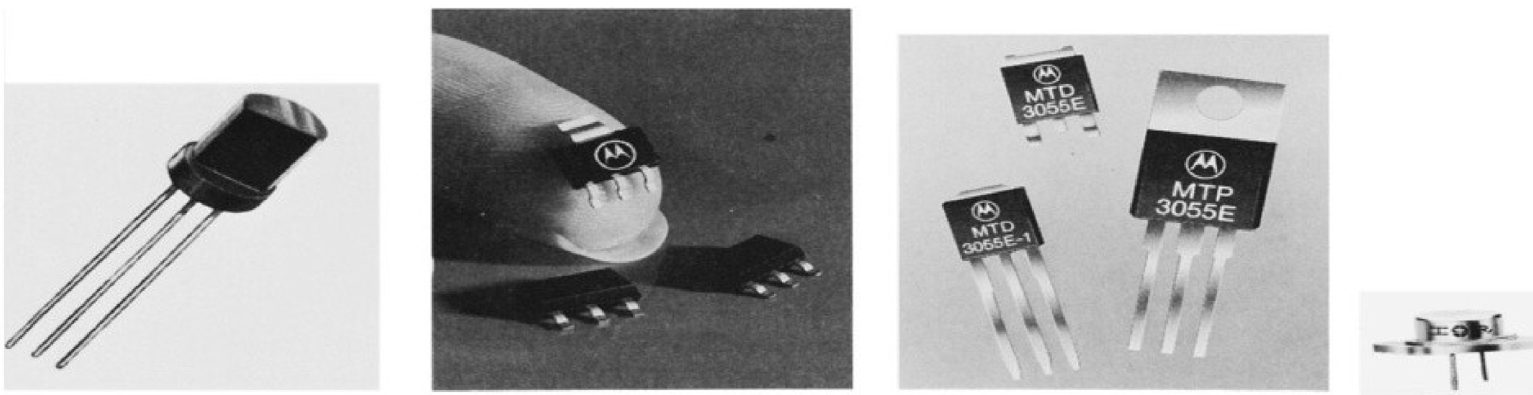
TRANSISTOR - Introduction



(a) (b) (c) (d)

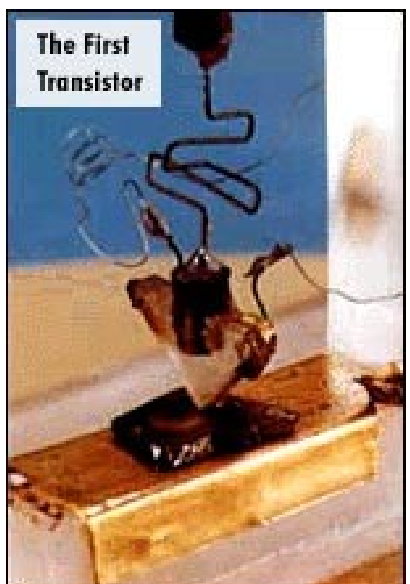
Introduction

- Beside diodes, the most popular semiconductor devices is transistors. Eg: Bipolar Junction Transistor (BJT)
- Transistors are often said to be the most significant invention of the 20th Century.
- If cells are the building blocks of life, transistors are the building blocks of the digital revolution. Without transistors, the technological wonders you use every day -- cell phones, computers, cars -- would be vastly different, if they existed at all.
- Transistors are more complex and can be used in many ways
- Most important feature: can amplify signals and as switch
- Amplification can make weak signal strong (make sounds louder and signal levels greater), in general, provide function called Gain

Who Invented the Transistor?

- In the mid 1940's a team of scientists working for Bell Telephone Labs in Murray Hill, New Jersey, were working to discover a device to replace the then present vacuum tube technology. Vacuum tubes were the only technology available at the time to amplify signals or serve as switching devices in electronics. The problem was that they were expensive, consumed a lot of power, gave off too much heat, and were unreliable, causing a great deal of maintenance.

vacuum tube



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The Transistor

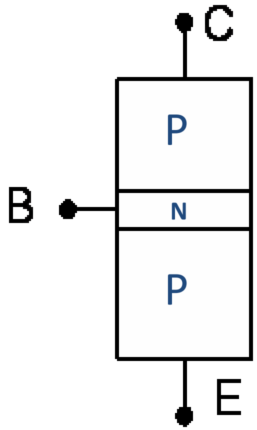
- The scientists that were responsible for the 1947 invention of the transistor were: John Bardeen, Walter Brattain, and William Shockley. Bardeen, with a Ph.D. in mathematics and physics from Princeton University, was a specialist in the electron conducting properties of semiconductors. Brattain, Ph.D., was an expert in the nature of the atomic structure of solids at their surface level and solid-state physics. Shockley, Ph.D., was the director of transistor research for Bell Labs.

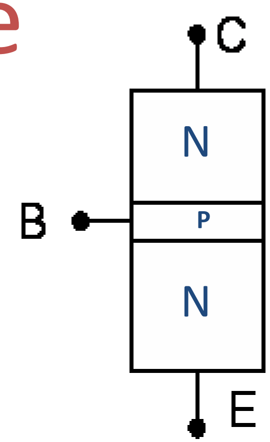
  Their original patent name for the transistor was: "Semiconductor amplifier; Three-electrode circuit element utilizing semi conductive materials." In 1956, the group was awarded the Noble Prize in Physics for their invention of the transistor. In 1977, John Bardeen was awarded the Presidential Medal of Freedom.

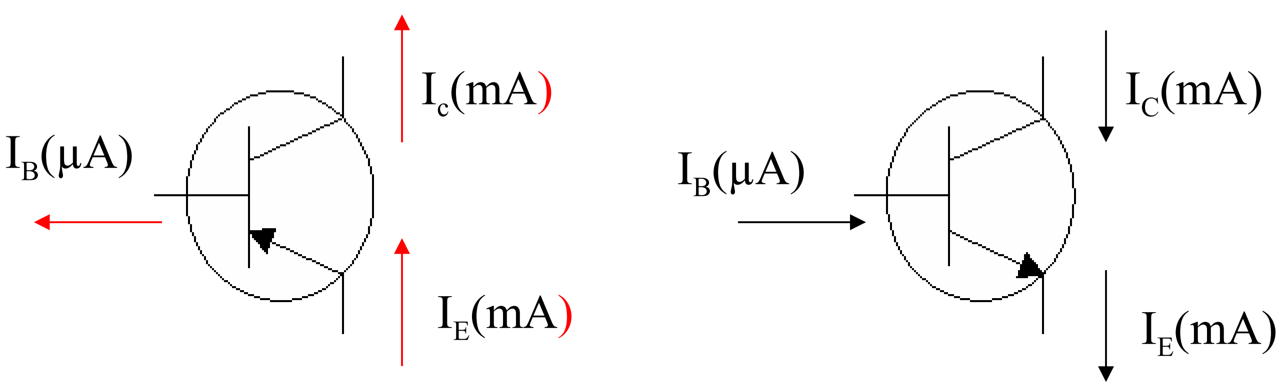
Transistor Structure

- BJT is bipolar because both holes (+) and electrons (-) will take part in the current flow through the device
  - N-type regions contains free electrons (negative carriers)
  - P-type regions contains free holes (positive carriers)
- 2 types of BJT
  - NPN transistor
  - PNP transistor
- The transistor regions are:
  - Emitter (E) – send the carriers into the base region and then on to the collector
  - Base (B) – acts as control region. It can allow none,some or many carriers to flow
  - Collector (C) – collects the carriers

PNP and NPN transistor structure



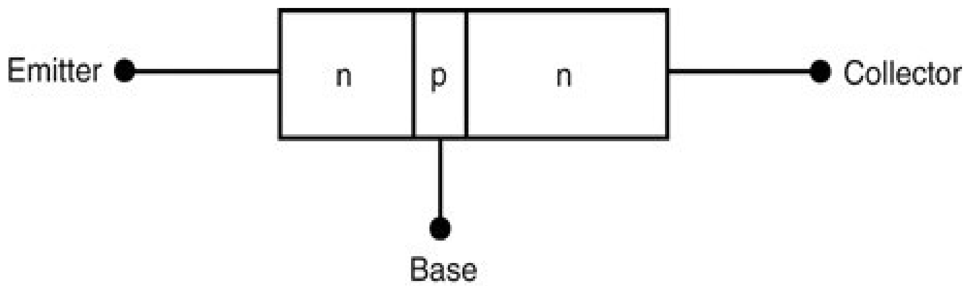




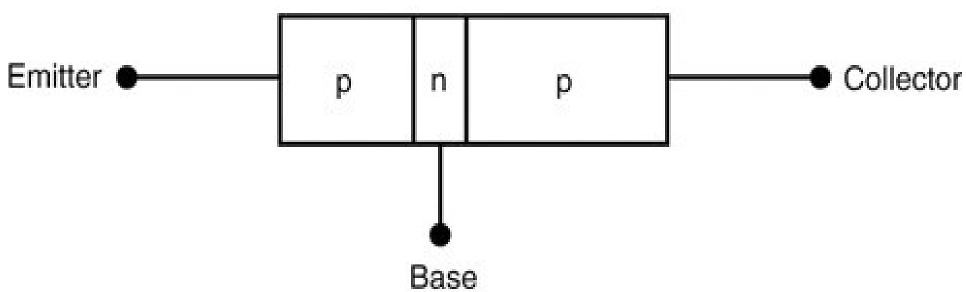
Arrow shows the current flows

Transistor Construction

- **A transistor has three doped regions.**
- **For both types, the base is a narrow region sandwiched between the larger collector and emitter regions.**



