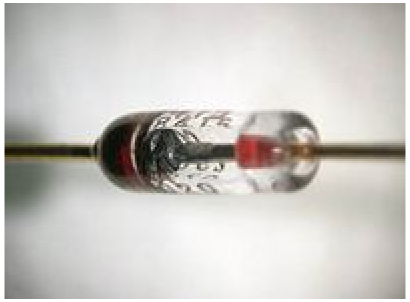
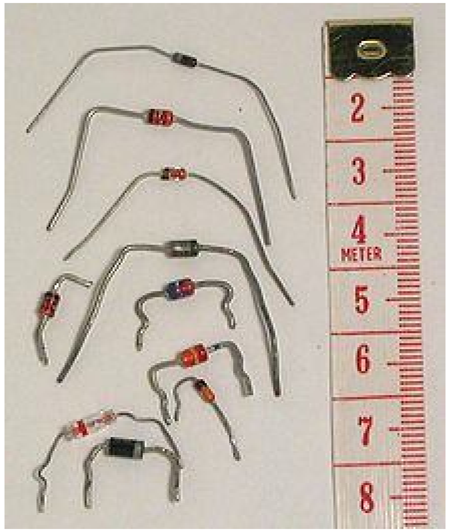
Unit IV

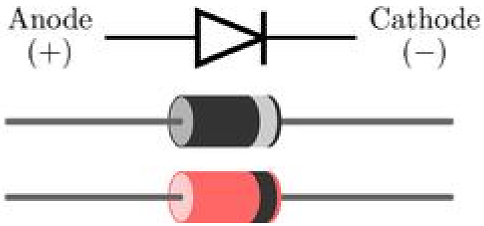
Power Semiconductor devices

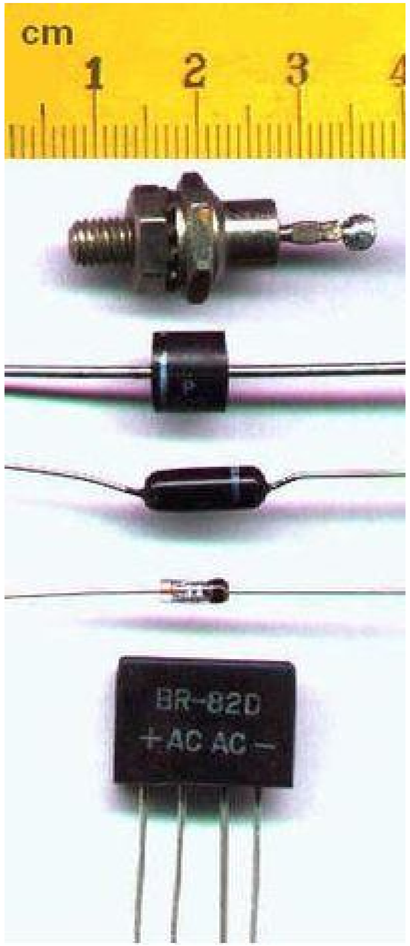
Operating mechanism of power devices including diodes, Zener diode
BJTs, MOSFETs, IGBTs, forward and reverse characteristics,
Break down characteristics and their applications



DIODE







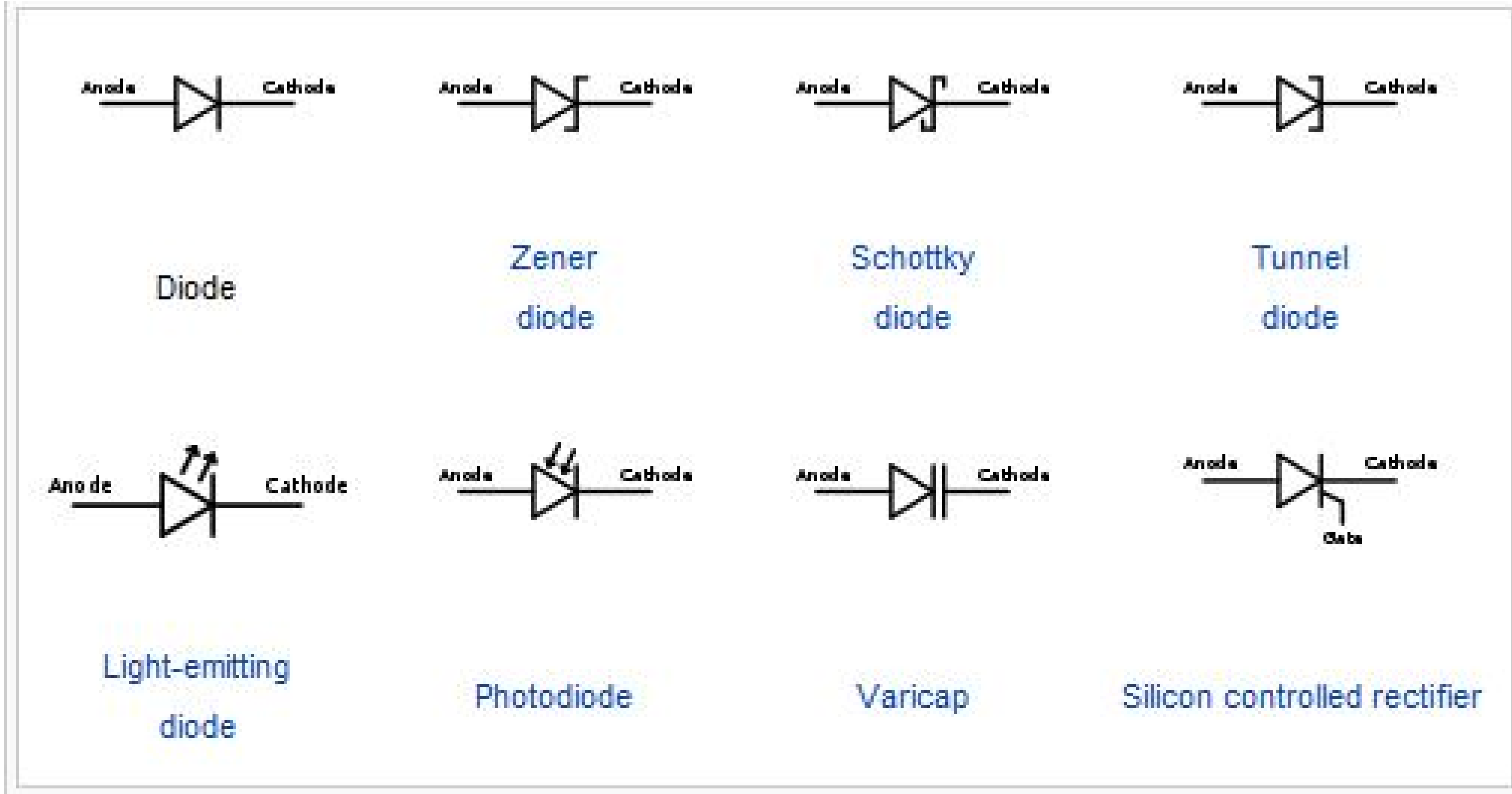
Diode – some facts

- In electronics, a diode is a two-terminal electronic component that conducts electric current in only one direction.
- Diodes were the first semiconductor electronic devices.
- The discovery of crystals' rectifying abilities was made by German physicist Ferdinand Braun in 1874.
- The first semiconductor diodes, called cat's whisker diodes, were made of mineral crystals such as galena.
- Today most diodes are made of silicon, but other semiconductors such as germanium are sometimes used.

