Engineering and Architecture Analog Electronics Fundamentals **EEE223** Lec 9

Transistors

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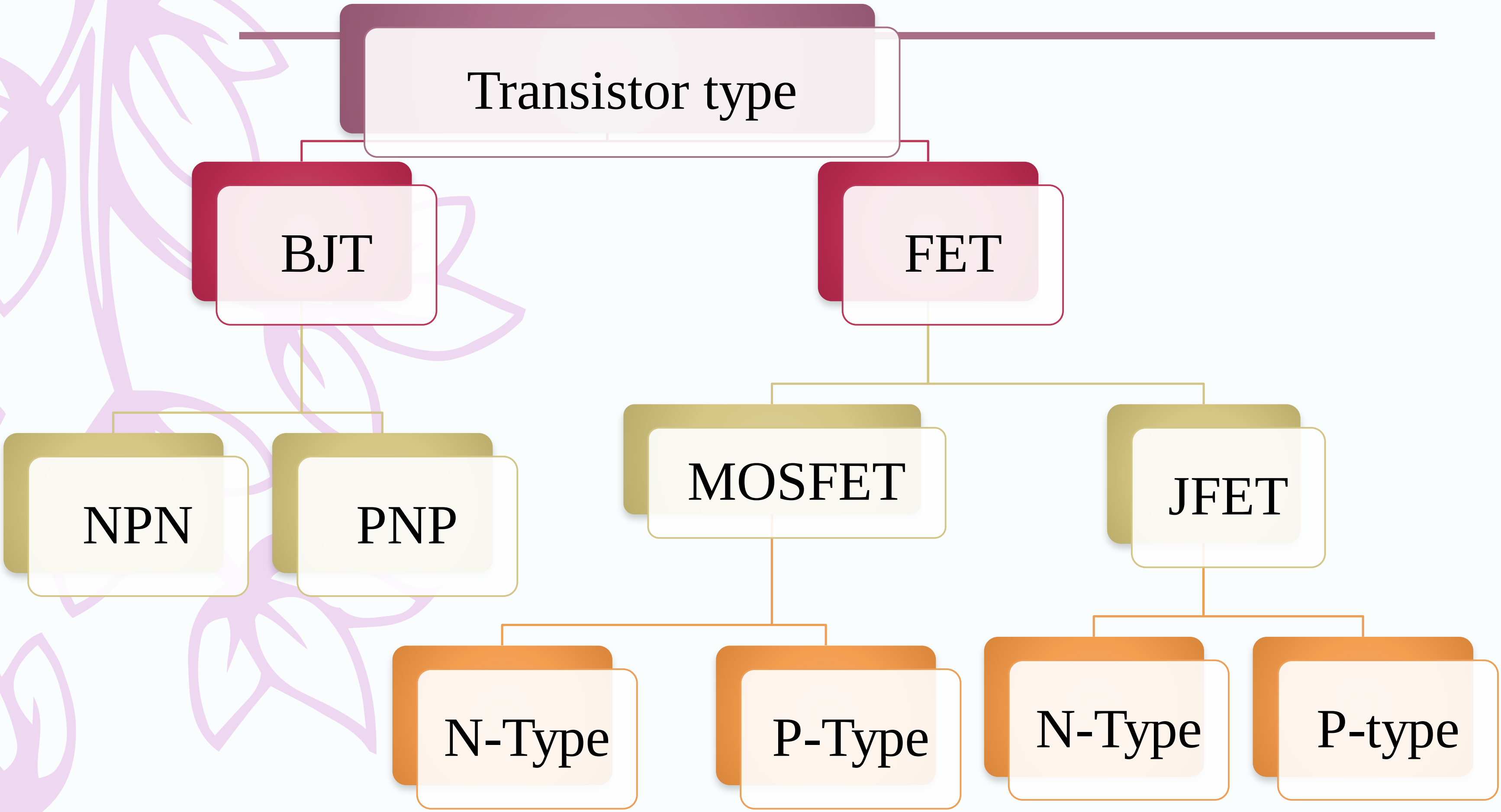
Transistors

– Transistors are semiconductor devices that act as either electrically controlled switches or amplifier controls. With a transistor, a small voltage and/or current applied to a control lead acts to control a larger electric flow through its other two leads.

– Transistors are used in almost every electric circuit you can imagine. For example, you find transistors in switching circuits, amplifier circuits, oscillator circuits, current-source circuits, voltage-regulator circuits, power-supply circuits, digital logic ICs, and almost any circuit that uses small control signals to control larger currents.