(a)



(b)

- **The <u>emitter</u> region is heavily doped and its job is to emit carriers into the base.**

- **The <u>base</u> region is very thin and lightly doped.**
- **Most of the current carriers injected into the base pass on to the collector.**

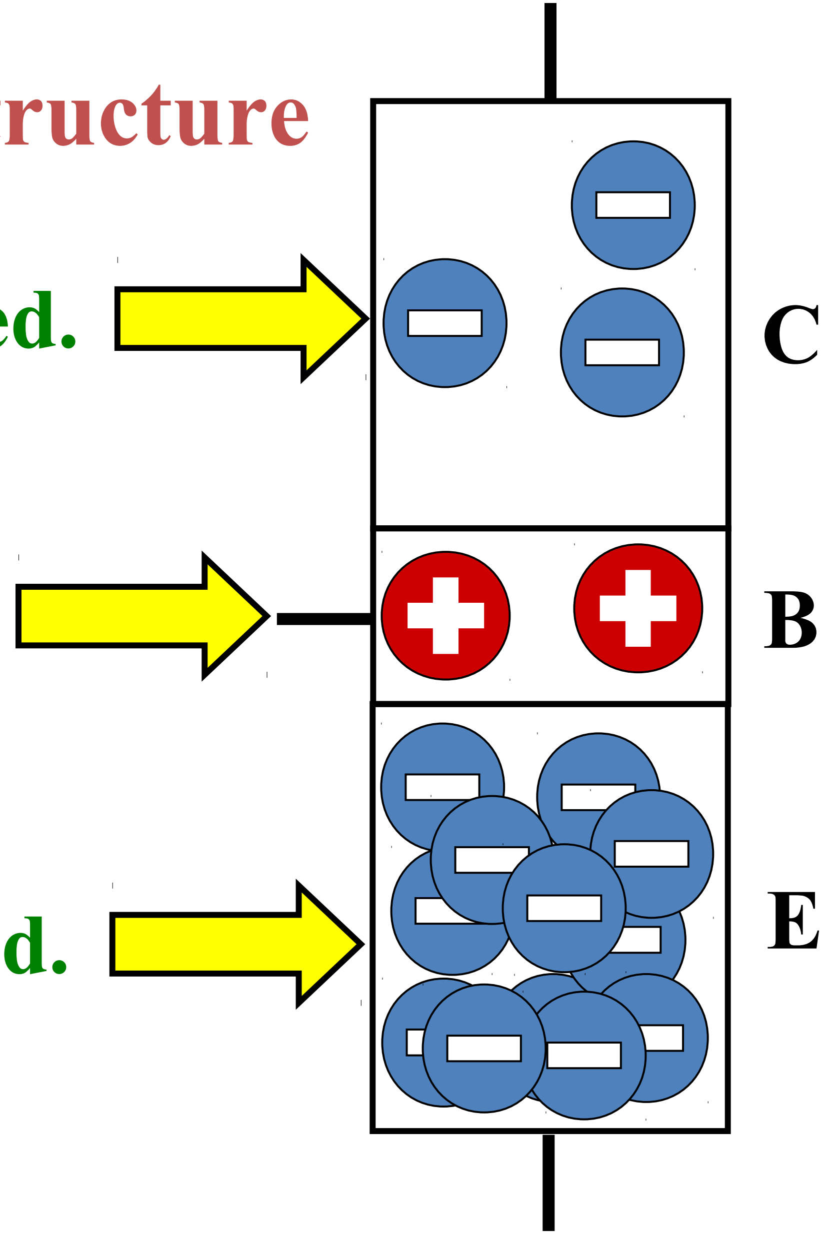
- **The <u>collector</u> region is moderately doped and is the largest of all three regions.**

NPN Transistor Structure

The collector is lightly doped.

The base is thin and
is lightly doped.

The emitter is heavily doped.

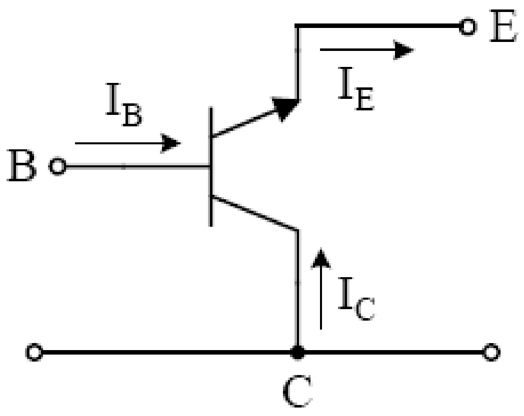


Transistor configuration

- Transistor configuration –is a connection of transistor to get variety operation.
- 3 types of configuration:
  - *Common Collector*.
  - *Common Base*.
  - *Common Emitter*

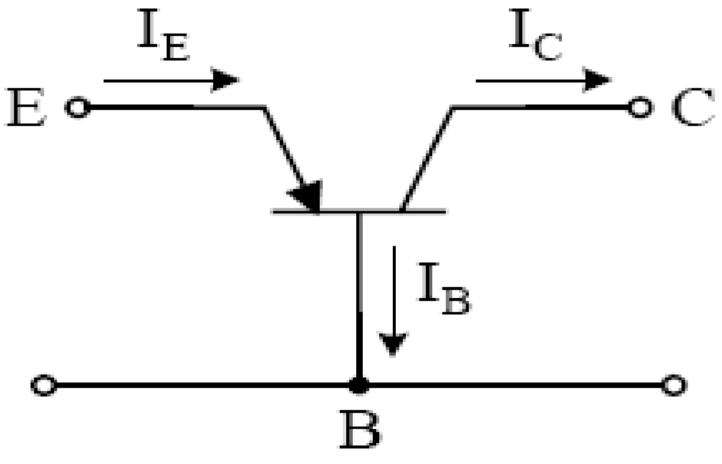
Common-Collector Configuration

- The input signal is applied to the base terminal and the output is taken from the emitter terminal.
- Collector terminal is common to the input and output of the circuit
- Input – BC
- Output – EC



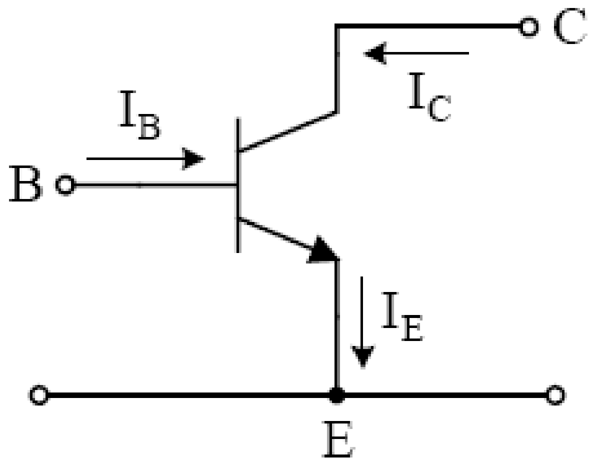
Common-Base Configuration

- Base terminal is a common point for input and output.
- Input – EB
- Output – CB
- Not applicable as an amplifier because the relation between input current gain (I_E) and output current gain (I_C) is approximately 1



