Review of Fundamentals of Electricity

Physics → Circuit Analysis → Electronics → Systems
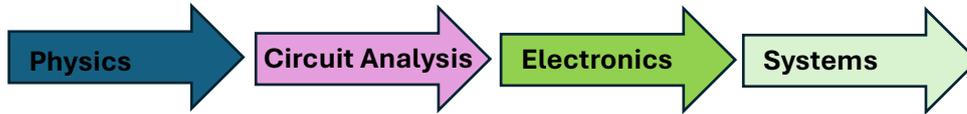
DC Analysis

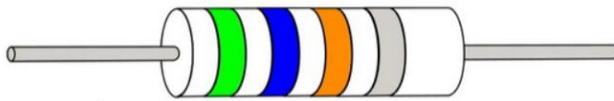## Linear Circuit elements

1.1   Résistor   Resistance R   unit Ohm (Ω)

We construct resistors by attaching terminals to a piece of conductive material. On a microscopic level current consists of electrons moving through the material.
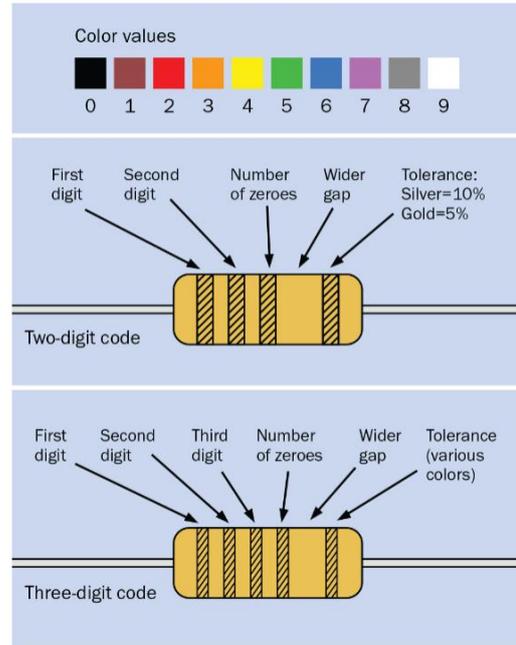
Materials used to construct resistor : metals, their alloys and carbon.

Surface mounted resistor
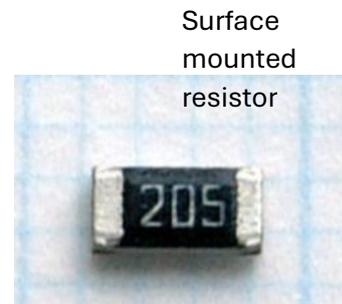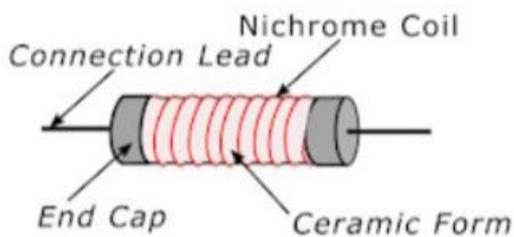
Resistor Color Code

Color	1st Band	2nd Band	3rd Band Multiplier	4th Band Tolerance
Black	0	0	x 1	
Brown	1	1	x 10	+/- 1%
Red	2	2	x 100	+/- 2%
Orange	3	3	x 1K	
Yellow	4	4	x 10K	
Green	5	5	x 100K	+/- 0.5%
Blue	6	6	x 1M	+/- 0.25%
Violet	7	7	x 10M	+/- 0.10%
Gray	8	8	x 100M	+/- 0.05%
White	9	9	x 1G	
Gold			x 0.1	+/- 5%
Silver			x 0.01	+/- 10%

NB: La troisième bande (bague de couleur) peut représentée 10^{-1} pour l'Or (gold) et 10^{-2} pour l'Argent

Tableau des séries normalisées des résistances

Série E3 à E24

Série	Valeurs dans la série
E3 (± 20 %)	100, 220, 470
E6 (± 10 %)	100, 150, 220, 330, 470, 680
E12 (± 10 %)	100, 120, 150, 180, 220, 270, 330, 390, 470, 560, 680, 820
E24 (± 5 %)	100, 110, 120, 130, 150, 160, 180, 200, 220, 240, 270, 300, 330, 360, 390, 430, 470, 510, 560, 620, 680, 750, 820, 910

D'où viennent les valeurs des séries de résistances ?

Exemple

Les résistances de la série E12 sont composées des 12 valeurs arrondies des nombres théoriques

suivants : $\sqrt[12]{10^n}$ où n est un entier supérieur ou égal à 0.

Les 12 valeurs normalisées sont donc : **1 – 1,2 – 1,5 – 1,8 – 2.2 – 2.7 – 3,3 – 3,9 – 4,7 – 5,6- 6,8- 8,2 –**

un moyen mnémotechnique pour retenir les dix couleurs principales est par exemple (a mnemonic way to remember the ten main colors is for example) :

« Ne Manger Rien Ou Jeune Voila Bien Votre Grande Bétise. »

0	**Ne**	**N**oir
1	**Manger**	**M**arron
2	**Rien**	**R**ouge
3	**Ou**	**O**range
4	**Jeuner**	**J**aune
5	**Voila**	**V**ert
6	**Bien**	**B**leu
7	**Votre**	**V**iolet
8	**Grande**	**G**ris
9	**Bétise**	**B**lanc

NB:
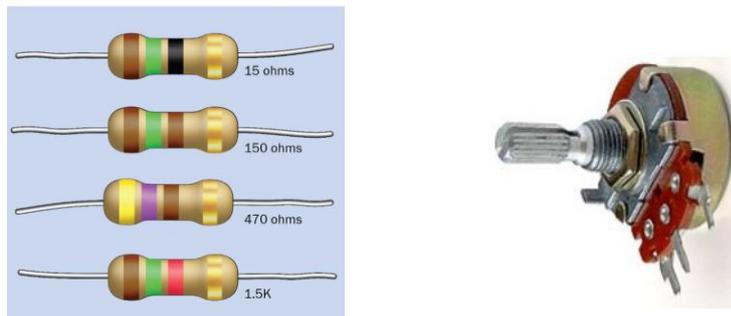
Resistance is related to physical parameters.

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

Where is the resistivity of the material is ρ (Ωm); L the length of the resistor and A (m^2) the cross sectional area of a cylinder or bar.
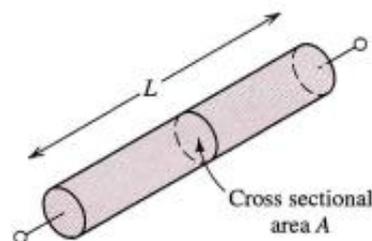

Figure 1.38 Resistors often take the form of a long cylinder (or bar) in which current enters one end and flows along the length.

Table 1.3. **Resistivity Values ($\Omega \cdot$ m) for Selected Materials at 300 K**

| Conductors	
Aluminum	2.73×10^{-8}
Carbon (amorphous)	3.5×10^{-5}
Copper	1.72×10^{-8}
Gold	2.27×10^{-8}
Nichrome	1.12×10^{-6}
Silver	1.63×10^{-8}
Tungsten	5.44×10^{-8}
Semiconductors	
Silicon (device grade) depends on impurity concentration	10^{-5} to 1
Insulators	
Fused quartz	$> 10^{21}$
Glass (typical)	1×10^{12}
Teflon	1×10^{19}

Materials can be classified as insulators, conductors or semiconductors.

- **Insulators**: materials with very high resistivity (conduct very little current at least for moderate voltage). Ideal insulator has infinite resistance.
- **Conductors** : materials with lowest resistivity. Conduct easily electrical current.
- **Semiconductors** are materials with resistivity between those of conductors and insulators. Semiconductors are useful in constructing electronic devices like diode, transistors.

Resistors Symbols

Fixed Value   Potentiometer   Rheostat

Varistor   LDR   Thermistor
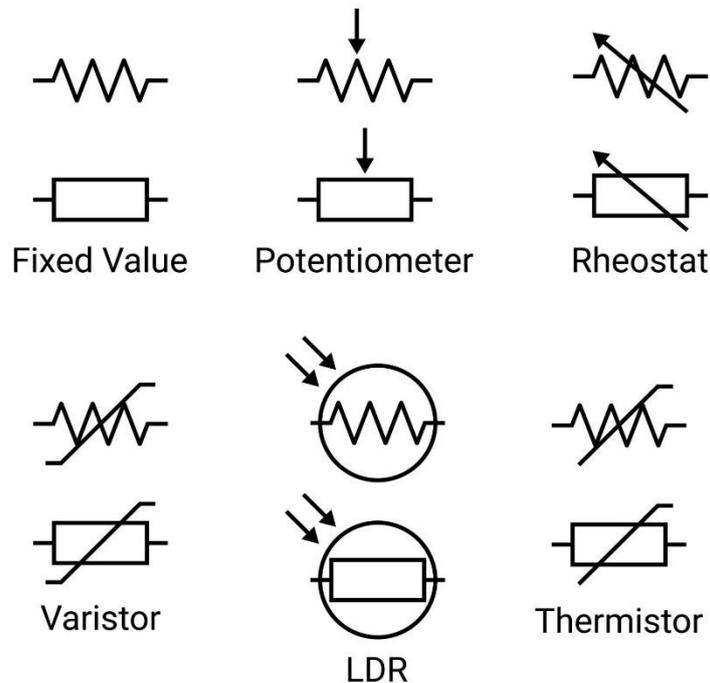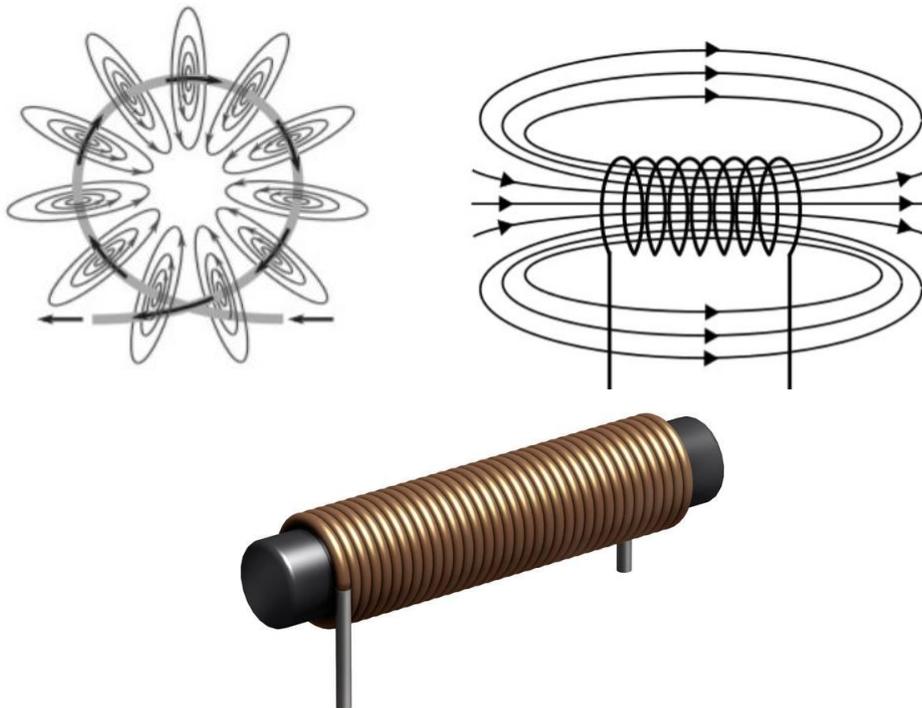
1.2   Inductor L Inductance L   unit Henry (H)
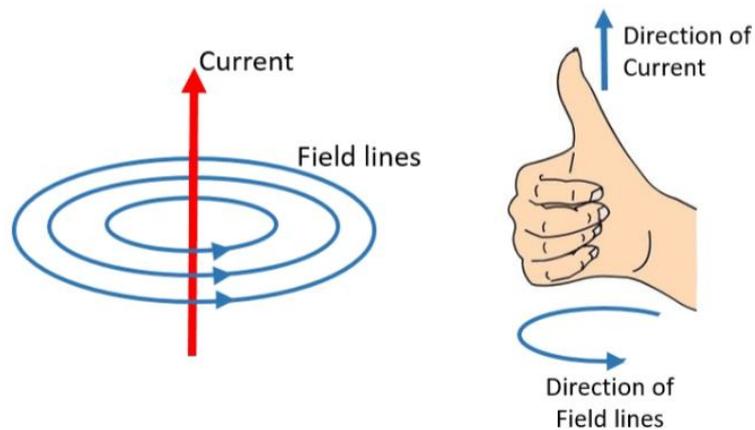
An inductor is constructed by coiling a wire around some type of form. Frequently the coil form is composed of a magnetic material such iron or iron oxides that increase the magnetic field or flux for a given current.
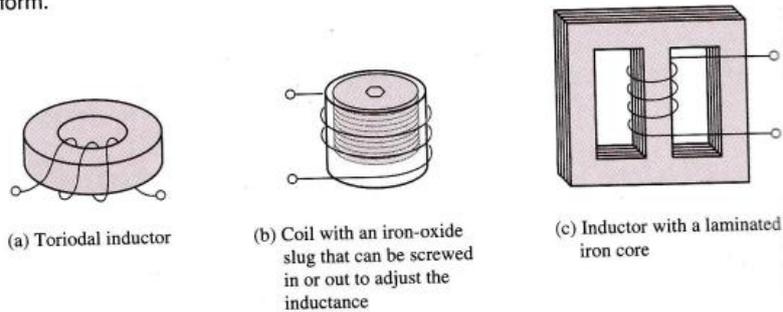
Current flowing through a coil creates a magnetic field or flux that links the coil.