Types of semiconductor diodes

- Cat’s whisker or crystal diodes
- Constant current diodes
- Esaki or tunnel diodes (to generate radio frequency oscillations)
- Gunn diodes
- Light-emitting diodes (LEDs) – (to produce light)
- Laser diodes
- Thermal diodes
- Photodiodes
- PIN diodes
- Schottky diodes
- Varicap or varactor diodes (to electronically tune radio and TV receivers)
- Zener diodes (to regulate voltage)

Some diode symbols



Numbering and coding schemes

- EIA/JEDEC standard
- European Pro Electron standard:

EIA/JEDEC

- A standardized 1N-series numbering system was introduced in the US by EIA/JEDEC (Joint Electron Device Engineering Council) about 1960.
- Among the most popular in this series were: 1N34A/1N270 (Germanium signal), 1N914/1N4148 (Silicon signal),

  1N4001-1N4007 (Silicon 1A power rectifier) and 1N54xx (Silicon 3A power rectifier)

European Pro Electron

- Introduced in 1966 and comprises two letters followed by the part code.
- The first letter -material used (A = Germanium and B = Silicon)
- Second letter - general function of the part (for diodes: A = low-power/signal, B = Variable capacitance, X = Multiplier, Y = Rectifier and Z = Voltage reference), for example:
- AA-series germanium low-power/signal diodes (e.g.: AA119)
- BA-series silicon low-power/signal diodes (e.g.: BAT18 Silicon RF Switching Diode)
- BY-series silicon rectifier diodes (e.g.: BY127 1250V, 1A rectifier diode)
- BZ-series silicon zener diodes (e.g.: BZY88C4V7 4.7V zener diode)

Other common numbering / coding systems

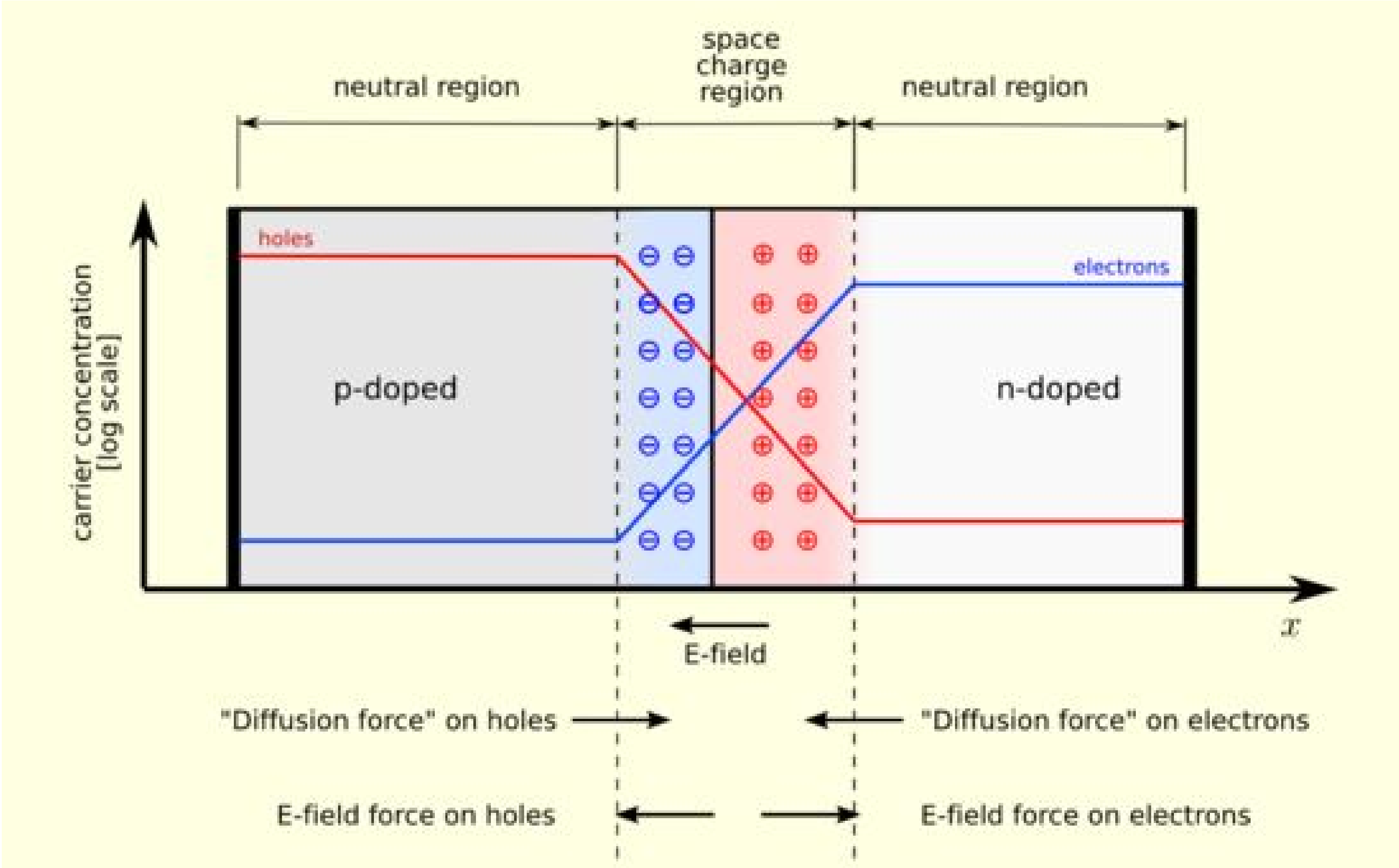
- These systems are (generally manufacturer-driven) include:
- GD-series germanium diodes (ed: GD9) — this is a very old coding system
- OA-series germanium diodes (e.g.: OA47) — a coding sequence developed by Mullard, a UK company

- As well as these common codes, many manufacturers or organisations have their own systems too for example:
- HP diode 1901-0044 = JEDEC 1N4148
- UK military diode CV448 = Mullard type OA81 = GEC type GEX2

P-N Junction diode

- P-N junctions are elementary "building blocks" of almost all semiconductor electronic devices such as diodes, transistors, solar cells, LEDs, and integrated circuits;
- The discovery of the p–n junction is usually attributed to American physicist Russell Ohl of Bell Laboratories
- Schottky junction is a special case of a p-n junction, where metal serves the role of the n-type semiconductor.

