Electrical Science - I
(IEC-102)

Lecture-01

Course Overview

Course Objective

To learn systematic methods to analyze a linear electric circuits.

Electric Circuit Analysis: Given an electric circuit, you should be able to solve for various voltages and currents in the circuit.

Need for Analysis

- Majority of engineering systems now have at least one electrical sub system in it.

- So, an understanding of electrical systems is essential to understanding the behavior of many systems.

Background Expected

- Calculus (Solving 1st and 2nd order ODEs)
- Complex Numbers
- Basic notion of charge, current, voltage, resistance, capacitance, inductance etc.
- Basic Electrical Laws

Grading Plan

- Assignments/Quizzes – 15%
- Mid Exam – 35%
- End Semester Exam – 50%

Course Content

- **INTRODUCTION** - Introduction to systems, Linear Systems, Electrical Systems/Circuits, Charge, Current, Voltage, Power, Voltage and current sources, Physical and mathematical representations, Ohm's law, KCL, KVL, Loops and nodes, Series and parallel connections, Voltage and current division.

- **CIRCUIT ANALYSIS** - Nodal analysis, Mesh analysis, super mesh and super node, principles of linearity, superposition, Superposition theorem, Thevenin and Norton theorems and their equivalent circuits, Maximum power transfer theorem, Source transformations, Delta-Wye conversion.

Course Content

- **TIME DOMAIN ANALYSIS** - Capacitor, Inductor and their combinations, Principle of duality, RL and RC Circuits–Transient response (source free response), Introducing forcing functions – step and rectangular pulse, Complete response – Natural and Forced response, Natural response of an RLC circuit, cases of damping, complete response - forced and natural response.

- **SINUSOIDAL STEADY-STATE ANALYSIS** - Sinusoidal and complex force functions and their characteristics, Forced response to sinusoidal functions, Phasor, Impedance, Admittance, Phasor diagrams.

Course Content

- **TWO PORT NETWORKS** - Characterization of a four-terminal network based on its terminal voltages and currents, Two-port parameters – Impedance and Admittance, Relation between Z and Y parameters.

- **FREQUENCY DOMAIN ANALYSIS** - Impedance and admittance in 'S', Nodal and Mesh Analysis in S domain, Poles, Zeros, Transfer functions, Parallel and series resonance, Bode diagrams.

Texts/References

1. Fundamentals of Electric Circuits by Alexander & Sadiku
2. Engineering Circuit Analysis by Hayt, Kemmerly & Durbin
3. Engineering Circuit Analysis by Irwin & Nelms

