Amateur Radio Technician Exam Preparation

ARRL
The National Association for Amateur Radio®

Amateur Radio Technician Exam Prep Course

Module 3

Electricity, Components, and Circuits

3.1 Electricity
3.2 Components and Units
3.3 Radio Circuits

Fundamentals of Electricity

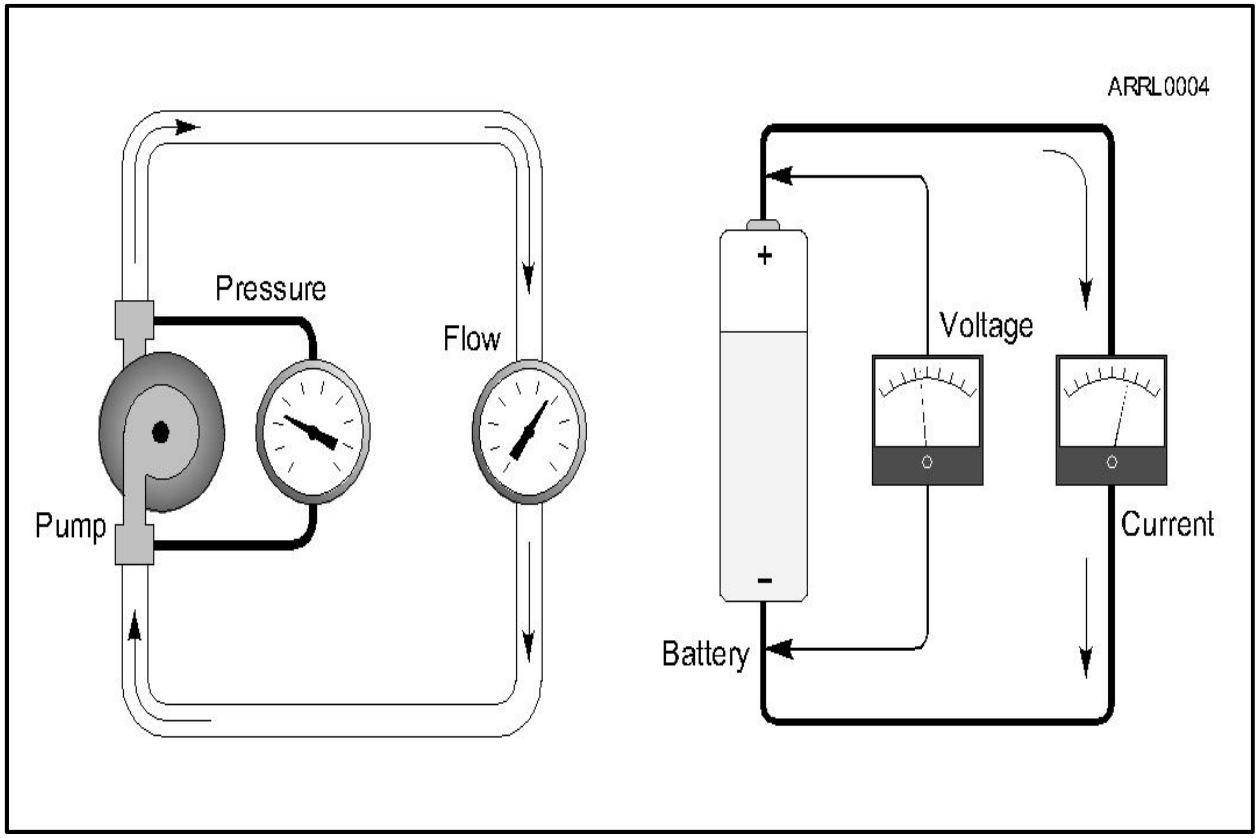
- Radios are powered by electricity and radio signals are a form of electrical energy
- A basic understanding of how we control electricity allows you to better install and operate your radio
- Electrical charge can be positive or negative
  - Opposite charges attract each other (like charges repel)
- Electrical current is the flow of ***electrons***
  - Electrons are negatively-charged atomic particles, usually surrounding an atom's positively-charged nucleus of protons (positive) and neutrons (neutral – no charge)
  - Electrons move in response to an ***electromotive force*** and can move independently of atoms

Basic Electrical Concepts

- Current: the movement of electrons, measured in *amperes* (***A***) by an *ammeter*, and represented by ***I*** (capital letter "i") in formulas
- Voltage: the amount of electromotive force (emf), also called electrical potential, measured in *volts* (***V***) by a *voltmeter*, represented by ***E*** or ***V*** in formulas
- Resistance: the opposition to the movement of electrons, measured in *ohms* (***Ω***) by an *ohmmeter* and represented by ***R*** (sometimes Ω in scientific publications) in formulas
- Resistance is like friction and turns electrical energy into heat when current flows
- *Conductors* permit current flow (low resistance) and *insulators* block current flow (high resistance)

Basic Electrical Concepts (cont.)

- The flow of water through a pipe is a good analogy to understand the three characteristics of electricity and how they are related



Basic Electrical Concepts (cont.)

- *Polarity* refers to the convention that determines which voltages are positive and negative
- Voltage from a *source* of electrical energy causes current to flow
- *Resistance* is a material's opposition to the flow of current
- Voltage, current, and resistance affect each other
  - For example, higher voltage (bigger push) causes more current (more flow)

PRACTICE QUESTIONS

Electrical current is measured in which of the following units?

A. Volts
B. Watts
C. Ohms
D. Amperes

T5A01 D 3-1

What is the name for the flow of electrons in an electric circuit?

A. Voltage
B. Resistance
C. Capacitance
D. Current

T5A03 D 3-1

What is the electrical term for the force that causes electron flow?

A. Voltage
B. Ampere-hours
C. Capacitance
D. Inductance

T5A05 A 3-1

Which of the following describes alternating current?

A. Current that alternates between a positive direction and zero
B. Current that alternates between a negative direction and zero
C. Current that alternates between positive and negative directions
D. All these answers are correct

T5A09 C 3-1

Which instrument would you use to measure electric potential?