Transistors Types



Types of transistors:

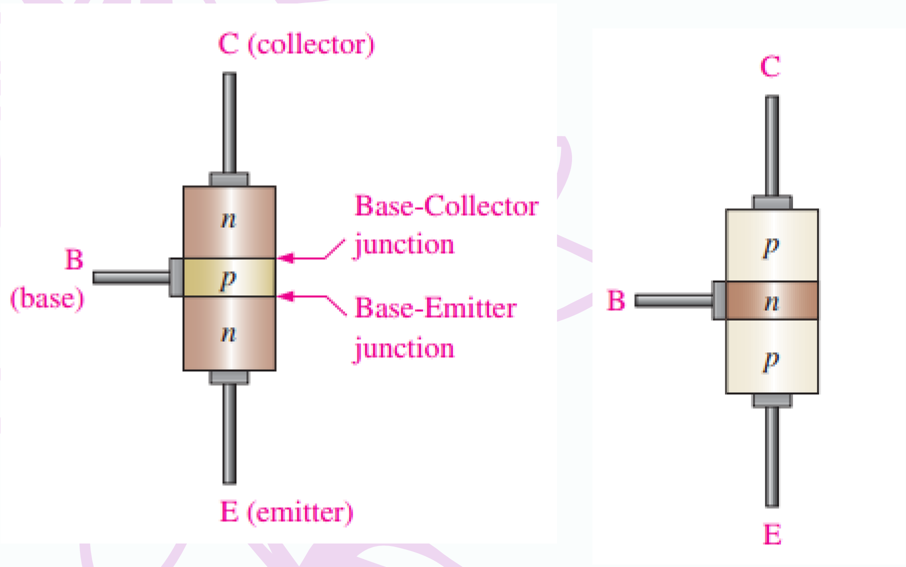
– There are two types of transistor:

  – Bipolar Junction Transistor (BJT)

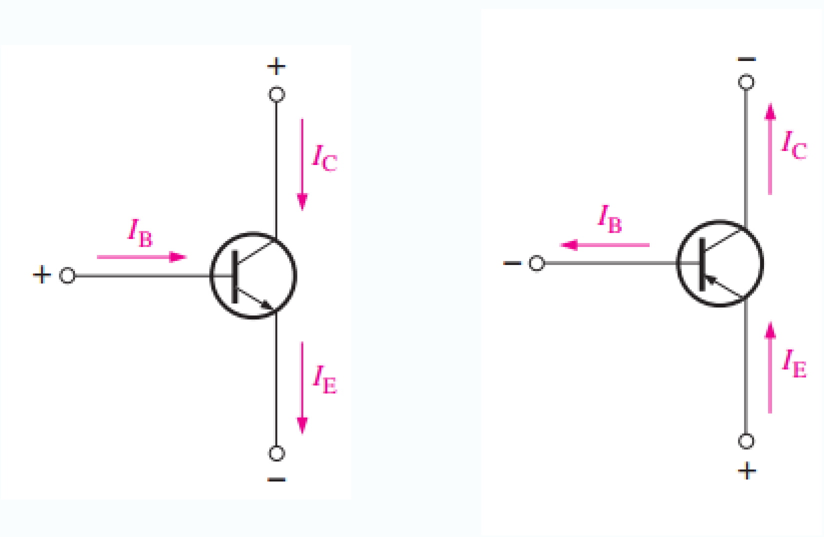
  – Field Effective Transistor (FET)

Bipolar Junction Transistor (BJT)

- The **BJT is** constructed with three doped semiconductor regions separated by two pn junctions. The three regions are called emitter, base, and collector.
- Physical representations of the two types of BJTs are shown in the figure below. 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 as current carriers in the transistor structure.



