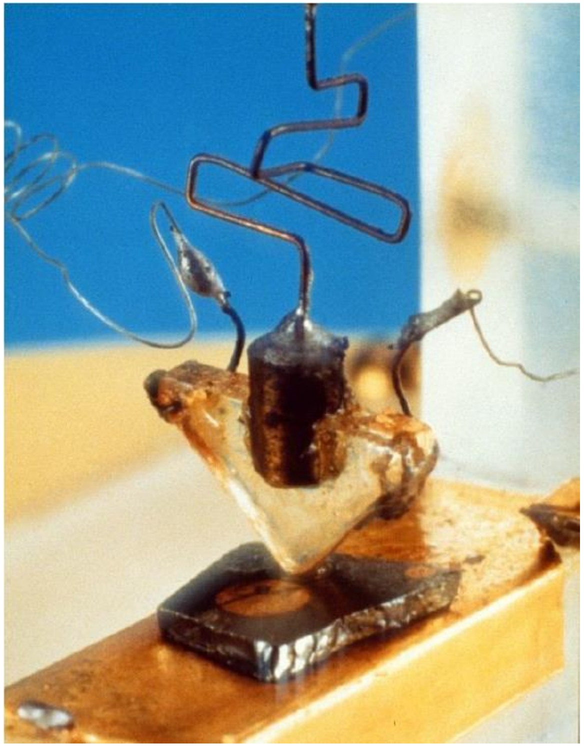
- Physical structure of a NPN transistor
- Three basic circuit types of a NPN transistor
- Current components of a NPN transistor
- I-V characteristic


Input
Microphone
[redacted]
Receiver
Output



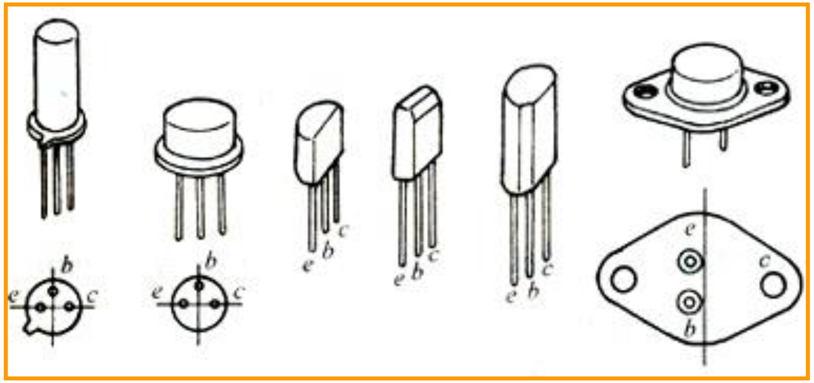
Input
Amplifier
Output
c
b
e
Microphone
Receiver