A. An ammeter
B. A voltmeter
C. A wavemeter
D. An ohmmeter

T7D01 B 3-1

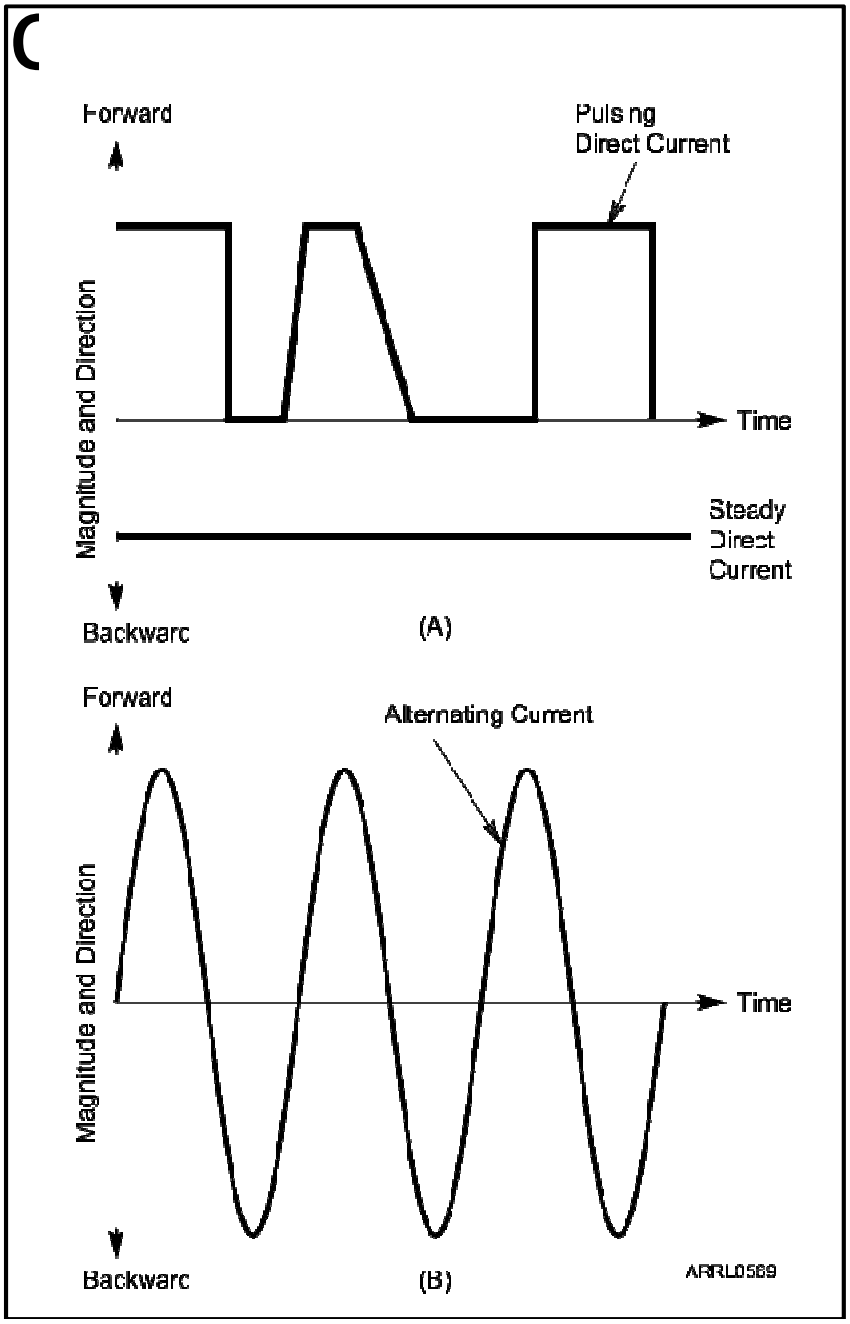
Which instrument is used to measure electric current?

A. An ohmmeter
B. An electrometer
C. A voltmeter
D. An ammeter

T7D04 D 3-1

The Two Kinds o

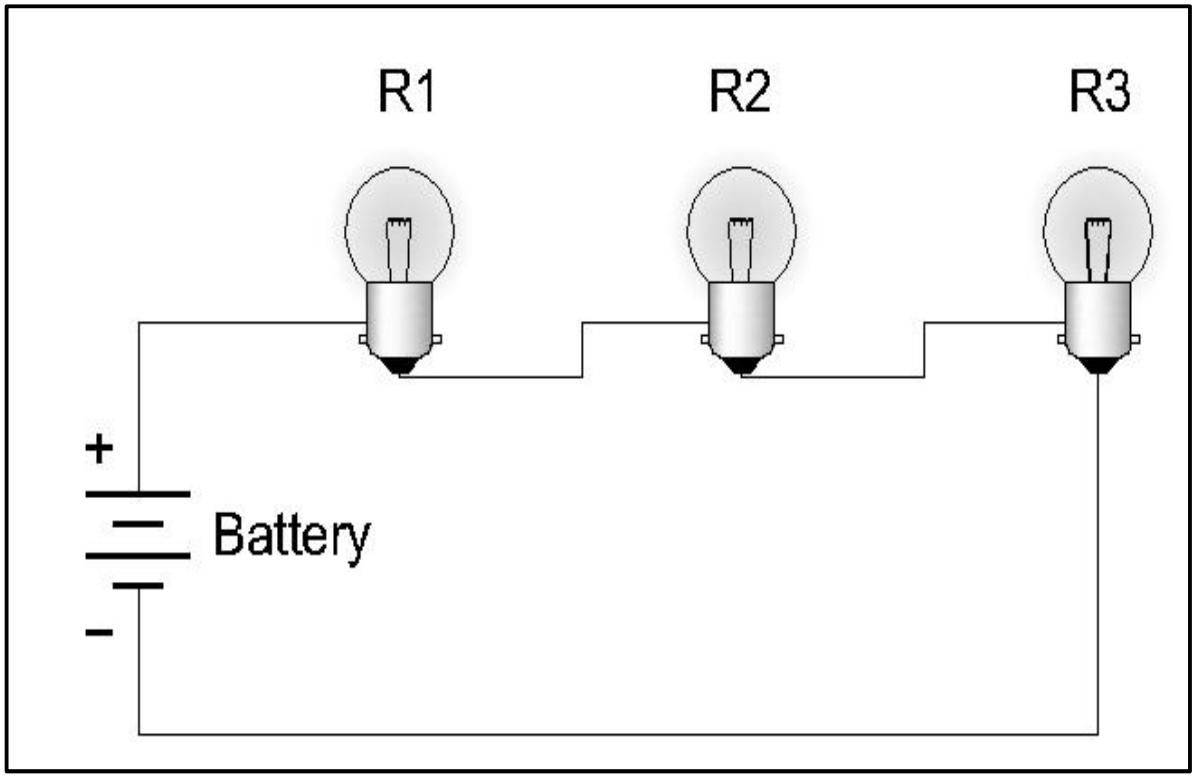
- Current that flows in only one direction, is called *direct current* (DC)
  - Batteries are a common source of DC
- Current that flows in one direction then in the opposite direction is called *alternating current* (AC)
  - Household current is AC



