Mechatronics (ROB-GY 5103 Section A)

- **Today's lecture:**
  Basic Electronics Review
  (See Topics #3 and #5 from Main Text for details)

Fundamental Electrical Variables

Charge

- Symbol (q)
- SI Unit: Coulomb (C)
  - elementary charge e = 1.602×10^{-19} C

Current

- Symbol ($I(t) = dq/dt$)
- SI Unit: Ampere (A)
  - A = C/s
- **Positive convention!**

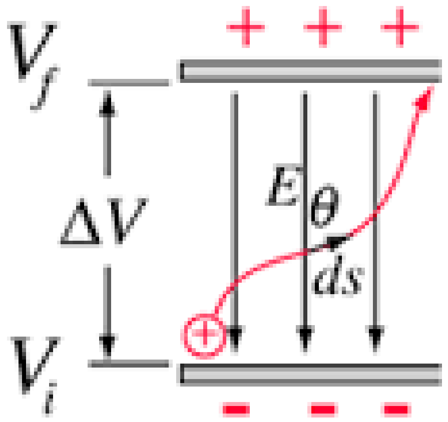
Electric Field

- Symbol (E)
- Derived SI Unit: (N/C)
  - Force = qE

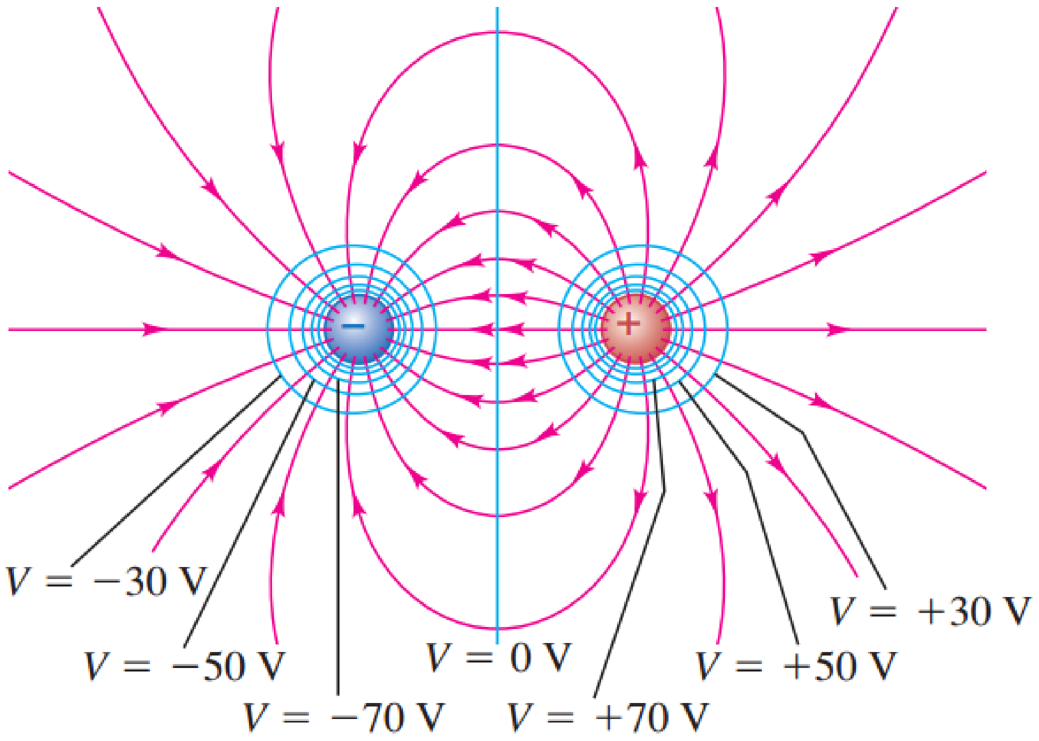
Voltage

$$V_f - V_i = -\int \vec{E}\cdot\vec{ds}$$

Moving a positive charge along the curved path indicated would require the integral to calculate, but in this case would give the same voltage difference.

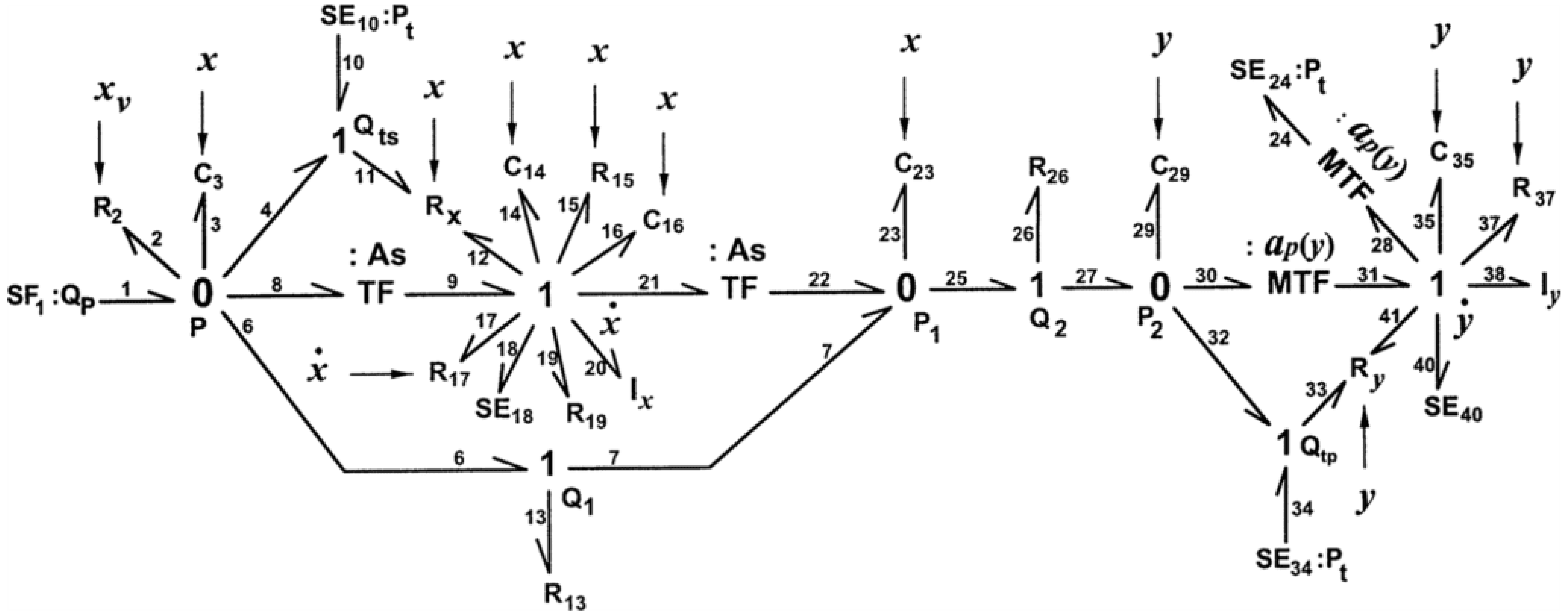


(b) An electric dipole



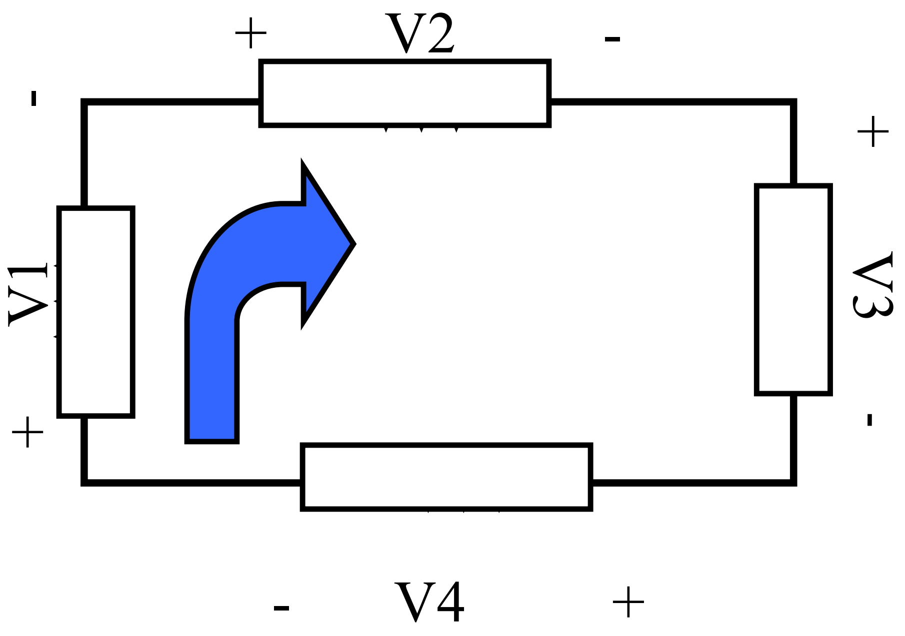
Aside: Bond Graph Modeling

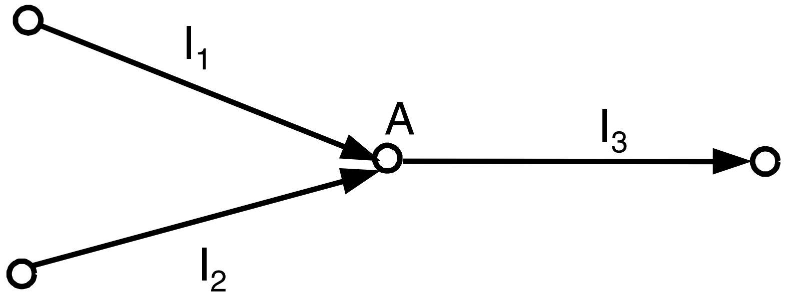
- Current is a **Through Variable** and Voltage is an **Across Variable**
- Across vs Through variables generalizes beyond electrical engineering



Kirchoff's Laws

- **Voltage Law:** The algebraic sum of voltage around a loop is zero.
- **Current Law:** Algebraic sum of all currents entering and leaving a node is zero.





Fundamental Electrical Properties

Resistance = 1/Conductance

- Part of Ohm's Law : IR = V
- What factors affect flow?
  - Actual electron speed ~10^6 m/s vs drift speed ~10^{-4} m/s
- Symbol (R)
- SI Unit: Ohm (Ω)

$$R = \frac{\rho L}{A}$$

ρ = resistivity
L = length
A = cross sectional area

- For conductance (G), the unit is the Mho (℧)

Applications

- Limiting current in electric circuits.
- Lowering voltage levels in electric circuits **(voltage divider)**.
- As current sensor **(shunt resistor).**
- Photoresistor are used to detect “light” condition.
- In electronic circuits, resistors are used as pull-up and pull-down elements to avoid floating signal levels.