Common-Emitter Configuration

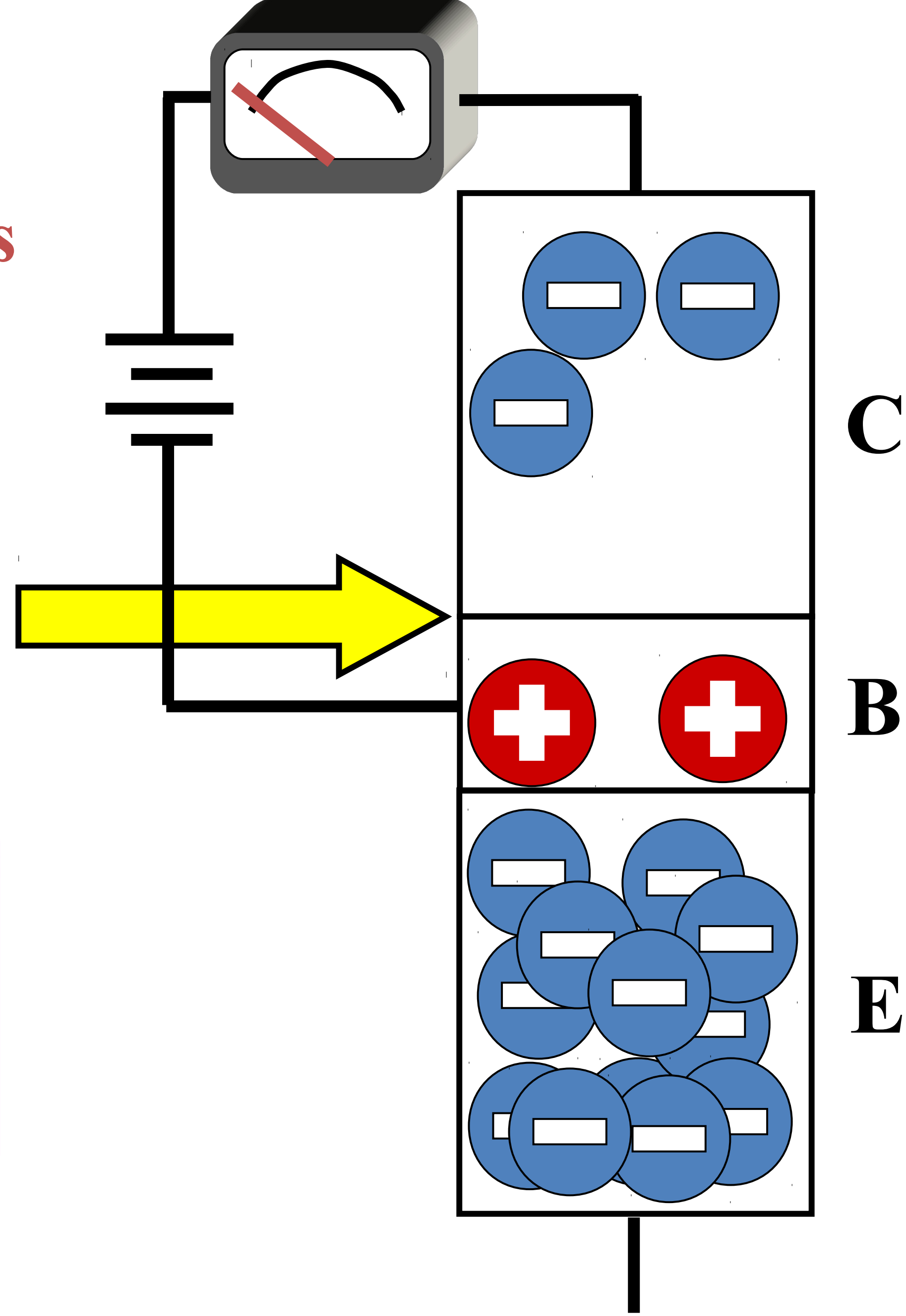
- Emitter terminal is common for input and output circuit
- Input – BE
- Output – CE
- Mostly applied in practical amplifier circuits, since it provides good voltage, current and power gain



NPN Transistor Bias

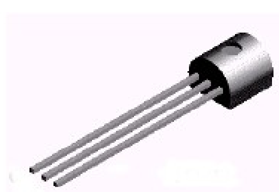
No current flows.

The C-B junction is reverse biased.

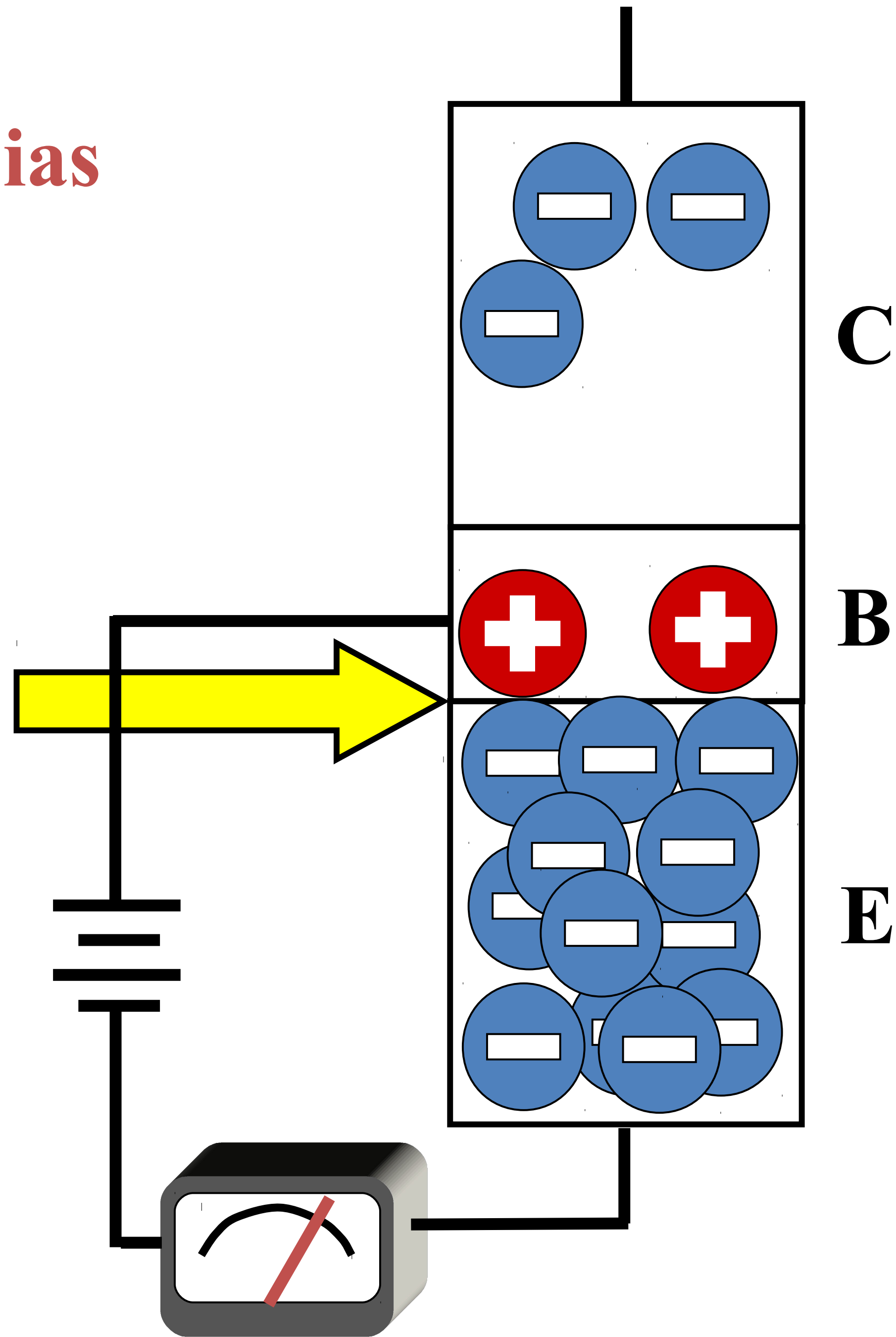


NPN Transistor Bias

The B-E junction is forward biased.