Current Flow

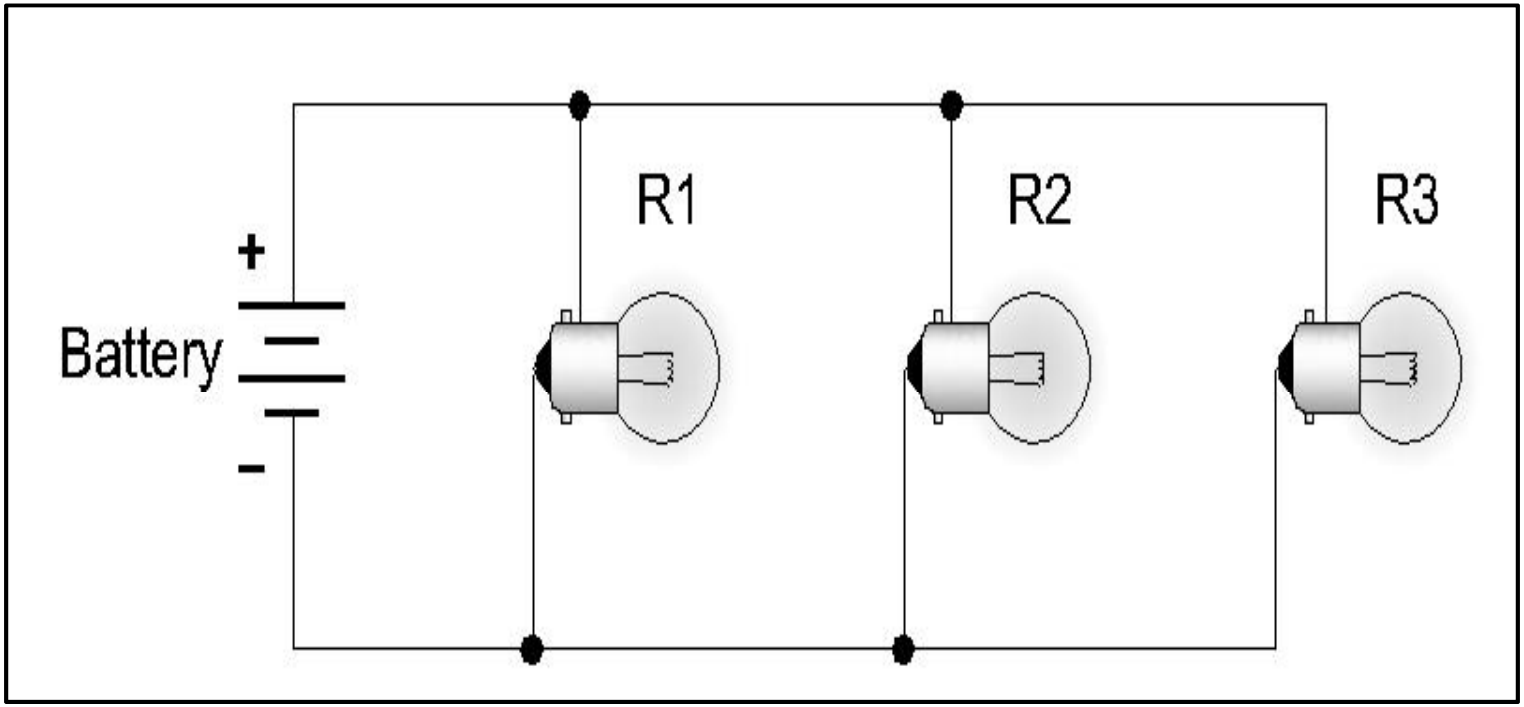
- A *circuit* is any path through which current can flow
- Electrical circuits are made from *components* and the connections between them
- If two or more components are connected in a circuit so that the same current must flow through all of them, that is a *series* circuit
- A *short circuit* is a direct connection between two points in a circuit
- An *open circuit* is made by breaking a current

Series Circuit



*Same **CURRENT** at all points in the circuit. Series circuits provide one and only one path for current flow.*

Parallel Circuit



*Same **VOLTAGE** at all parts of the circuit. Parallel circuits provide multiple paths for current flow.*

PRACTICE QUESTIONS

In which type of circuit is DC current the same through all components?

A. Series
B. Parallel
C. Resonant
D. Branch

T5D13 A 3-2

In which type of circuit is voltage the same across all components?

A. Series
B. Parallel
C. Resonant
D. Branch

T5D14 B 3-2

How is a voltmeter connected to a component to measure applied voltage?

A. In series
B. In parallel
C. In quadrature
D. In phase

T7D02 B 3-2

When configured to measure current, how is a multimeter connected to a component?

A. In series
B. In parallel
C. In quadrature
D. In phase

T7D03 A 3-2

Multimeters

- The basic electrical test instruments are simple meters: voltmeters, ammeters, and ohmmeters
- So that a separate meter isn't needed for each parameter, the *multimeter* was invented
  - Short for "multifunction meter"
  - Measures all three electrical values of voltage, current, and resistance
  - Other names: *VOM* (volt-ohm meter) or *DVM* (digital volt meter)
- Ways meters are damaged …

PRACTICE QUESTIONS

Which of the following can damage a multimeter?

A. Attempting to measure resistance using the voltage setting
B. Failing to connect one of the probes to ground
C. Attempting to measure voltage when using the resistance setting
D. Not allowing it to warm up properly

T7D06 C 3-4

Which of the following measurements are made using a multimeter?

A. Signal strength and noise
B. Impedance and reactance
C. Voltage and resistance
D. All these choices are correct

T7D07 C 3-4

What reading indicates that an ohmmeter is connected across a large, discharged capacitor?

A. Increasing resistance with time
B. Decreasing resistance with time
C. Steady full-scale reading
D. Alternating between open and short circuit

T7D10 A 3-4

Which of the following precautions should be taken when measuring in-circuit resistance with an ohmmeter?

A. Ensure that the applied voltages are correct
B. Ensure that the circuit is not powered
C. Ensure that the circuit is grounded
D. Ensure that the circuit is operating at the correct frequency

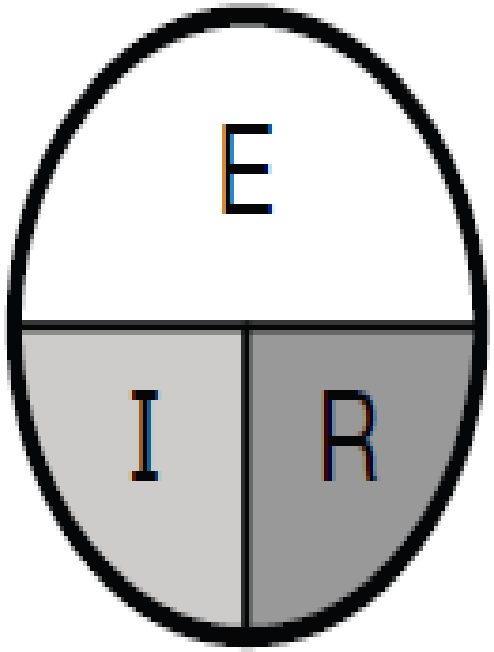
T7D11 B 3-4

Which of the following precautions should be taken when measuring high voltages with a voltmeter?