Office Hours

5:00 – 7:00 pm on Friday

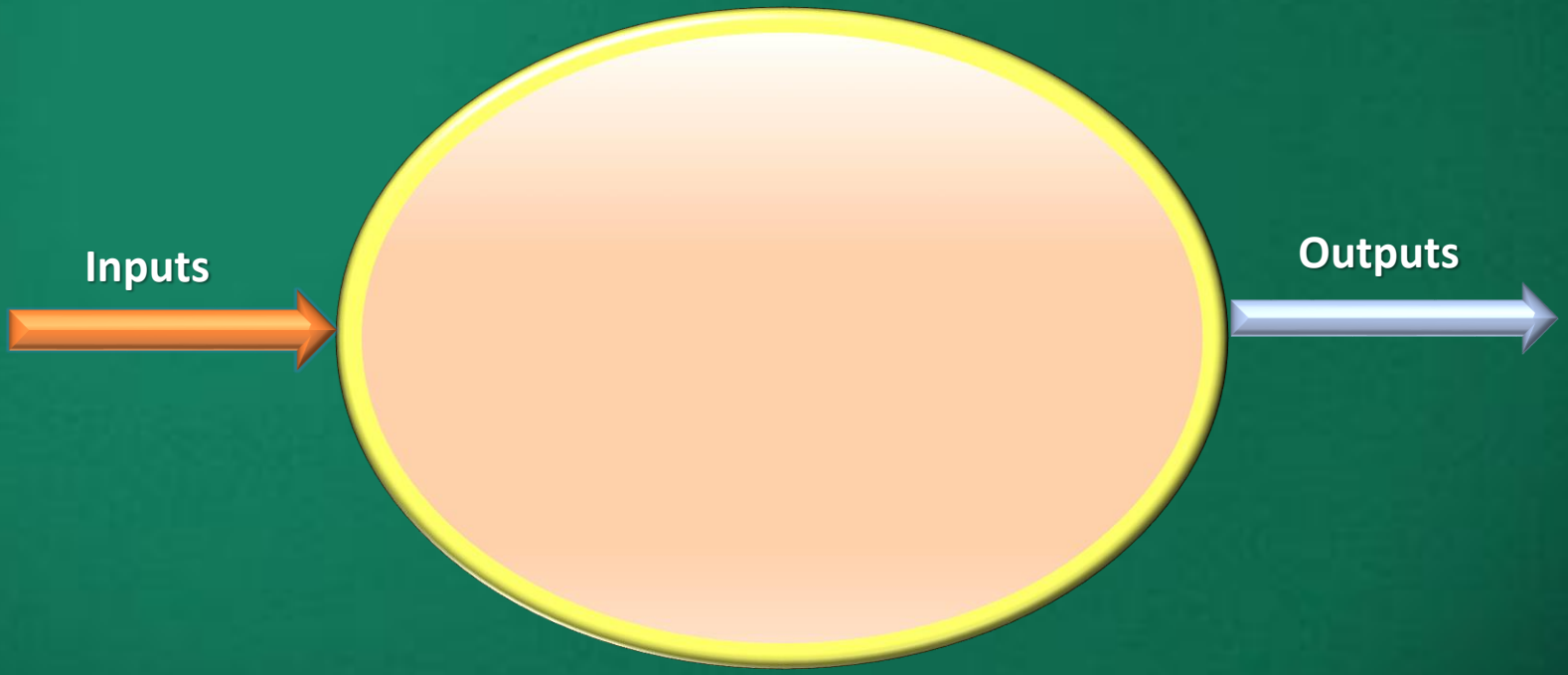
System

- A system is a collection of components which are co-ordinated together to perform a function.

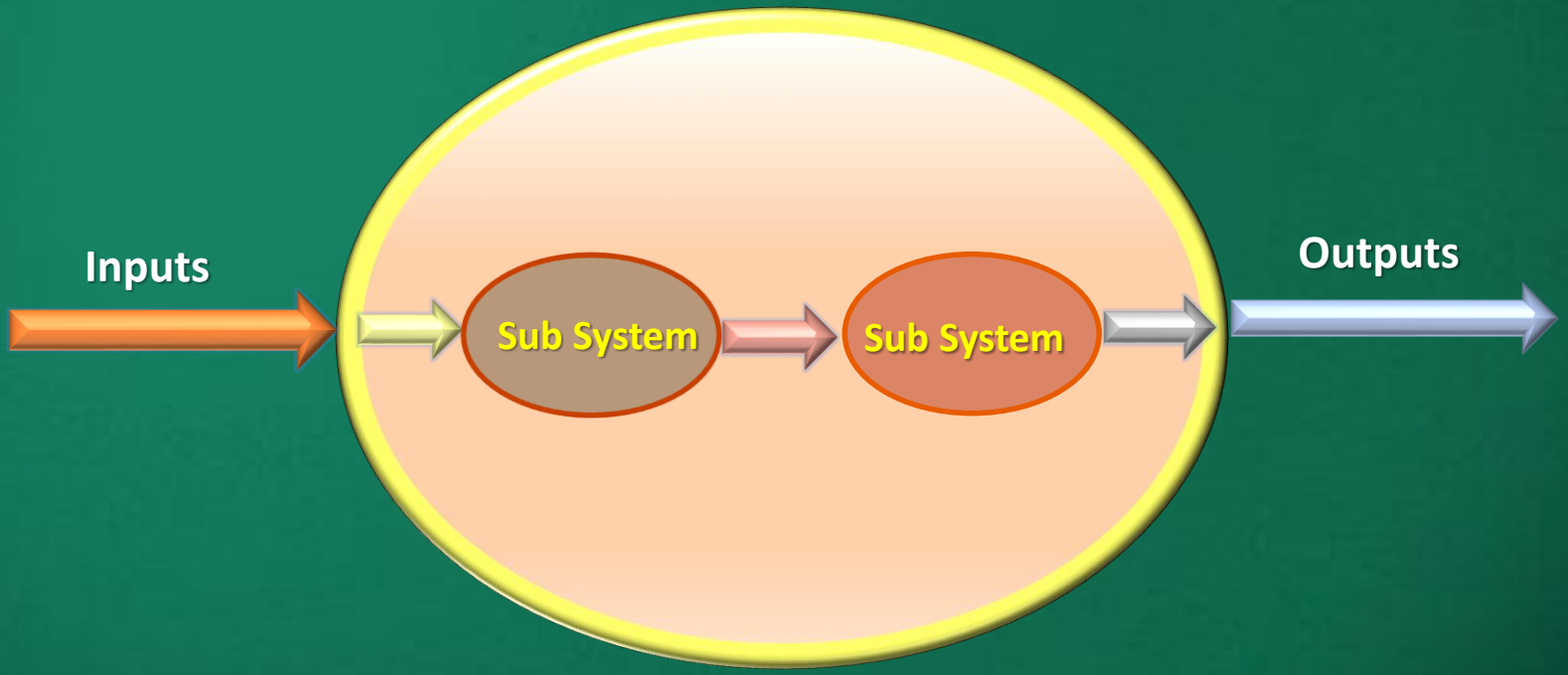
- Systems interact with their environment across a separating boundary.