Inductor with ferrite core to increase the inductance.

Figure 3.15 An inductor is constructed by coiling a wire around some type of form.

(a) Toriodal inductor

(b) Coil with an iron-oxide slug that can be screwed in or out to adjust the inductance

(c) Inductor with a laminated iron core

| Inductor	Fixed	Variable	Pre-set	Shape
Air Core				
Iron Core				
Ferrite Core				

## 1.3   Capacitor   Capacitance C   unit Farad (F)
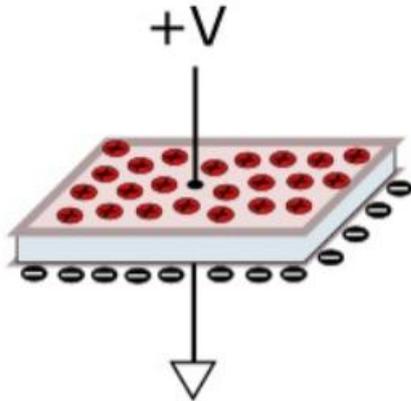
Capacitors are constructed by separating two sheets of conductor, which is usually metallic, by a thin layer of insulating material.

In a parallel-plate capacitor, the sheets are flat and parallel as shown in the figure. The insulating material between the plates, called a dielectric, can be air, Mylar, polyester, polypropylene, mica, or a variety of other materials.

Let us consider what happens as current flows through the capacitor. Suppose that current flows downward, as shown in figure xx . In most metals, current consists of electrons moving, and conventional current flowing downward represents electrons actually moving upward. As the electrons move upward they collect on the lower plate of the capacitor. Thus the lower plate accumulates a net negative charge that produces an electric field in the dielectric. This electric field forces electrons to leave the upper plate at the same rate that they accumulate on the lower plate. Therefore, current appears to flow through the capacitor. As the charge builds up, voltage appears across the capacitance.
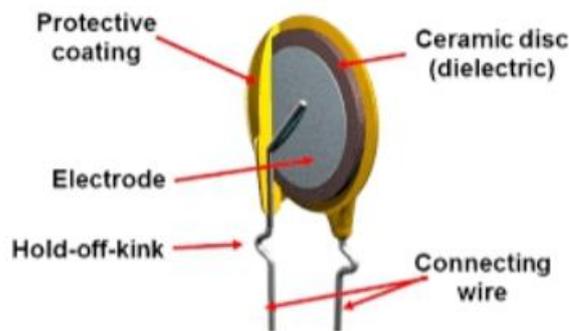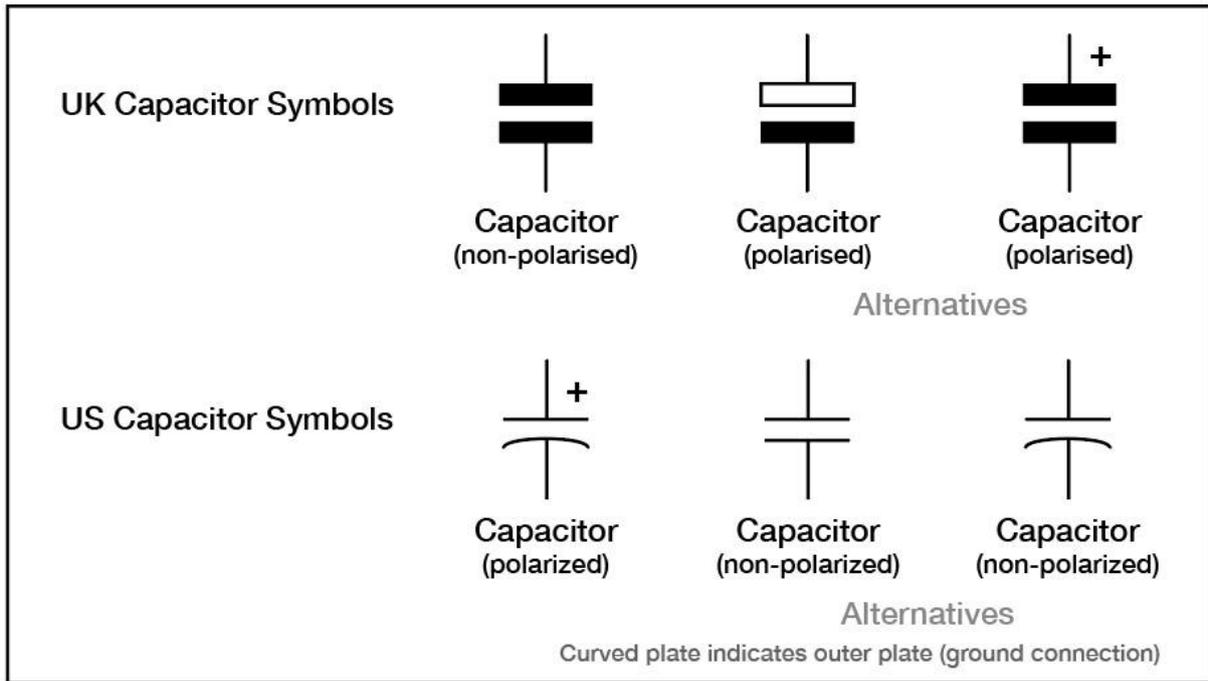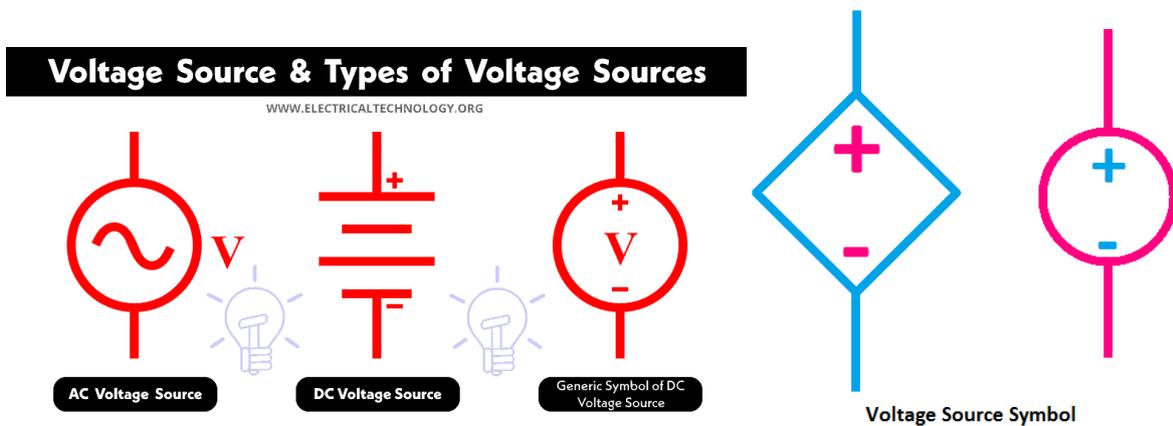
1.4 Voltage

Source   E or V   unit Volt (V)

EMF

EMF stands for Electromotive force. The name may give you the impression that electromotive force is a type of force. Actually, it is not. EMF or the Electromotive Force is an energy that can cause current to flow in an electrical circuit or device. This means that a current can flow in a circuit or a device, only if an EMF is provided.

Sources of EMF can be batteries, Solar cells, generators etc…EMF is denoted by the symbol E (sometime V) and is measured in unit Volt (V).

AC generator

Different ways to create a voltage source

- Friction : Van de Graaff generator
-
- **Magnetism**: Most common method of producing electrical energy produced by using generator powered by steam from nuclear power or coal, wind, or gasoline or diesel engines.
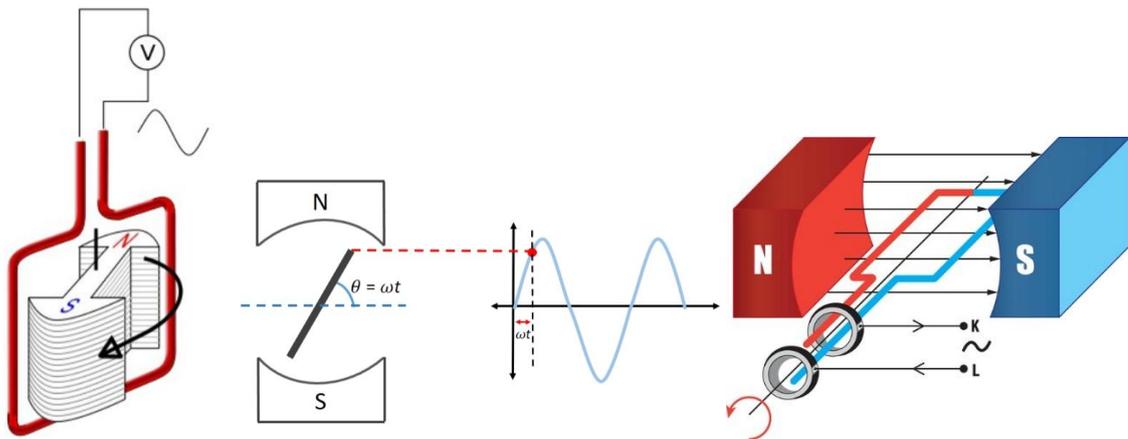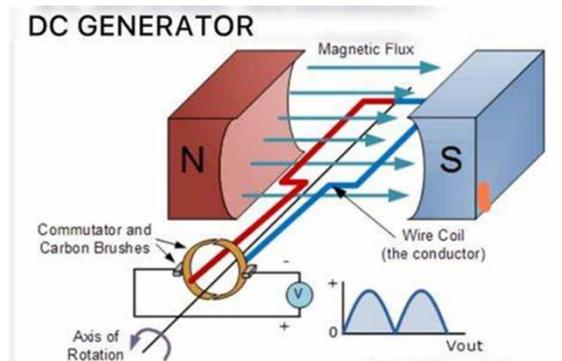

AC Generator principles

AC generator powered by gasoline or diesel engin

Whenever a conductor is placed in a varying magnetic field an EMF (Electromotive Force) gets induced across the conductor. If the conductor is in a circuit, this force causes current to flow in the circuit. The magnetic field can be varied by moving a magnet when near the conductor, by moving the conductor near a magnet, or by rotating a magnet while near a conductor. This is the working principle behind electric generators, electric motors, transformers and coils. An EMF (voltage) is created in a generator by rotating a magnet near a conductor.