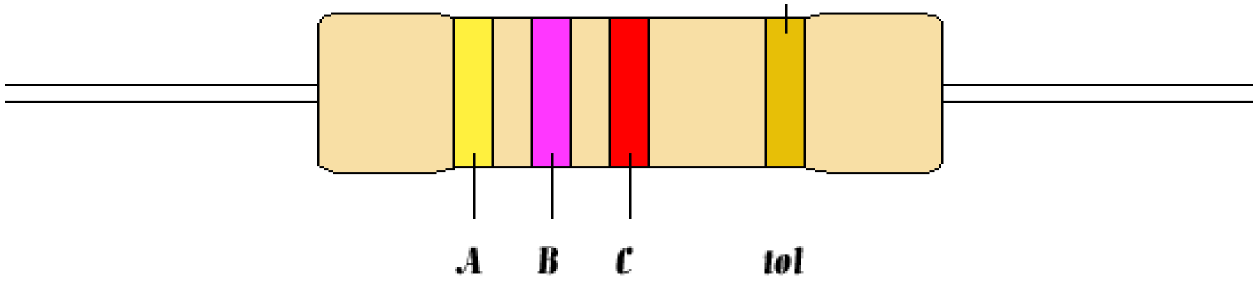
- **Please note the power rating of your resistors!**

Types

- Resistors can be made of:
    - Carbon film (decomposition of carbon film on a ceramic core).
    - Carbon composition (carbon powder and glue-like binder).
    - Metal oxide (ceramic core coated with metal oxide).
    - Precision metal film.
    - High power wire wound.

$$\text{Resistor value} = AB \times 10^{C} \pm tol\%(\Omega)$$

Symbol for resistor



Resistor Color Codes

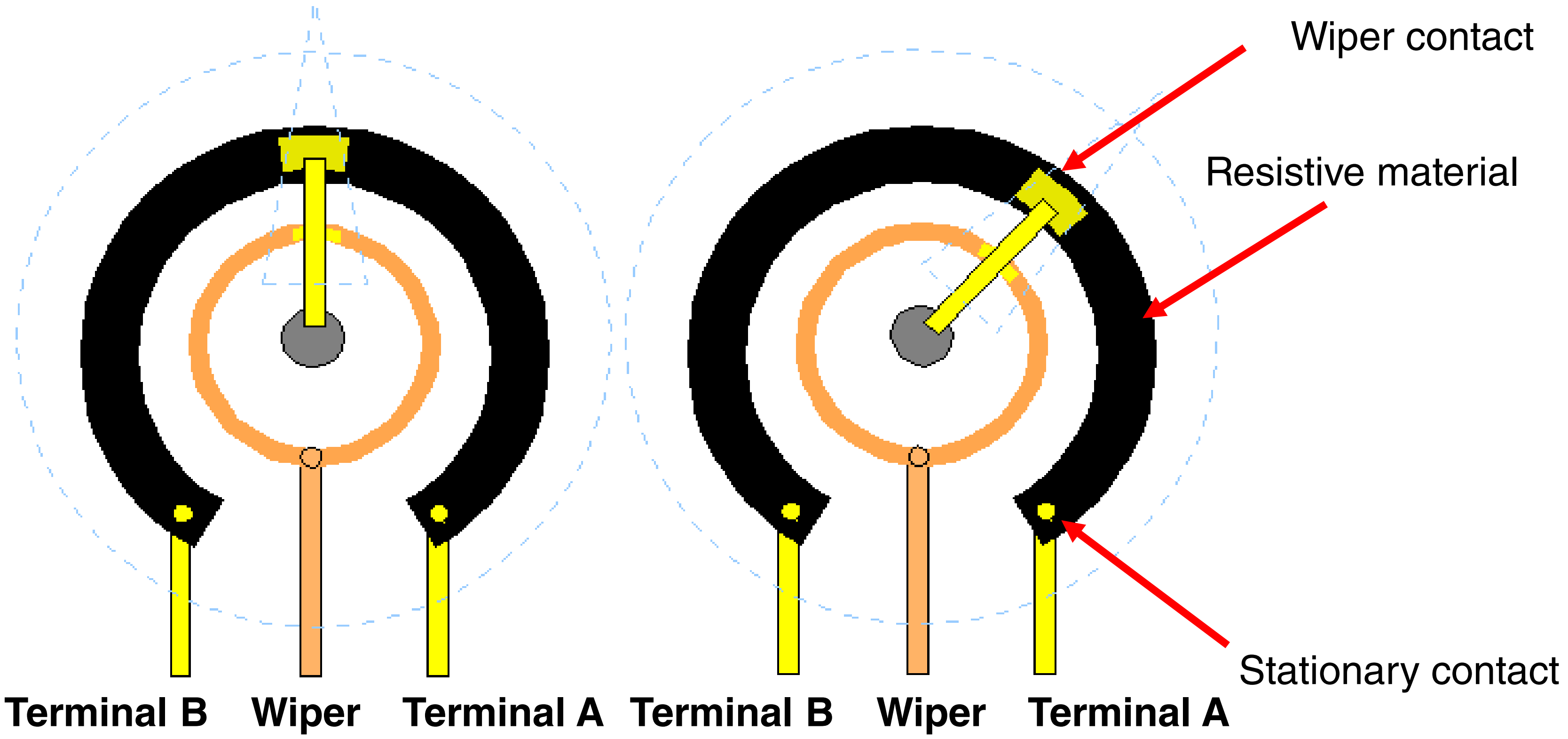
Color	Tolerance
Brown	±1%
Red	±2%
Gold	±5%
Silver	±10%
None	±20%

Band color	Digit	Multiplier
Black	0	X1
Brown	1	X10
Red	2	X100
Orange	3	X1000
Yellow	4	X10000
Green	5	X100000
Blue	6	X1000000
Purple	7	X10000000
Grey	8	X100000000
White	9	X1000000000
Silver	-	x.01
Gold	-	x.1

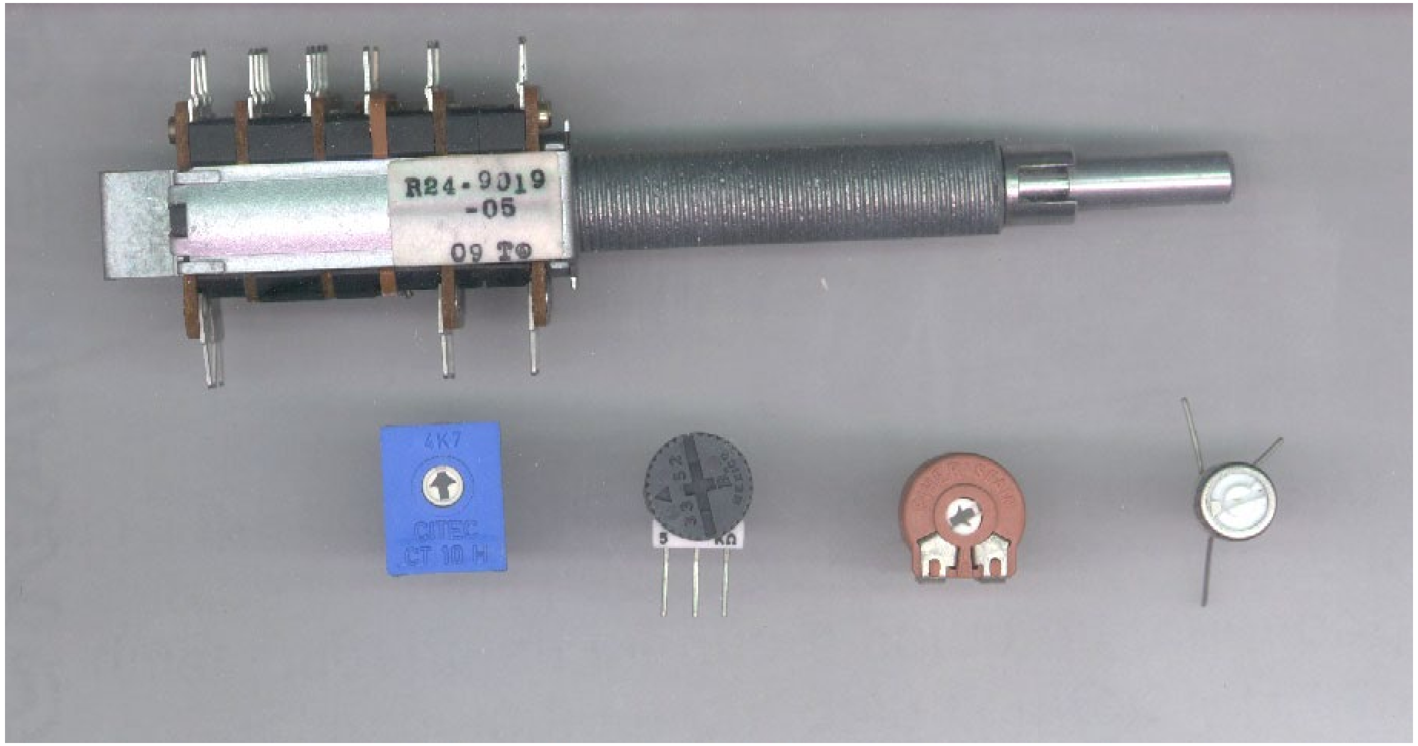
Variable Resistor

Symbol for variable resistor

- Example: Rotary Potentiometer

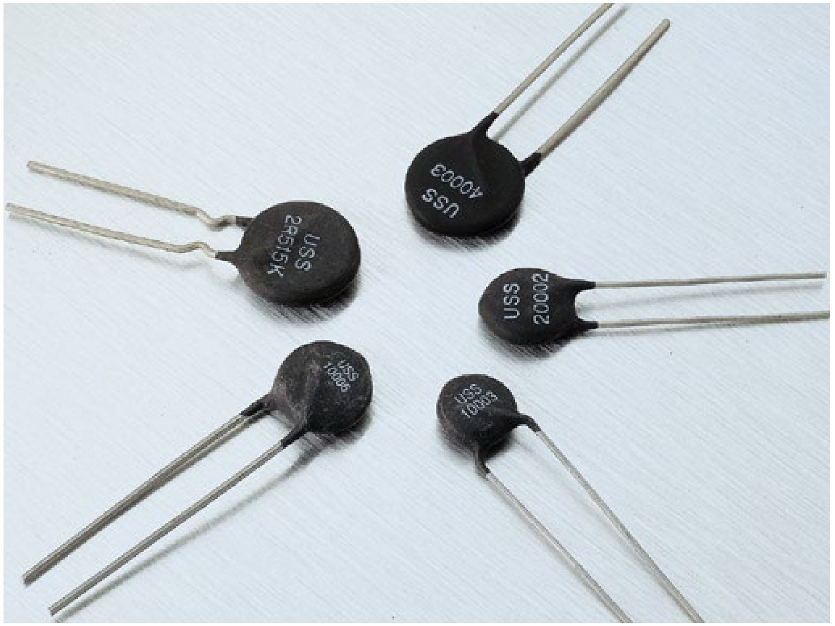


Rotary vs Linear Pots



Variable Resistor: Other Examples

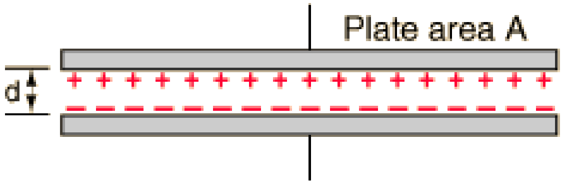
Photoresistor



Thermistor

Capacitance

- Symbol (C)
- SI Unit: Farad (F)
- Ability to store electric charge: $q = CV$
- For a parallel plate capacitor, the permittivity of the dielectric material ϵ in between the plates matters
  - ϵ_0 permittivity of space
  - k relative permittivity of dielectric