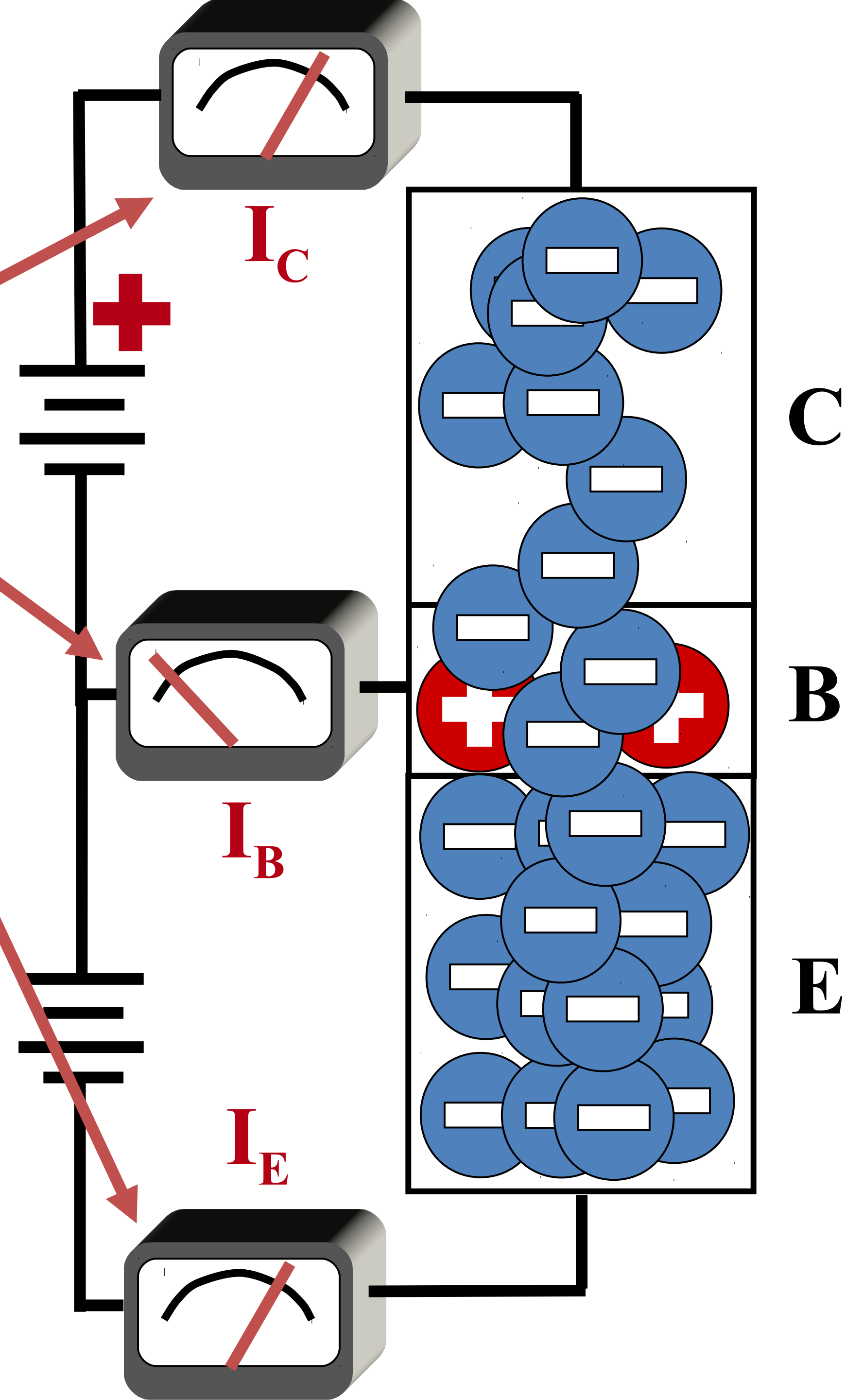


Current flows.



NPN Transistor Bias

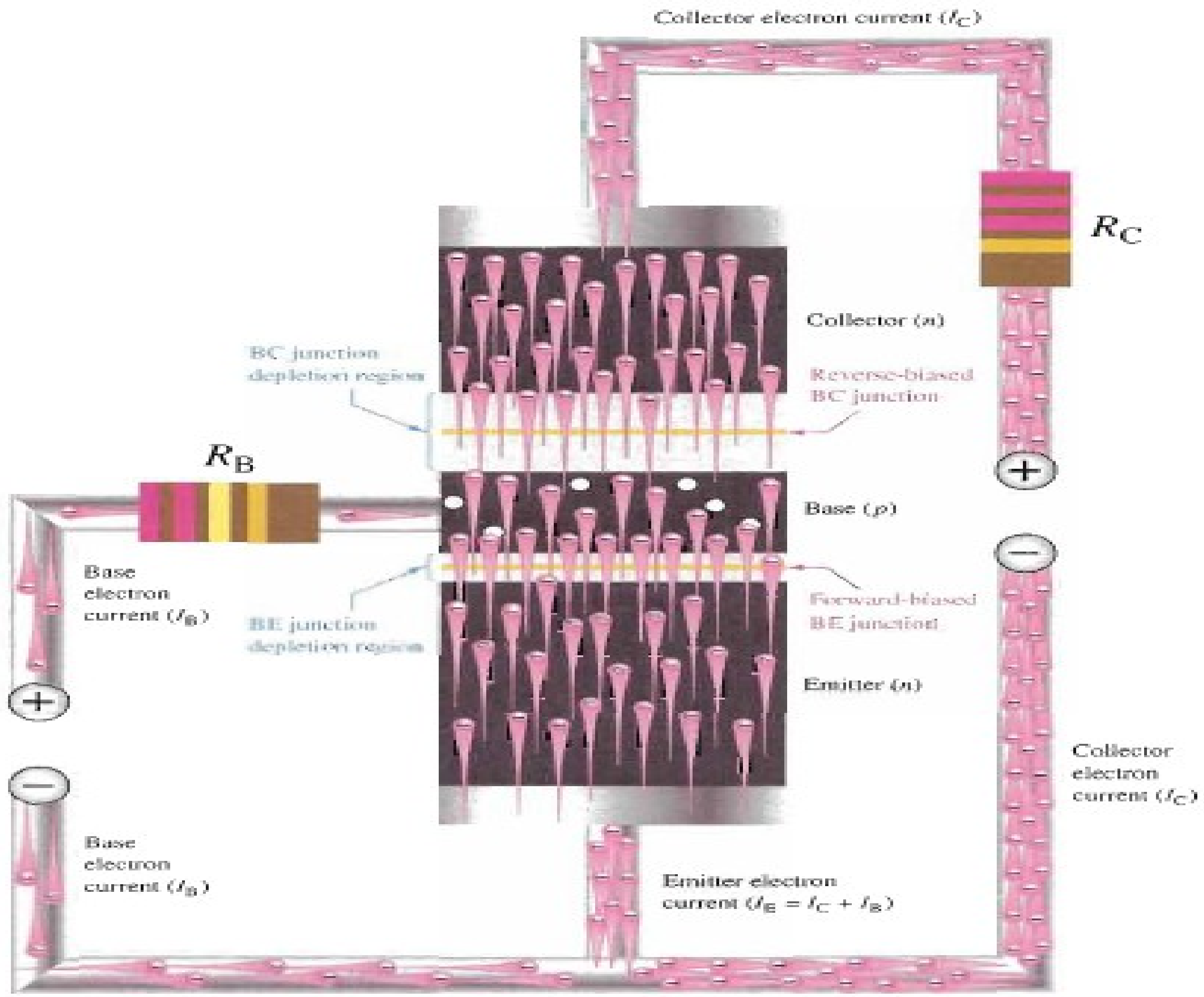
Current flows everywhere.



When both junctions are biased....

Note that I_B is smaller than I_E or I_C.