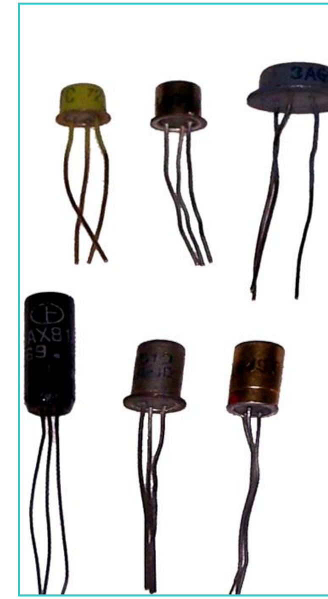

Input
Amplifier
Output
c
b
e
Microphone
Receiver
Battery

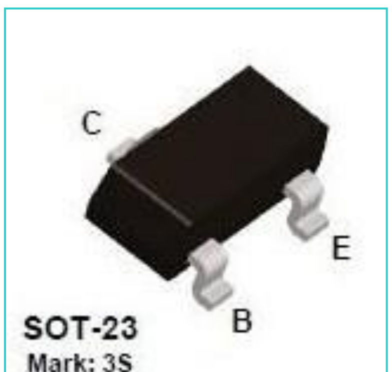


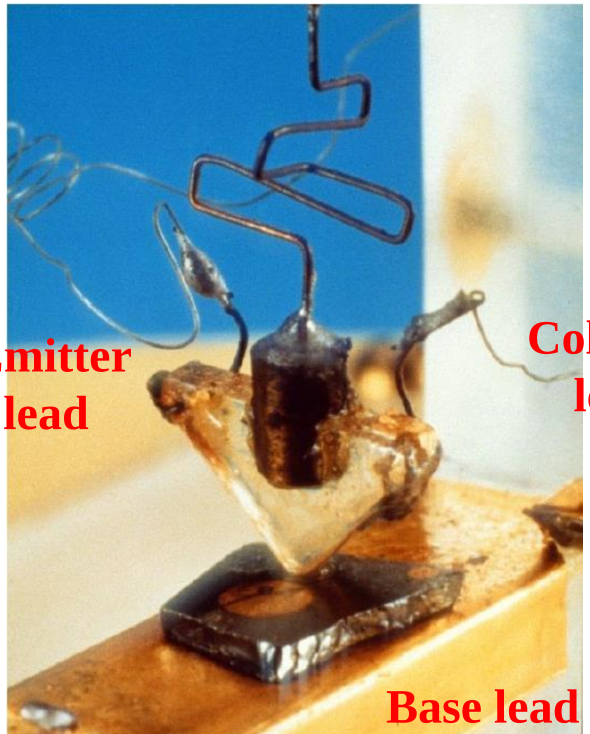
First BJT in 1948 at the Bell Telephone Lab

John Bardeen
William Schockley
Walter Brattain


e
b
c




C
E
B
SOT-23
Mark: 3S



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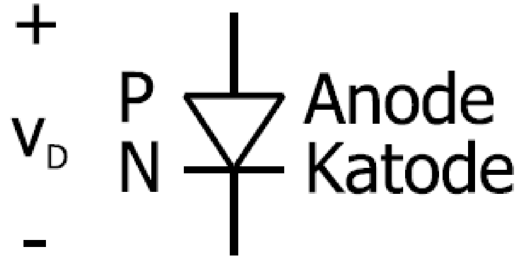
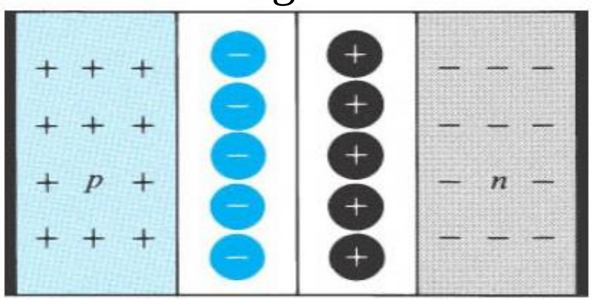
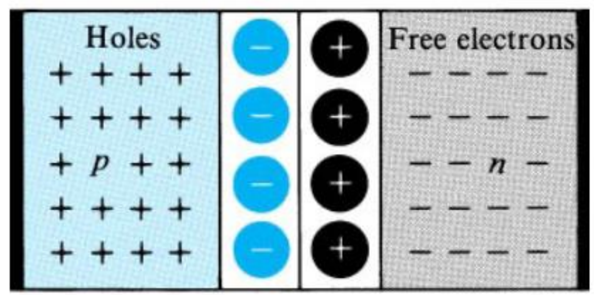