$$C = \frac{\varepsilon A}{d} = \frac{k\varepsilon_0 A}{d}$$

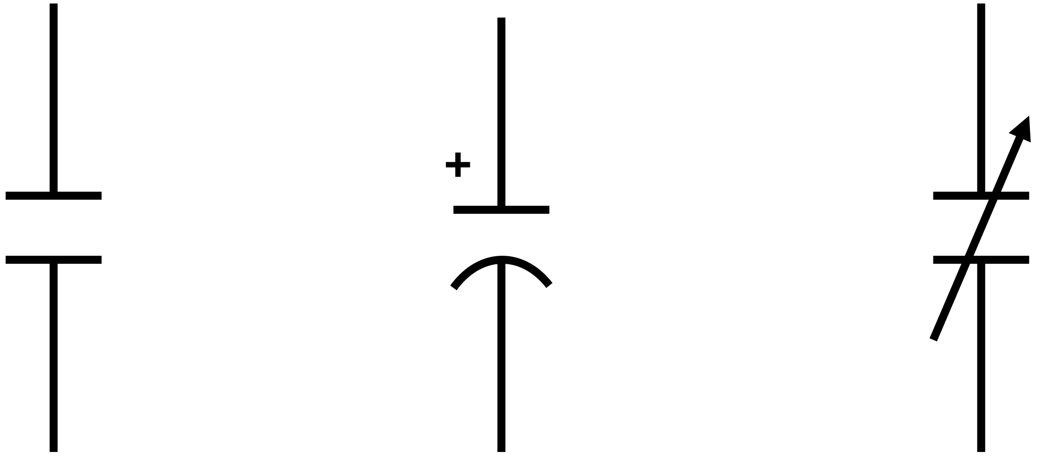
Capacitors

- Store energy in electrical field : $CV^2/2$

$$\frac{d}{dt}[q = CV] \longrightarrow \frac{dq}{dt} = C\frac{dv}{dt} \longrightarrow I(t) = C\frac{dv}{dt}$$

$$V(t) = \frac{1}{C}\int_0^t I(\tau)d\tau$$

- “Smoothing” effect



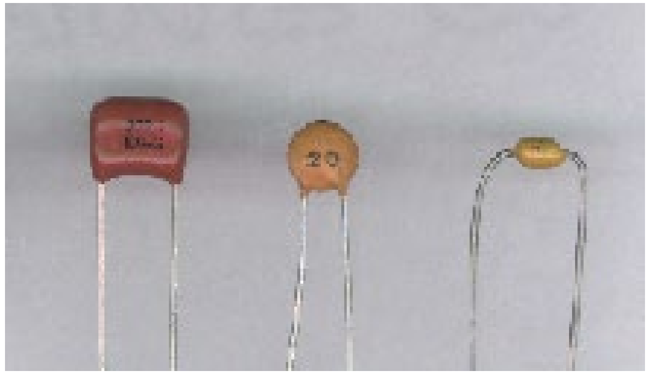
Fixed capacitor **Polarized capacitor** **Variable capacitor**

Choosing Capacitors

- Usual factors:
  - Accuracy/Tolerance
  - Cost
- Capacitance
- Polarized/Non-polarized
- Temperature Stability
- Leakage Current

Types

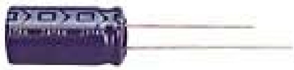
- Ceramic
  - very popular nonpolarized capacitor
  - small, inexpensive, but poor temperature stability and poor accuracy
  - ceramic dielectric and a phenolic coating
  - often used for bypass and coupling applications



- Electrolytic
  - Aluminum, tantalum electrolytic
  - Tantalum electrolytic capacitor has a larger capacitance when compared to aluminum electrolytic capacitor
  - Mostly polarized.
  - Greater capacitance but poor tolerance when compared to nonelectrolytic capacitors.
  - Bad temperature stability, high leakage, short lives

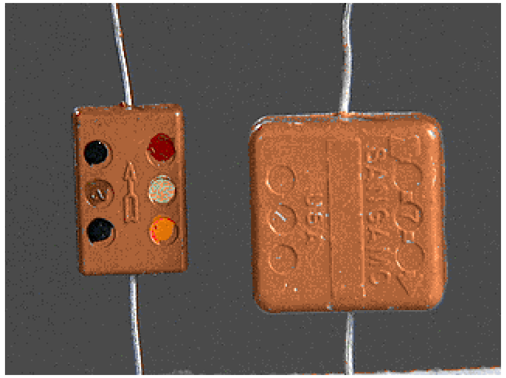
Axial lead

Radial lead

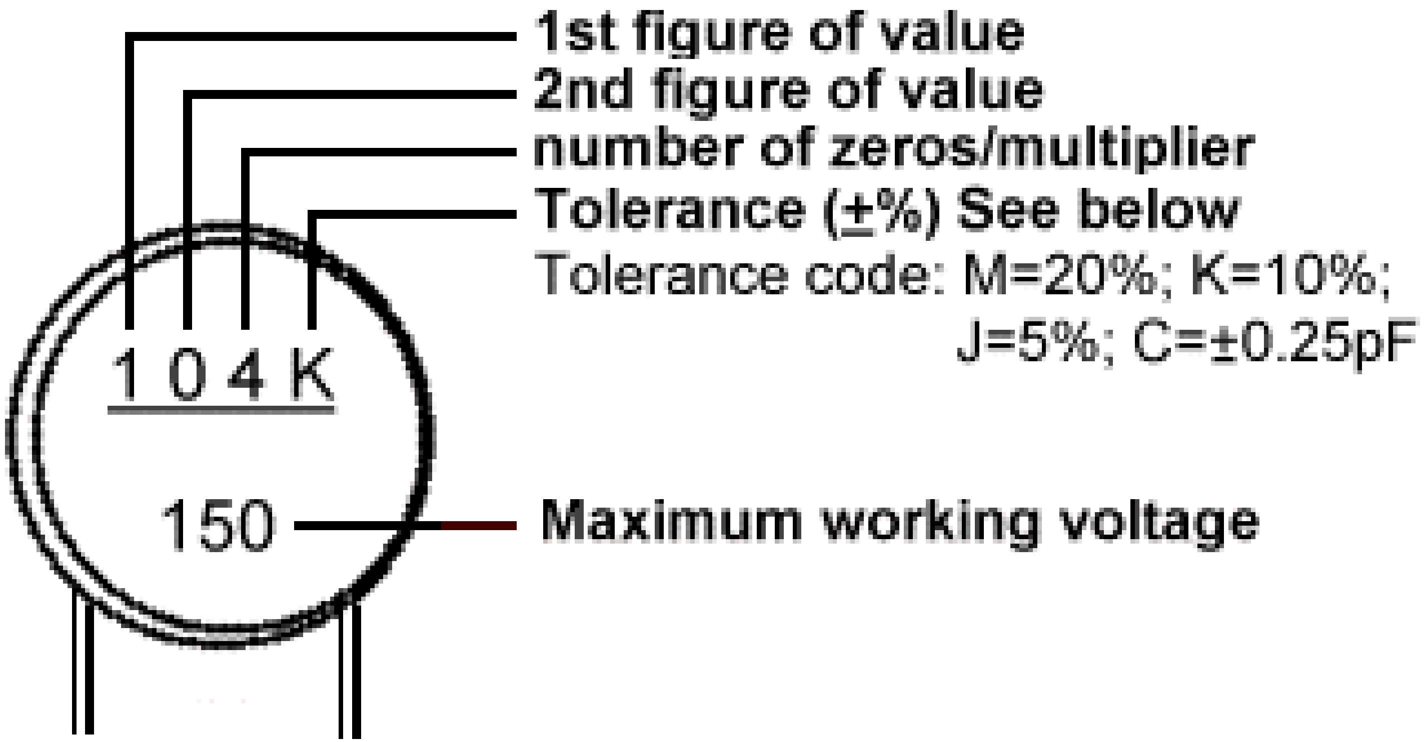


Types

- Mylar
  - very popular, nonpolarized
  - reliable, inexpensive, low leakage
  - poor temperature stability
- Mica
  - extremely accurate, low leakage current
  - constructed with alternate layers of metal foil and mica insulation, stacked and encapsulated
  - small capacitance
  - often used in high-frequency circuits (i.e. RF circuits)



Reading Capacitance

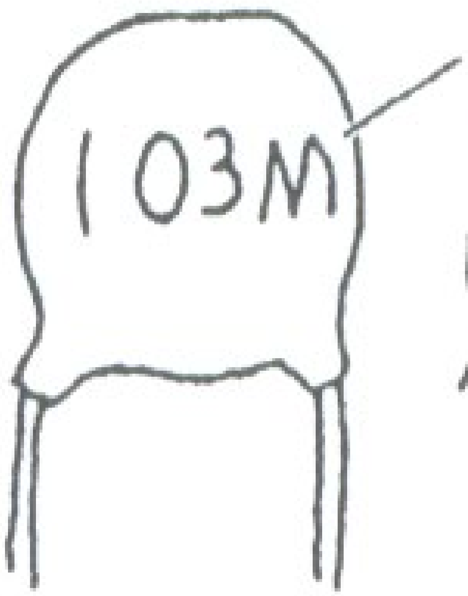


$$10\times10^{4}\,\text{pF}=10^{5}\times10^{-12}\,\text{F}=10^{-7}\,\text{F}=0.1\times10^{-6}\,\text{F}=0.1\,\mu\text{F}$$

- Thus, we have a 0.1μF capacitor with ±10% tolerance.