A. Ensure that the voltmeter has very low impedance
B. Ensure that the voltmeter and leads are rated for use at the voltages to be measured
C. Ensure that the circuit is grounded through the voltmeter
D. Ensure that the voltmeter is set to the correct frequency

T0A12 B 3-4

Ohm's La

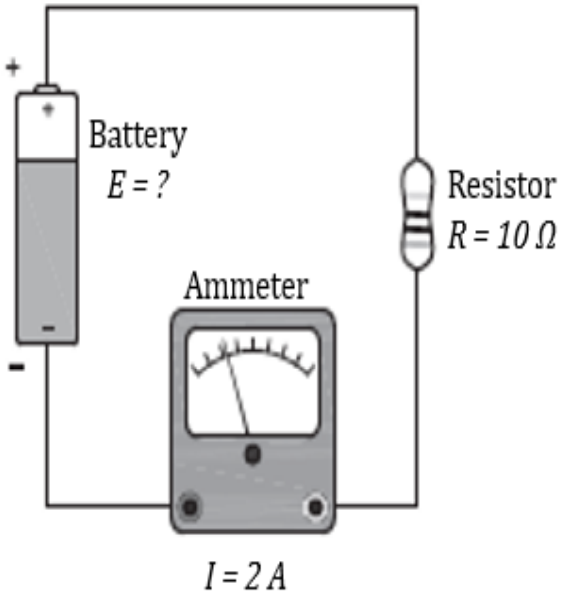


- E represents voltage
  - Units – volts (V)
- I represents current
  - Units – amperes (A)
- R represents resistance
  - Units – ohms (Ω)

R = E / I
I = E / R
E = I x R

Figure 3.5A — Simple diagram to help remember the Ohm's Law. If you know any two of the quantities, the equation to find the third — just cover up the unknown quantity. The positions of the remaining two symbols show if you have to multiply (side-

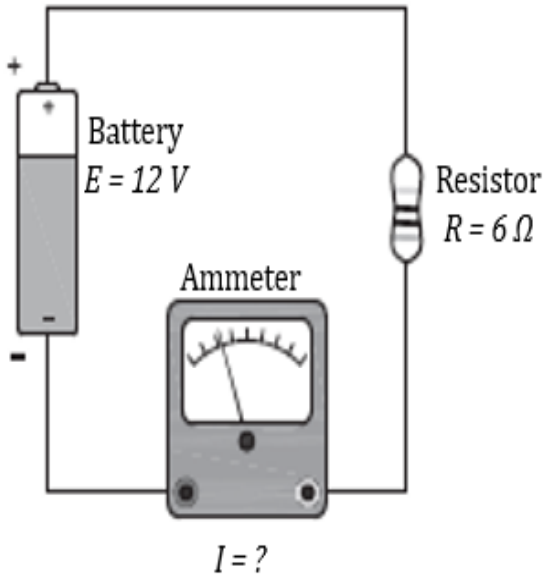
Examples of how to use Ohm's Law



Given I = 2 Amperes
R = 10 Ohms

Find: E (voltage)

E = I × R = 2 × 10 = 20 Volts
Voltage Equals 20 Volts



Given E = 12 Volts
R = 6 Ohms

Find: I (current)

I = E / R = 12 6 = 2 Amps

Current Equals 2 Amperes

More Ohm's Law Examples

What is the resistance of a circuit in which a current of 3 amperes flows when connected to 90 volts?

$$R = E / I = 90\ V / 3\ A = 30\ \Omega$$

What is the current in a circuit with an applied voltage of 120 volts and a resistance of 80 ohms?

$$I = E / R = 120\ V / 80\ \Omega = 1.5\ A$$

What is the voltage across a 2-ohm resistor if a current of 0.5 amperes flows through it?

$$E = I \times R = 0.5\ A \times 2\ \Omega = 1\ V$$

PRACTICE QUESTIONS

What are the units of electrical resistance?

A. Siemens
B. Mhos
C. Ohms
D. Coulombs

T5A04 C 3-5

Why are metals generally good conductors of electricity?

A. They have relatively high density
B. They have many free electrons
C. They have many free protons
D. All these choices are correct

T5A07 B 3-5

Which of the following is a good electrical insulator?

A. Copper
B. Glass
C. Aluminum
D. Mercury

T5A08 B 3-5

What formula is used to calculate current in a circuit?

A. $I = E \times R$

B. $I = E / R$

C. $I = E + R$

D. $I = E - R$

T5D01 B 3-5

What formula is used to calculate voltage in a circuit?

A. E = I x R

B. E = I / R

C. E = I + R

D. E = I – R

T5D02 A 3-5

What formula is used to calculate resistance in a circuit?

A. R = E x I

B. R = E / I

C. R = E + I

D. R = E – I

T5D03 B 3-5

What is the resistance of a circuit in which a current of 3 amperes flows when connected to 90 volts?

A. 3 ohms
B. 30 ohms
C. 93 ohms
D. 270 ohms

T5D04 B 3-6

What is the resistance of a circuit for which the applied voltage is 12 volts and the current flow is 1.5 amperes?

A. 18 ohms
B. 0.125 ohms
C. 8 ohms
D. 13.5 ohms

T5D05 C 3-6

What is the resistance of a circuit that draws 4 amperes from a 12-volt source?

A. 3 ohms
B. 16 ohms
C. 48 ohms
D. 8 ohms

T5D06 A 3-6

What is the current in a circuit with an applied voltage of 120 volts and a resistance of 80 ohms?

A. 9600 amperes

B. 200 amperes

C. 0.667 amperes

D. 1.5 amperes

T5D07 D 3-6

What is the current through a 100-ohm resistor connected across 200 volts?

A. 20,000 amperes
B. 0.5 amperes
C. 2 amperes
D. 100 amperes

T5D08 C 3-6

What is the current through a 24-ohm resistor connected across 240 volts?

A. 24,000 amperes
B. 0.1 amperes
C. 10 amperes
D. 216 amperes

T5D09 C 3-6

What is the voltage across a 2-ohm resistor if a current of 0.5 amperes flows through it?

A. 1 volt

B. 0.25 volts

C. 2.5 volts

D. 1.5 volts

T5D10 A 3-6

What is the voltage across a 10-ohm resistor if a current of 1 ampere flows through it?

A. 1 volt
B. 10 volts
C. 11 volts
D. 9 volts

T5D11 B 3-7

What is the voltage across a 10-ohm resistor if a current of 2 amperes flows through it?