Depletion region



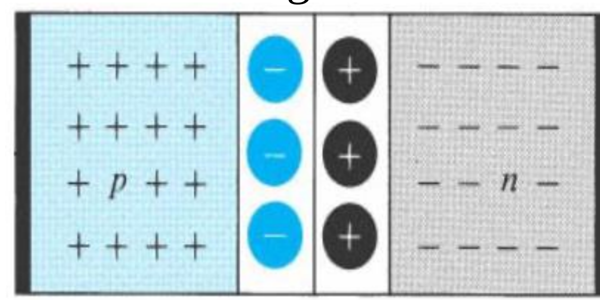
$v_D < 0$

Depletion region

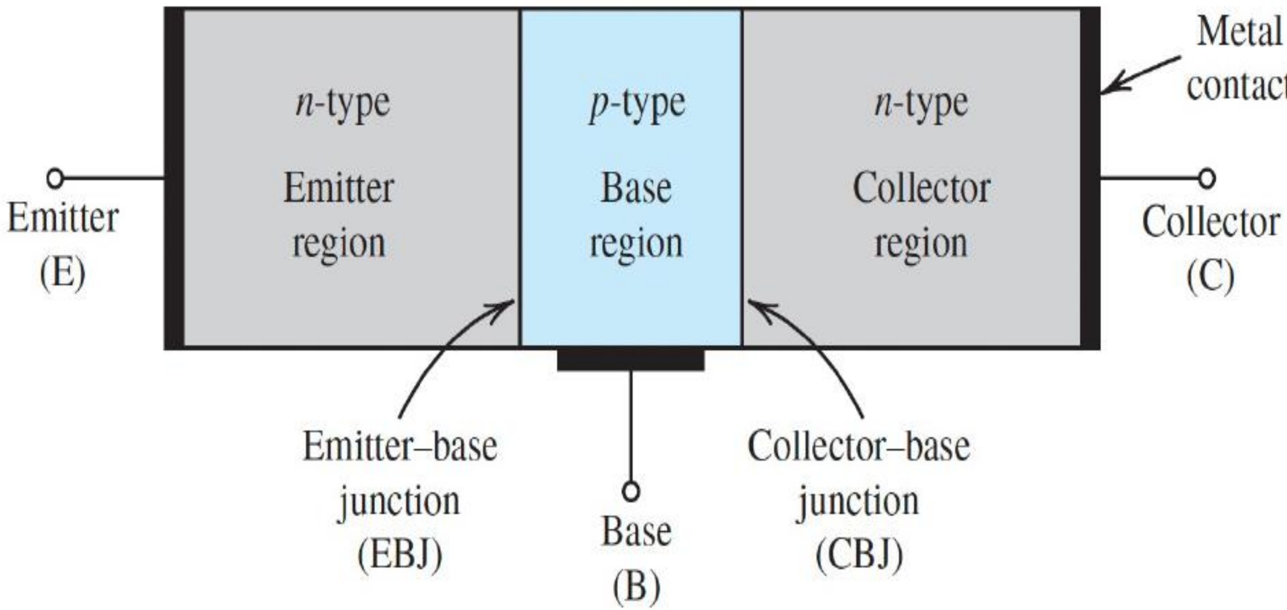


$v_D = 0$

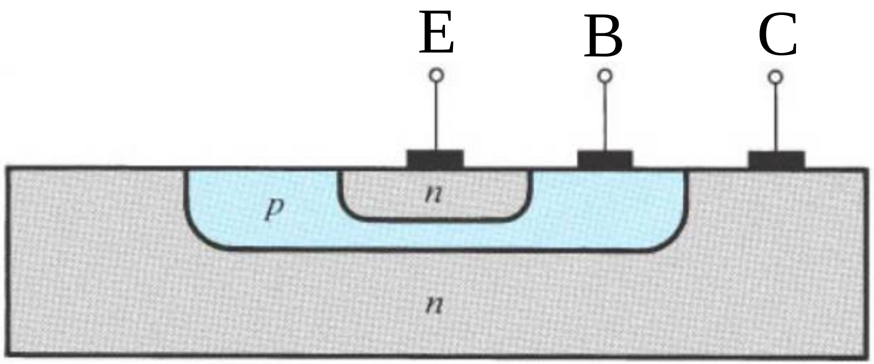
Depletion region



$v_D > 0$

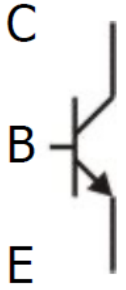


Metal contact
n-type
Emitter region
p-type
Base region
n-type
Collector region
Emitter (E)
Collector (C)
Emitter–base junction (EBJ)
Base (B)
Collector–base junction (CBJ)

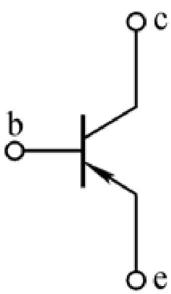


3 areas, each with its own contact:

- N-doped area: “Emitter (E or e)”
- P-doped area: “Base (B or b)”
- N-doped area: “Collector (C or c)”