DC Generator principle
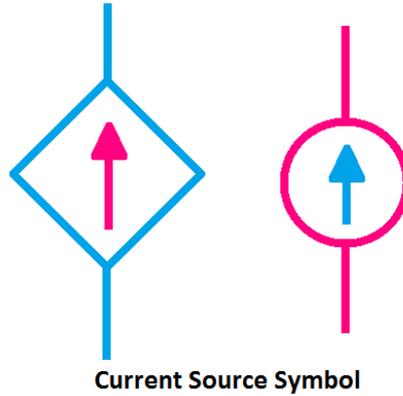
- **Chemicals**: Battery

- Light: Solar cell / panel

- Heat : application in Thermocouple
- Pressure: application in Piezoelectric sensors (Capteur de pression piézoeletrique): Changes in pressure is converted in electrical charges
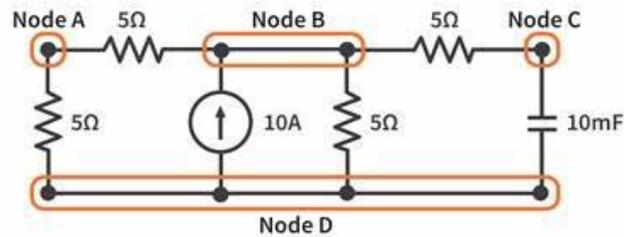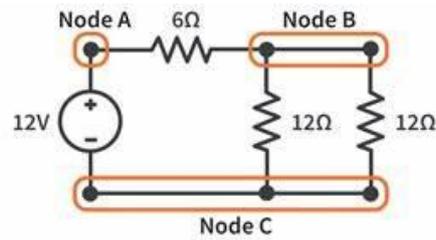
1.5   Current source   I   unit Ampere (A)
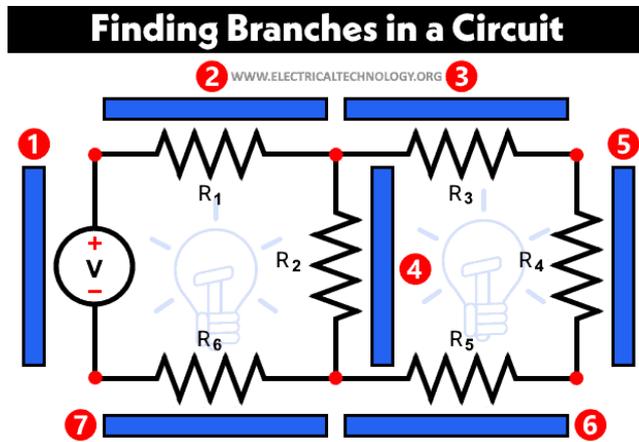

Current Source Symbol

2   Electrical circuit

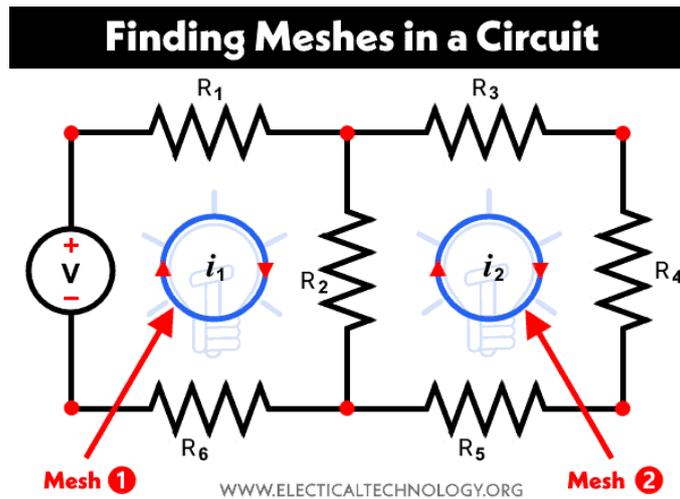## 2.1   Definitions : Nodes, Branches and Loops

- **A node** is a junction of connecting wires. Every point on a node is at the same potential (same voltage)

- **A branch** any circuit element between two nodes

- **A loop or Mesh** is a closed path that begins and ends at the same node

2.2 Ohm's Law

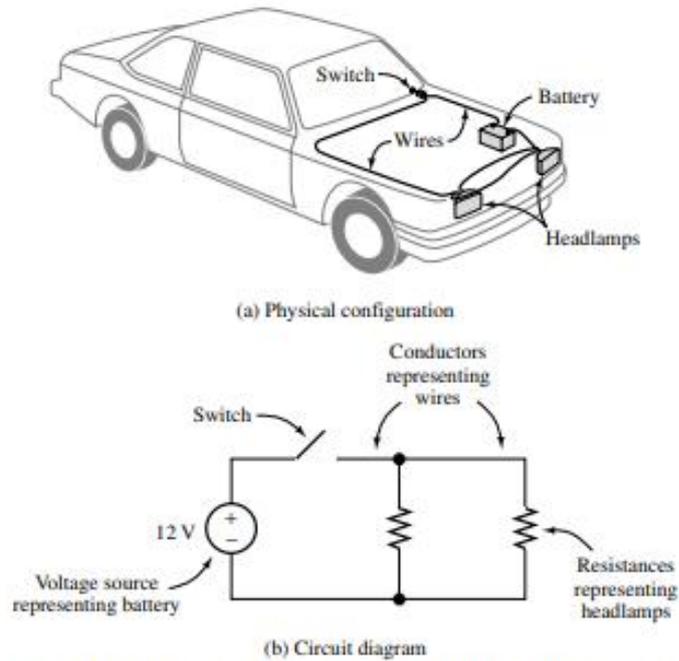(a) Physical configuration
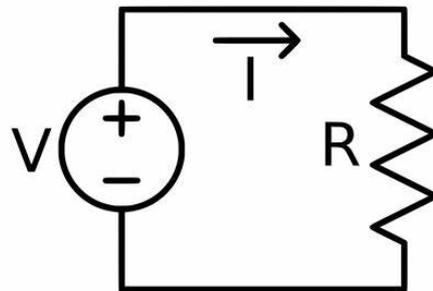

(b) Circuit diagram

Figure 1.2 The headlight circuit. (a) The actual physical layout of the circuit. (b) The circuit diagram.

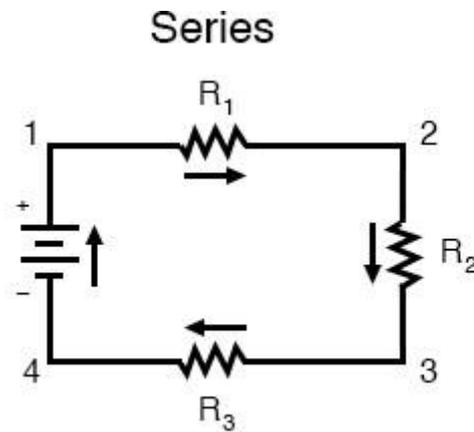$$\text{Effect} = \frac{\text{Cause}}{\text{Opposition}} \qquad I = \frac{V}{R}; \qquad V = RI \qquad \text{or} \qquad R = \frac{V}{I}$$
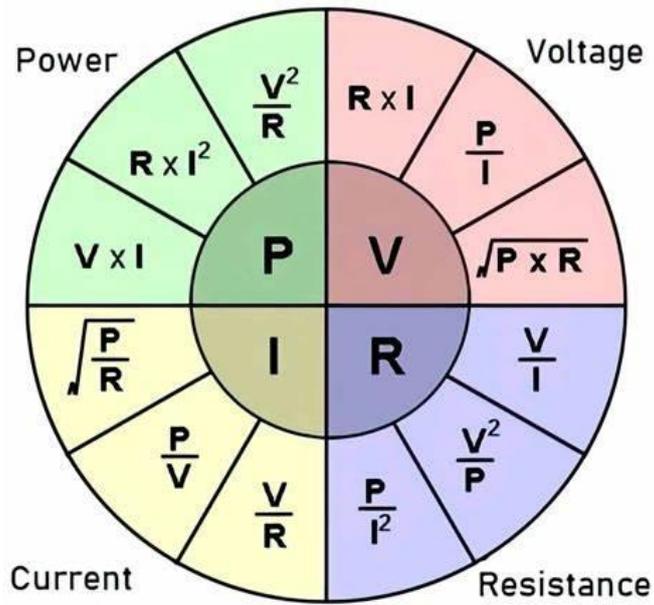
P = VI is the power dissipated in the resistor R. Unit of electrical power is Watts.

2.3 Series and Parallel circuits

Resistors in series

The same current I flows through all elements in series.
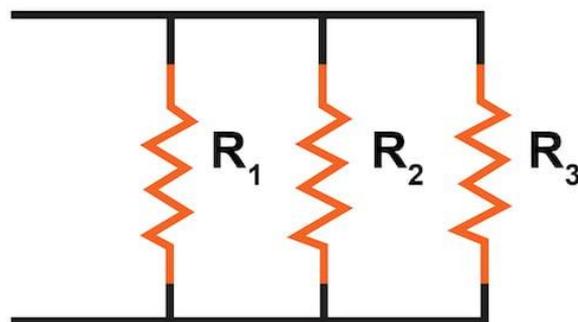
$$R_{eq} = R_{14} = R_1 + R_2 + R_3.$$

For a series combination of resistors, the equivalent resistance is found by simply adding the individual resistance values:

$$R_{eq} = \sum_{i=1}^{N} R_i$$

Parallel circuit

A parallel circuit is a circuit in which any number of components are connected across two common terminals, such that they share a common voltage.

Parallel Circuit

For a parallel combination of resistors, the reciprocal of the equivalent resistance is the sum of the reciprocals of the individual resistances.

$$\frac{1}{R_{eq}} = \sum_{i=1}^{N} \frac{1}{R_i}$$

2.4 Voltage and Current dividers

Voltage divider

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$
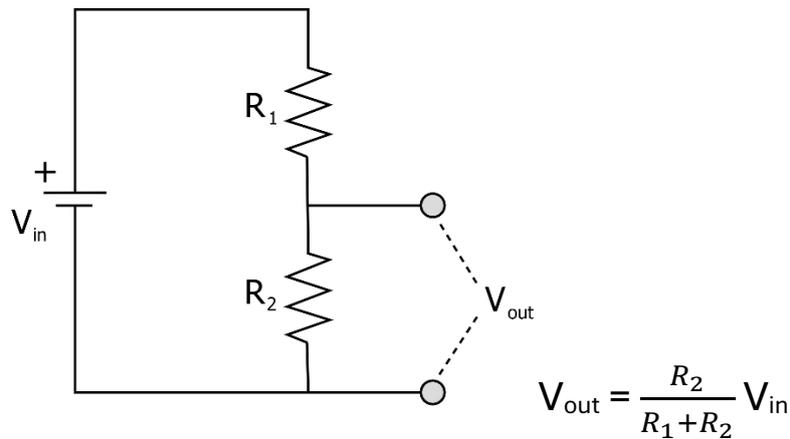
Current divider

Current Divider Rule

- Allows us to determine how the current flowing into a node is split between the various parallel resistors

$$I_X = I_{TOT}\left(\frac{R_T}{R_X}\right)$$

Formula

$$I_{x=} \frac{R_t}{R_x} * I_t$$

where

$$R_t = R_1 || R_x$$

3   Kirchhoff's Current Law (KCL)
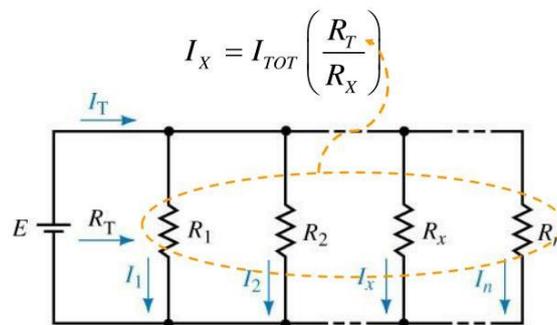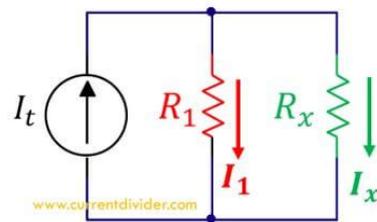
3.1   KCL

KCL: the algebraic sum of the currents entering and leaving a node or a junction of a circuit is zero. In other words:

$$\sum I_{entering} = \sum I_{leaving}$$

3.2   Application using Nodal Analysis

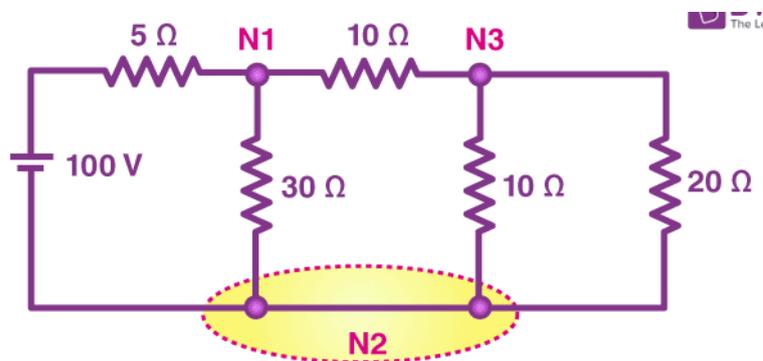Step 1: identify the nodes in circuit

Step 2: consider only nodes where 3 or more components meet.