Reading Capacitance

Ceramic

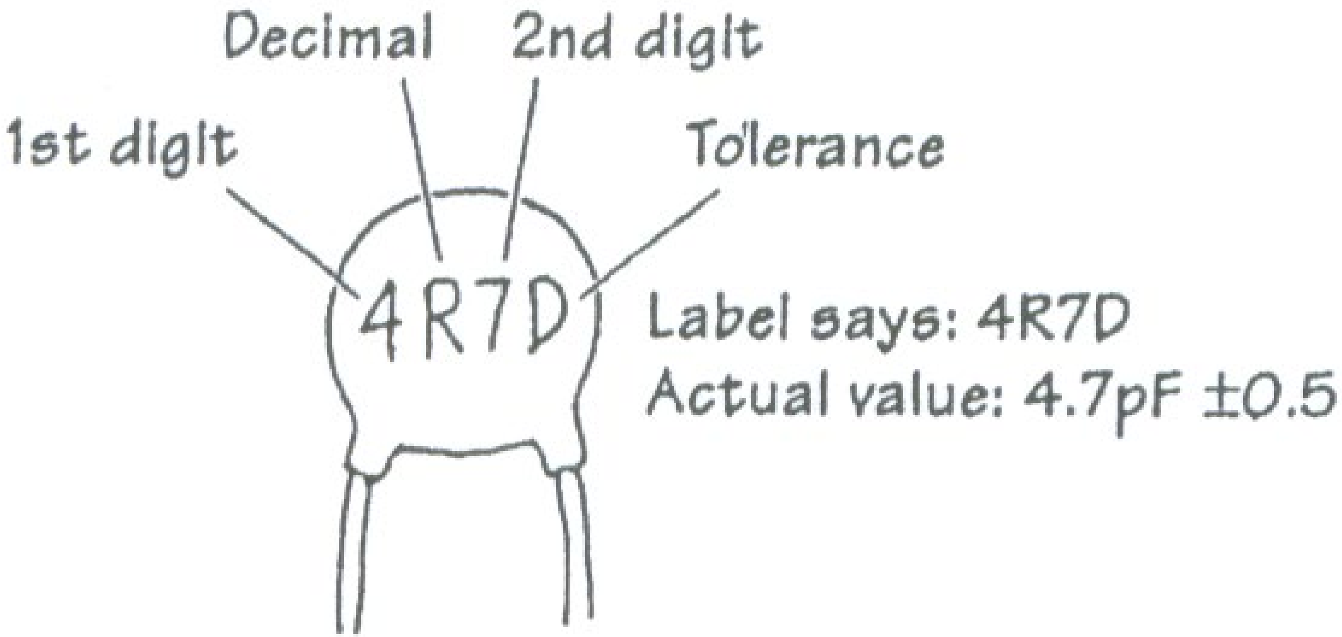


Label represents a tolerance

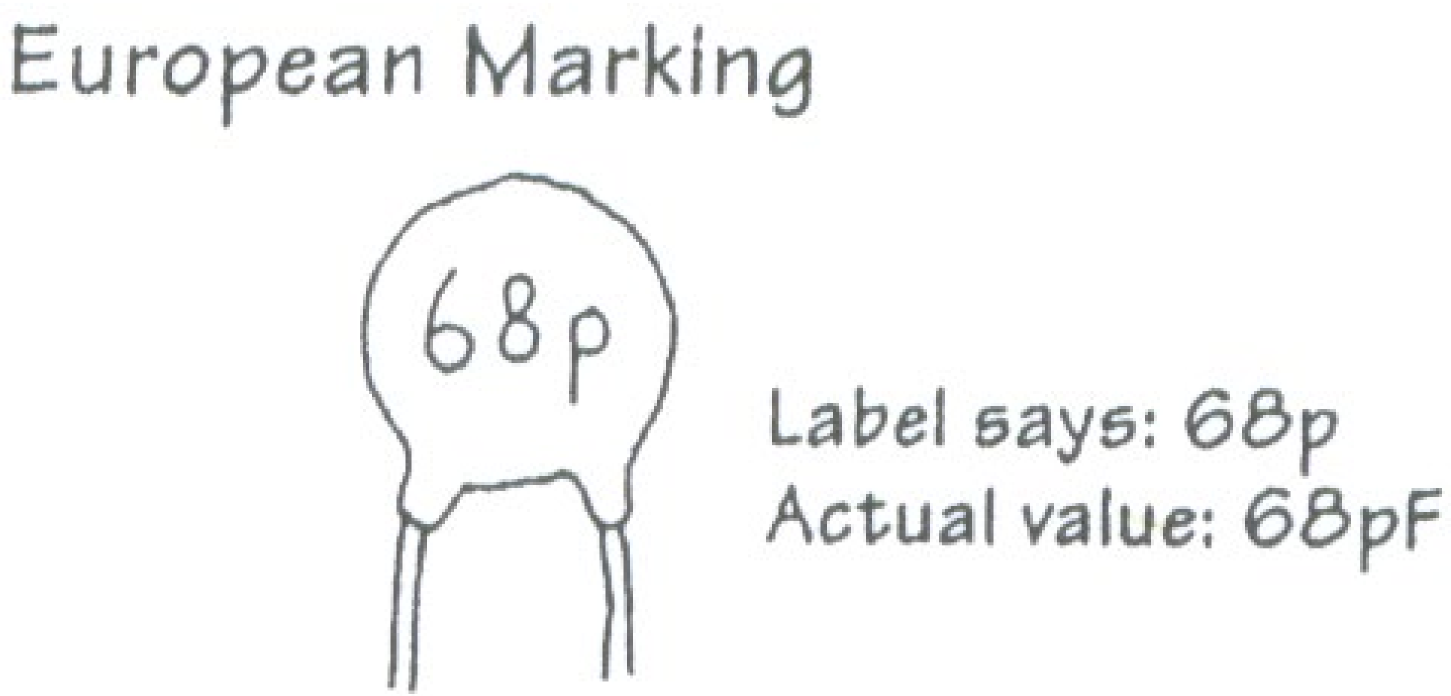
Label says: 103M

Actual value: 0.01µF ±20%

Reading Capacitance

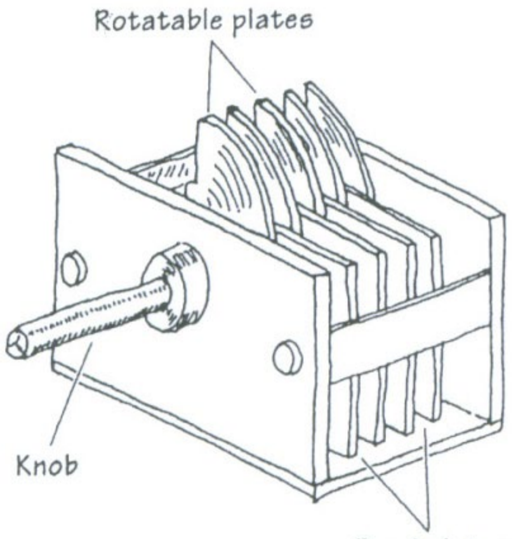


Reading Capacitance

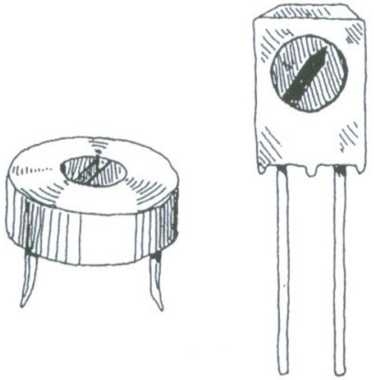


Variable Capacitors

- Devices that can be made to change capacitance values with the twist of a knob.
- Air-variable or trimmer forms
    - Air-variable capacitor consists of two sets of aluminum plates (stator and rotor) that mesh together but do not touch. Often used in frequency adjusted tuning applications (i.e., tuning communication receivers over a wide band of frequencies).
    - A trimmer capacitor is a smaller unit that is designed for infrequent fine-tuning adjustment (i.e., fine-tuning fixed-frequency communications receivers, crystal frequency adjustments, adjusting filter characteristics)



Trimmers



Inductance

- Symbol (L)
- SI Units: Henry (*H*)
- Inductors store energy in the magnetic field

$$\lambda \propto I \text{ or } \lambda = LI$$

- Faraday's Law $V(t) = \dfrac{d\lambda}{dt}$

V : Voltage induced across an inductor

λ : magnetic flux (unit: Webers, Wb) through the coil windings (a coil made using resistance-less wires) due to current flowing through inductor.

$$V(t) = \frac{d}{dt}(\lambda) = \frac{d}{dt}(LI) = L\frac{dI}{dt}$$

$$I(t) = \frac{1}{L}\int_0^t V(\tau)d\tau$$

- "Smoothing" effect

Inductance

- Inductance of a coil of wire

$$L = \frac{\mu_0 N^2 \pi r^2}{\ell}$$

– μ_0 = permeability of free space

– N = number of turns in coil

– ℓ = length of resistance-less wire used in coil

– r = radius of coil cross section.

•If number of turns per unit length is "n", then N= $n\ell$, so:

$$L = \frac{\mu_0 (n^2 \ell^2) \pi r^2}{\ell} = \mu_0 n^2 \ell \pi r^2 = \mu_0 n^2 \ell A$$

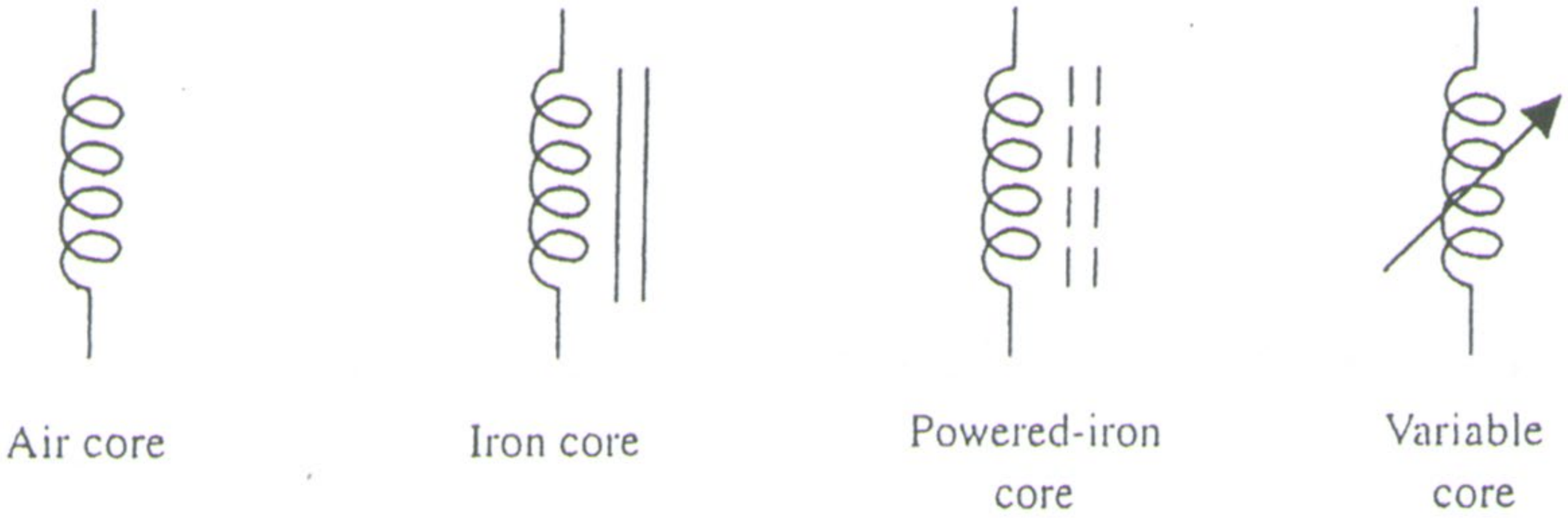
–A = cross-sectional area of coil.

–If a magnetizable material forms the core of coil, then permeability μ will be larger than μ_0.