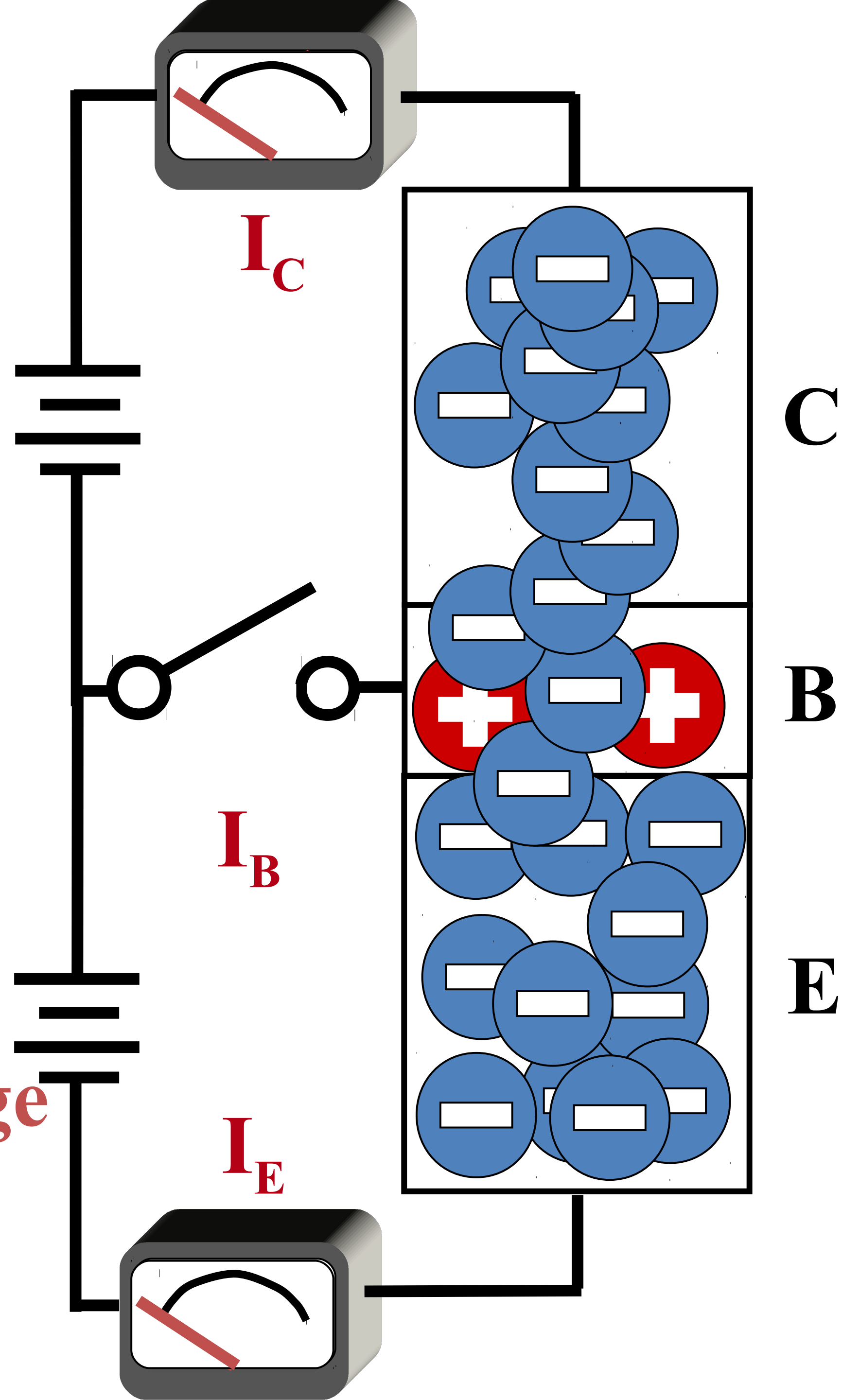
Transistor operation



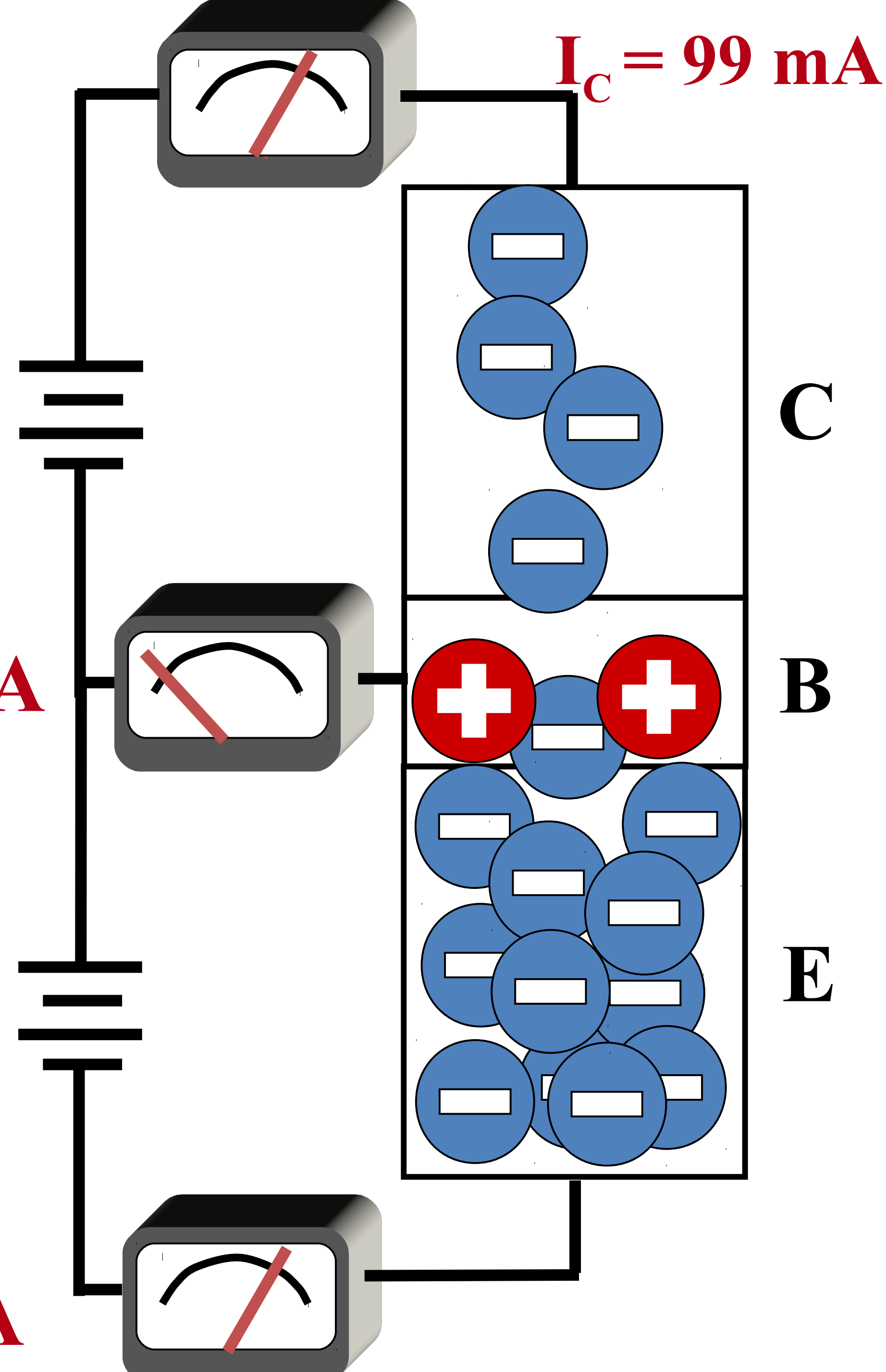
Note: when the switch opens, all currents go to zero.

Although I_B is smaller it controls I_E and I_C.

Gain is something small controlling something large (I_B is small).



The current gain from base to collector is called β.