Step 3: assume that one of the nodes is the reference node (usually the bottom one is chosen).

Step 4: assume voltages at other nodes are V_1, V_2, V_3 etc ...

Step 5:form node equations at each node and solve for results V_i and other parameters.

Example

4   Kirchhoff's Voltage Law (KVL)

4.1   KVL

KVL : The algebraic sum of the voltages equals zero for any closed path (loop) in an electrical circuit.

$$\sum_{closed\ Path} V = 0$$

4.2   Application using Loop or Mesh Analysis

Using **loop analysis method**, write the system of the equations you would use to solve for the currents i_1, i_2, and i_3, in the circuit shown below.
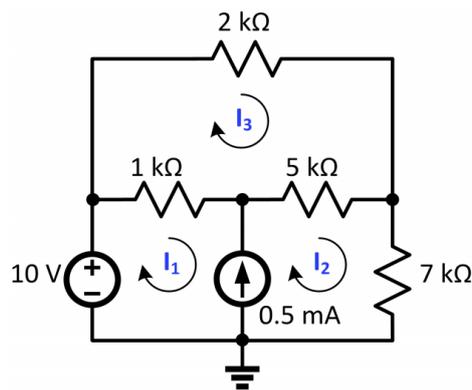
When several mesh currents flow through one element, we consider the current in that element to be the algebraic sum of the mesh currents

5   Source transformation

A voltage source having an internal resistance R_{se} (in series) connected to a load R_L can be transformed in current source having an internal resistance R_{sh} (in parallel) connected to the load.

$$R_{se} = R_{sh}$$
$$\&$$
$$V_1 = I_1 \, R_{sh}$$

6   Thevenin and Norton Equivalence

Thevenin's theorem: any two-terminal, dc network can be replaced by an equivalent circuit consisting of a voltage source and a series of resistor

Thevenin Equivalent
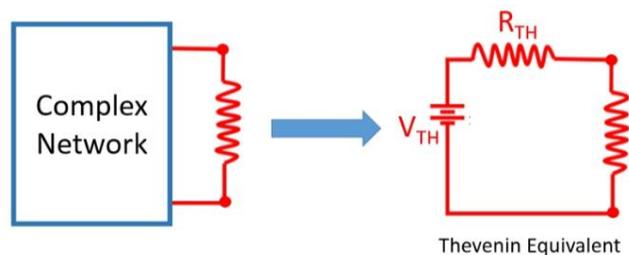
Example

We want to find the current in the 10 ohm resistor.
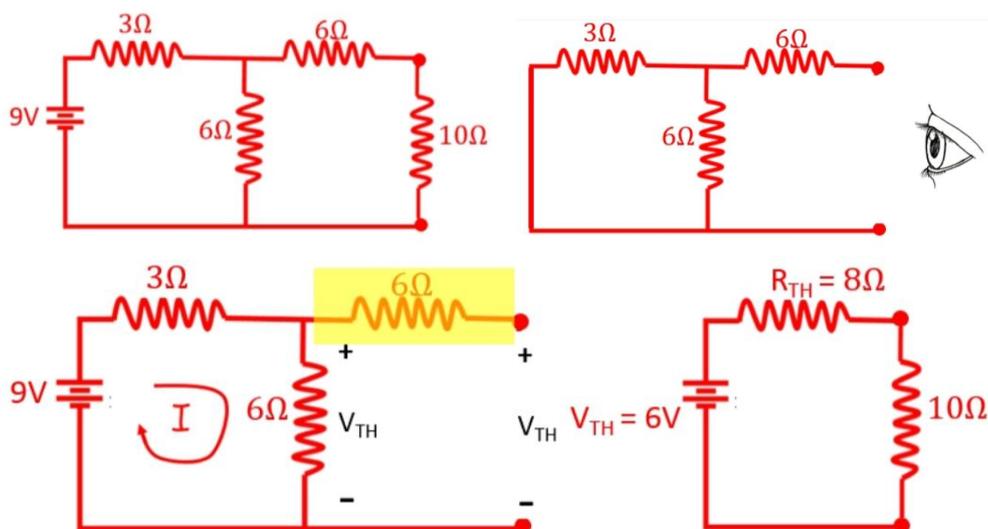
$R_{Th} = R_{OC}$ *(Open circuit resistance)*

To zero a voltage source, replace it with a short.   *(only for independent source!)*

To zero a current source, replace it with an open.   *(only for independent source!)*

$$V_{Th} = V_{OC} \quad \textit{(open-circuit voltage)}$$

Thus, the Thévenin source voltage Vt is equal to the open-circuit voltage of the original network.

Norton's theorem: Any two-terminal, dc network can be replaced by an equivalent circuit consisting of a current source and a parallel resistor.

Norton Equivalent
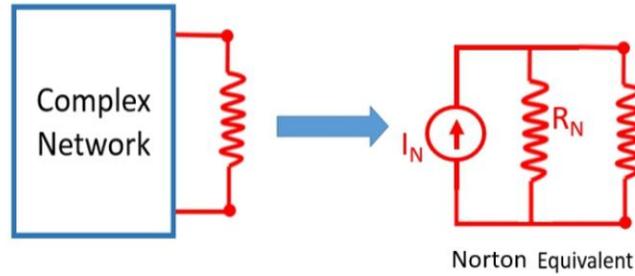
Example
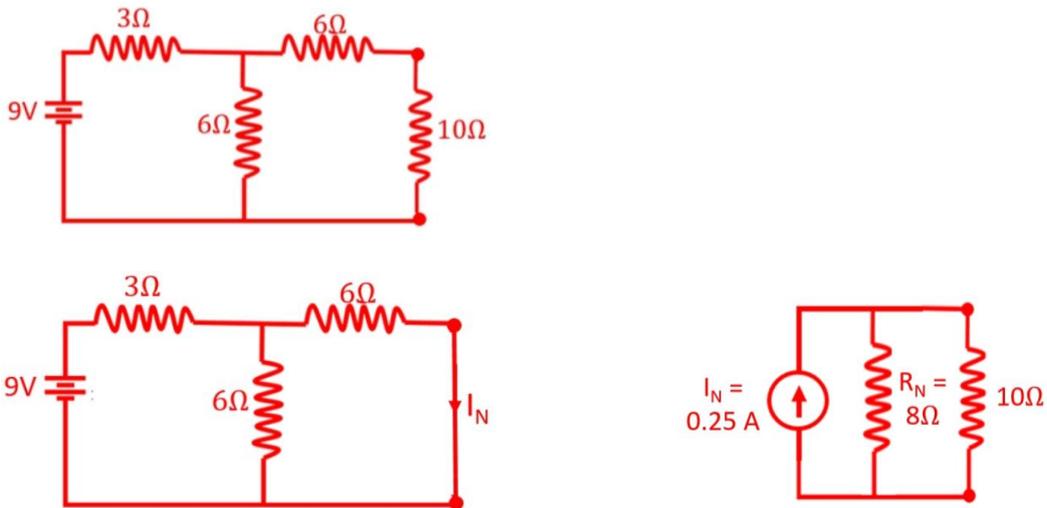
$$I_N = I_{SC} \quad \text{(short- circuit current)}$$

$R_N = R_{Th} = R_{OC}$ Norton resistance = Thevenin resistance = Open circuit resistance.

Steps to apply Thevenin and Norton theorems

Summary Table 1-2	Thevenin and Norton Values	
Process	Thevenin	Norton
Step 1	Open the load resistor.	Short the load resistor.
Step 2	Calculate or measure the open-circuit voltage. This is the Thevenin voltage.	Calculate or measure the short-circuit current. This is the Norton current.
Step 3	Short voltage sources and open current sources.	Short voltage sources, open current sources, and open load resistor.
Step 4	Calculate or measure the open-circuit resistance. This is the Thevenin resistance.	Calculate or measure the open-circuit resistance. This is the Norton resistance.

7   Superposition Theorem

Theorem: The effect or response in a component when 2 or more energy sources (voltage or current sources) are applied together is equal to the sum of effect/responses when the sources are applied individually.

The superposition principle states that any response in a linear circuit is the sum of the responses for each independent source acting alone with the other independent sources zeroed. When zeroed, current sources become open circuits and voltage sources become short circuits.
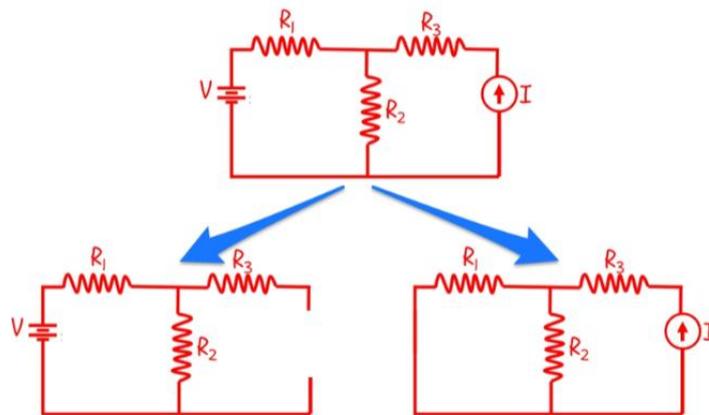
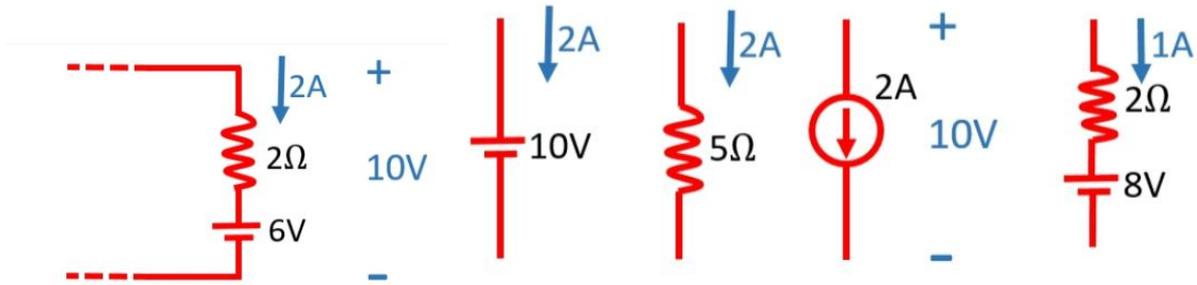$$V_{R2}' = \frac{V}{R_1 + R_2} R_2 \qquad\qquad V_{R2}'' = \frac{R_1 R_2}{R_1 + R_2} I$$

$$V_{R2} = V_{R2}' + V_{R2}''$$

8   Substitution theorem

Theorem: any branch of a dc network can be replaced by a different combination of elements as long as the new combination of elements will maintain the same voltage across and current through, as the original branch.

Example

Correction in the last figure R= 1Ω and I = 2 A

AC Analysis

With DC (Direct Current), electric current flows only one direction. With AC (Alternating Current), current direction reverses periodically.