Types

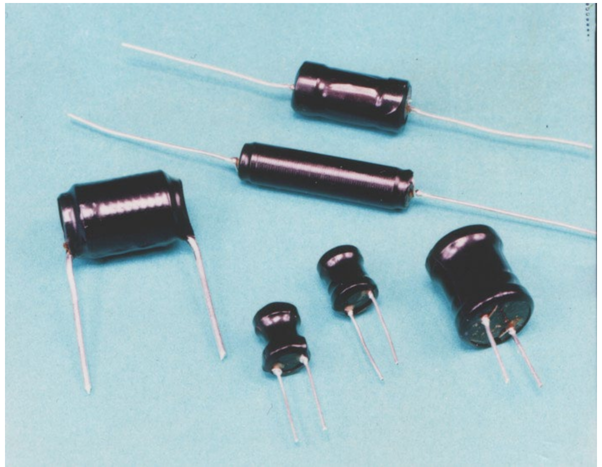
- Antenna coil
  - contains an iron core that magnifies magnetic field effects
  - used to tune in ultra-high-frequency signals, i.e. RF signals
- Tuning coil
  - screw-like “magnetic field blocker” that can be adjusted to select the desired inductance value
  - used in radio receivers to select a desired frequency.

Types

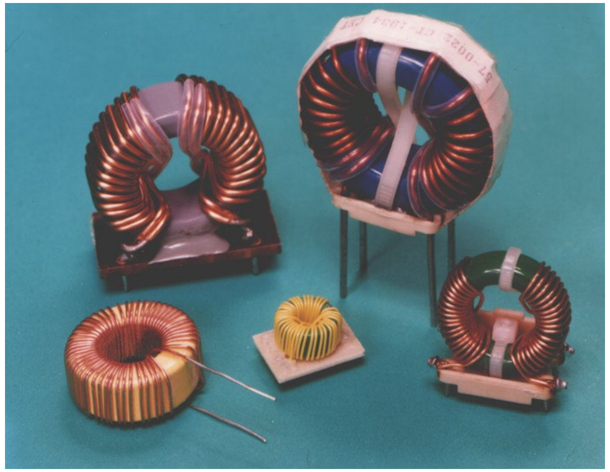


Types

- Chokes
  - general-purpose inductors that act to limit or suppress fluctuating current.
  - some use a resistor-like color code to specify inductance values.



- Toroidal coil
  - resembles a donut with a wire wrapping
  - high inductance per volume ratios, high quality factors, self-shielding, can be operated at extremely high frequencies



Transformers

DC Isolation

–acts exclusively as an isolation device; does not increase or decrease the secondary voltage

–usually come with an electrostatic shield between the primary and secondary. Often come with a three-wire plug and receptacle that can be plugged directly into a power outlet

High Frequency

–often come with air or powered-iron cores

–used for high frequency applications, i.e. matching RF transmission lines to other devices (transmission line to antenna)

Audio

–used primarily to match impedances between audio devices

–work best at audio frequencies from 150Hz to 12kHz

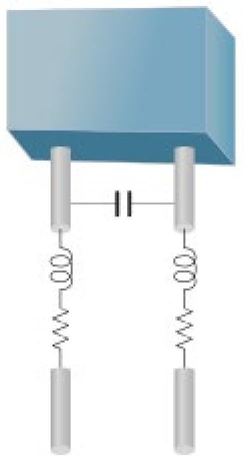
–come in a variety of shapes and sizes, typically contain a center tap

Capacitance and Inductance

- Lead to interesting transient behavior
  - ODEs vs Algebraic Equations
- DC vs AC
- RC circuit vs RLC circuit

Things can have…

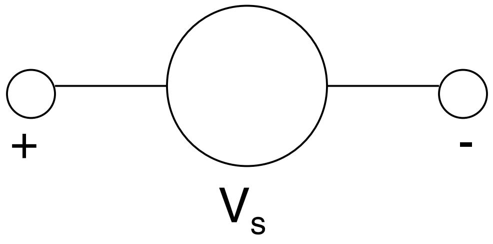
- Resistance/capacitance/inductance without being designed as resistors/capacitors/inductors
  - Unintentional: Parasitic/stray resistance/capacitance/inductance
    - Parasitic capacitance in cheap LED bulbs
- Equivalent circuit modeling
  - DC motors, batteries, etc.



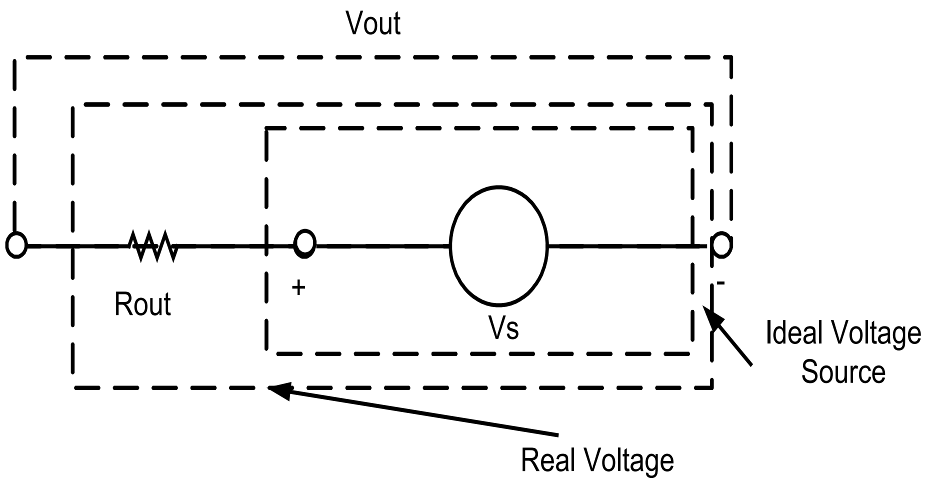
Sources

Voltage Source

- Ideal:
  - –zero output resistance
  - –can supply as much current as needed by the load
  - –maintains the prescribed voltage across its terminals



- Real:
  - –modeled as an ideal voltage source in series with a small resistor (R_{out})



$$V_{out} = V_s - V_{R_{out}}$$

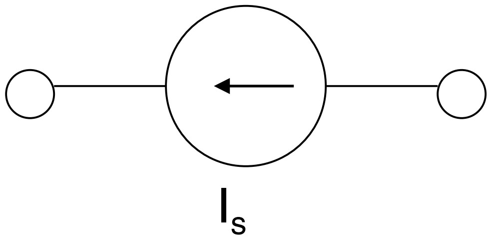
- If the load across the real voltage source is a resistance R_L, then:

$$V_{out} = \left(\frac{R_L}{R_L + R_{out}}\right) V_s$$

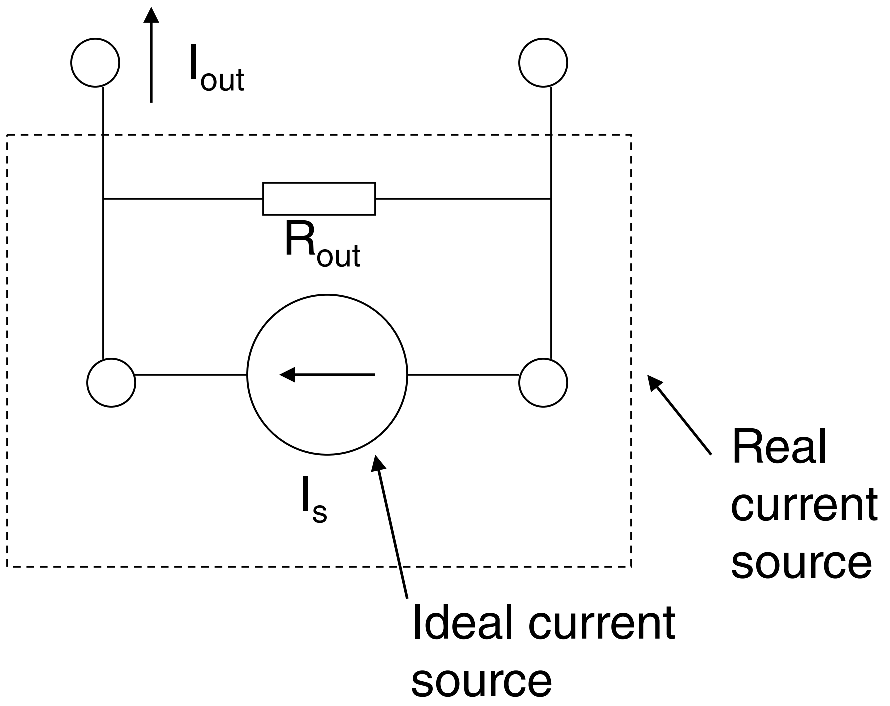
- If $R_L >> R_{out}$, then $V_{out} \cong V_S$

Current Source

- Ideal:
  - –infinite output resistance
  - –supply as much voltage as needed by the load
  - –prescribed current irrespective of the voltage across terminals



- Real:
  - –modeled as an ideal current source in parallel with a large resistor (R_{out})