npn and **pnp** structure



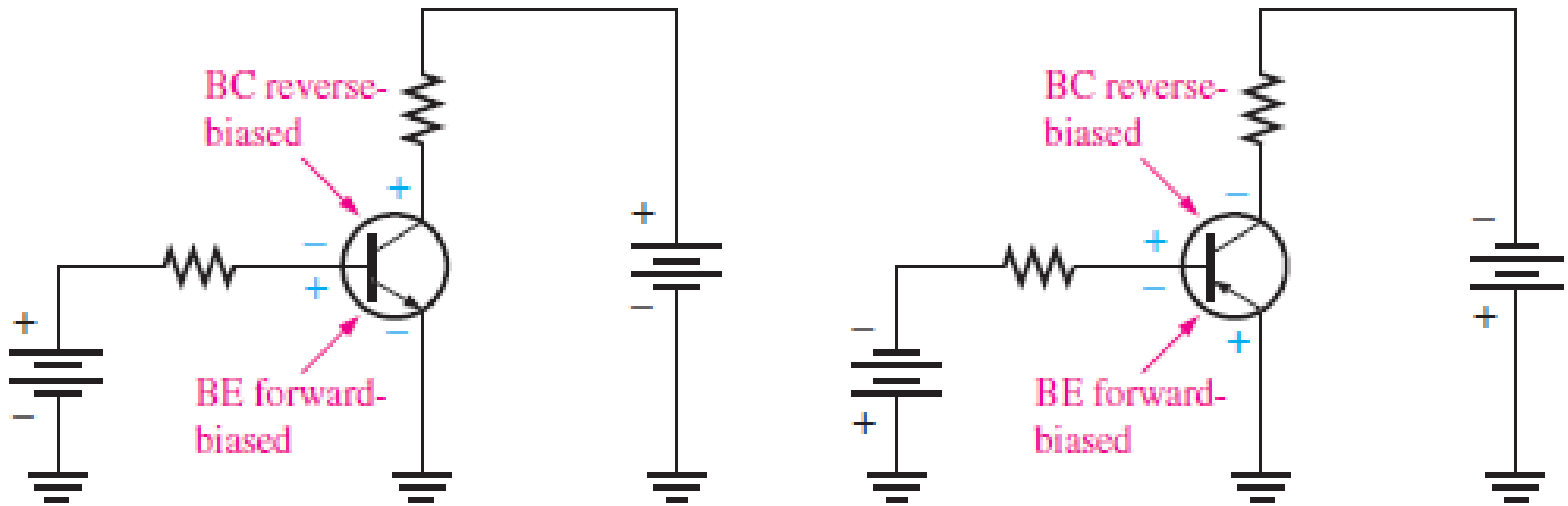
Standard BJT Symbols

Basic BJT Operation

– In order for a BJT to operate properly as an amplifier, the two pn junctions must be correctly biased with external dc voltages.

– The npn transistor will be used mainly 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.