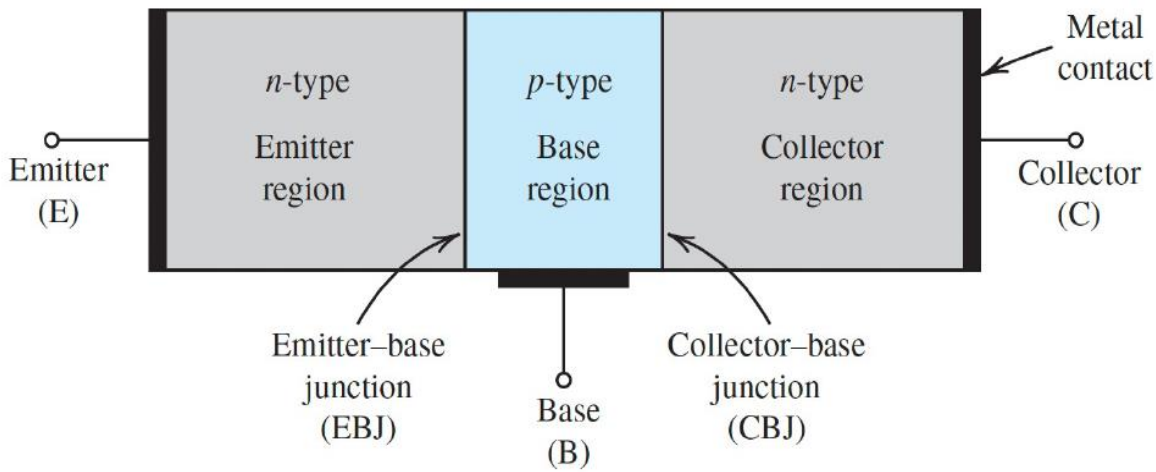


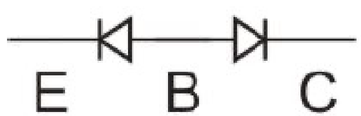
NPN



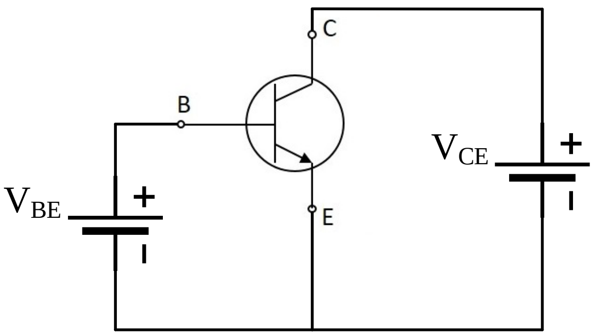
PNP

Emitter area: highly doped density
Collector area: low doped density and large area
Base area: thin, around 1 – 2 *um*, lowest doped density

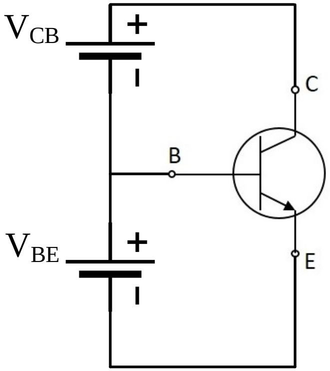

n-type
Emitter region
p-type
Base region
n-type
Collector region
Metal contact
Emitter (E)
Collector (C)
Emitter–base junction (EBJ)
Base (B)
Collector–base junction (CBJ)


E
B
C

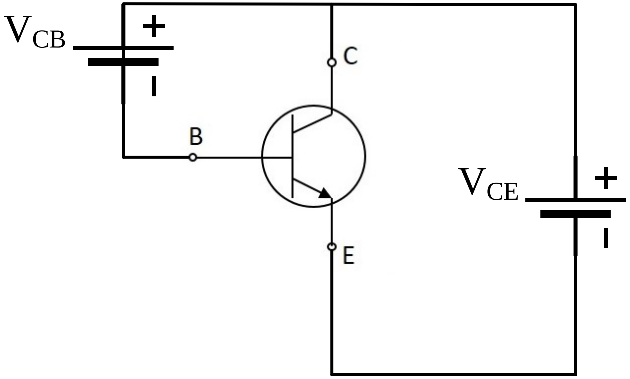
?=?