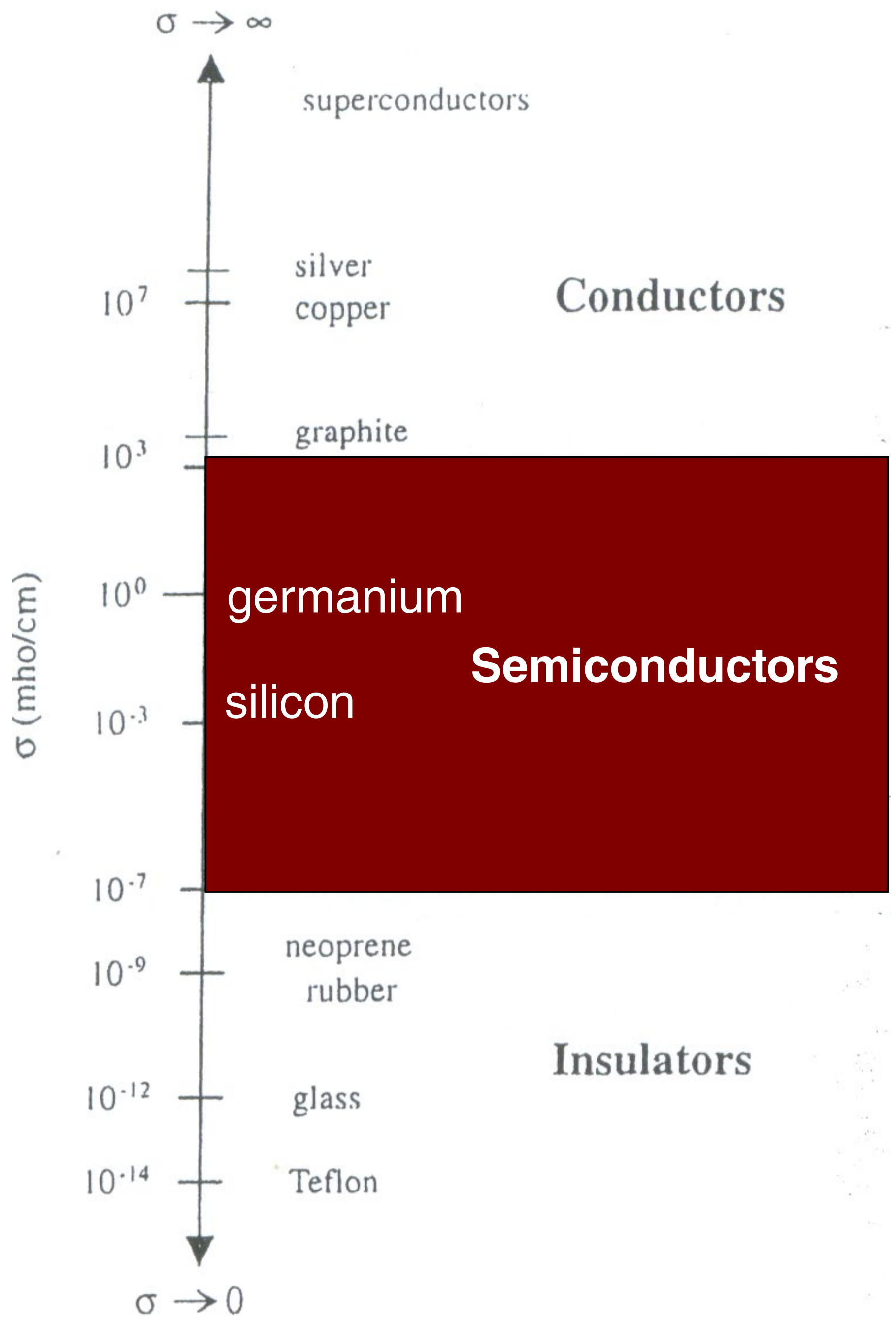


- If the load across the real current source is a resistance R_L, then: $I_{out} = I_s - I_{R_{out}}$