Whereas resistors convert electrical energy into heat, inductors and capacitors are **energy-storage elements**. They can store energy and later return it to the circuit. Capacitors and inductors do not generate energy—only the energy that has been put into these elements can be extracted. Thus, like resistors, they are said to be **passive** elements.
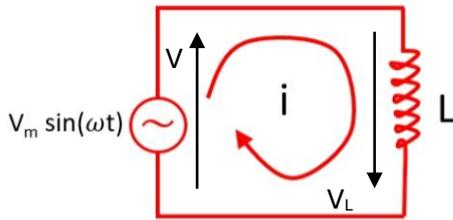
9 AC through resistor

$$i = \frac{v}{R} = \frac{V_m \sin(\omega t)}{R}$$

$$= \left(\frac{V_m}{R}\right) \sin(\omega t)$$
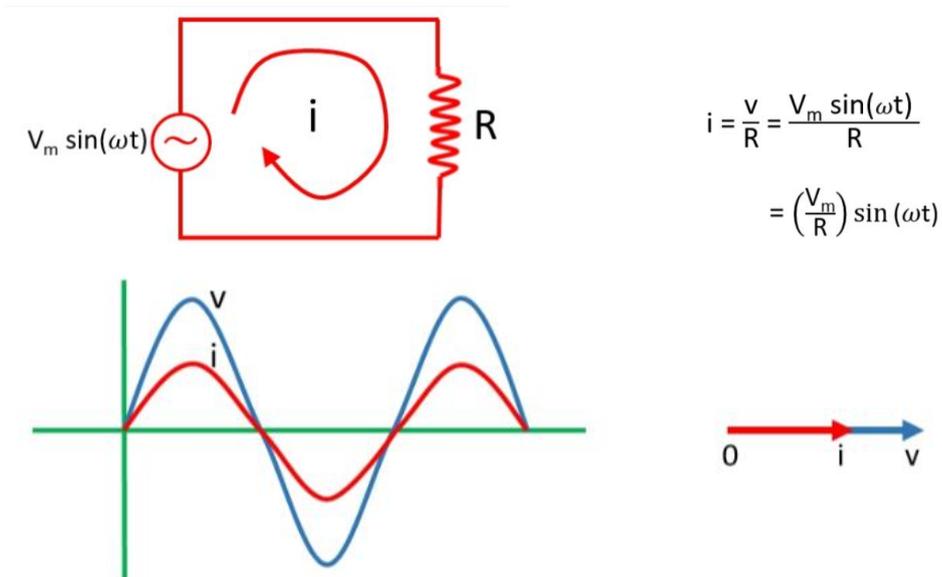
The current through the resistor and the applied voltage are in phase (phase shift φ = 0)

23

10   AC through inductor

Inductance accounts for energy stored in magnetic fields.

The voltage across an ideal inductor is proportional to **the time derivative of the current**. $V = L\frac{di}{dt}$

$$X_L = \omega L = 2\pi f\, L$$

$$v_L = -L\frac{di}{dt}$$

Since the applied emf and the induced emf oppose each other,

$$V = -v_L$$

$$\Rightarrow V_m \sin \omega t = L\frac{di}{dt}$$

$$i = \int \frac{V_m \sin \omega t}{L}\, dt = \frac{-V_m}{\omega L}\cos \omega t$$

$$\boxed{i = \frac{V_m}{X_L}\sin\left(\omega t - \frac{\pi}{2}\right)}$$

$$I_m = \frac{V_m}{X_L}$$
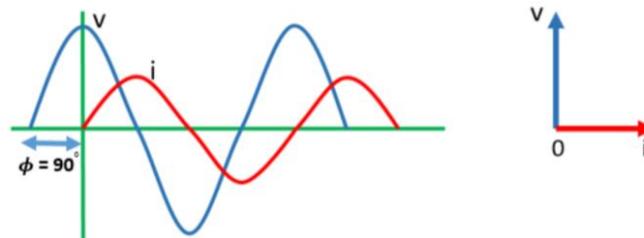
The current through the inductor lags the applied voltage 90° or $\frac{\pi}{2}$

ELI :mnémo

11   AC through a capacitor

Capacitance is the circuit property that accounts for energy stored in electric fields.

The voltage across an ideal capacitor is proportional to **the time integral of the current**.

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f\, C}$$

$$i = \frac{dq}{dt} = C\,\frac{dv}{dt}$$
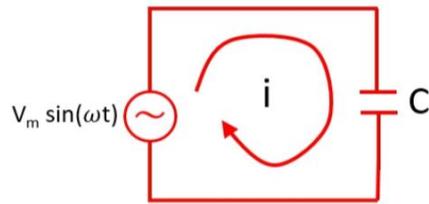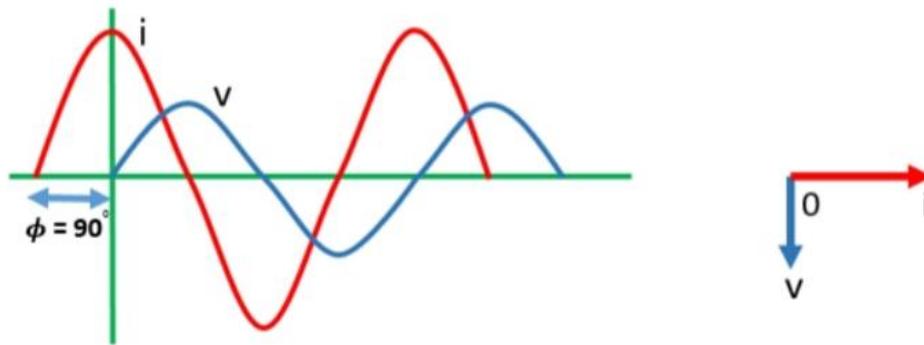
$$i = C\,\frac{d(V_m \sin \omega t)}{dt}$$

$$= V_m C\,\frac{d(\sin \omega t)}{dt} = V_m \omega C \cos \omega t$$

$$i = \frac{V_m}{X_C}\,\sin(\omega t + \frac{\pi}{2})$$

The current through the capacitor leads the applied voltage by 90° or $\frac{\pi}{2}$

ICE : mnémo

12 Transient analysis

A circuit whose circuit parameters or conditions remain constant, is said to be in a steady state. But a circuit isn't always in steady state, when a circuit or a portion of the circuit is switched on or off, there is a sudden change in circuit parameters (like amplitude, frequency etc..). A certain amount of time is taken for these changes to take place, this duration is called the Transient period and this phenomenon is known as **Transient**. Once the transient period is over, the circuit settles down and attains the steady state, if not disturbed further.

So when you switch on a circuit, there are 2 responses:

- One is the transient response or the natural response and
- the other is the steady state response or forced response.

All the circuit analysis we did till now was to find the steady state response, we ignored the transient response. Transients are due to the presence of energy storing elements (capacitors and inductors) in a circuit. These elements don't respond instantly to change in circuit conditions.

Transient response of RL circuit to DC excitation.

$$i(0^-) = i(0^+) = 0$$
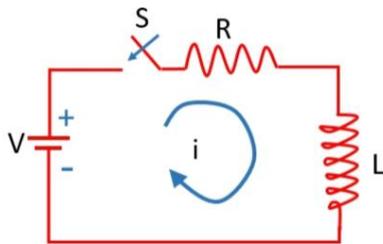
$$\therefore i(t) = \frac{V}{R} - \frac{V}{R}e^{-Rt/L}$$

$$V = iR + L\frac{di}{dt}$$

Steady state response

Transient response
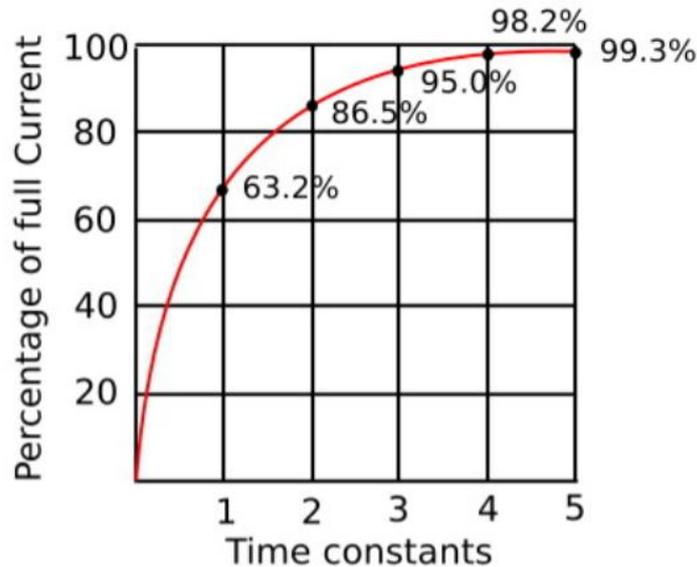
The constant $\tau = \frac{L}{R}$ is called the time constant of the circuit. This values decides how fast this circuit will reach steady state. Typically current will reach steady state after t = 5τ. The important thing to note is that after the brief transient period, Inductor acts as a short circuit (just like a normal wire) in a DC circuit.

Transient response of RC circuit to DC excitation

$$v_C(0^-) = v_C(0^+) = 0$$

$$\therefore v_C(t) = V - Ve^{-t/RC}$$

Steady state response   Transient response

$$v_C(t) + RC\frac{dv_C(t)}{dt} = V$$
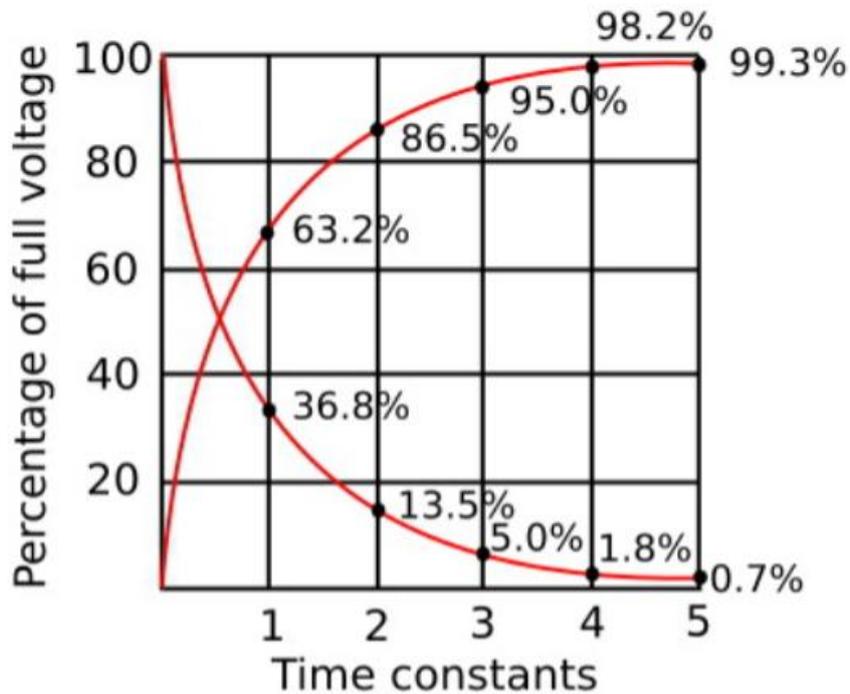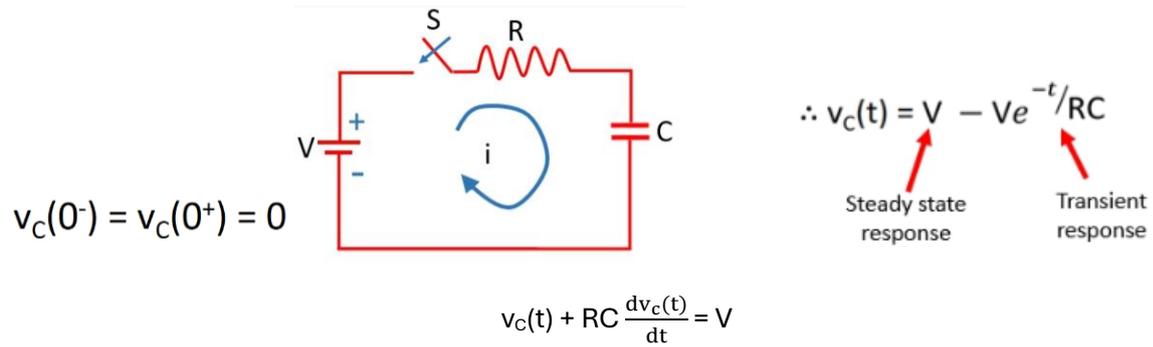
The constant τ = RC is the time constant of the circuit. In a DC circuit, the capacitor acts as an open circuit in a steady state.

13   Power   symbol P   unit Watt (W)

$$1W = \frac{1\text{Joule}}{1\text{ second}}$$ (a bulb of 60 W use 60 Joules of electrical energy per second to light)

Power is the instantaneous rate at which a work is being done.