Unbiased diode



- For silicon diodes, the built-in potential is approximately 0.7 V, 0.3 V for Germanium and 0.2 V for Schottky

I-V characteristics of P Junction diode

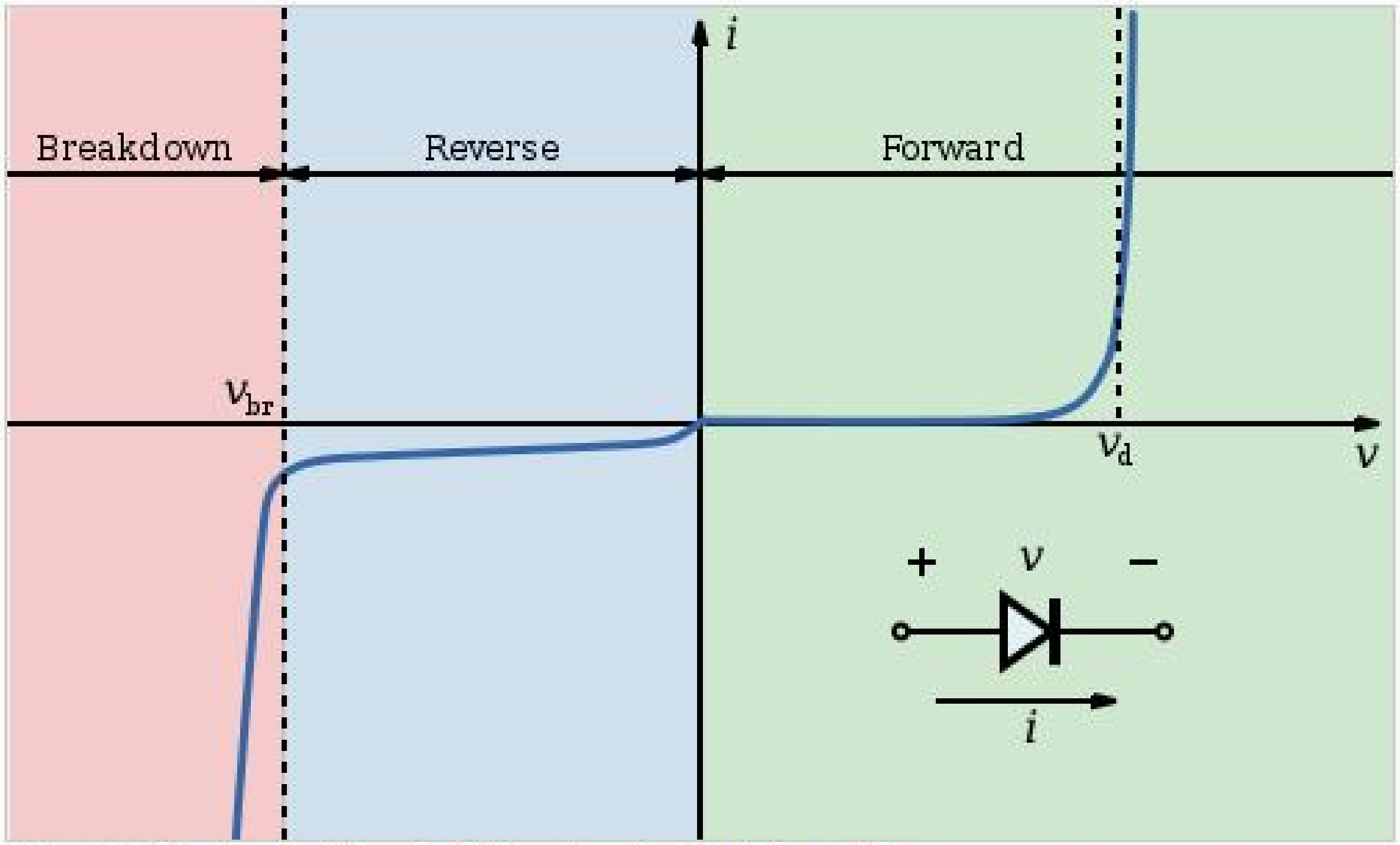
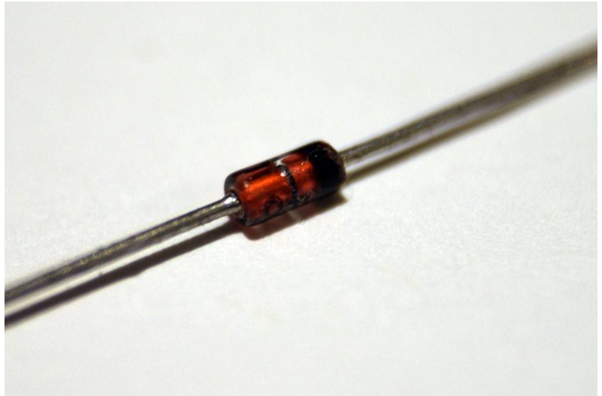
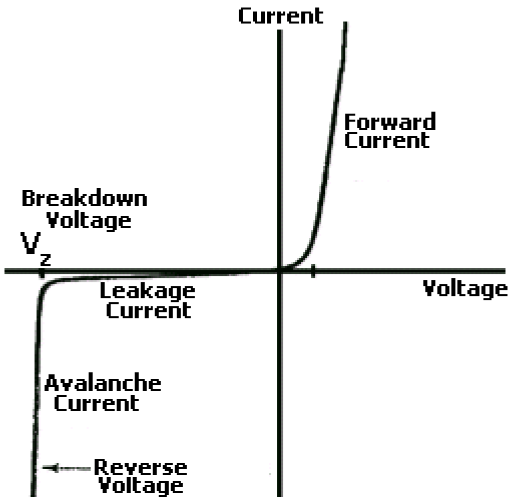


Figure 5: I–V characteristics of a P-N junction diode (not to scale).

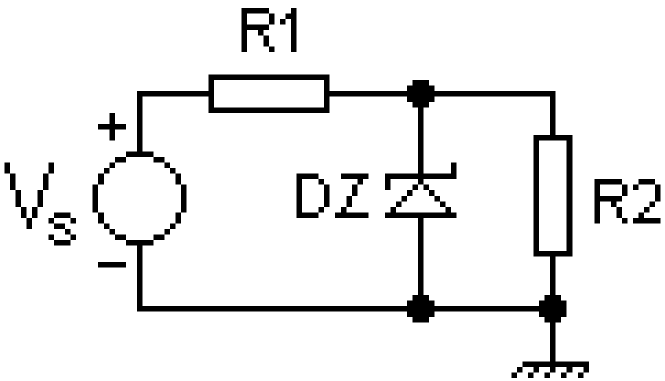
Zener diode

- A Zener diode is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener knee voltage" or "Zener voltage".
- The device was named after Clarence Zener, who discovered this electrical property.
- Breakdown voltage for commonly available zener diodes can vary widely from 1.2 volts to 200 volts.