Common emitter



Common base

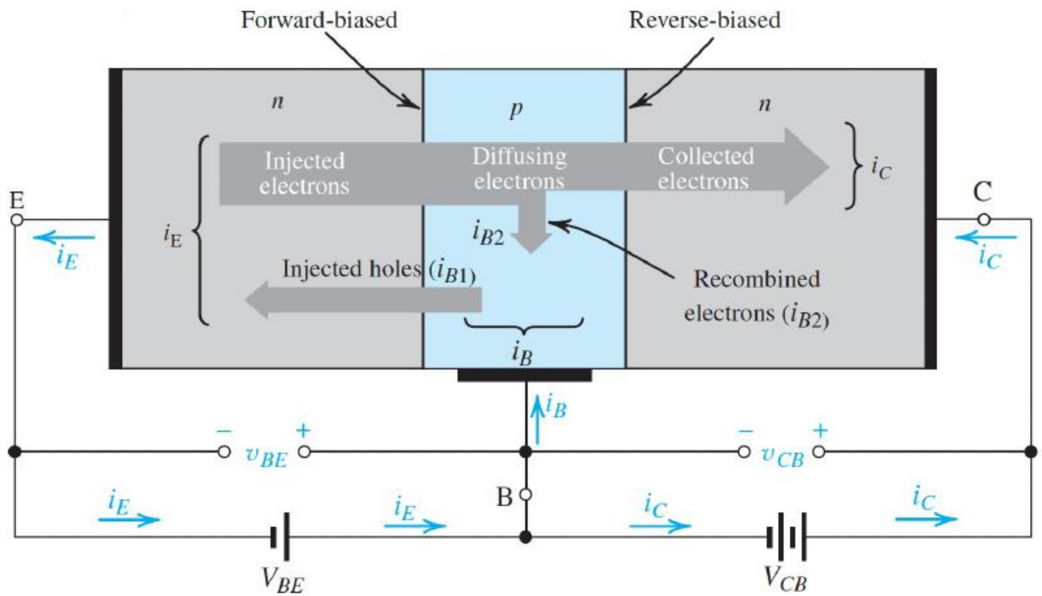


Common collector

Quite similar

Emitter: Emits electrons;
Collector: Collects electrons;

What is forward biased and reverse biased?



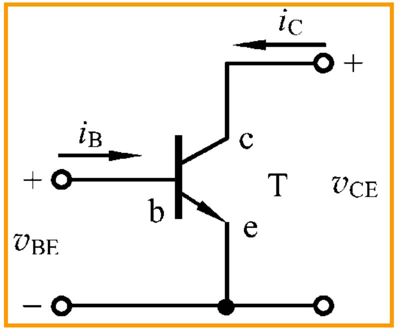
Current components:

- Electrons E $\longrightarrow$ B $\longrightarrow$ C => Collector current (i_C) (BE voltage controls the current)
- Electrons E $\longrightarrow$ B => Base current (i_B)
- Holes B $\longrightarrow$ E => Base current (i_B)

How about emitter current (i_E)?

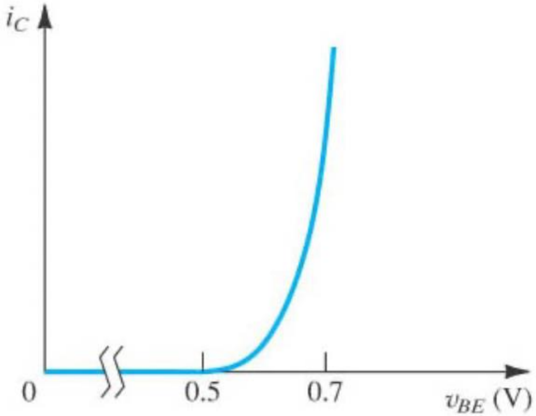
Mode	EBJ	CBJ
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward

$i_C \sim \upsilon_{BE}$ curve:



At active mode

$$i_C = I_S \left(e^{(\upsilon_{BE}/V_T)} - 1 \right) \approx I_S e^{(\upsilon_{BE}/V_T)}$$