Consider the circuit element shown in Figure below. Because the current i is the rate of flow of charge and the voltage v is a measure of the energy transferred per unit of charge, the product of

the current and the voltage is the rate of energy transfer. In other words, the product of current and voltage is power:

$$p = vi$$

The physical units of the quantities:
Volt x Amperes = (Joules/Coulomb)x(Coulombs/second) = Joules/second = Watts

Refer to below and notice that the current reference enters the positive polarity of the voltage. We call this arrangement the passive reference configuration. Provided that the references are picked
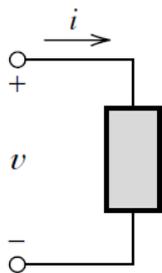
in this manner, a positive result for the power calculation implies that energy is being absorbed by the element. On the other hand, a negative result means that the element is supplying energy to other parts of the circuit.

If the current reference enters the negative end of the reference polarity, we compute the power as p = −vi.

Then, as before, a positive value for p indicates that energy is absorbed by the element, and a negative value shows that energy is supplied by the element. If the circuit element happens to be an electrochemical battery, positive power means that the battery is being charged. In other words, the energy absorbed by the battery is being stored as chemical energy. On the other hand, negative power indicates that the battery is being discharged. Then the energy supplied by the battery is delivered to some other element in the circuit.

13.1 Watt's law:

P = VI   voltage across a circuit multiplied by the current through the circuit.

Electrical energy

E(J) = Pt = VIt

Work is done when a force causes a motion. In electronics : voltage (force) creates current, causing electrons to move in a circuit.

Power is the metric that is used to determine

- output,
- efficiency,
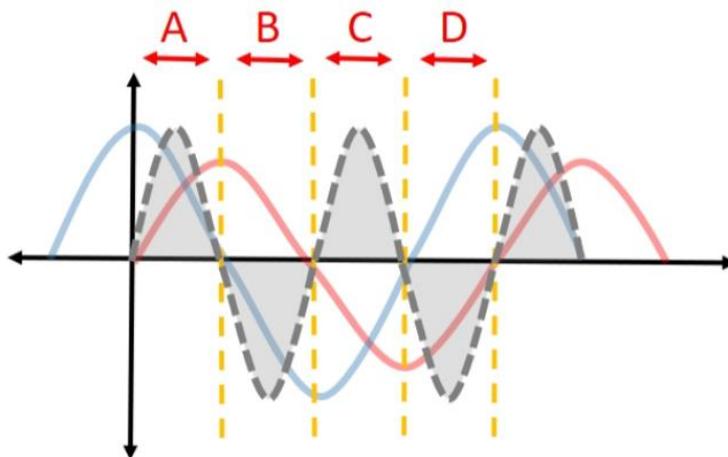- How much energy is converted into work

Power in resistor

$P = RI^2$
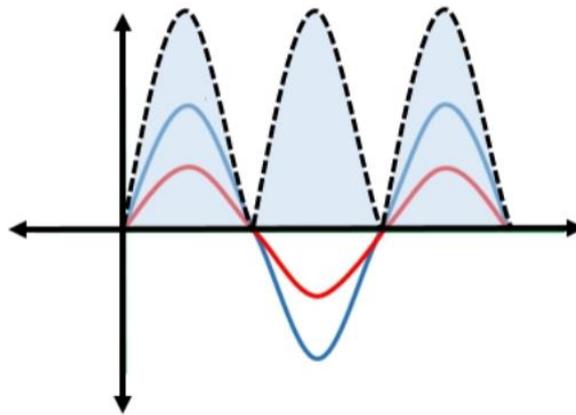
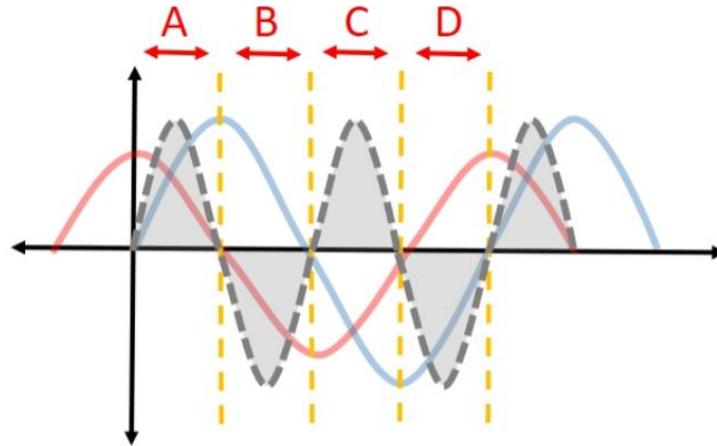Current in red, voltage in bleu and power in dash.

Power in inductor

Current in red, voltage in bleu and power in dash.

$P_{moy} = 0$

Power in capacitor

Current in red, voltage in bleu and power in dash.

$$P_{cmoy} = 0$$

14 Transformer

A transformer consists of a ferromagnetic core around which two wire coils, one referred to as the primary winding, and the other referred to as the secondary winding, are wound. When AC current is applied to the primary winding the coil creates a changing magnetic field.

The changing magnetic flux in the iron core causes the magnetic field to reach the secondary coil. When the magnetic field reaches the secondary coil, it forces the electrons within it to move, creating an electric current.

It was found that when using a solid core, currents, called eddy currents, were generated in the core causing energy loss in the form of heat. To reduce these losses, cores are now made of laminated sheets of ferromagnetic material.

Many transformers are constructed with an E core. As shown above, the E core is shaped like a capital E. After the windings have been wound on the E core, a bar is placed on the open end of the E.

A transformer's function is to step-up or step -down the voltage from the primary to the secondary winding. This is done by setting the ratio of coil windings on one side relative to the other. If a transformer has 100 windings on the primary and 50 windings on the secondary, it will have a 2:1 step – down transformer, cutting the voltage in half.

If a transformer has 50 windings on the primary and 200 windings on the secondary, it will have a 1:4 step up transformer, the voltage quadruples from the primary to the secondary.
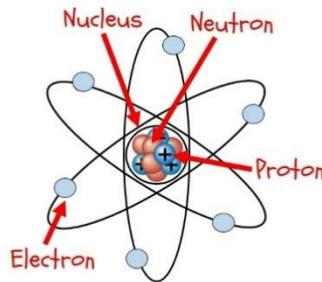
Though a transformer may step voltage up or down, ignoring losses, power stays the same, so it will provide more current, in inverse to the turns ratio, in the secondary.

primary

secondary
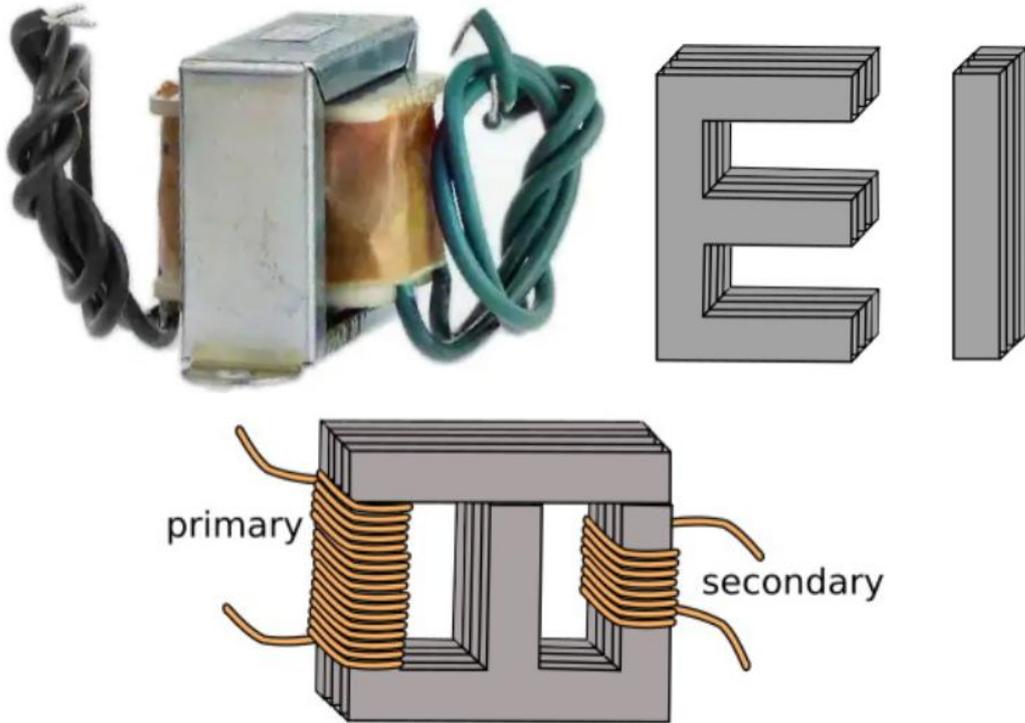
Diode

1   Conductors

Atom structure

The SI unit of electric charge is Coulomb (C) and it is the charge possessed by 6.24 x 10^{18} electrons.

Figure 2-1   Copper atom.
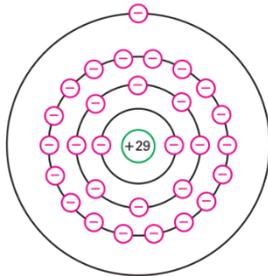
Figure 2-2   Core diagram of copper atom.
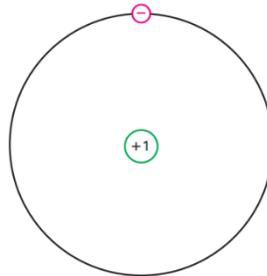
Copper atom

Stable Orbits

The Core

Free Electron

The best conductors (silver, copper, and gold) have one valence electron, whereas the best insulators have eight valence electrons.

2   Semiconductors

Figure 2-3   (a) Silicon atom; (b) core diagram.

(a)   (b)
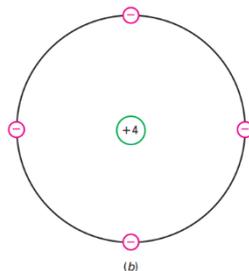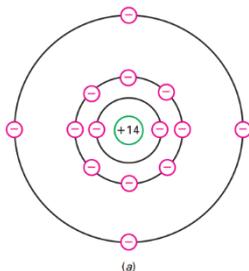
A semiconductor is an element with electrical properties between those of a conductor and those of an insulator.

The best semiconductors have four valence electrons as Germanium and Silicon

A semiconductor can be doped to have an excess of free electrons or an excess of holes. Because of this, there are two types of doped semiconductors.

Intrinsic semiconductors

An intrinsic semiconductor is a pure semiconductor. A silicon crystal is an intrinsic semiconductor if every atom in the crystal is a silicon atom.

Figure 2-4   (*a*) Atom in crystal has four neighbors; (*b*) covalent bonds.
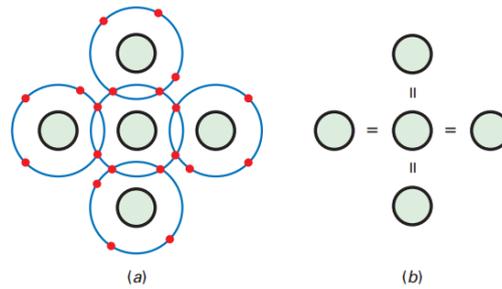
Extrinsic Semiconductors (Doping a Semiconductor)

One way to increase conductivity of a semiconductor is by doping. This means adding impurity atoms to an intrinsic crystal to alter its electrical conductivity. A doped semiconductor is called an extrinsic semiconductor.

Figure 2-8   (*a*) Doping to get more free electrons; (*b*) doping to get more holes.