$$I_{out} = \left(\frac{R_{out}}{R_L + R_{out}}\right) I_s$$

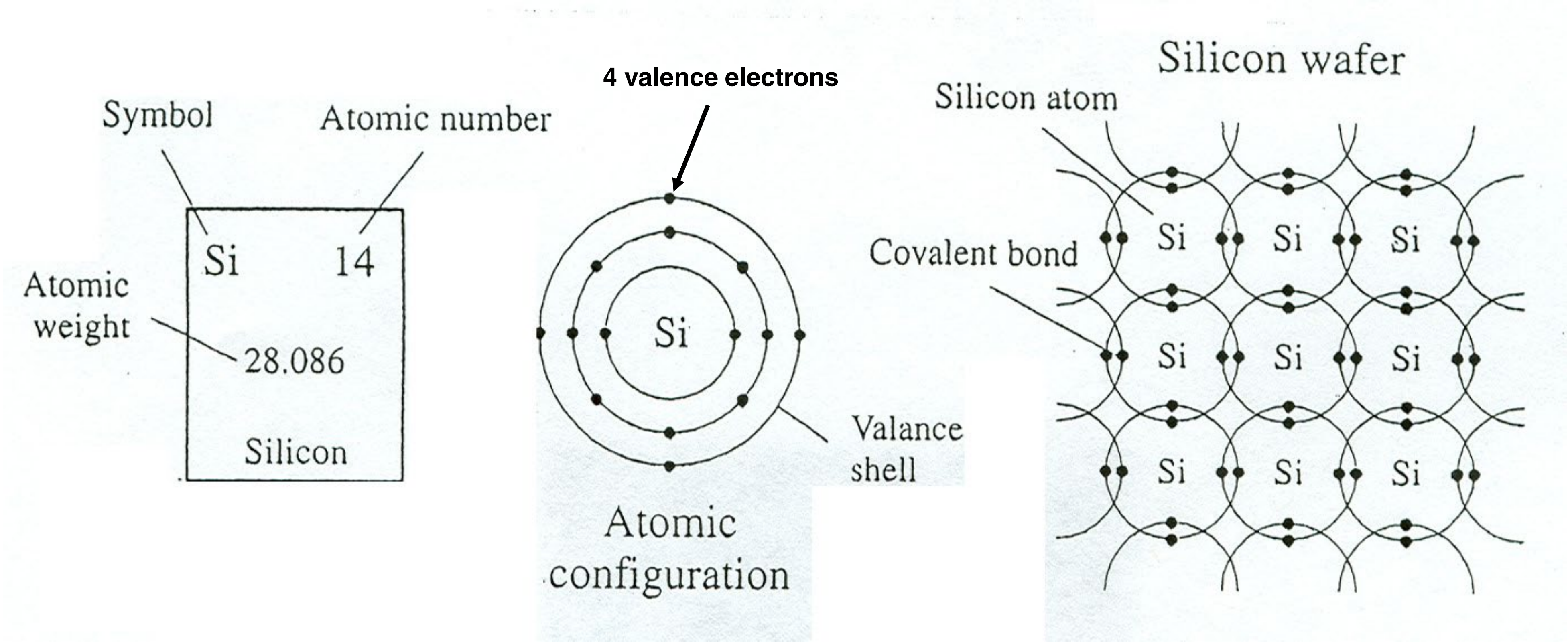
Semiconductor Revolution

Semiconductors



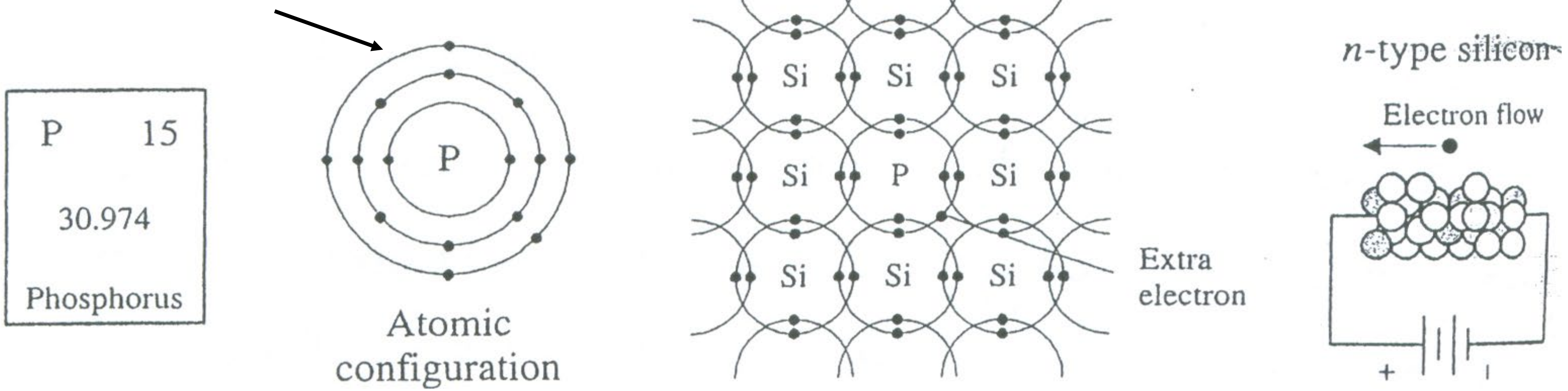
Chemistry

- Pure silicon is an insulator
- Octet rule for valence electrons



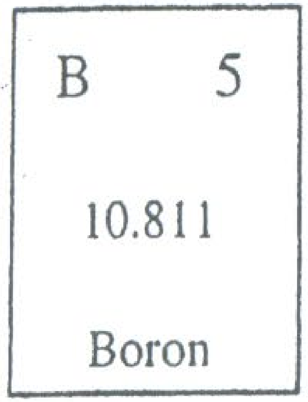
N-type Silicon

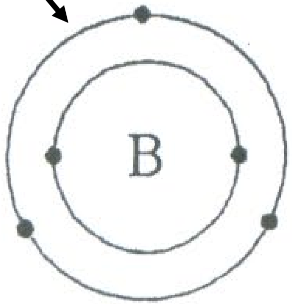
5 valence electrons



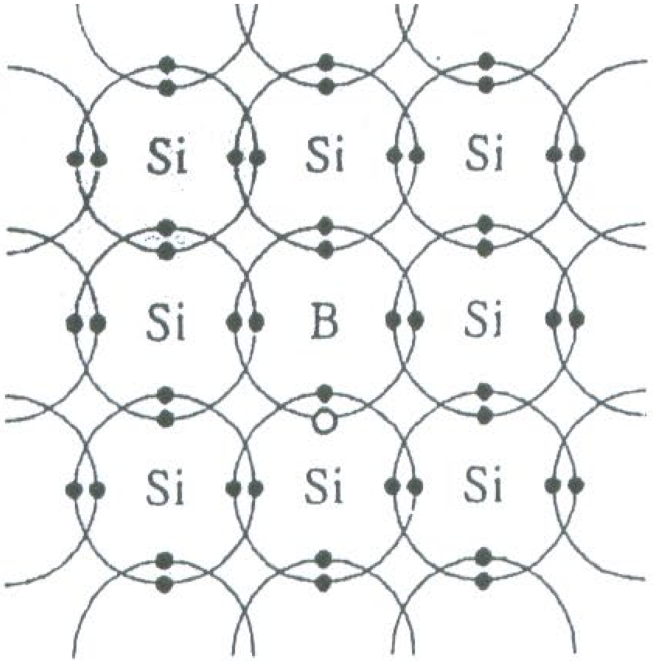
P-type Silicon

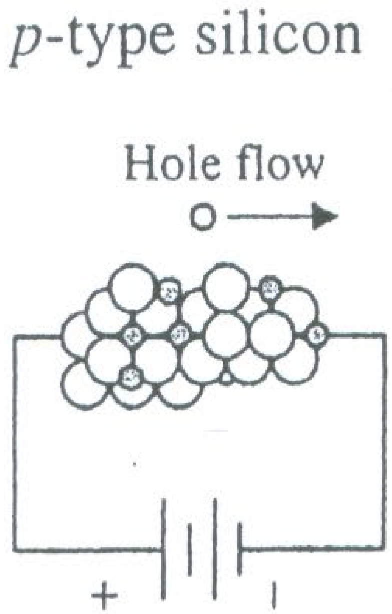
3 valence electrons





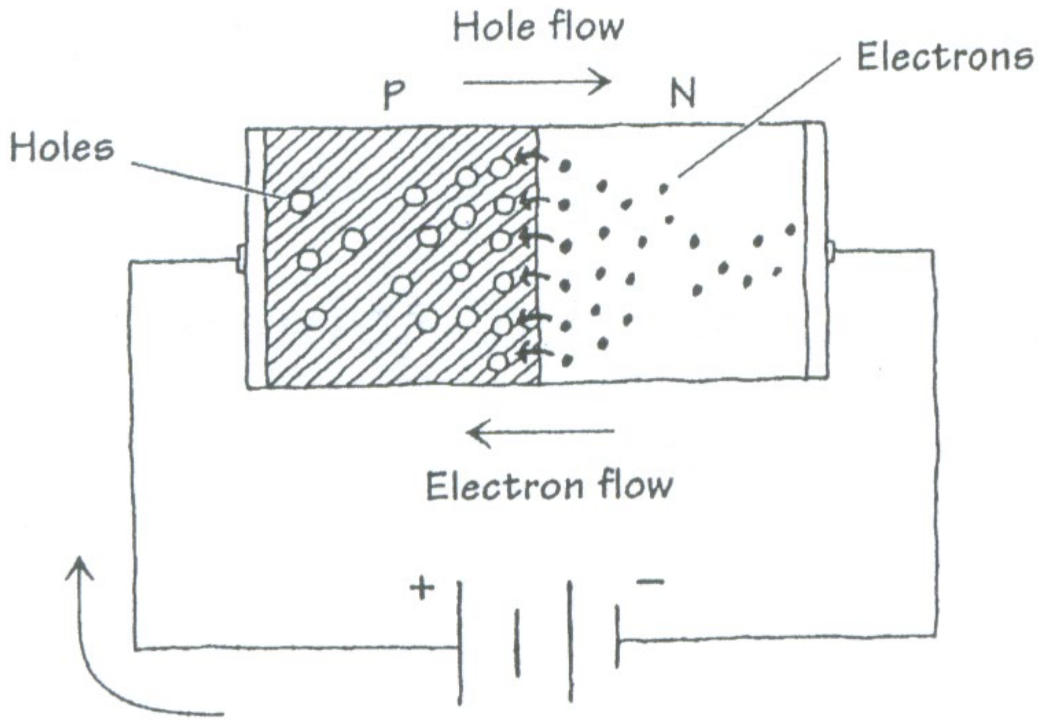
Atomic configuration

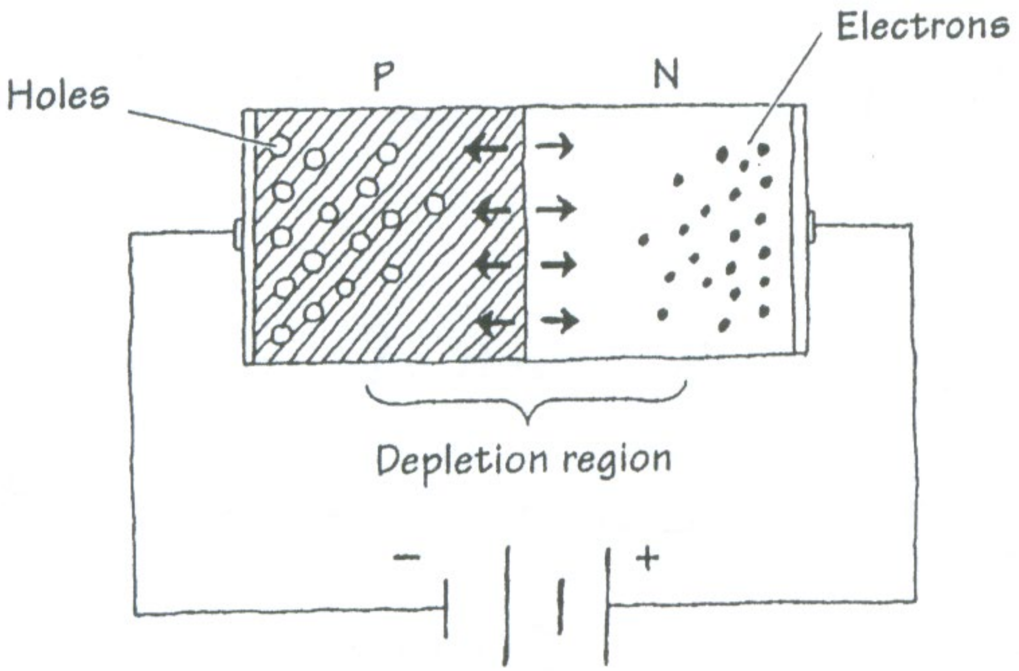




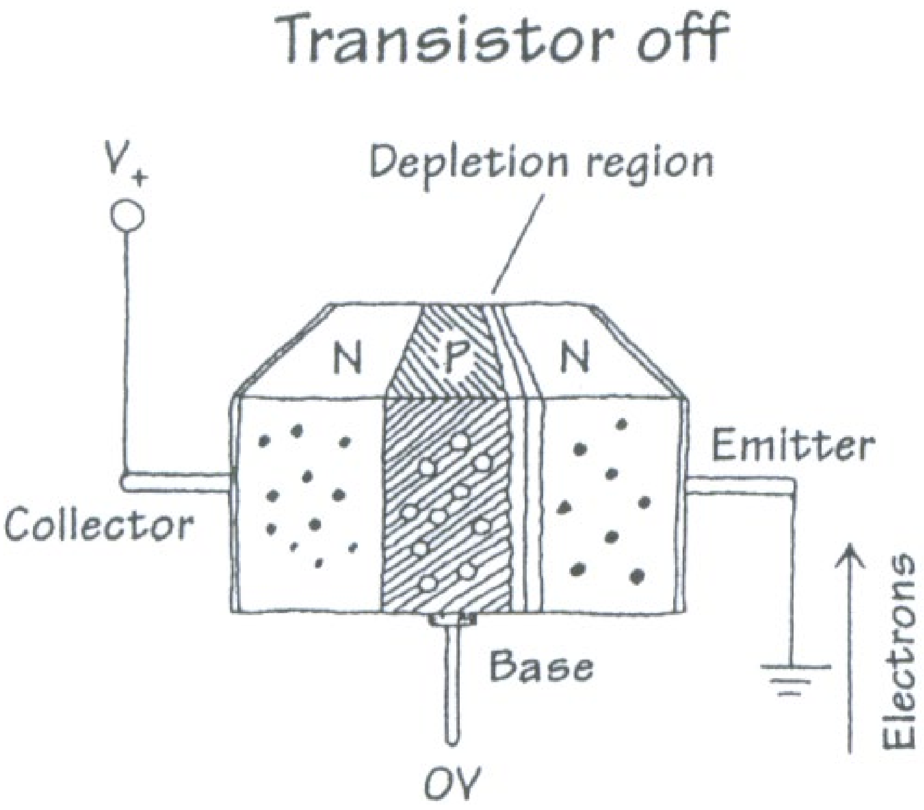
PN Junction Diode

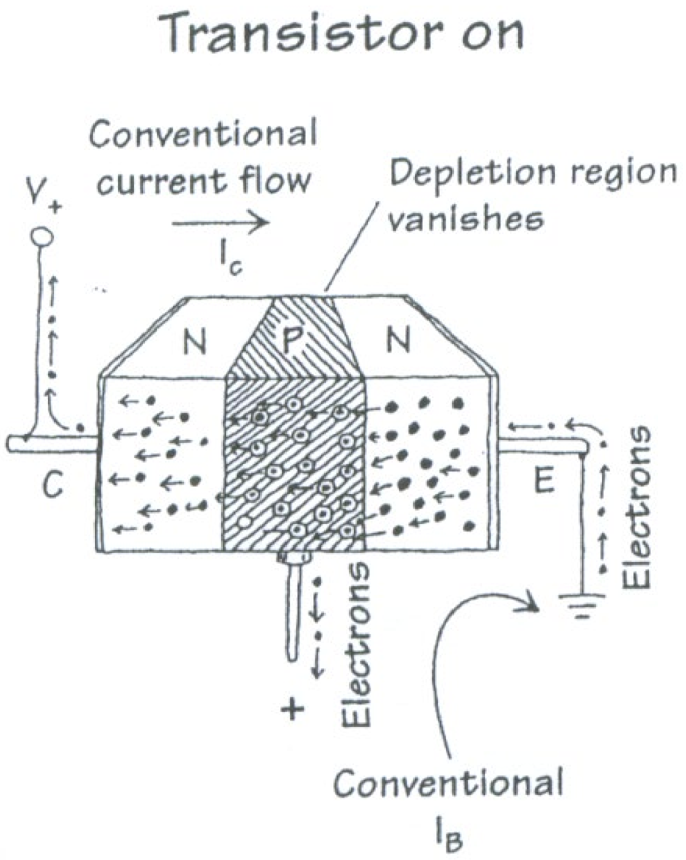
- Both N- and P-type Silicon are electrically neutral
- Barrier voltage (~0.6V) due to depletion region at the “border” of PN junction must be overcome





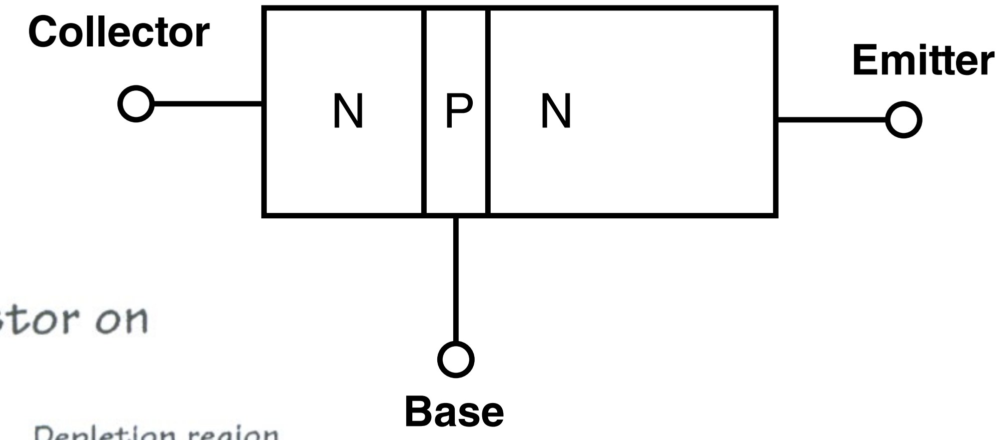
NPN Bipolar Junction Transistor (BJT)

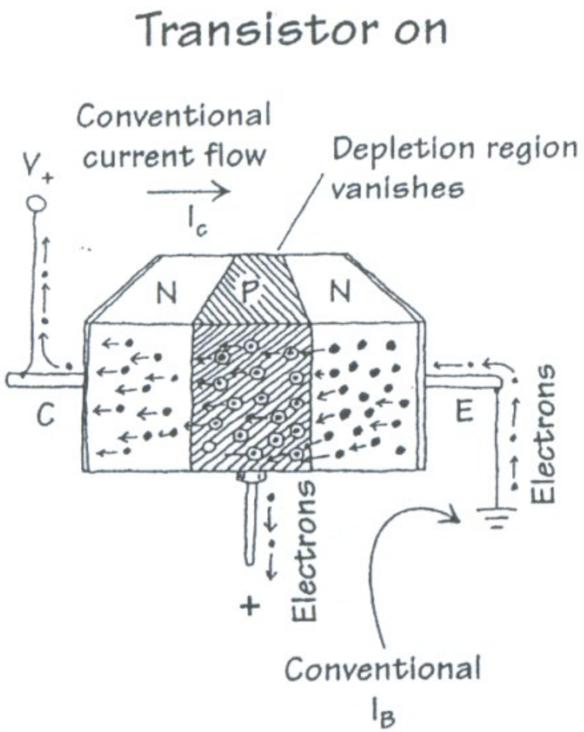


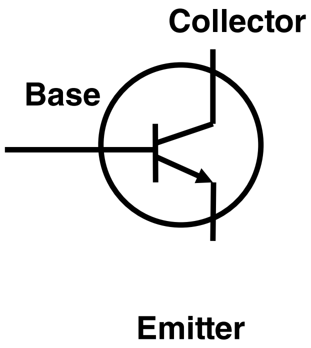


NPN Bipolar Junction Transistor (BJT)

- An npn transistor is made by sandwiching a thin slice of p-type semiconductor between two n-type semiconductors.
- Emitter is heavily doped and gives off electrons easily.
- Base is lightly doped and receives most electrons.
- Collector is moderately doped.