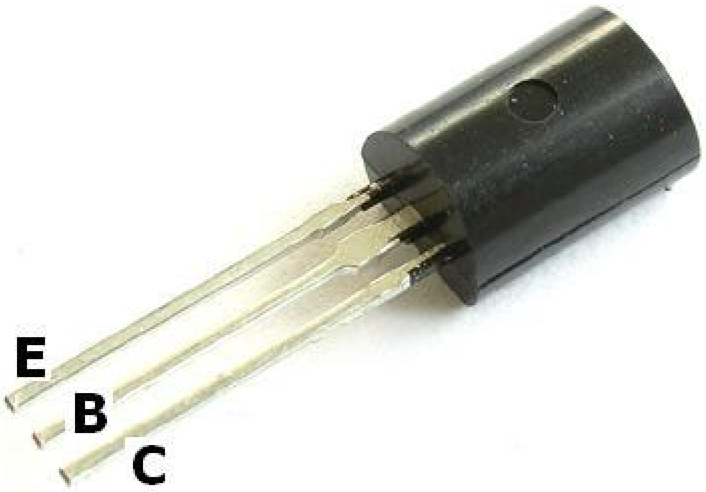
Zener diode as voltage regulator



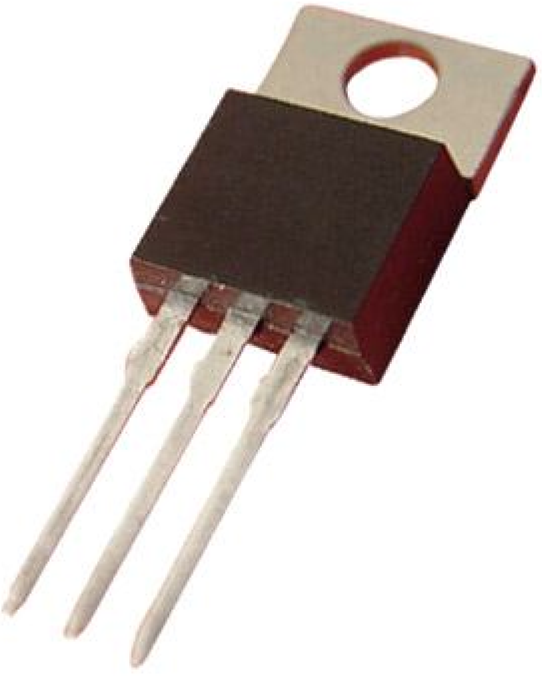
$$R1 = \frac{V_S - V_Z}{I_Z + I_{R2}}$$

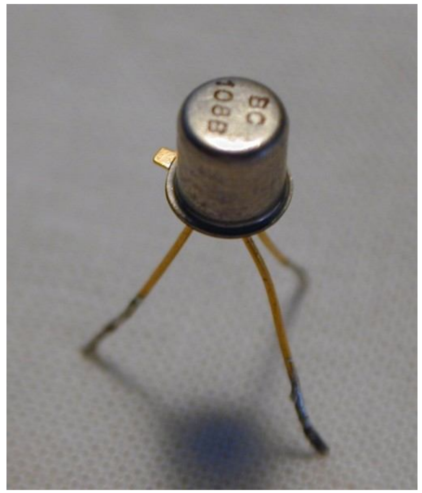
Diodes - Applications

- Radio demodulation
- Power conversion
- Over-voltage protection
- Logic gates
- Ionizing radiation detectors
- Temperature measurements
- Current steering



Bipolar Junction Transistor



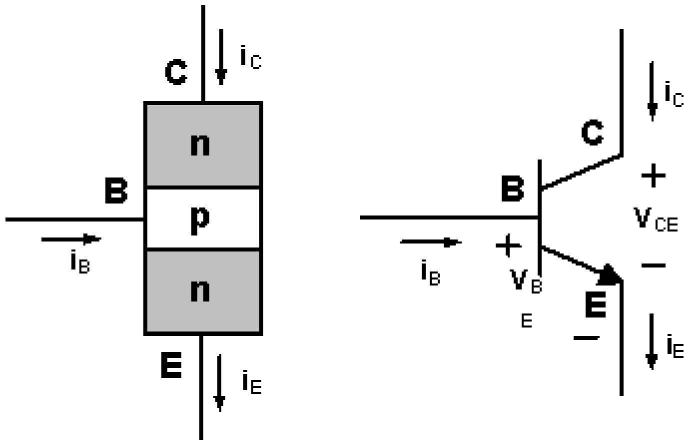


Bipolar Junction Transistors (BJTs)

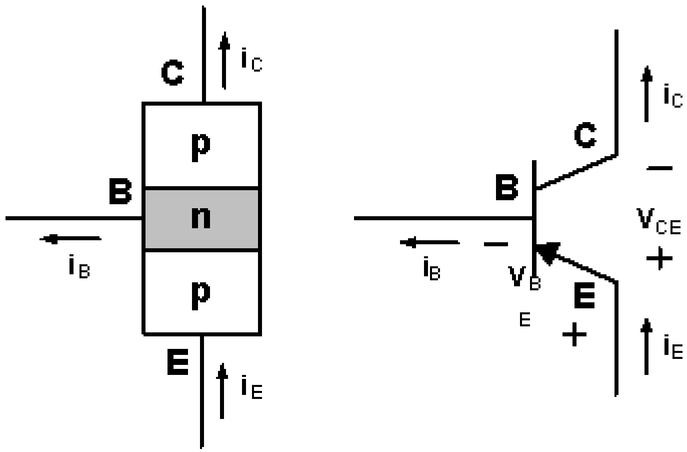
- The bipolar junction transistor is a semiconductor device constructed with three doped regions.
- These regions essentially form two ‘back-to-back’ p-n junctions in the same block of semiconductor material (silicon).
- The most common use of the BJT is in linear amplifier circuits (linear means that the output is proportional to input). It can also be used as a switch (in, for example, logic circuits).