- The interaction is defined in terms of variables.
  - System inputs
  - System Outputs

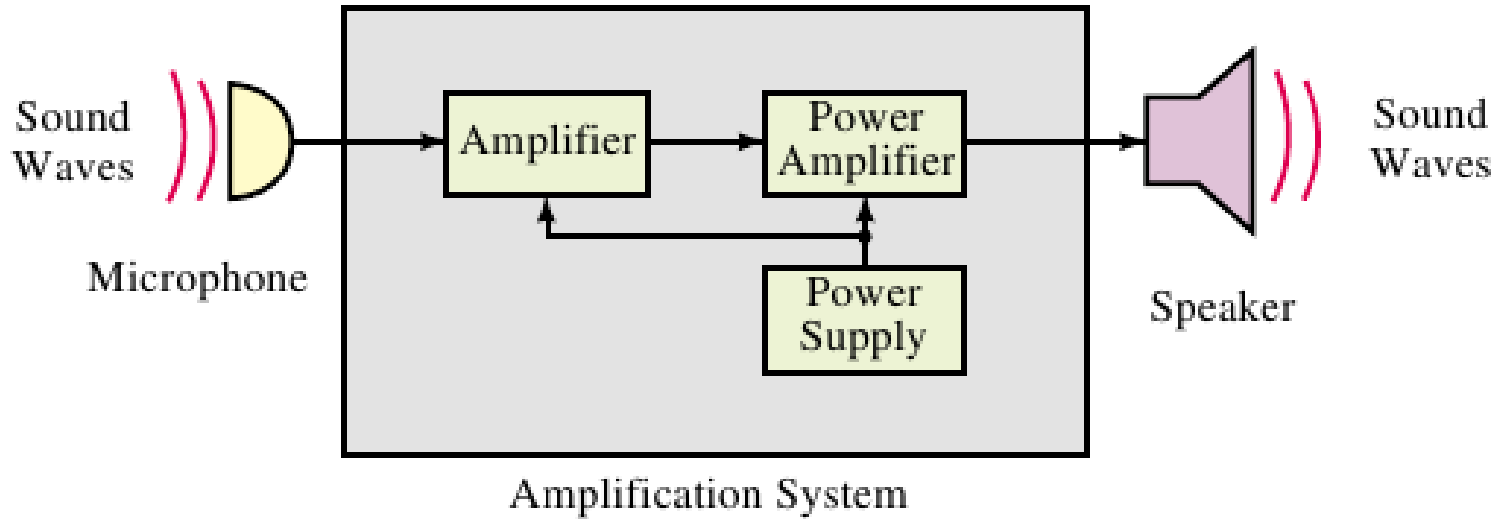
System



System

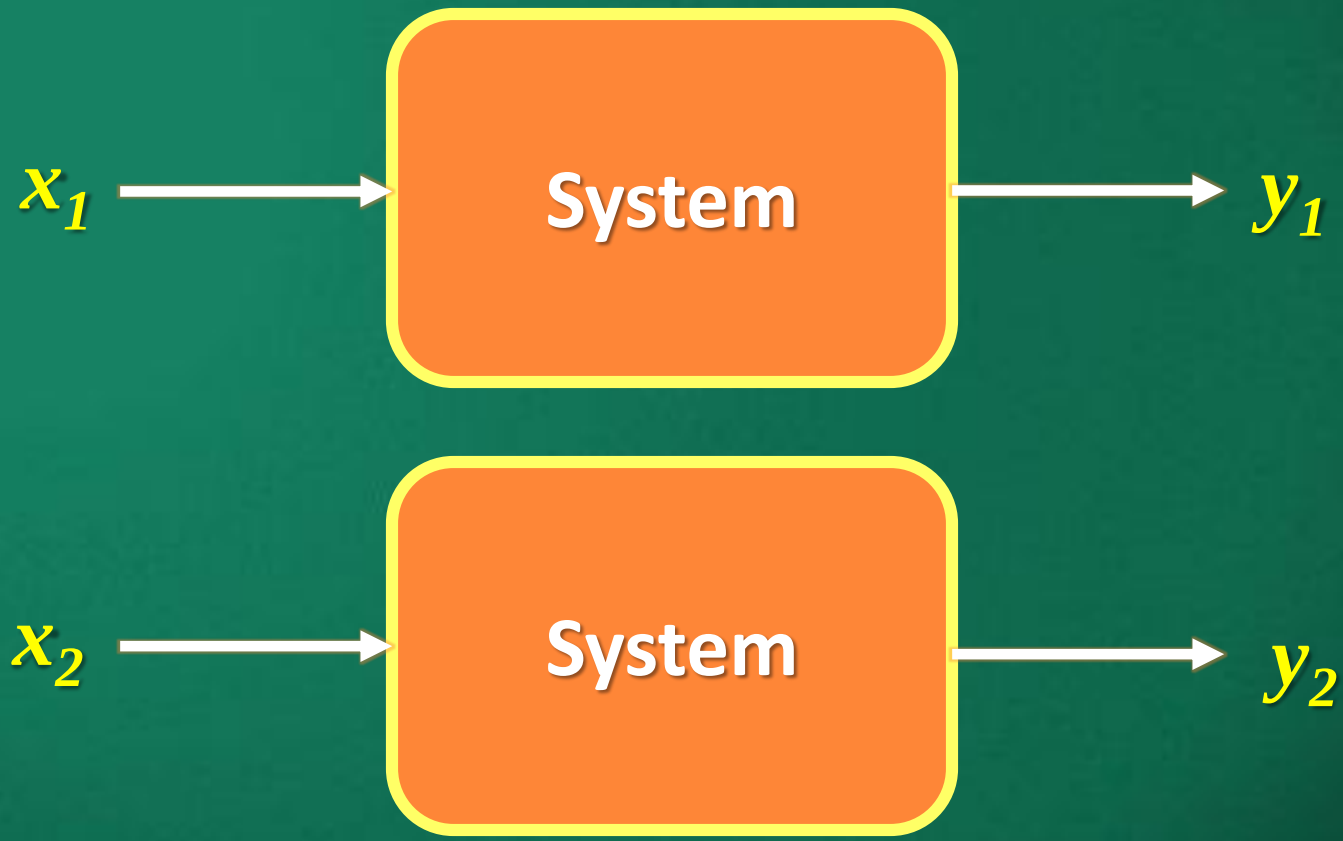


Public Addressing System



Linear Systems

Linear Systems



Linear Systems (Additivity)

Linear Systems (Additivity)