A. 8 volts

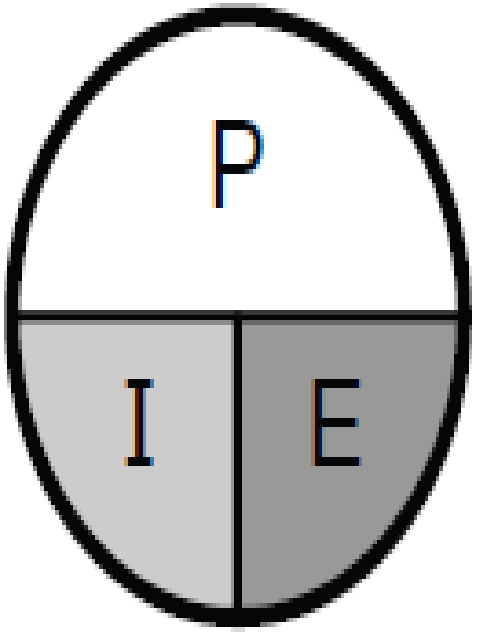
B. 0.2 volts

C. 12 volts

D. 20 volts

T5D12 D 3-7

Power



- *Power*, represented by the symbol P, is the rate at which electrical energy is used
  - Measured in *watts* (W)

$$P = I \times E$$

$$E = P / I$$

$$I = P / E$$

- A device that consumes or dissipates power

Figure 3.5B — Simple diagram to help remember the Ohm's Law. If you know any two of the quantities, the equation to find the third — just cover up the unknown quantity. The positions of the remaining two symbols show if you have to multiply (side-

Example Power Calculations

How much power is delivered by a voltage of 13.8 volts DC and a current of 10 amperes?

$$P = E \times I = 13.8\ V \times 10\ A = 138\ W$$

How much current is required to deliver 120 watts at a voltage of 12 volts DC?

$$I = P / E = 120\ W / 12\ V = 10\ A$$

PRACTICE QUESTIONS

Electrical power is measured in which of the following units?

A. Volts
B. Watts
C. Watt-hours
D. Amperes

T5A02 B 3-7

Which term describes the rate at which electrical energy is used?

A. Resistance
B. Current
C. Power
D. Voltage

T5A10 C 3-7

What is the formula used to calculate electrical power (P) in a DC circuit?

A. $P = I \times E$

B. $P = E / I$

C. $P = E - I$

D. $P = I + E$

T5C08 A 3-7

How much power is delivered by a voltage of 13.8 volts DC and a current of 10 amperes?

A. 138 watts

B. 0.7 watts

C. 23.8 watts

D. 3.8 watts

T5C09 A 3-7

How much power is delivered by a voltage of 12 volts DC and a current of 2.5 amperes?

A. 4.8 watts

B. 30 watts

C. 14.5 watts

D. 0.208 watts

T5C10 B 3-7

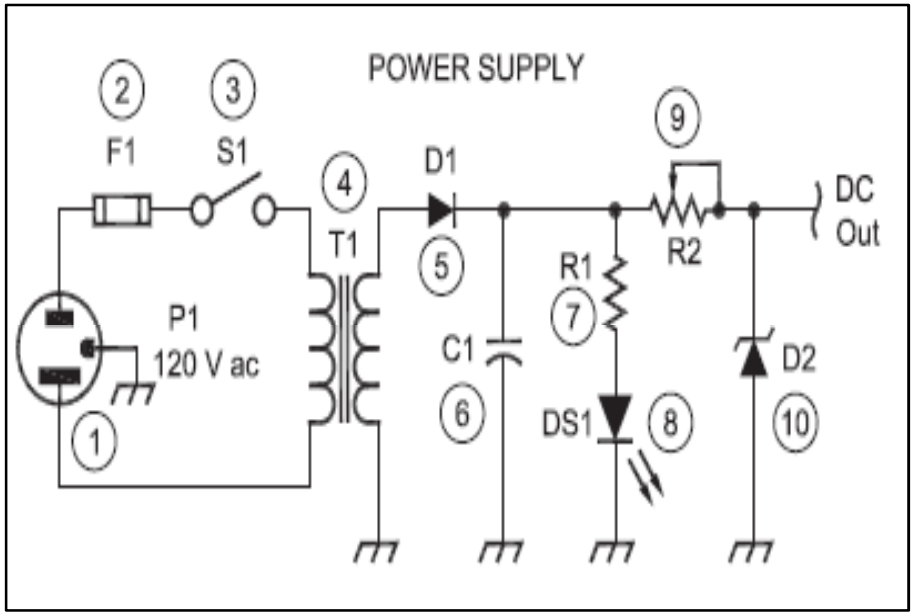
How much current is required to deliver 120 watts at a voltage of 12 volts DC?

A. 0.1 amperes
B. 10 amperes
C. 12 amperes
D. 132 amperes

T5C11 B 3-7

Components and Units

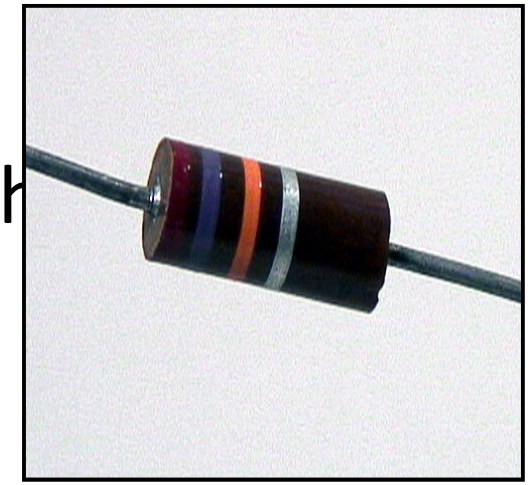
- Components in electrical circuits performs functions such as storing or using energy, routing current, or amplifying signals
- The three most basic types of electronic components are resistors, capacitors and inductors