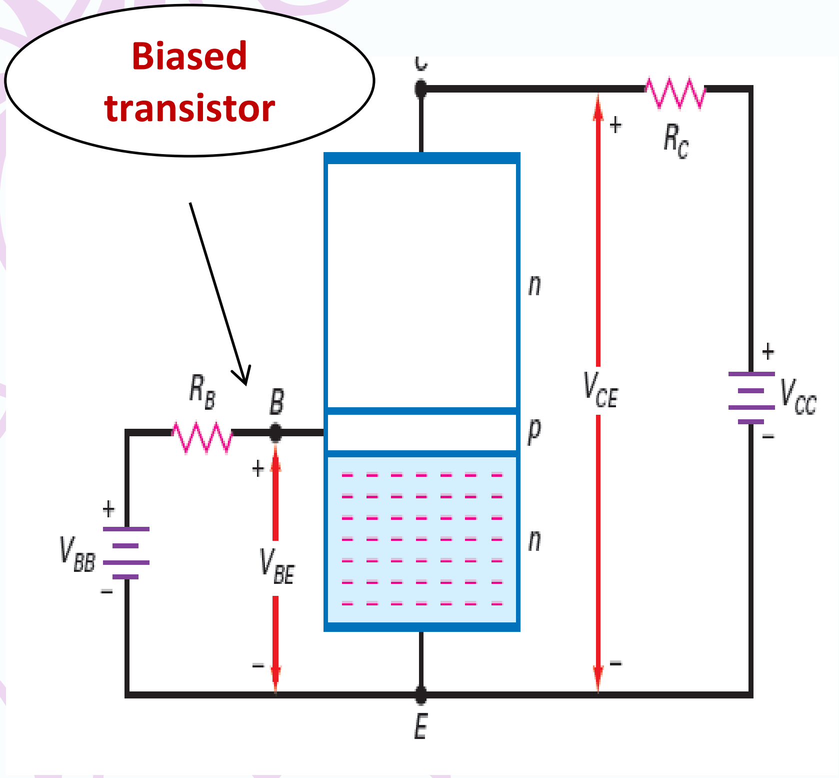
Biasing

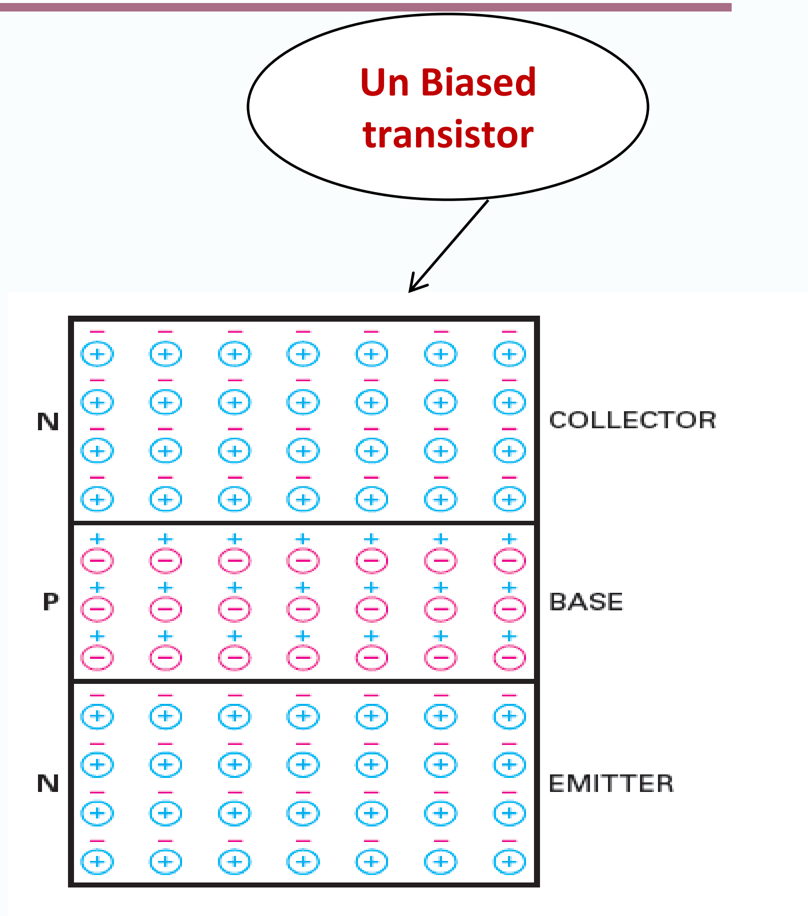


(a) *npn* (b) *pnp*

Forward-reverse bias of a BJT

Biasing


Biased transistor
C
R_C
n
p
n
R_B
B
V_{BB}
V_{BE}
V_{CE}
V_{CC}
E


Un Biased transistor
N
P
N
COLLECTOR
BASE
EMITTER

Operation

- The heavily doped n-type emitter region has a very high density of conduction-band (free) electrons.
- These free electrons easily diffuse through the forward biased BE junction into the lightly doped and very thin p-type base region.
- The base has a low density of holes, which are the majority carriers.

- A small percentage of the total number of free electrons injected into the base region recombine with holes and move as valence electrons through the base region and into the emitter region as hole current.
- When the electrons that have recombined with holes as valence electrons leave the crystalline structure of the base, they become free electrons in the metallic base lead and produce the external base current.

- Most of the free electrons that have entered the base do not recombine with holes because the base is very thin.
- As the free electrons move toward the reverse-biased BC junction, they are swept across into the collector region by the attraction of the positive collector supply voltage.
- The free electrons move through the collector region, into the external circuit, and then return into the emitter region along with the base current.
- The emitter current is slightly greater than the collector current because of the small base current that splits off from the total current injected into the base region from the emitter.