Types

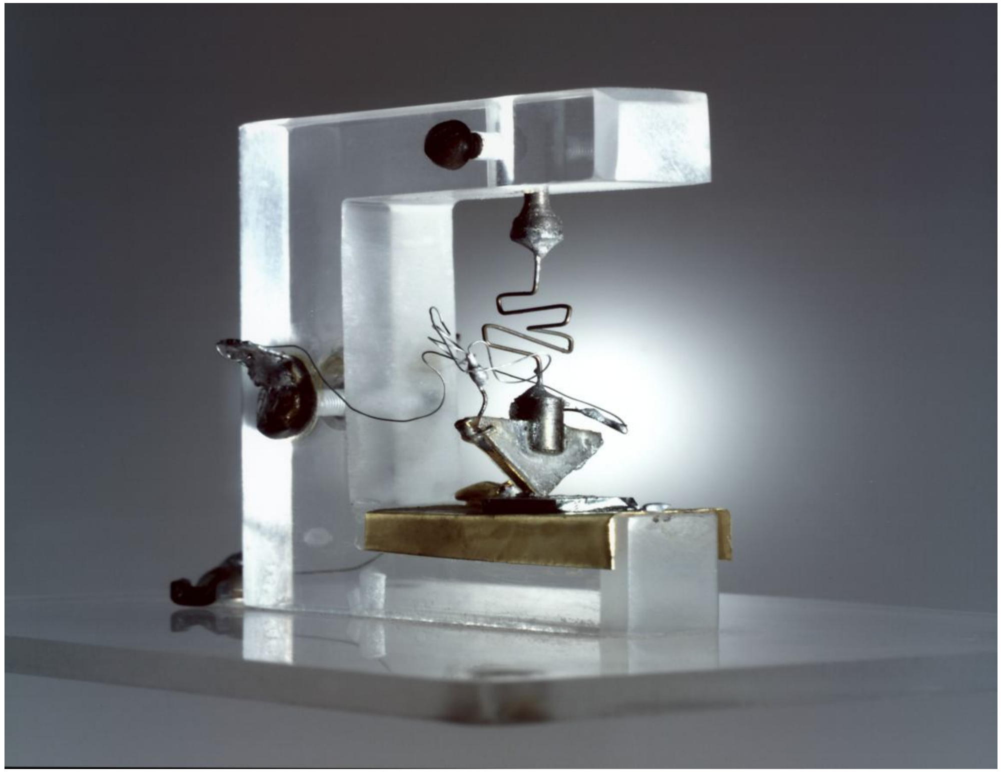
- NPN



- PNP

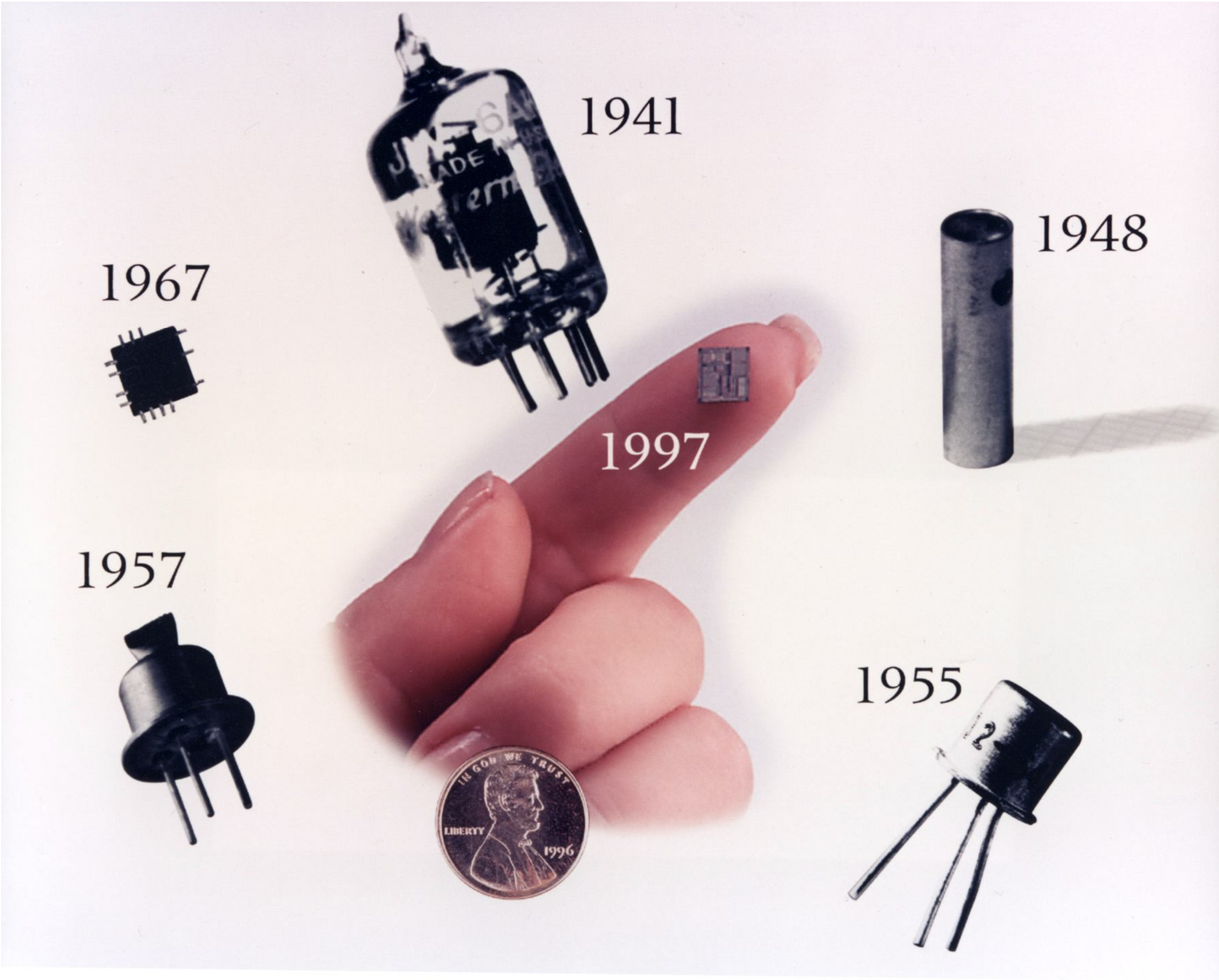


A picture of the first transistor ever assembled, invented in Bell Labs in 1947.



Bell Laboratories' germanium junction transistor fabricated in 1950

Transistor development



Major Milestones in Transistor Electronics

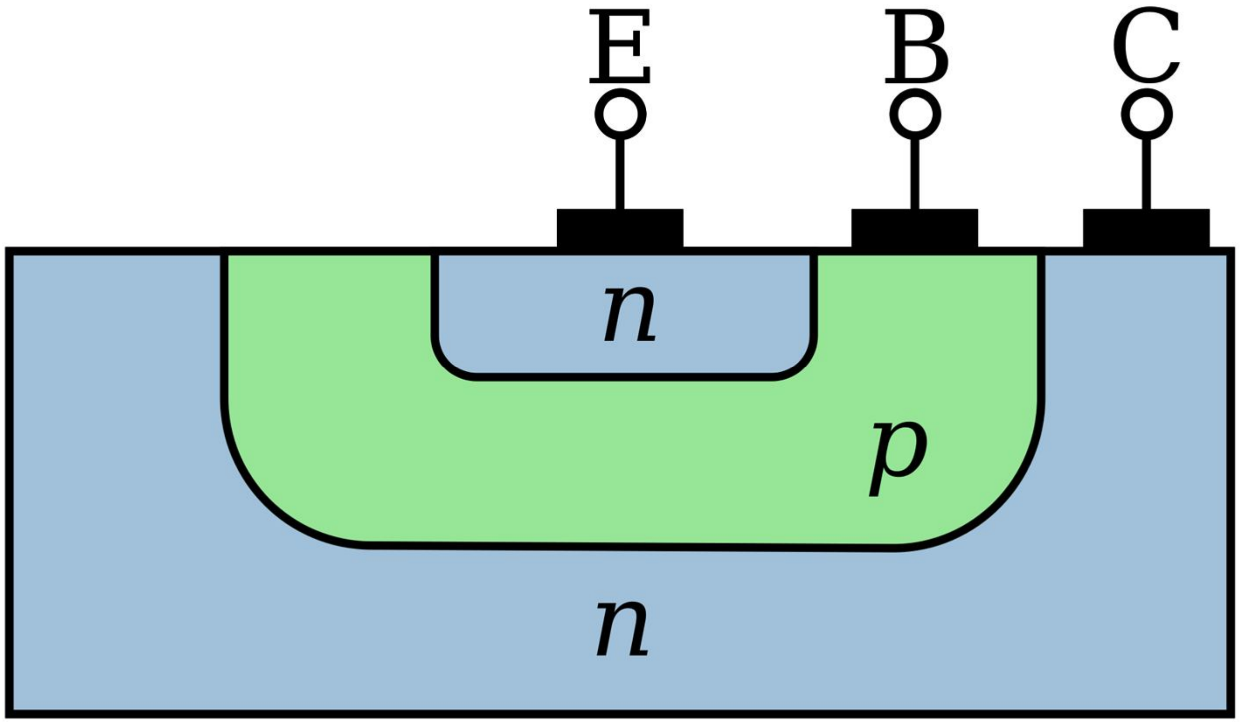
from Bell Laboratories Record magazine - January 1975, p.74