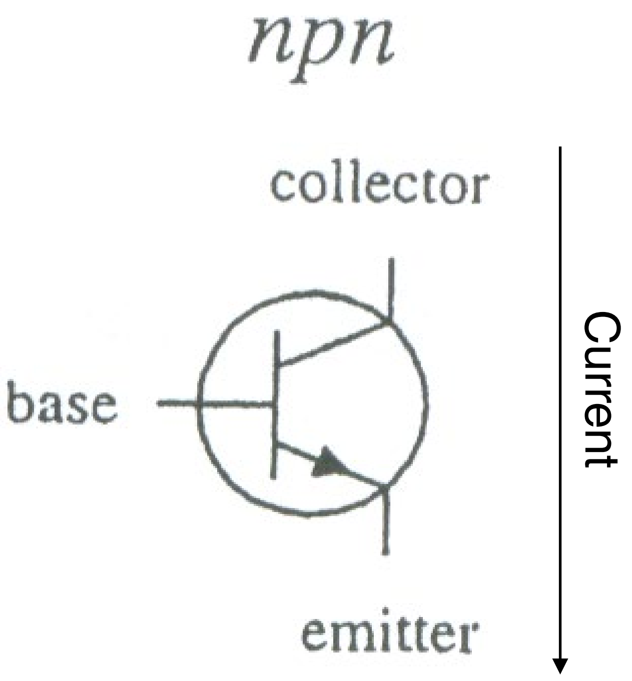


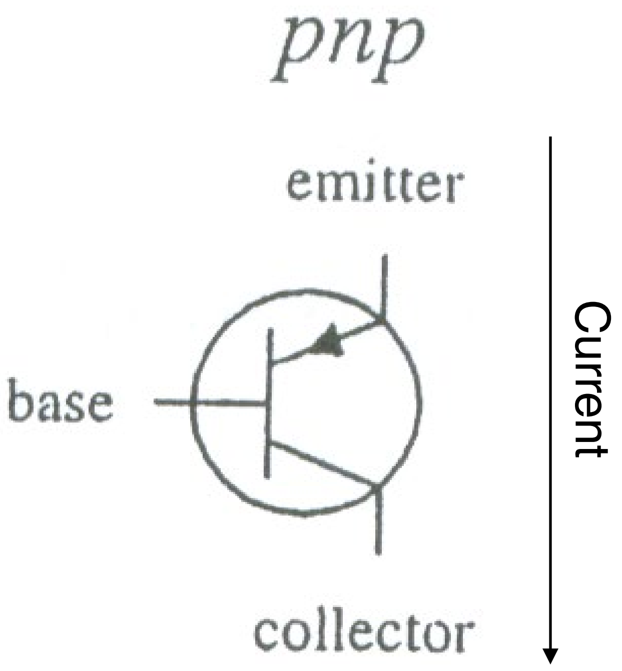




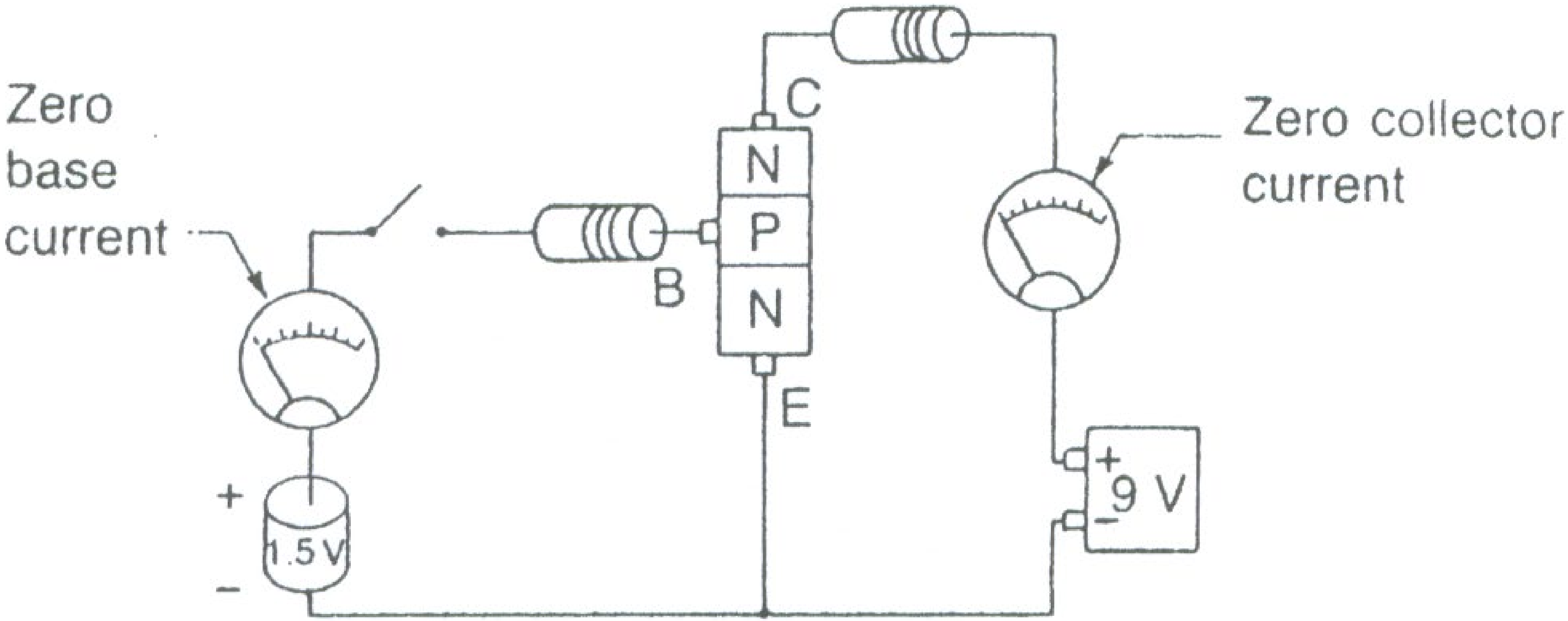
NPN/PNP Bipolar Junction Transistor (BJT)

- NPN: a small input current and a positive voltage applied @ its base (with $V_B > V_E$) allows a large current to flow from collector to emitter.
- PNP: a small output current and a negative voltage @ its base (with $V_B < V_E$) allows a much larger current to flow from emitter to collector.
- **NPN switches ON by a high signal while PNP switches ON by a low signal**

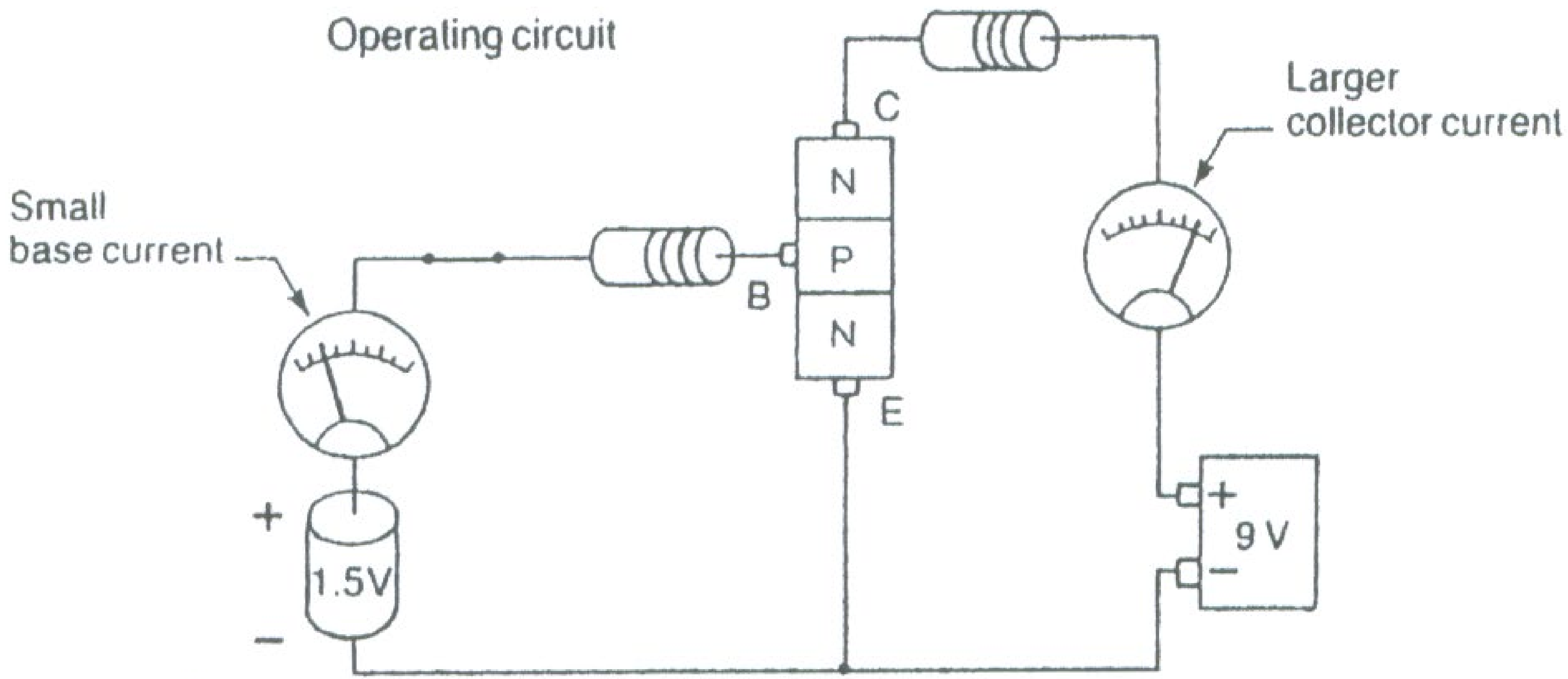




NPN BJT Circuit



NPN BJT Circuit



More Transistors

- Bipolar Junction Transistor (BJT)
    - NPN and PNP
- Junction Field Effect Transistor (JFET)
    - N-channel and P-channel
- Metal Oxide Semiconductor FET (MOSFET)
    - Depletion type (n- and p-channel) and enhancement type (n- and p-channel)
- Unijunction FET (UJT)

Superconductor Revolution?