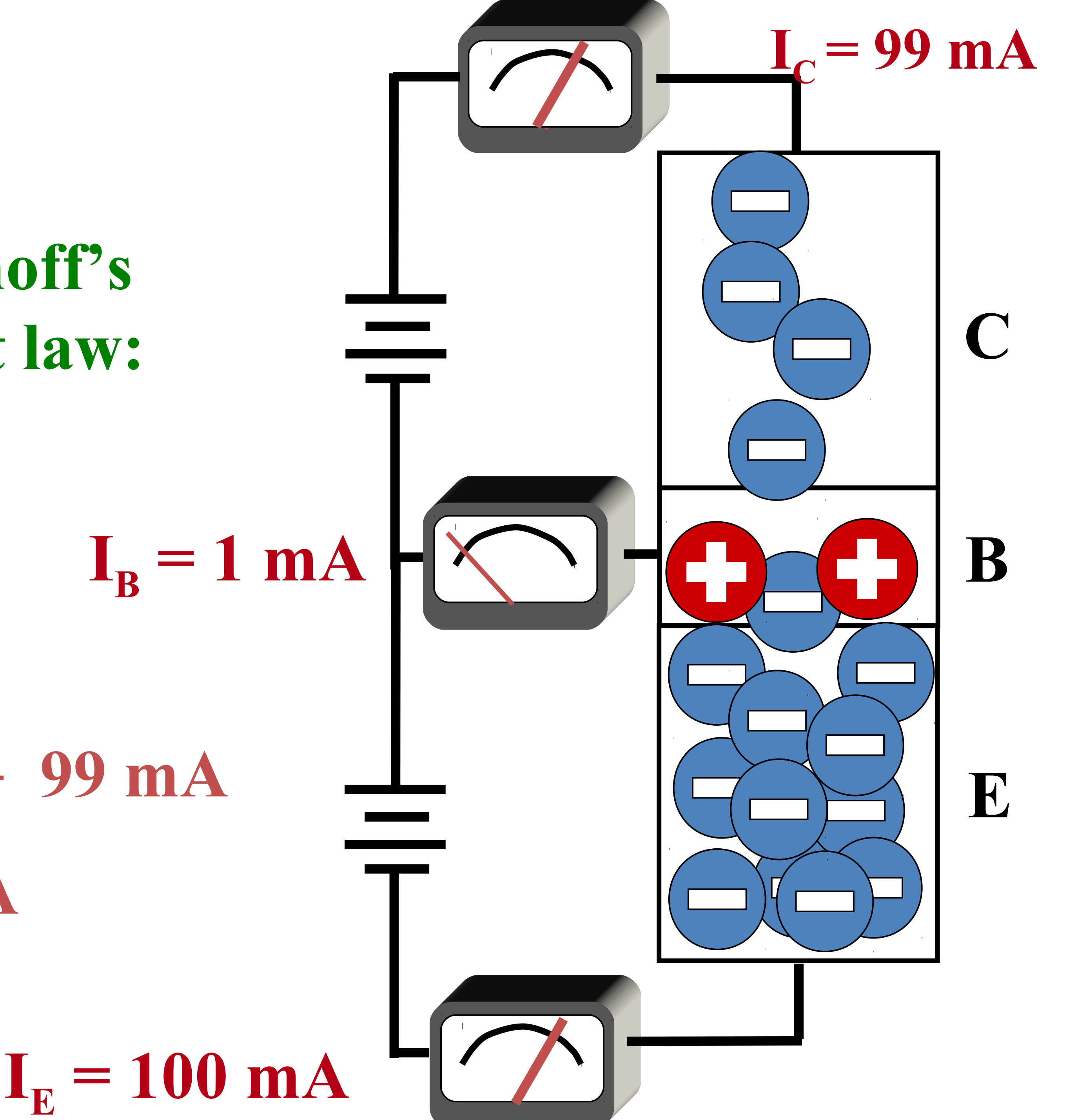
$I_B = 1$ mA

$I_E = 100$ mA

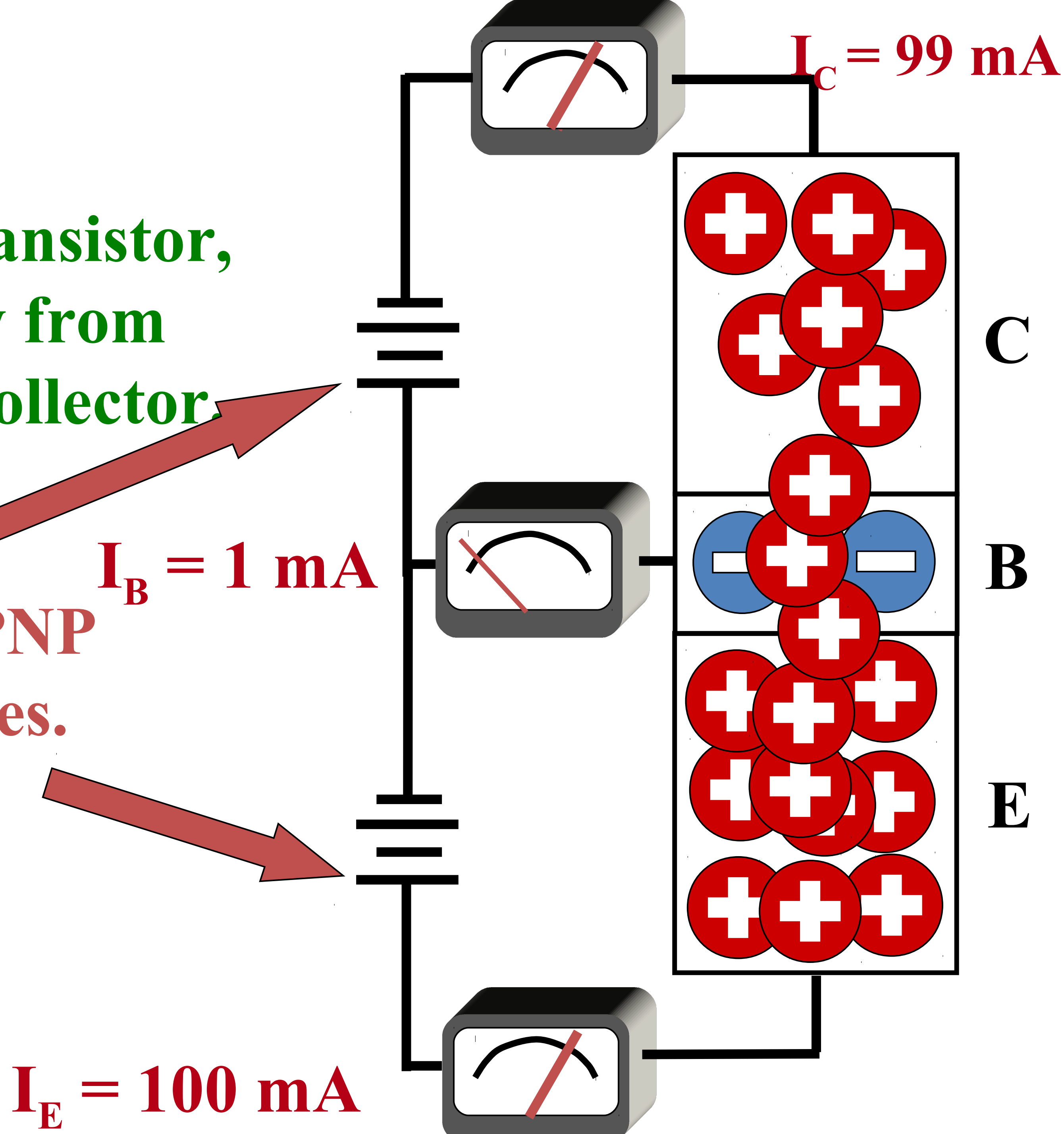
$$\beta = \frac{99\ \text{mA}}{1\ \text{mA}} = 99$$

Kirchhoff's current law:

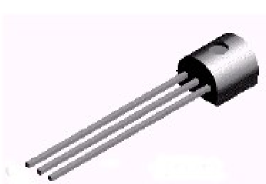
$$I_E = I_B + I_C$$
$$= 1\ \text{mA} + 99\ \text{mA}$$
$$= 100\ \text{mA}$$



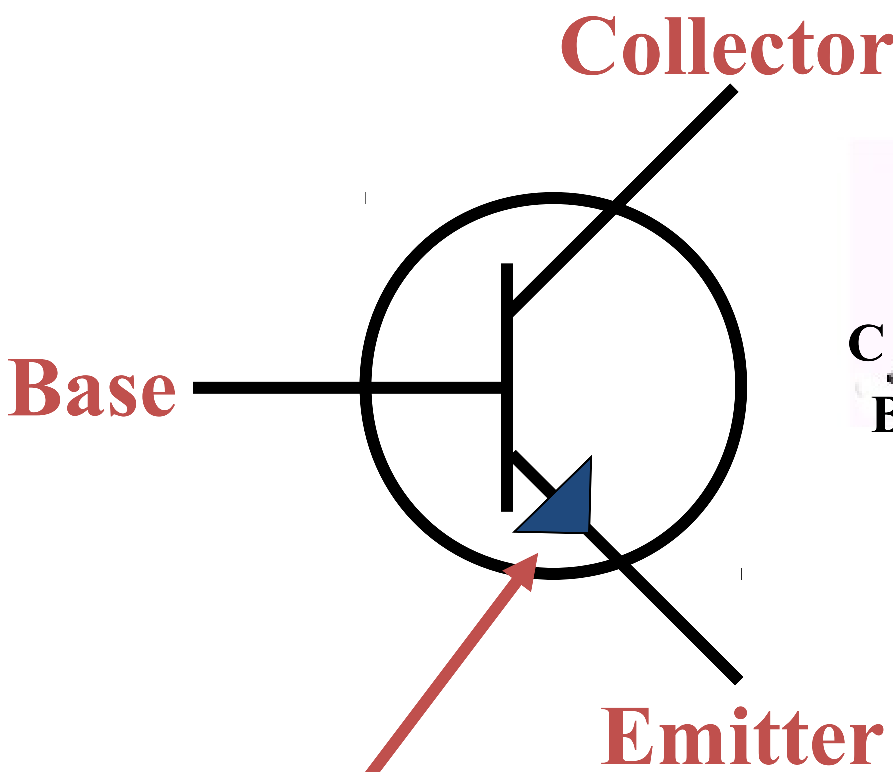
In a PNP transistor, holes flow from emitter to collector.

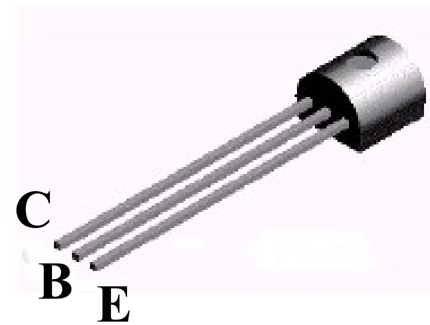


Notice the PNP bias voltages.