- 1948 - POINT CONTACT TRANSISTOR
- 1950 - SINGLE-CRYSTAL GERMANIUM
- 1951 - GROWN JUNCTION TRANSISTOR
- 1952 - ALLOY JUNCTION TRANSISTOR
- 1952 - ZONE MELTING AND REFINING
- 1952 - SINGLE-CRYSTAL SILICON
- 1955 - DIFFUSED -BASE TRANSISTORS
- 1957 - OXIDE MASKING
- 1960 - PLANAR TRANSISTOR
- 1960 - MOS TRANSISTOR
- 1960 - EPITAXIAL TRANSISTOR
- 1961 - INTEGRATED CIRCUITS

npn Structure

- The emitter (E) and is heavily doped (n-type).
- The collector (C) is also doped n-type.
- The base (B) is lightly doped with opposite type to the emitter and collector (i.e. p-type in the npn transistor).

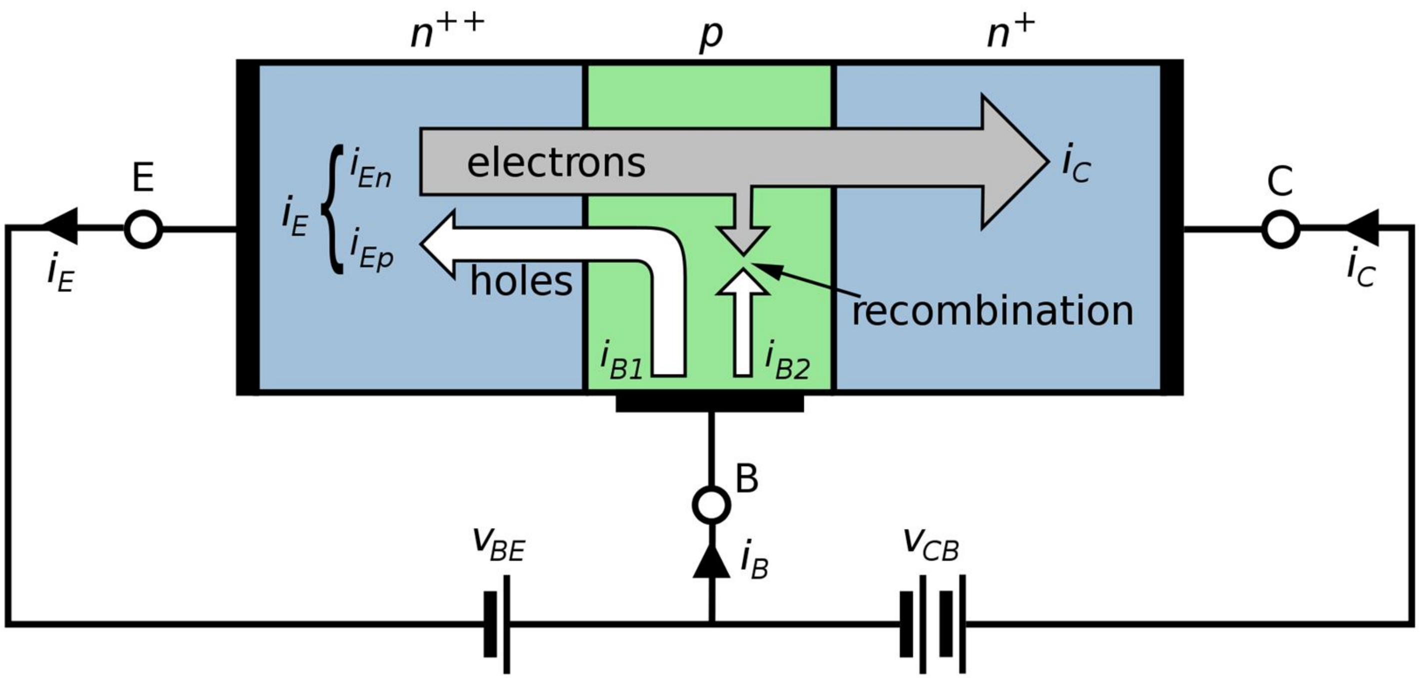
Structure *(Cross Section)*



BJT Circuits

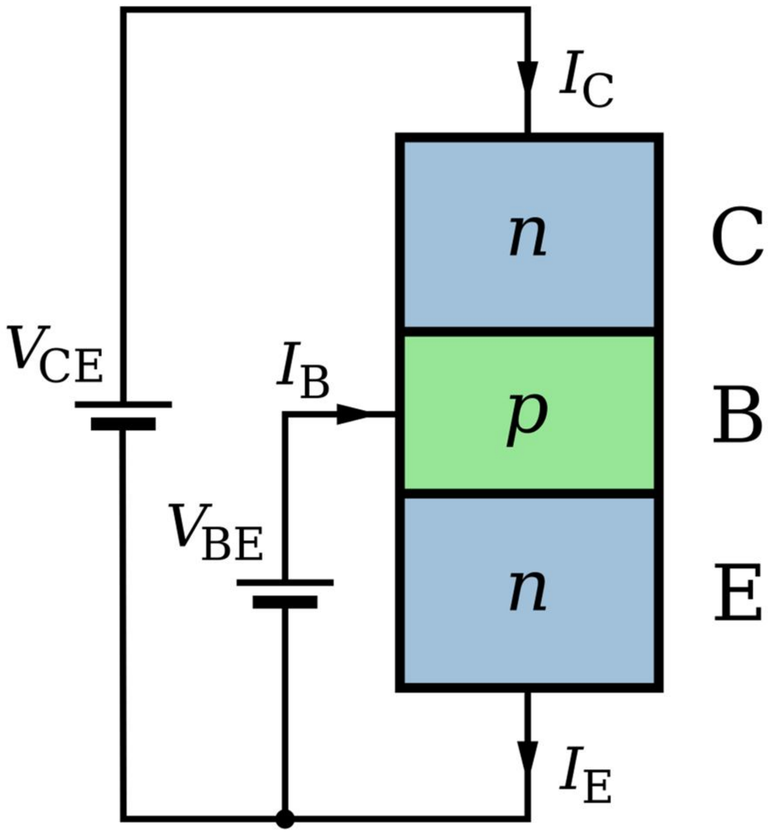
- Most electronic devices take the signal between two input terminals and deliver from it an output signal between two output terminals.
- The BJT has only three terminals so one of these is usually shared (i.e. made common) between input and output circuits.
- We thus talk about common emitter (CE), common base (CB) and common collector (CC) configurations.