$$I_S = \frac{A_E q D_n n_i^2}{N_B W_B}$$

$$V_T = \frac{kT}{q} \approx 26mV$$

A_E: cross-sectional area of emitter area

q : electron charge = 1.6 * 10 $^{-19}$ C

D_n: diffusivity of electrons

n_i : number of thermally generated electrons

N_B: doping density in base

W_B: the width of base

T : absolute temperature

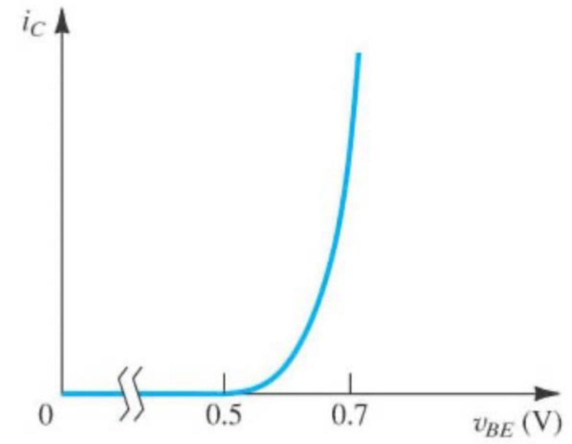
Could be controlled by manufacturing.

Temperature dependent

How much does i_C change if v_{BE} increases by 60mv?

$$i_C = I_S\left(e^{(\upsilon_{BE}/V_T)} - 1\right) \approx I_S e^{(\upsilon_{BE}/V_T)}$$

$$I_S = 5\times10^{-16}\ \text{A}$$



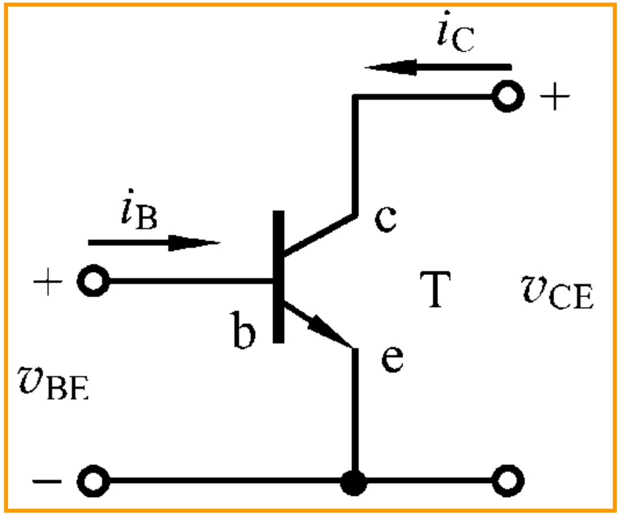
$i_B \sim \upsilon_{BE}$ curve:

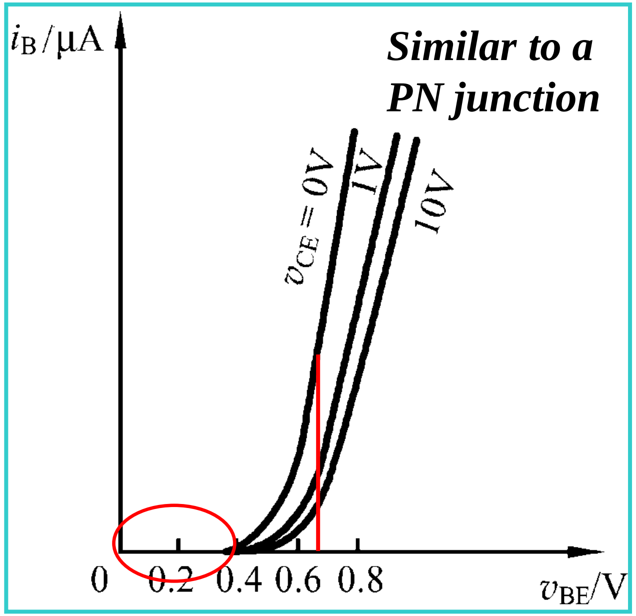
Active mode:

- Emitter forward biased;
- Collector reverse biased;