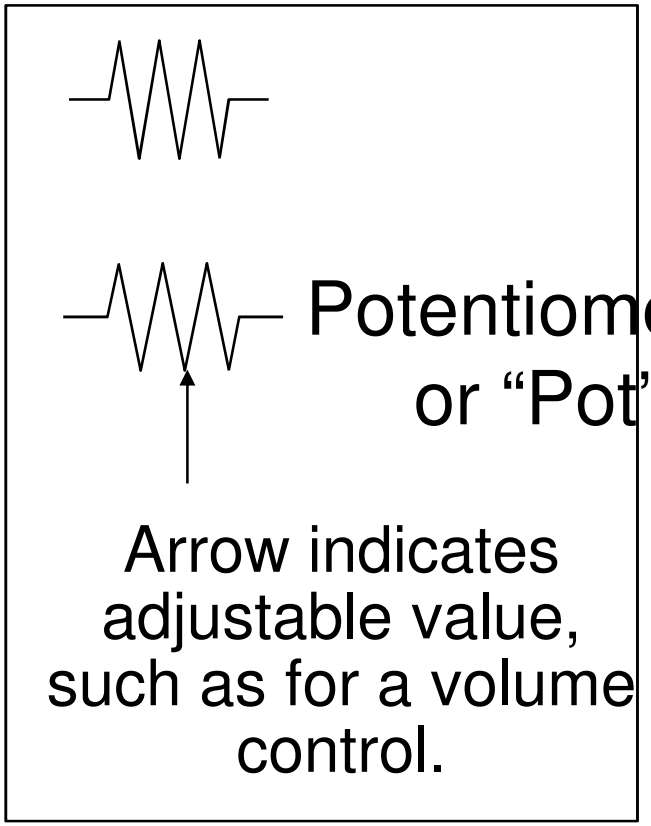


More on schematics later …

Resistors

- Function: To restrict the flow of current, just as a valve in a water pipe restricts the flow through the pipe
- Resistance measured in ohms (**Ω**)
- I = E / R
- E = I x R
- R = E / I





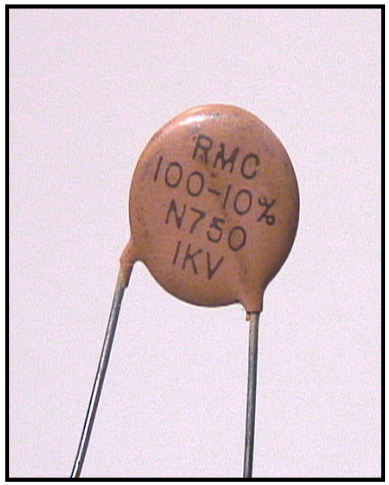
Resistor Schematic

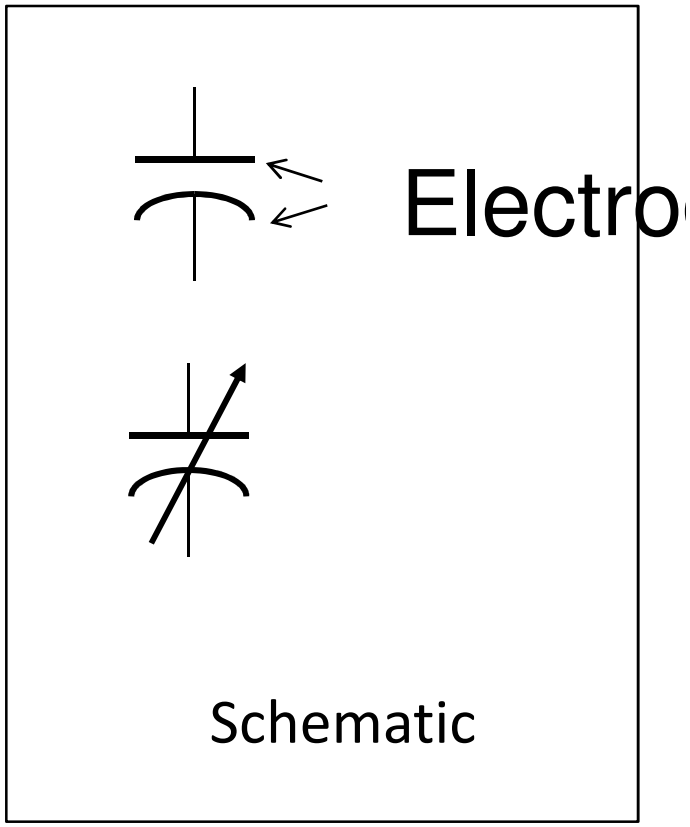
Large Variety of Resistors!

Capacitors

- The function of a capacitor is to store electrical energy – called *capacitance*
- Schematic symbol
- Acts like a battery
- Picture

Stores energy in an electric field created by voltage between the electrodes with insulating dielectric material between