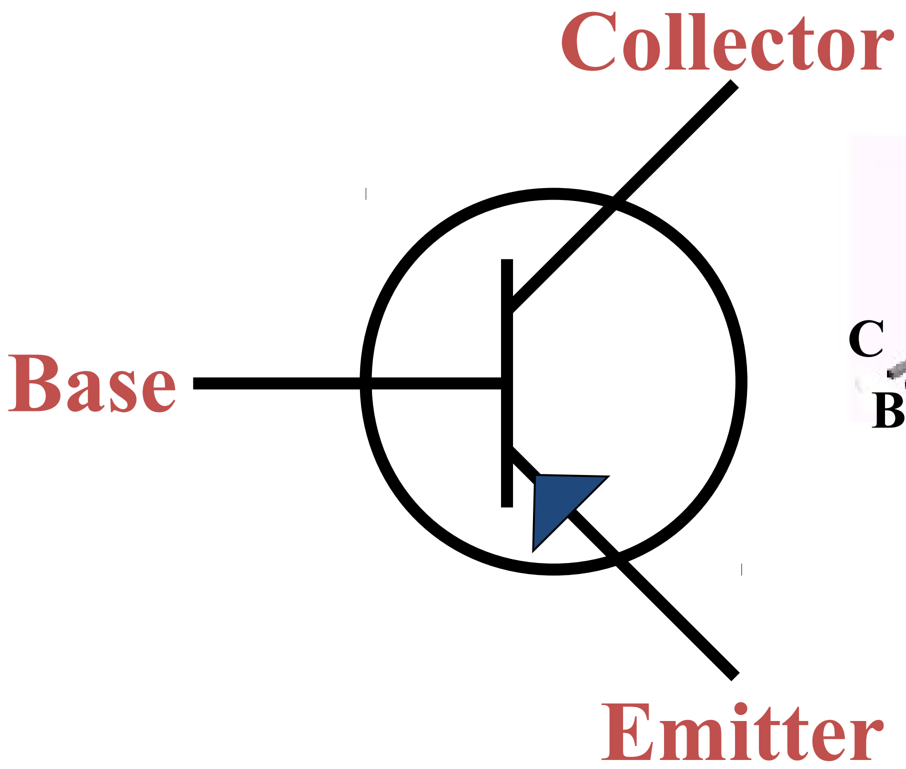
NPN Schematic Symbol

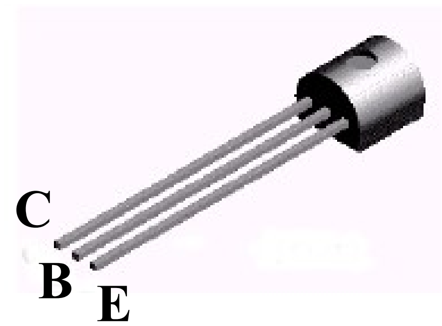




Memory aid: **NPN** means **N**ot **P**ointing i**N**.

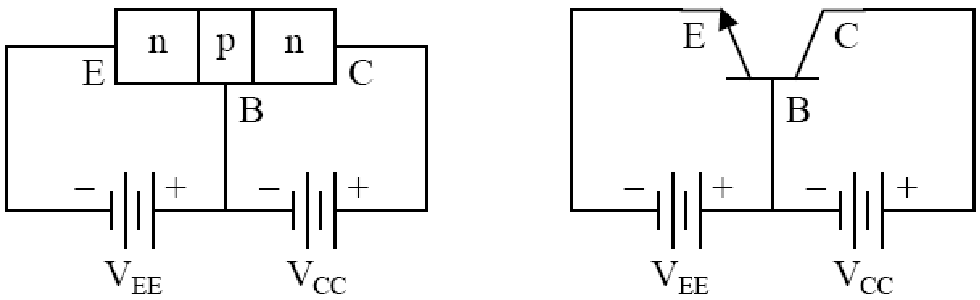
PNP Schematic Symbol



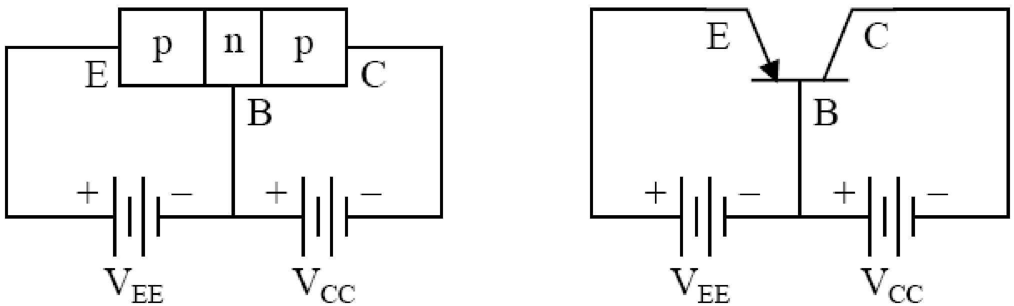


Memory aid: NPN means Pointing iN Properly.

Recall: NPN and PNP Bias



(a) transistor npn

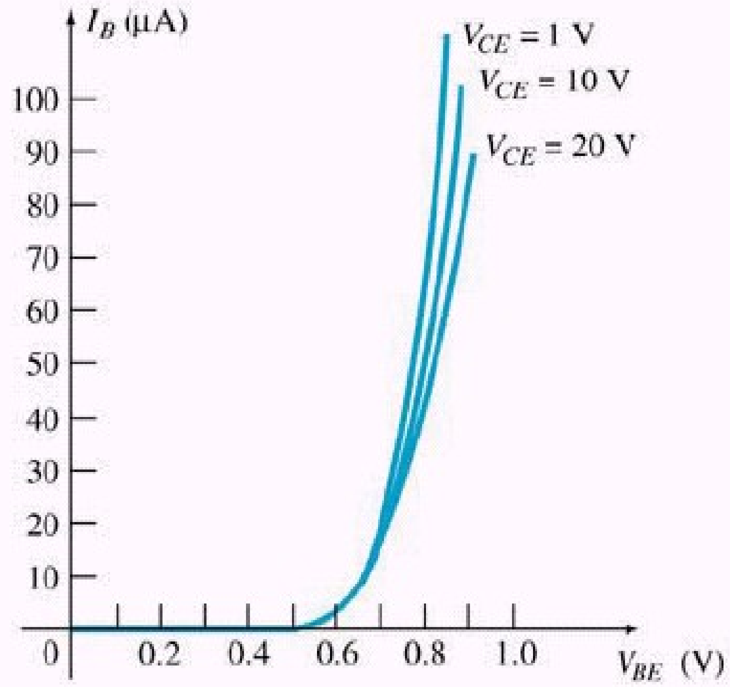


(a) transistor pnp

- Fundamental operation of pnp transistor and npn transistor is similar except for:
  - role of electron and hole,
  - voltage bias polarity, and
  - Current direction

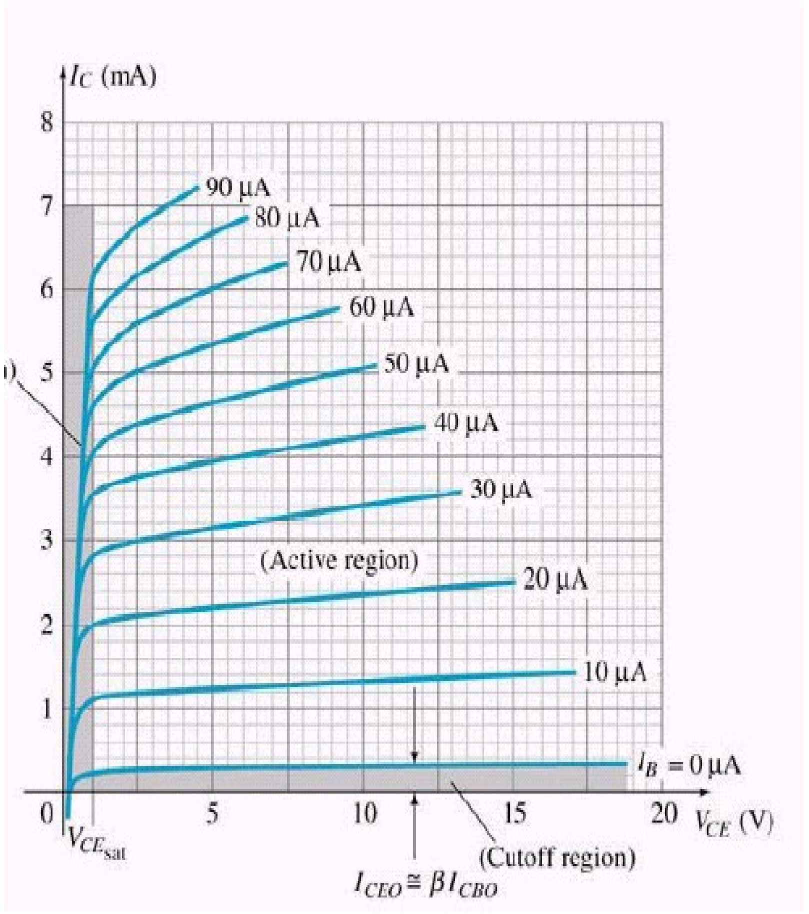
I-V Characteristic for CE configuration : Input characteristic

- Input characteristic: input current (I_B) against input voltage (V_{BE}) for several output voltage (V_{CE})
- From the graph
  - $I_B = 0$ A $V_{BE} < 0.7$V (Si)
  - $I_B =$ value $V_{BE} > 0.7$V (Si)
- The transistor turned on when $V_{BE} = 0.7$V



I-V Characteristic for CE configuration : Output characteristic

- Output characteristic: output current (I_C) against output voltage (V_{CE}) for several input current (I_B)
- 3 operating regions:
  - Saturation region
  - Cut-off region
  - Active region



I-V Characteristic for CE configuration : Output characteristic

- Saturation region – in which both junctions are forward-biased and I_C increase linearly with V_{CE}

- Cut-off region – where both junctions are reverse-biased, the I_B is very small, and essentially no I_C flows, I_C is essentially zero with increasing V_{CE}

- Active region – in which the transistor can act as a linear amplifier, where the BE junction is forward-biased and BC junction is reverse-biased. I_C increases drastically although only small changes of I_B.