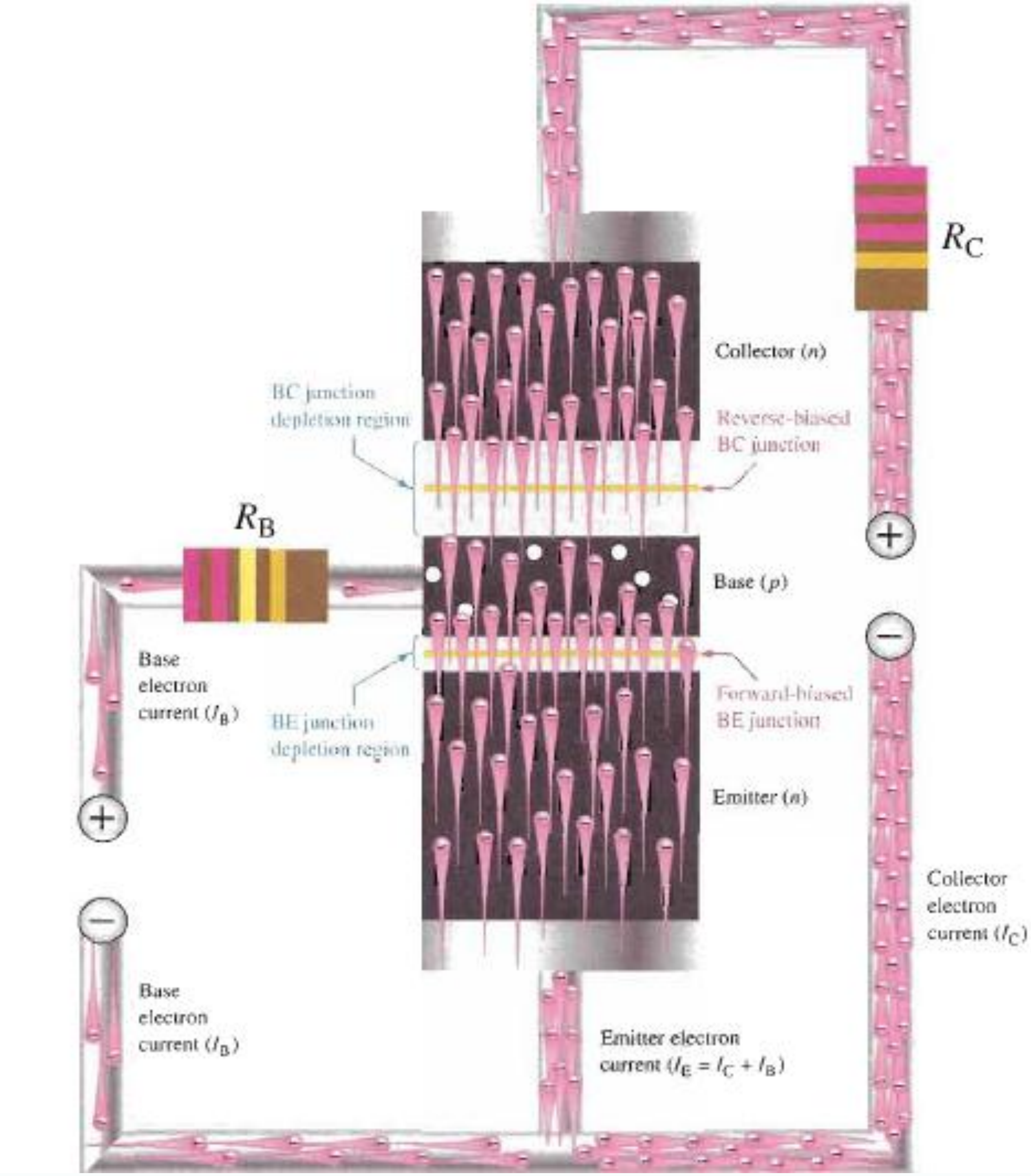
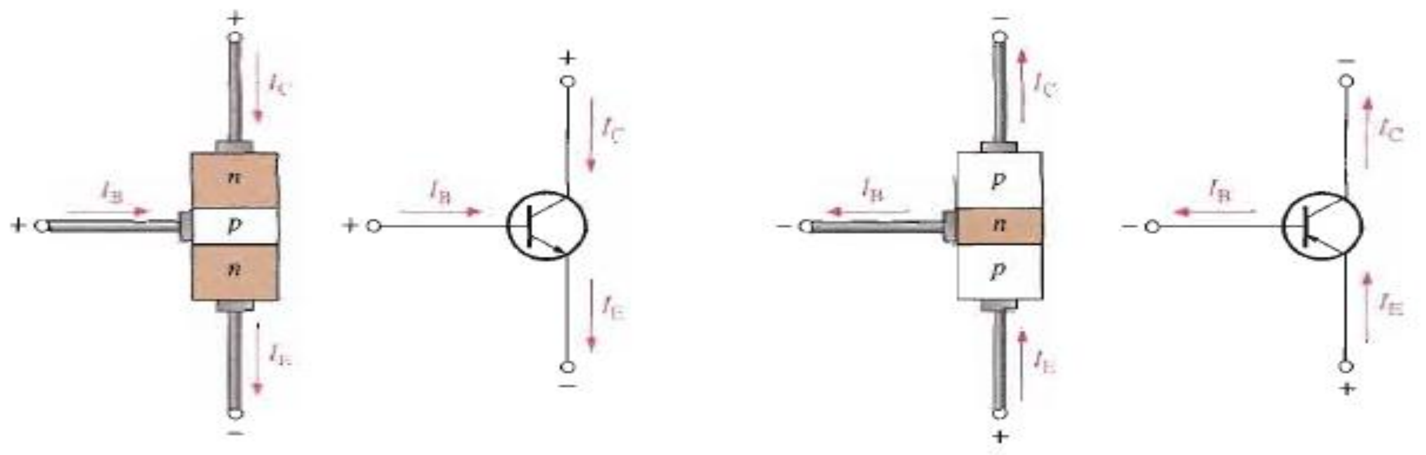