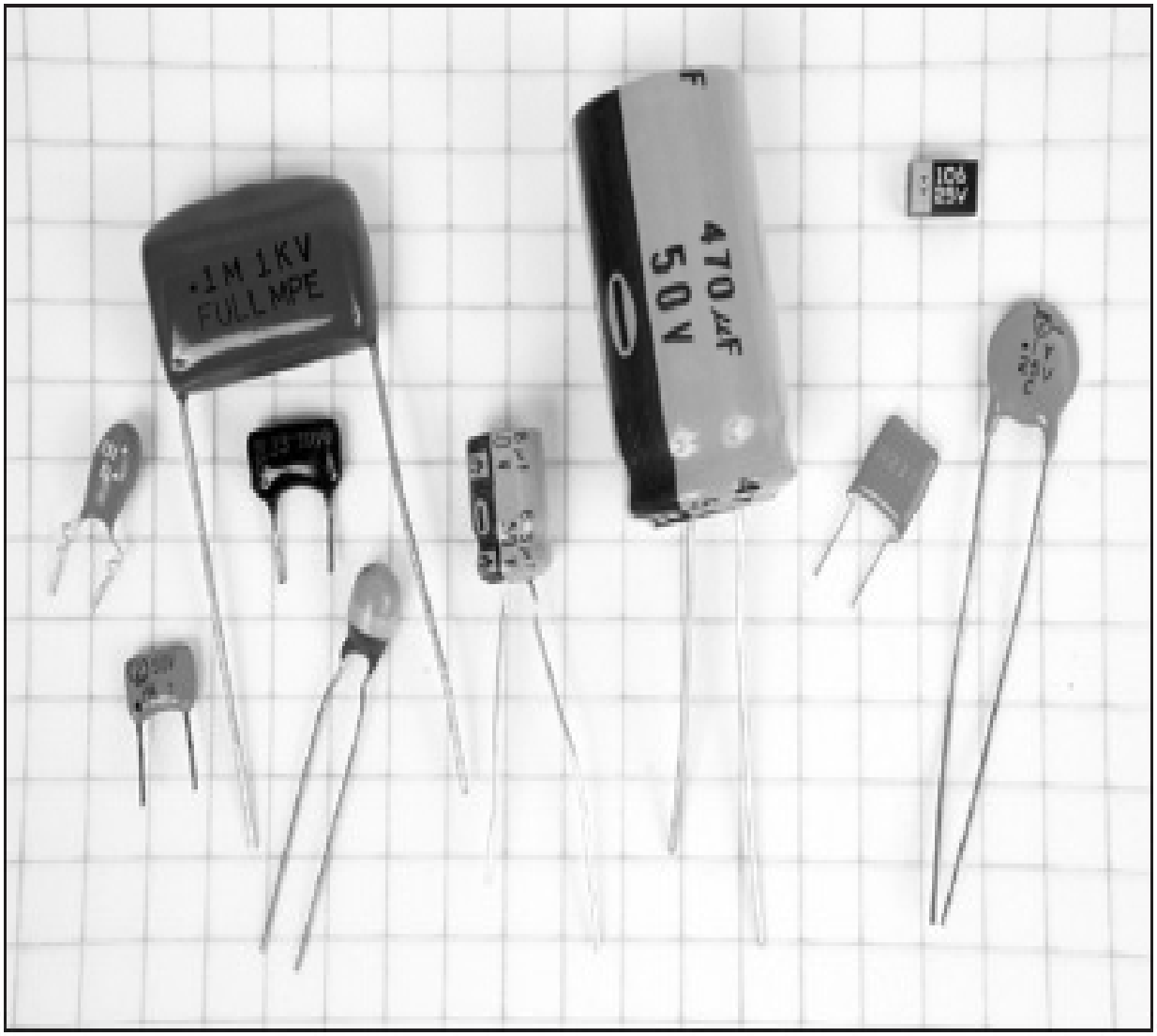




Capacitors (cont.)

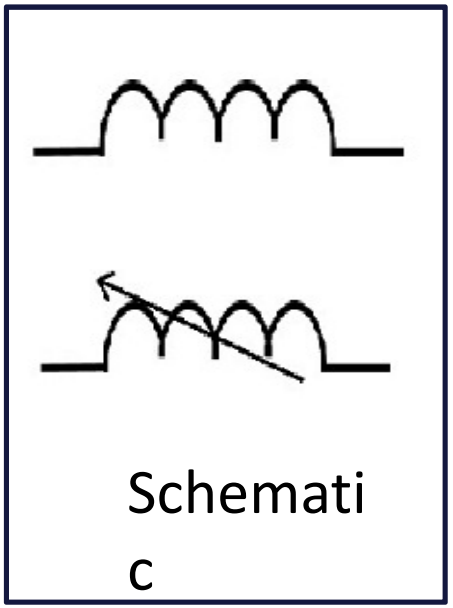
- Store electrical energy in the *electric field* created by a voltage between two conducting surfaces or *electrodes*
- Electrodes are separated by an insulator or *dielectric*
- Storing energy this way is called *capacitance*, and it is measured in *farads* (F)

Large Variety of Capacitors!



Inductors

- Function: To store energy in the magnetic field created by current flowing in a wire
- Called *inductance*, measured in *henrys* (H)
- Made from wire wound in coil, sometimes around a of magnetic material that concentrates the magneti energy



Schemati
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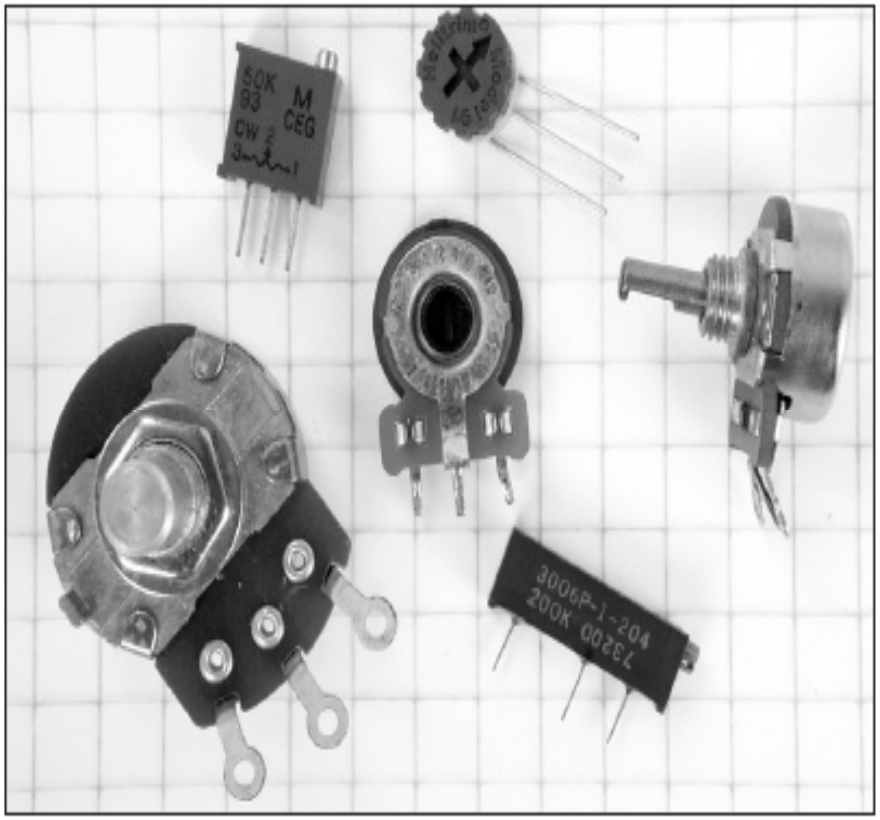
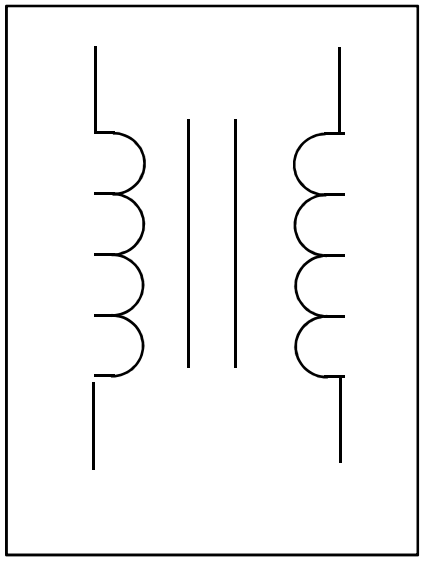
Variable Components

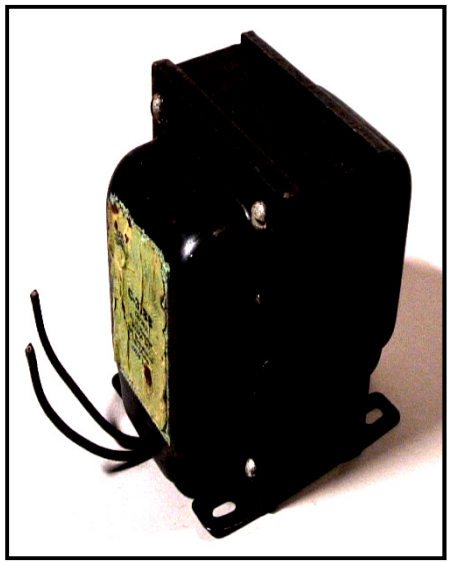
- All three types of basic components are also available as adjustable or variable models
- A variable resistor is also called a *potentiometer*, frequently used to adjust voltage or potential, such as for a



Transformers



- Made from two or more inductors that share their stored energy
- Allows energy to be transferred from one inductor to another while changing the combination of voltage and current
- Example: A transformer is used to transfer energy



PRACTICE QUESTIONS

What describes the ability to store energy in an electric field?