● FREE ELECTRON
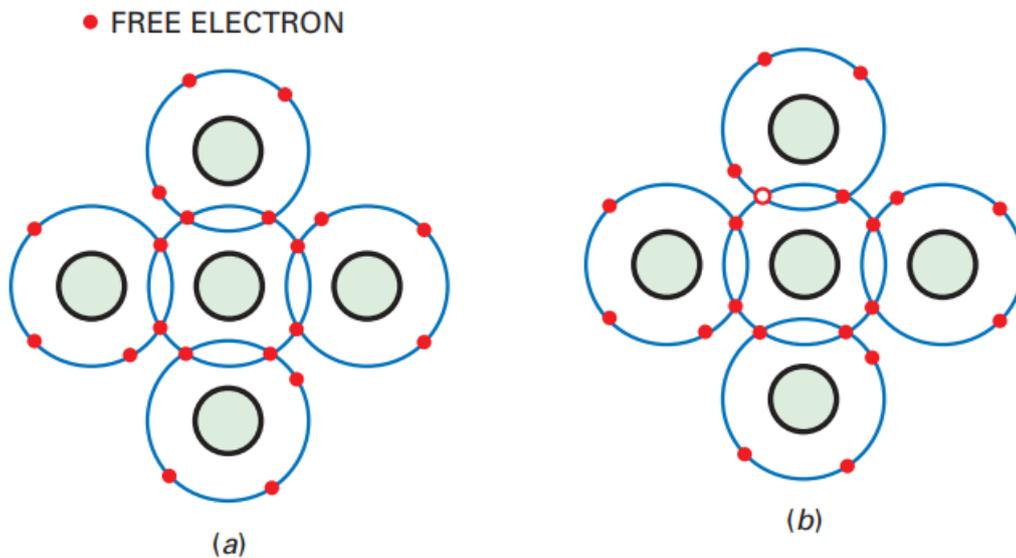
Figure 2-11   Two types of semiconductor.
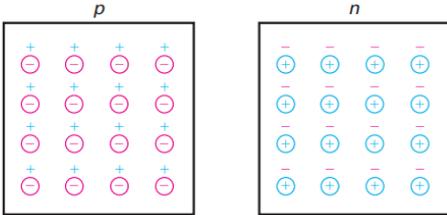
Figure 2-12   The *pn* junction.
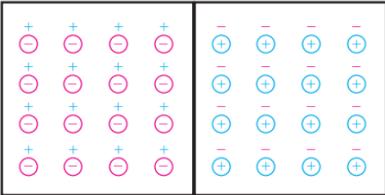
Figure 2-13   (*a*) Creation of ions at junction; (*b*) depletion layer.

IONS

DEPLETION LAYER

(*a*)

(*b*)
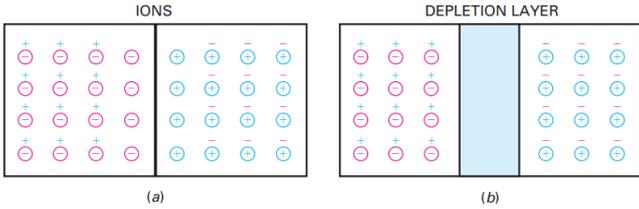
Figure 214   Forward bias.
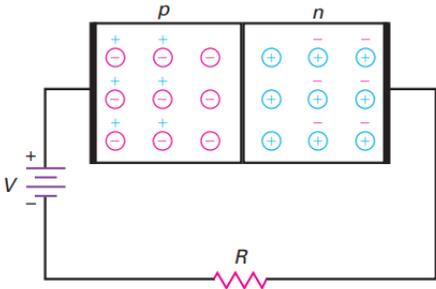
tisim **Figure 215** Reverse bias.
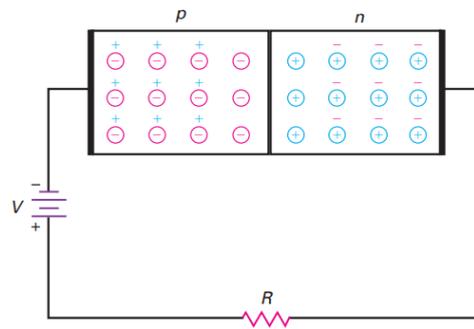
Figure 2-16 (*a*) Depletion layer; (*b*) increasing reverse bias widens depletion layer.
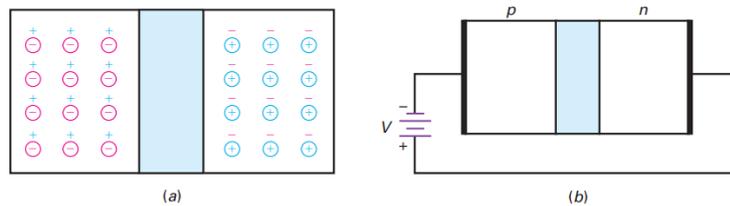
The width of this shaded region is proportional to the reverse voltage. As the reverse voltage increases, the depletion layer gets wider.

Figure 3-1 Diode. (*a*) Schematic symbol; (*b*) diode case styles; (*c*) forward bias.
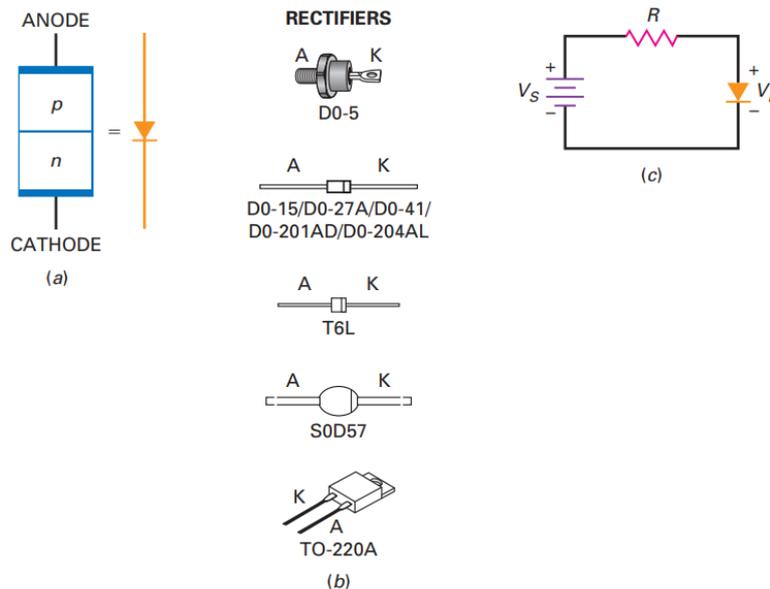
LED : Light Emitting Diode

Optoelectronics is the technology that combines optics and electronics. This fi eld includes many devices based on the action of a pn junction. Examples of optoelectronic devices are light-

emitting diodes (LEDs), photodiodes, optocouplers, and laser diodes. Our discussion begins with the LED. LEDs have replaced incandescent lamps in many applications because of the LED's lower energy consumption, smaller size, faster switching and longer lifetime. Figure 5-19 shows the parts of a standard low-power LED. Just as in an ordinary diode, the LED has an anode and a cathode that must be properly biased. The outside of the plastic case typically has a flat spot on one side which indicates the cathode side of the LED. The material used for the semiconductor die will determine the LED's characteristics.

Figure 5-20a shows a source connected to a resistor and an LED. The outward arrows symbolize the radiated light. In a forward-biased LED, free electrons cross the pn junction and fall into holes. As these electrons fall from a higher to a lower energy level, they radiate energy in the form of photons. **In ordinary diodes, this energy is radiated in the form of heat**. But in an LED, the energy is radiated as light. This effect is referred to as electroluminescence.

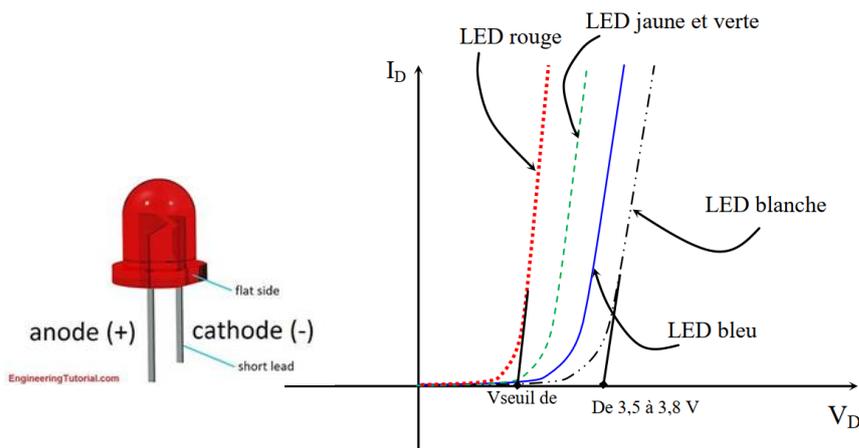The color of the light, which corresponds to the wavelength energy of the photons, is primarily determined by the energy band gap of the semiconductor materials that are used. By using elements like gallium, arsenic, and phosphorus, a manufacturer can produce LEDs that radiate red, green, yellow, blue, orange, white or infrared (invisible) light. LEDs that produce visible radiation are useful as indicators in applications such as instrumentation panels, internet routers, and so on. The infrared LED finds applications in security systems, remote controls, industrial control systems, and other areas requiring invisible radiation.

Characteristic Diode curves of LED
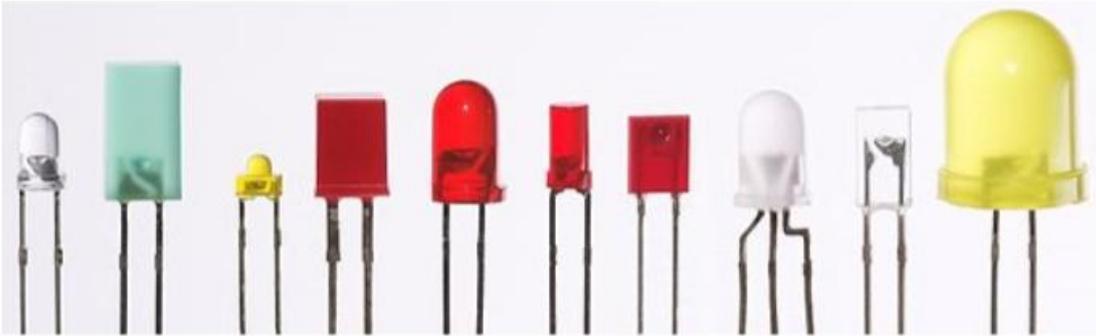
Figure 5-19 Parts of an LED.

Epoxy lens/case
Wire bond
Reflective cavity
Semiconductor die
Anvil ⎱ Leadframe
Post ⎰
Flat spot
+ −
Anode   Cathode
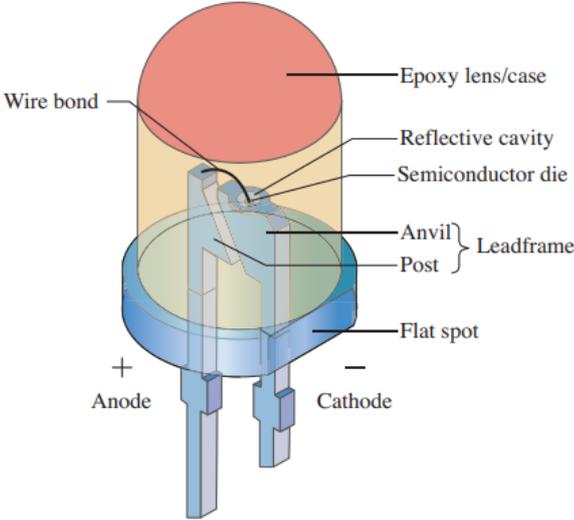
Figure 5-20 LED indicator. (*a*) Basic circuit; (*b*) practical circuit; (*c*) typical LEDs.