Illustration of BJT Action

Transistor Currents

- The directions of the currents in an npn transistor and its schematic symbol are as shown in figure (a); those for a pnp transistor are shown in figure (b).
- Notice that the arrow on the emitter inside the transistor symbols points in the direction of conventional current.



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

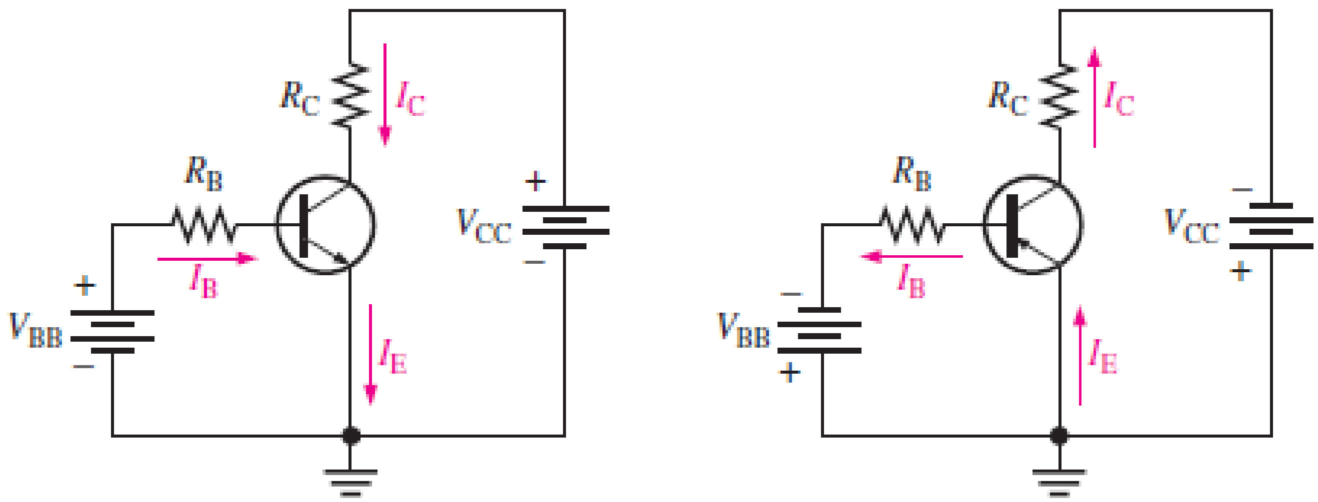
– These diagrams show that the emitter current (IE) is the sum of the collector current (IC) and the base current (IB)

$$I_E = I_C + I_B$$

- IB is very small compared to IE or IC.
- The capital-letters subscripts indicates dc values.

Transistor Characteristics and Parameters

– When a transistor is connected to dc bias voltages, for both npn and pnp types, V_{BB} forward-biases the base-emitter junction, and V_{CC} reverse-biases the base-collector junction.



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

DC Beta (β_{DC}) and DC Alpha (α_{DC})

– The dc current gain of a transistor is the ratio of the dc collector current **(I_C)** to the dc base current (**I_B**) and is designated dc beta **(β_{DC}).**

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

– Typical values of **β_{DC}** range from less than 20 to 200 or higher. **β_{DC}** is usually designated as an equivalent hybrid (h) parameter, **h_{FE}**, on transistor datasheets.

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

- The ratio of the dc collector current (I_C) to the dc emitter current (I_E) is the dc **alpha** (α_{DC}).

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

- values of α_{DC} range from 0.95 to 0.99 or greater, but α_{DC} is always less than 1.

EXAMPLE

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

Solution

$\beta_{DC} = I_C / I_B$ = 3.65mA/50 µA=73

$I_E = I_C + I_B$ = 3.65 mA + 50 µA = 3.70 mA

EXAMPLE

– A transistor has a collector current of 10 mA and a base current of 40 A. What is the current gain of the transistor?

$$\beta_{dc} = \frac{10\ \text{mA}}{40\ \mu\text{A}} = 250$$

EXAMPLE

A transistor has a collector current of 2 mA. If the current gain is 135, what is the base current?