A. Inductance
B. Resistance
C. Tolerance
D. Capacitance

T5C01 D 3-8

What is the unit of capacitance?

A. The farad
B. The ohm
C. The volt
D. The henry

T5C02 A 3-8

What describes the ability to store energy in a magnetic field?

A. Admittance
B. Capacitance
C. Resistance
D. Inductance

T5C03 D 3-8

What is the unit of inductance?

A. The coulomb
B. The farad
C. The henry
D. The ohm

T5C04 C 3-8

What electrical component opposes the flow of current in a DC circuit?

A. Inductor
B. Resistor
C. Inverter
D. Transformer

T6A01 B 3-8

What type of component is often used as an adjustable volume control?

A. Fixed resistor
B. Power resistor
C. Potentiometer
D. Transformer

T6A02 C 3-8

What electrical parameter is controlled by a potentiometer?

A. Inductance
B. Resistance
C. Capacitance
D. Field strength

T6A03 B 3-8

What electrical component stores energy in an electric field?

A. Varistor
B. Capacitor
C. Inductor
D. Diode

T6A04 B 3-8

What type of electrical component consists of conductive surfaces separated by an insulator?

A. Resistor
B. Potentiometer
C. Oscillator
D. Capacitor

T6A05 D 3-8

What type of electrical component stores energy in a magnetic field?

A. Varistor
B. Capacitor
C. Inductor
D. Diode

T6A06 C 3-8

What electrical component is typically constructed as a coil of wire?

A. Switch
B. Capacitor
C. Diode
D. Inductor

T6A07 D 3-8

What component changes 120 V AC power to a lower AC voltage for other uses?

A. Variable capacitor
B. Transformer
C. Transistor
D. Diode

T6D06 B 3-8

Reactance and Impedance

- In a resistor, AC voltages and currents are exactly in step, or *in phase*
- In capacitors and inductors, voltage and current have a *phase difference*
- Capacitors and inductors store energy, rather than dissipating it like resistors
- Energy storage creates an effect called *reactance* (symbol *X*) that acts like a resistance in opposing the flow of AC current
  - Capacitors create capacitive reactance (X_C)
  - Inductors create inductive reactance (X_L)
  - The effects of each are complementary

Reactance and Impedance (cont.)

- The combination of *resistance* (R) and *reactance* (X) is called *impedance*, represented by the symbol Z
- Impedance represents a circuit's *opposition* to both AC and DC currents
- Radio circuits almost always have both resistance and reactance, so impedance is often used as a general term to mean the circuit's opposition to AC current flow

PRACTICE QUESTIONS

What is the unit of impedance?

A. The volt
B. The ampere
C. The coulomb
D. The ohm

T5C05 D 3-10

What is impedance?

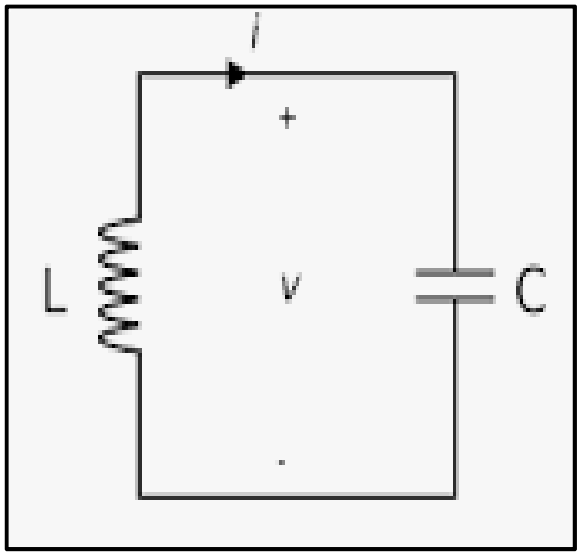
A. The opposition to AC current flow
B. The inverse of resistance
C. The Q or Quality Factor of a component
D. The power handling capability of a component

T5C12 A 3-10

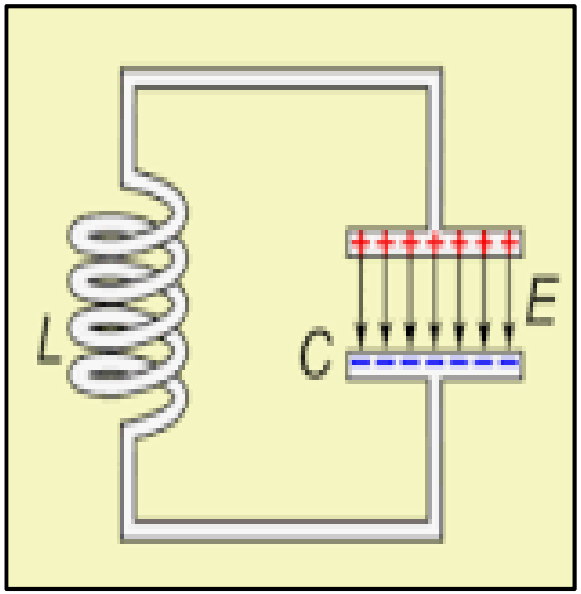
Resonance

- Circuits that contain both a capacitor and an inductor are called *resonant* circuits or *tuned* circuits
- A component's reactance depends on frequency
  - X_L increases with frequency while X_C decreases
- At the frequency for which a circuit's X_L and X_C are *equal*, their effects cancel
  - This is the circuit's *resonant frequency*
- At *resonance*, a circuit has *only resistance*, which affects AC and DC current equally
- A tuned circuit acts as a *filter*, passing or rejecting signals at its resonant frequency

Resonant or Tuned Circuit



- *Capacitors* and *inductors* connected together create a tuned circuit
- When X_L and X_C are equal, the circuit is resonant
- If C or L are adjustable, the resonant frequency can be varied or *tuned*



PRACTICE QUESTIONS

Which of the following is combined with an inductor to make a resonant circuit?

A. Resistor
B. Zener diode
C. Potentiometer
D. Capacitor

T6D08 D 3-10

Which of the following is a resonant or tuned circuit?

A. An inductor and a capacitor in series or parallel
B. A linear voltage regulator
C. A resistor circuit used for reducing standing wave ratio
D. A circuit designed to provide high-fidelity audio

T6D11 A 3-10