(*a*)

(*b*)

I_D

BREAKDOWN

REVERSE
CURRENT

FORWARD
REGION

V_D

KNEE ≈ 0.7 V

REVERSE
REGION

Anode   Cathode
(+)   (−)
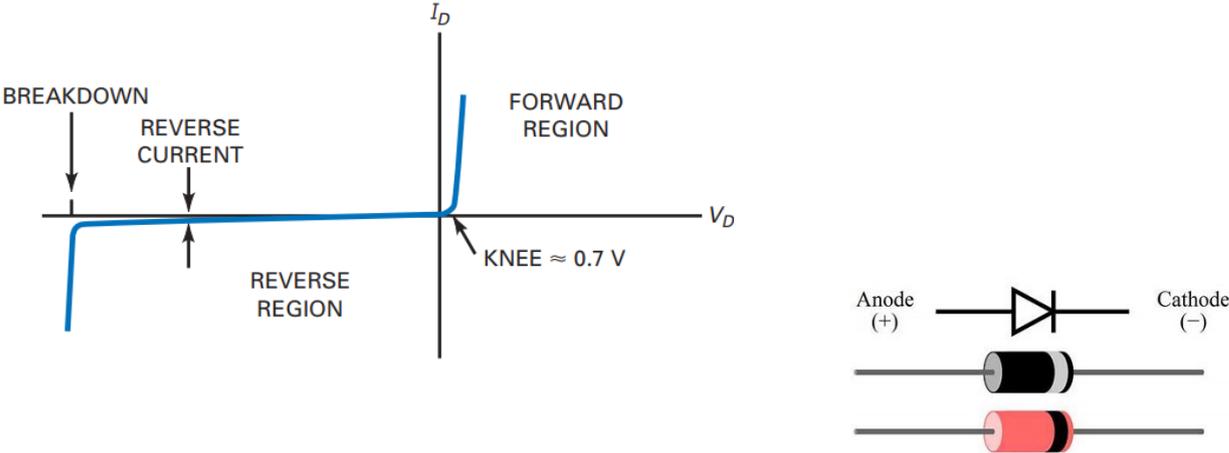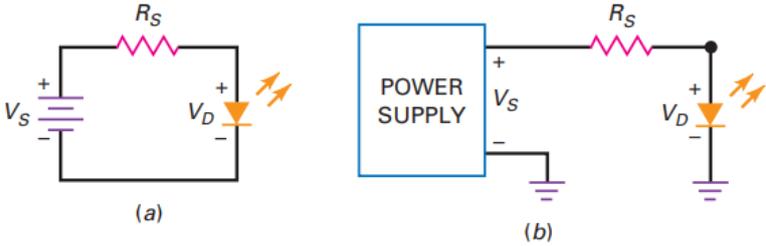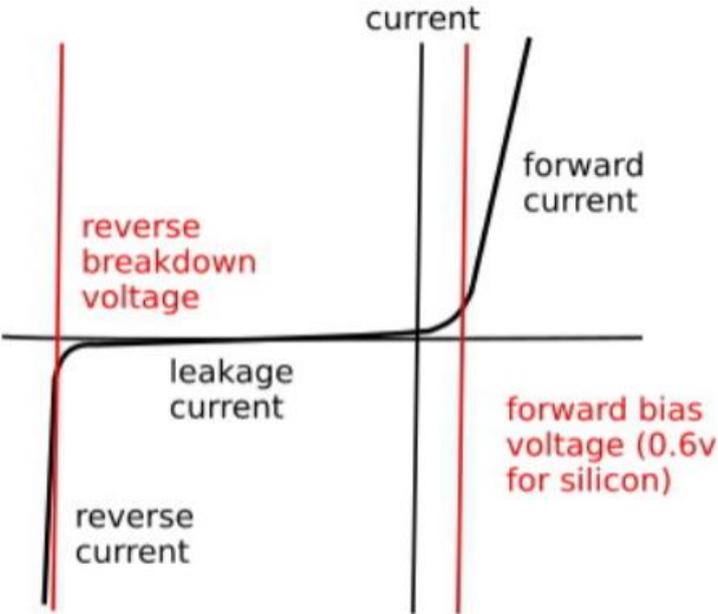
Characteristic diode curves : current vs voltage I(V)

Summary Table 2-1	Diode Bias	
	Forward bias	**Reverse bias**
V_s polarity	(+) to P material (−) to N material	(−) to P materials (+) to N material
Current flow	Large forward current if $V_s > 0.7$ V	Small reverse current (saturation current and surface leakage current) if $V_s <$ breakdown voltage
Depletion layer	Narrow	Wide

Summary Table 3-1 — Diode Approximations

	First or ideal	Second or practical	Third
When used	Troubleshooting or quick analysis	Analysis at technician level	High-level or engineering-level analysis
Diode curve			
Equivalent circuit	Reverse bias / Forward bias	0.7 V Reverse bias / Forward bias	0.7 V, R_B Reverse bias / Forward bias
Circuit example	V_{out} = 10 V	V_{out} = 9.3 V	V_{out} = 9.28 V
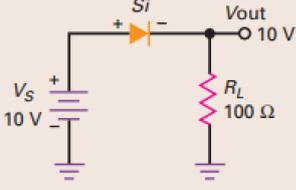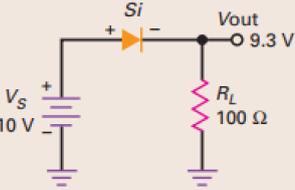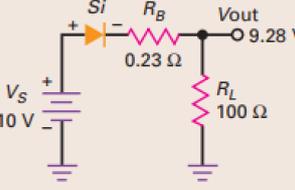
Reading a Data Sheet

Figure 3-15 Data sheet for 1N4001–1N4007 diodes. (Copyright Fairchild Semiconductor Corporation. Used by permission.)

FAIRCHILD
SEMICONDUCTOR®

May 2009

1N4001 - 1N4007
General Purpose Rectifiers

Features

- Low forward voltage drop.
- High surge current capability.

DO-41
COLOR BAND DENOTES CATHODE

1N4001 - 1N4007 — General Purpose Rectifiers

Absolute Maximum Ratings * $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Value							Units
		4001	4002	4003	4004	4005	4006	4007	
V_{RRM}	Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
$I_{F(AV)}$	Average Rectified Forward Current .375 " lead length @ $T_A = 75°C$	1.0							A
I_{FSM}	Non-Repetitive Peak Forward Surge Current 8.3ms Single Half-Sine-Wave	30							A
I^2t	Rating for Fusing (t<8.3ms)	3.7							A^2sec
T_{STG}	Storage Temperature Range	-55 to +175							°C
T_J	Operating Junction Temperature	-55 to +175							°C

* These ratings are limiting values above which the serviceability of any semiconductor device may by impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.0	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	50	°C/W

Electrical Characteristics $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Value	Units
V_F	Forward Voltage @ 1.0A	1.1	V
I_{rr}	Maximum Full Load Reverse Current, Full Cycle $\quad\quad\quad T_A = 75°C$	30	µA
I_R	Reverse Current @ Rated $V_R \quad\quad T_A = 25°C$ $\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad T_A = 100°C$	5.0 50	µA µA
C_T	Total Capacitance $V_R = 4.0V$, f = 1.0MHz	15	pF

© 2009 Fairchild Semiconductor Corporation
1N4001 - 1N4007 Rev. C2

1

www.fairchildsemi.com

Refer to the data sheet of the 1N4001, Fig. 3-15. The maximum peak repetitive reverse voltage, V_{RRM} on the data sheet, is the peak inverse voltage of this diode. The data sheet says that the 1N4001 can withstand a voltage of 50 V in the reverse direction.

The average rectified forward current $I_{F(av)}$, $I_{(max)}$, or I_0 is the dc or average current through the diode. For a half-wave rectifier, the diode current equals the dc load current. For a full-wave or bridge rectifier, it equals half the dc load current. The data sheet says that a 1N4001 can have a dc current of 1 A, which means that the dc load current can be as much as 2 A in a bridge rectifier. Notice also the surge-current rating I_{FSM}. The data sheet says that a 1N4001 can withstand 30 A during the first cycle when the power is turned on.

Summary Table 4-2	Capacitor-Input Filtered Rectifiers*		
	Half-wave	Full-wave	Bridge
Number of diodes	1	2	4
Rectifier input	$V_{p(2)}$	$0.5V_{p(2)}$	$V_{p(2)}$
DC output (ideal)	$V_{p(2)}$	$0.5V_{p(2)}$	$V_{p(2)}$
DC output (2d)	$V_{p(2)} - 0.7$ V	$0.5V_{p(2)} - 0.7$ V	$V_{p(2)} - 1.4$ V
Ripple frequency	f_{in}	$2f_{in}$	$2f_{in}$
PIV	$2V_{p(2)}$	$V_{p(2)}$	$V_{p(2)}$
Diode current	I_{dc}	$0.5I_{dc}$	$0.5I_{dc}$

*$V_{p(2)}$ = peak secondary voltage; $V_{p(out)}$ = peak output voltage; I_{dc} = dc load current.

RC filters

Figure 4-21 (a) RC filtering; (b) LC filtering; (c) voltage-regulator filtering; (d) three-terminal voltage regulator.
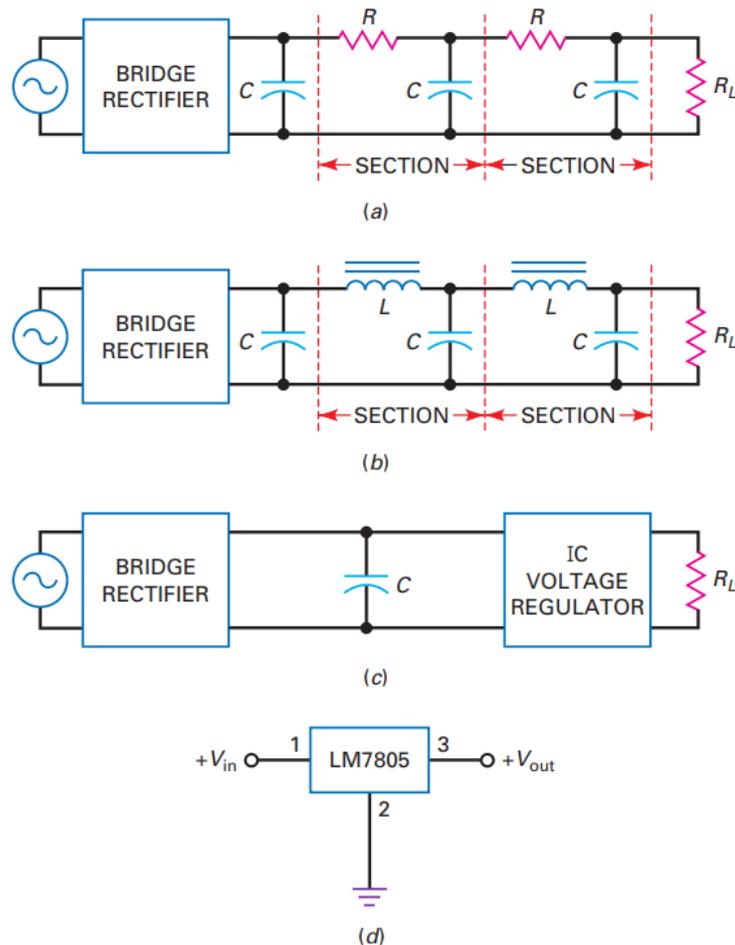
Before the 1970s, passive filters (R, L, and C components) were often connected between the rectifier and the load resistance. Nowadays, you rarely see passive filters used in semiconductor power supplies, but there might be special applications, such as audio power amplifiers, in which you might encounter them.

Figure 4-21a shows a bridge rectifier and a capacitor-input filter. Usually, a designer will settle for a peak-to-peak ripple of as much as 10% across the filter capacitor. The reason for not trying to get even lower ripple is because the filter capacitor would become too large. Additional filtering is then done by RC sections between the filter capacitor and the load resistor.

The RC sections are examples of a passive filter, one that uses only R, L, or C components. By deliberate design, R is much greater than X_C at the ripple frequency. Therefore, the ripple is reduced before it reaches the load resistor. Typically, R is at least 10 times greater than X_C. This means that each section attenuates (reduces) the ripple by a factor of at least 10. The disadvantage of an RC filter is the loss of dc voltage across each R. Because of this, the RC filter is suitable only for very light loads (small load current or large load resistance).

LC Filter

When the load current is large, the LC filters of Fig. 4-21b are an improvement over RC filters. Again, the idea is to drop the ripple across the series components, in this case, the inductors. By making X_L much greater than X_C, we can reduce the ripple to a very low level. The dc voltage drop across the inductors is much smaller than it is across the resistors of RC sections because the winding resistance is smaller.

The LC filter was very popular at one time. Now, it's becoming obsolete in typical power supplies because of the size and cost of inductors. For low-voltage power supplies, the LC filter has been replaced by an integrated circuit (IC). This is a device that contains diodes, transistors, resistors, and other components in a miniaturized package to perform a specific function. Figure 4-21c illustrates the idea. An IC voltage regulator, one type of integrated circuit, is between the filter capacitor and the load resistor. This device not only reduces the ripple, it also holds the output voltage constant. Figure 4-21d shows an example of a three-terminal voltage regulator. The LM7805 IC provides for a five-volt fixed positive output voltage, as long as the input voltage to the IC is at least 2 to 3 volts greater than the required output voltage. Other regulators in the 78XX series can regulate a range of output values, such as 9 V, 12 V, and 15 V. The 79XX series provides regulated negative output values. **Because of their low cost, IC voltage regulators are now the standard method used for ripple reduction.**