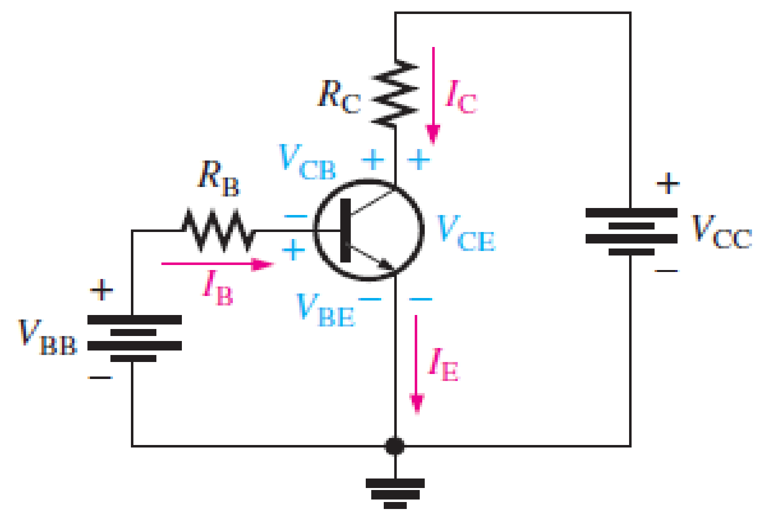
$$I_C = 175(0.1 \text{ mA}) = 17.5 \text{ mA}$$

A transistor has a collector current of 2 mA. If the current gain is 135, what is the base current?

$$I_B = \frac{2 \text{ mA}}{135} = 14.8 \ \mu\text{A}$$

BJT Circuit Analysis

– Consider the basic transistor bias circuit configuration in the figure. Three transistor dc currents and three dc voltages can be identified.



Transistor currents and voltages.

- The base-bias voltage source, V_{BB}, forward-biases the base-emitter junction, and the collector-bias voltage source, V_{CC}, reverse-biases the base-collector junction.
- When the base-emitter junction is forward-biased, it is like a forward-biased diode and has a nominal forward voltage drop of

$$V_{BE} =\sim 0.7\ V$$

- The characteristic of the base-emitter junction is the same as a normal diode curve.

– Since the emitter is at ground (0 V), by Kirchhoff's voltage law, the voltage across R_B *is*

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

– Also, by Ohm's law,

$$V_{RB} = I_B R_B$$

– Substituting for V_{RB} yields

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

– Solving for I_B,

$$I_B = (V_{BB} - V_{BE})/R_B$$

- The voltage at the collector with respect to the grounded emitter is

$$V_{CE} = V_{CC} - V_{RC}$$

- Since the drop across R_C is

$$V_{RC} = I_C R_C$$

- the voltage at the collector with respect to the emitter can be written as

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

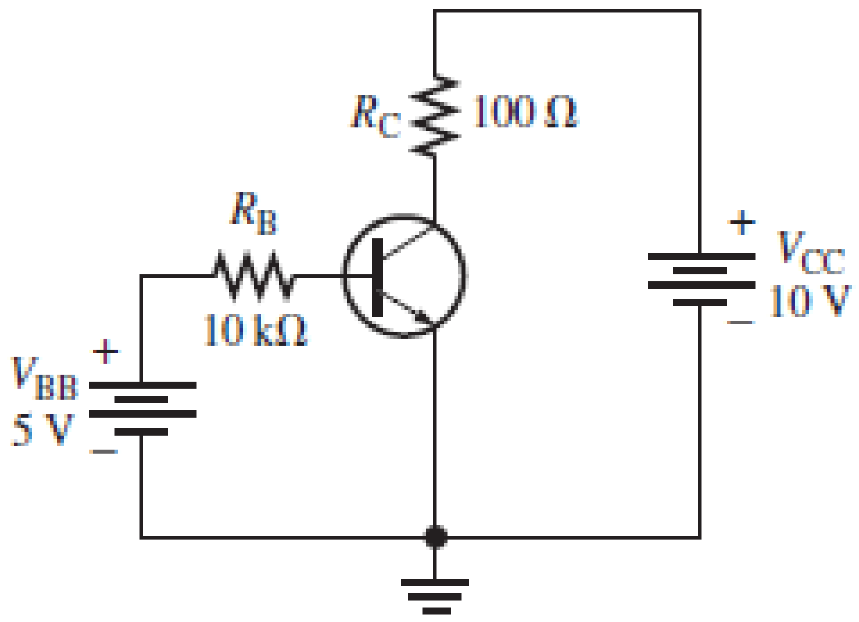
where $I_C = \beta_{DC} I_B$

- The voltage across the reverse-biased collector-base junction is

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

EXAMPLE

Determine IB, IC, IE, VBE, VCE, and VCB in the circuit of the figure. The transistor has a βDC = 150.