- Saturation and cut-off regions – areas where the transistor can operate as a switch

- Active region – area where transistor operates as an amplifier

Current Relationships

- Relations between I_C and I_E :

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

- Value of α usually 0.9998 to 0.9999, $\alpha \approx 1$
- Relations between I_C and I_B :

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

- Value of β usually in range of 50 → 400
- The equation, $I_E = I_C + I_B$ can also written in β

$$I_C = \beta I_B$$

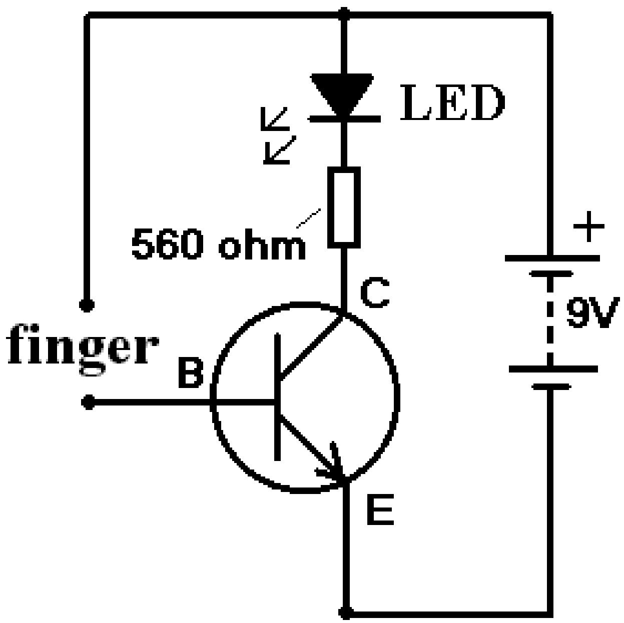
$$I_E = \beta I_B + I_B \quad => I_E = (\beta + 1) I_B$$

- The current gain factor , α and β is:

$$\alpha = \frac{\beta}{\beta + 1} \quad @ \quad \beta = \frac{\alpha}{\alpha - 1}$$

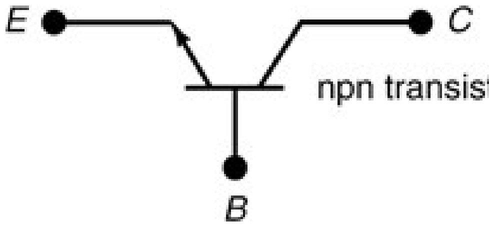
Simple Transistor Circuit

- Pictured below is a very simple circuit which demonstrates the use of **transistors**. When a finger is placed in the circuit where shown, a tiny current of around 0.1mA flows (assuming a finger resistance of 50,000 Ohms). This is nowhere near enough to light the LED which needs at least 10mA. However the tiny current is applied to the *Base* of the transistor where it is boosted by a factor (gain) of around 100 times and the LED lights!

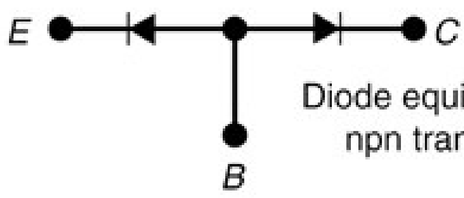


Checking a Transistor with an Ohmmeter

- An analog <u>ohmmeter</u> can be used to check a transistor because the emitter-base and collector-base junctions are p-n junctions.
- This is illustrated in Fig. where the npn transistor is replaced by its diode equivalent circuit.



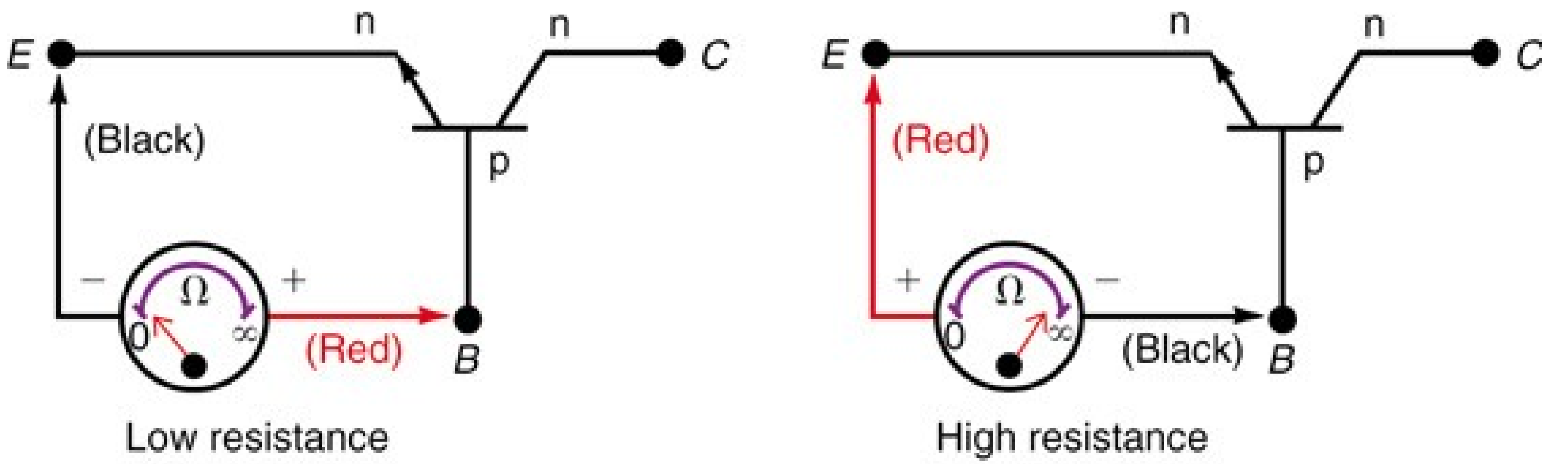
npn transistor



Diode equivalent of npn transistor

Checking a Transistor with an Ohmmeter

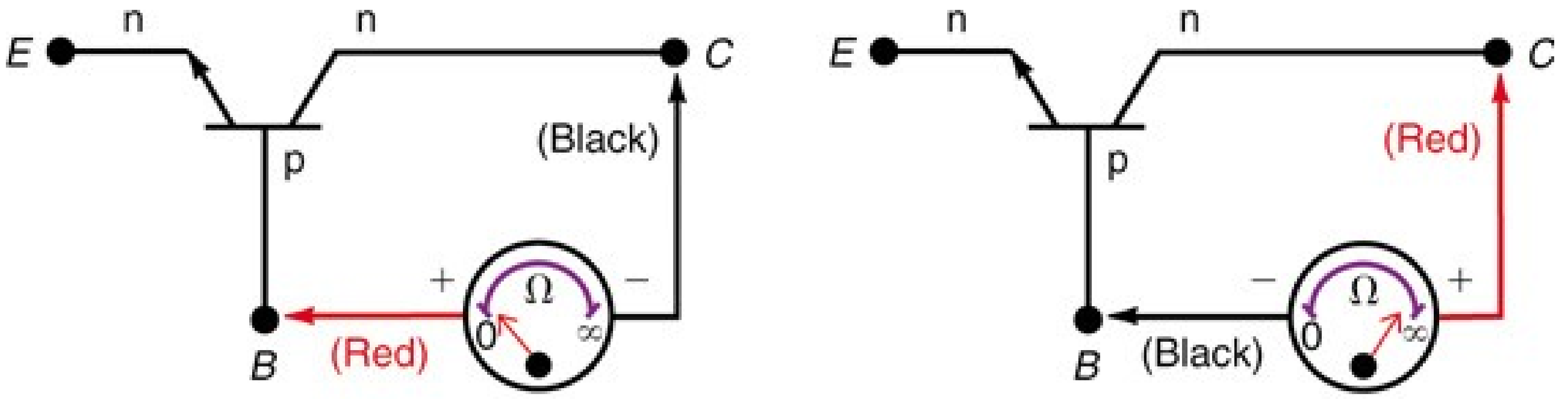
- To check the base-emitter junction of an npn transistor, first connect the ohmmeter as shown in Fig. 28-9 (a) and then reverse the ohmmeter leads as shown in (b).
- For a good p-n junction made of silicon, the ratio R_R/R_F should be equal to or greater than 1000:1.



(a) (b)

Checking a Transistor with an Ohmmeter

- To check the collector-base junction, first connect the ohmmeter as shown in Fig. 28-10 (a) and then reverse the ohmmeter leads as shown in (b).
- For a good p-n junction made of silicon, the ratio R_R/R_F should be equal to or greater than 1000:1.
- The resistance measured between the collector and emitter should read high or infinite for both connections of the meter leads.



Low resistance

(a)

High resistance

(b)

Checking a Transistor with an Ohmmeter

- Low resistance across the junctions in both directions: transistor is shorted.

- High resistance on both directions: transistor is open.

- In these cases, the transistor is defective and must be replaced.