Common Base



n^{++}
p
n^{+}
electrons
i_C
E
i_E
i_{En}
i_{Ep}
holes
recombination
C
i_C
i_E
i_{B1}
i_{B2}
B
v_{BE}
i_B
v_{CB}

Common Emitter



BJT Circuits

- The CE configuration is the one most commonly encountered since it provides both good current and voltage gain for ac signals.
- In the CE configuration the input is between the base and the emitter. The output is between the collector and the emitter.

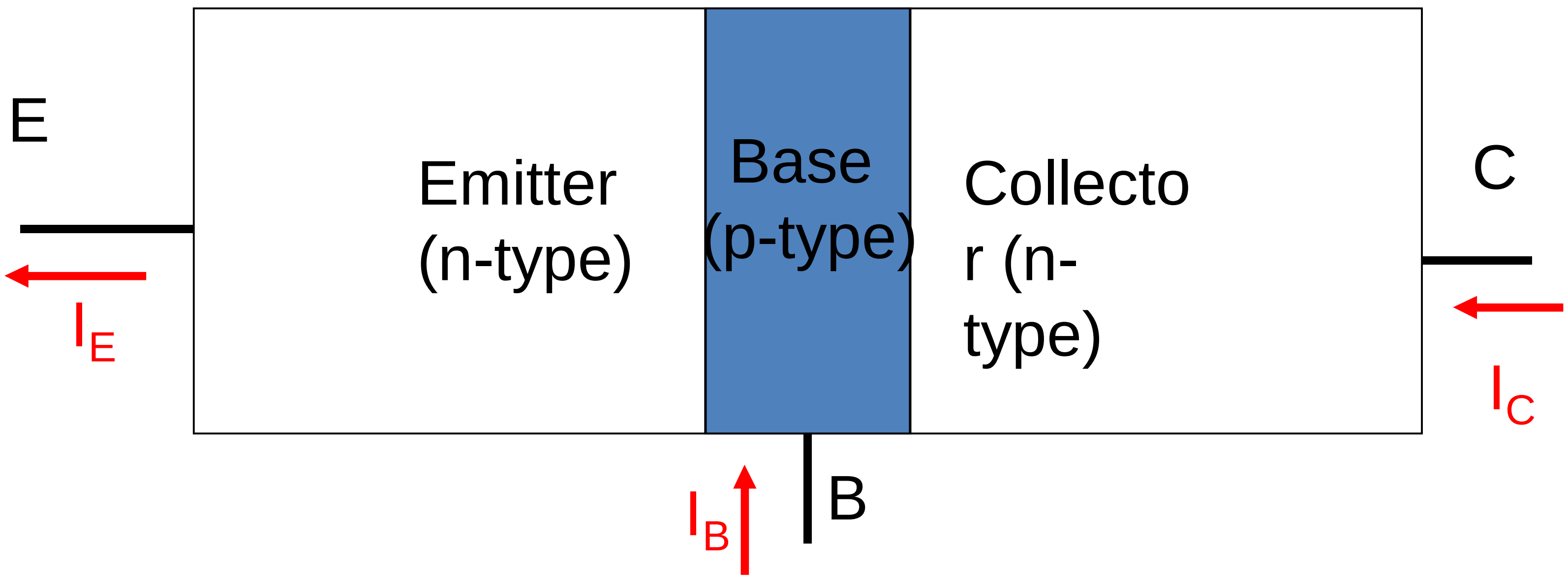
Current Directions (Convention)

- We define currents directions such that the collector current (I_C) and base current (I_B) flow into the device whereas the emitter current (I_E) flows out of the device.

- THIS IS IMPORTANT; we shall shortly treat the transistor as a current node and write