Solution

V_{BE} = 0.7 V. Calculate the base, collector, and emitter currents as follows:

$I_B = (V_{BB} - V_{BE}) / R_B$ = (5 V - 0.7 V)/10KΩ= 430 μA

$I_C = \beta_{DC} I_B$ = (150)(430 μA) = 64.5 mA

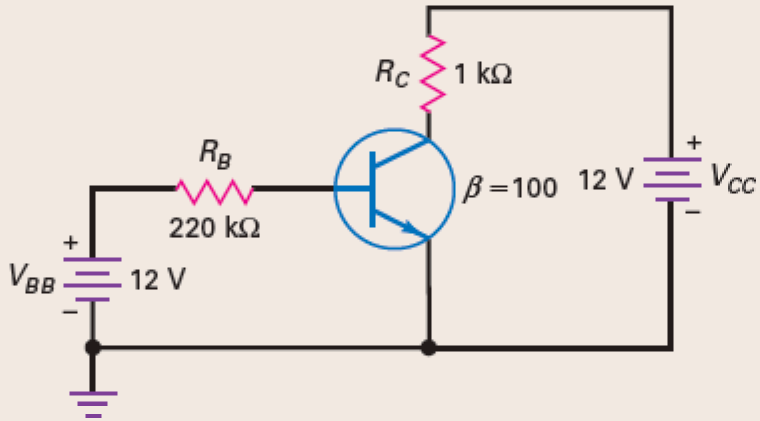
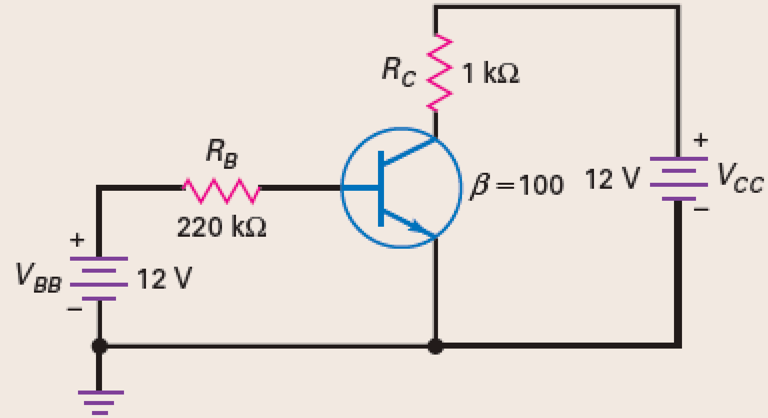
$I_E = I_C + I_B$ = 64.5 mA + 430 μA = 64.9 mA

Solve for V_{CE} and V_{CB}

$V_{CE} = V_{CC} - I_C R_C$ = 10 V - (64.5 mA)(100 Ω) = 10 V - 6.45 V = 3.55 V

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

Summary Table 6–1 Transistor Circuit Approximations

	Ideal	Second
Circuit		
When used	Troubleshooting or rough estimates	When more accurate calculations are needed. Especially when V_{BB} is small.
$V_{BE} =$	0 V	0.7 V
$I_B =$	$\frac{V_{BB}}{R_B} = \frac{12\ \text{V}}{220\ \text{k}\Omega} = 54.5\ \mu\text{A}$	$\frac{V_{BB} - 0.7\ \text{V}}{R_B} = \frac{12\ \text{V} - 0.7\ \text{V}}{220\ \text{k}\Omega} = 51.4\ \mu\text{A}$
$I_C =$	$(I_B)(\beta_{dc}) = (54.5\ \mu\text{A})(100) = 5.45\ \text{mA}$	$(I_B)(\beta_{dc}) = (51.4\ \mu\text{A})(100) = 5.14\ \text{mA}$
$V_{CE} =$	$V_{CC} - I_C R_C$ $= 12\ \text{V} - (5.45\ \text{mA})(1\ \text{k}\Omega) = 6.55\ \text{V}$	$V_{CC} - I_C R_C$ $= 12\ \text{V} - (5.14\ \text{mA})(1\ \text{k}\Omega) = 6.86\ \text{V}$

Thank You