$\upsilon_{CE} > \upsilon_{BE}$

$$i_B = f(u_{BE})\big|_{U_{CE}}$$



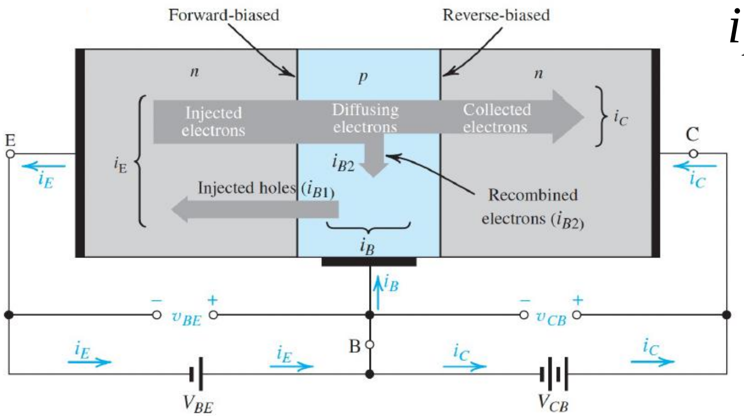


*U*on

Si: 0.5 – 0.7 V

Ge: 0.1 – 0.3 V

The analytical relationship between υ_{BE} and i_B



$$i_B = \left(\boxed{\frac{A_E q D_p n_i^2}{N_D L_p}} + \boxed{\frac{A_E q W n_i^2}{2\tau_b N_A}} \right) \left(e^{(\upsilon_{BE}/V_T)} - 1 \right)$$ (forget details)

Holes from B to E

Electrons from E to B

$$i_C = I_S \left(e^{(\upsilon_{BE}/V_T)} - 1 \right)$$

$$\beta = \frac{i_C}{i_B} = \frac{1}{\dfrac{D_p N_A W}{D_n N_D L_P} + \dfrac{W^2}{2 D_n \tau_B}}$$ (forget details)

- Electrons E $\longrightarrow$ B => Base current (i_B)
- Holes B $\longrightarrow$ E => Base current (i_B)

Big β, if:

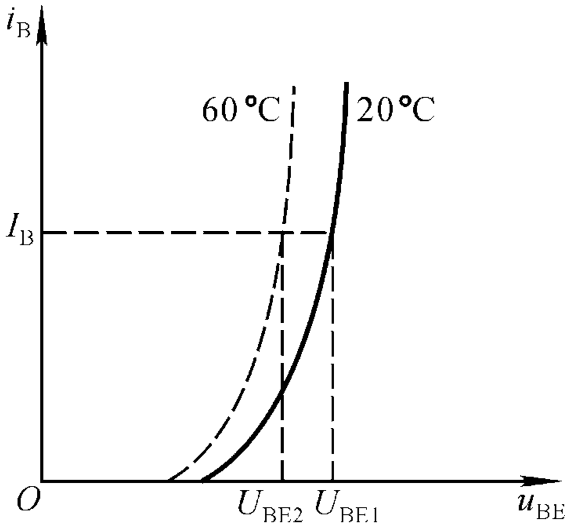
- W is small
- $N_A << N_D$

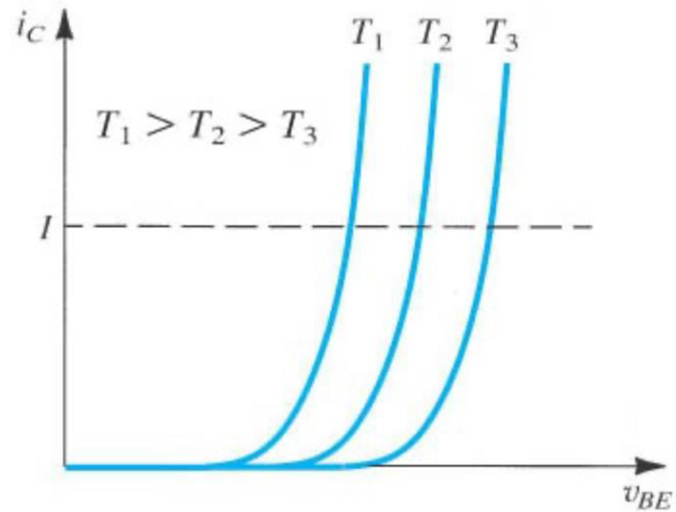
- Typically: 10 < β < 1000

Temperature effects on I-V curves

$$i_B = \left(\frac{A_E q D_p n_i^2}{N_D L_p} + \frac{A_E q W n_i^2}{2\tau_b N_A} \right)\left(e^{\left(\upsilon_{BE}/V_T\right)} - 1 \right)$$

$$i_C = \frac{A_E q D_n n_i^2}{N_B W_B}\left(e^{\left(\upsilon_{BE}/V_T\right)} - 1 \right)$$





Thanks