$$I_C + I_B = I_E \quad \text{(Kirchhoff)}$$

Current Flow Convention



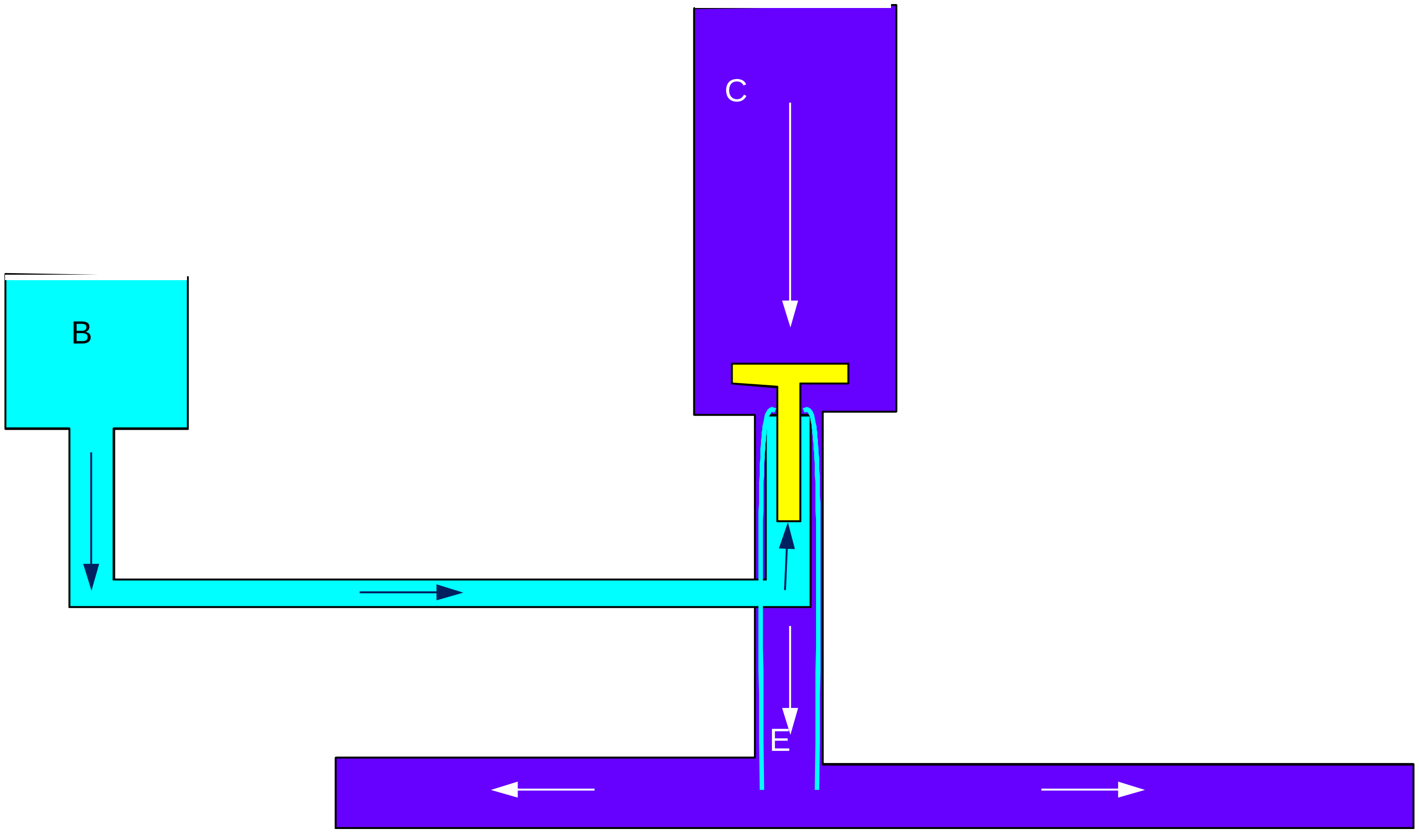
Basic Operation

- In normal operation for analogue (linear amplifier) circuits the emitter-base junction is forward biased and the collector-base junction is reverse biased.
- These ‘bias’ or ‘quiescent’ conditions are set by d.c. bias circuits.
- The forward bias between the base and emitter injects electrons from the emitter into the base and holes from the base into the emitter.
- As the emitter is heavily doped and the base lightly doped most of the current transport across this junction is due to the electrons flowing from emitter to base.

- The base is lightly doped and physically very thin.
- Thus only a small percentage of electrons flowing across the base-emitter (BE) junction combine with the available holes in this region.
- Most of the electrons (a fraction α which is close to 1, e.g. 0.98) flowing from the emitter into the base reach the collector-base (CB) junction.
- Once they reach this junction they are ‘pulled’ across the reverse biased CB junction into the collector region i.e. they are collected.
- Those electrons that do recombine in the base give rise to the small base current I_B.

- The electrons ‘collected’ by the collector at the C-B junction essentially form the collector current in the external circuit.
- There will also be a small contribution to collector current, called I_{CO}, from the reverse saturation current across the CB junction.
- The base current supplies positive charge to neutralise the (relatively few) electrons recombining in the base. This prevents the build up of charge which would hinder current flow.

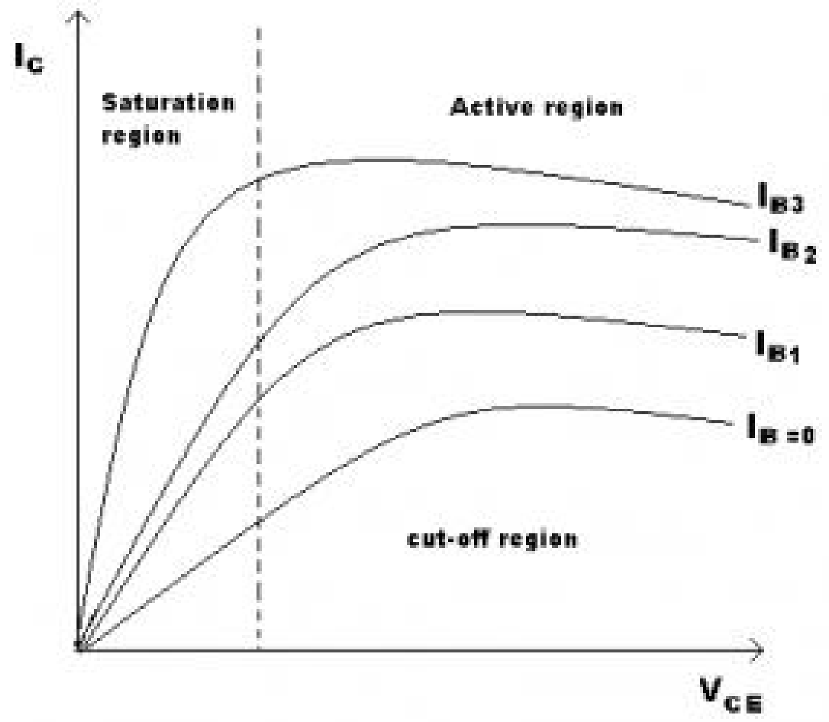
Analogy



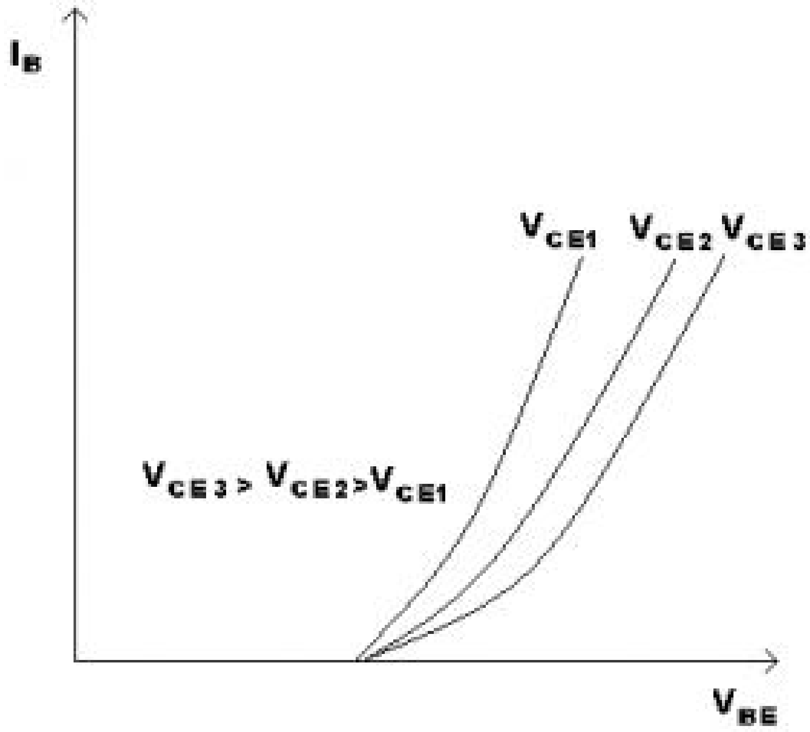
BJT Operation.
The Critical Knowledge!

- The (relatively large) collector current is directly controlled by the (much smaller) base current.
- **This is further illustrated and clarified in the following discussions of the BJT’s current-voltage characteristics.**

Output characteristic



Input characteristics



Modes of Operation

- Active Mode
- Cut-off mode
- Saturation Mode

Transistor Biasing

Region of operation	Emitter-Base Junction	Collector-Emitter Junction	Operation of a transistor
Active	FB	RB	Acts as an amplifier
Cut-off	RB	RB	Open switch
Saturation	FB	FB	Closed switch

Applications

- Bipolar junction transistors remain important devices for ultra-high-speed discrete logic circuits such as emitter coupled logic (ECL),
- power-switching applications and
- in microwave power amplifiers.
- BJTs are universally used in electrical circuits where current needs to be controlled.
  - Some of the areas are:
    - switching elements to control DC power to a load,
    - amplifiers for analog signals,