Linear Systems (Homogeneity)

Linear Systems (Homogeneity)

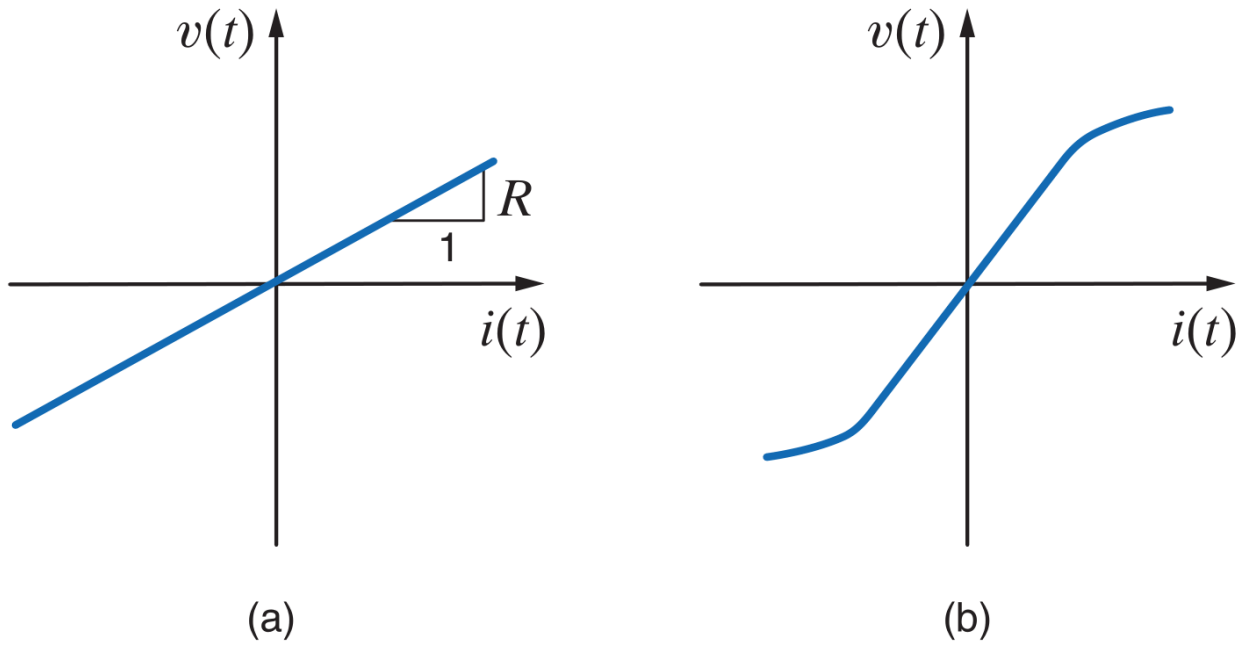
Linear Systems (Linearity Test)

Linear systems

An system which satisfies (passes) both additivity and homogeneity properties is termed as a linear system, otherwise it is termed as a nonlinear system.

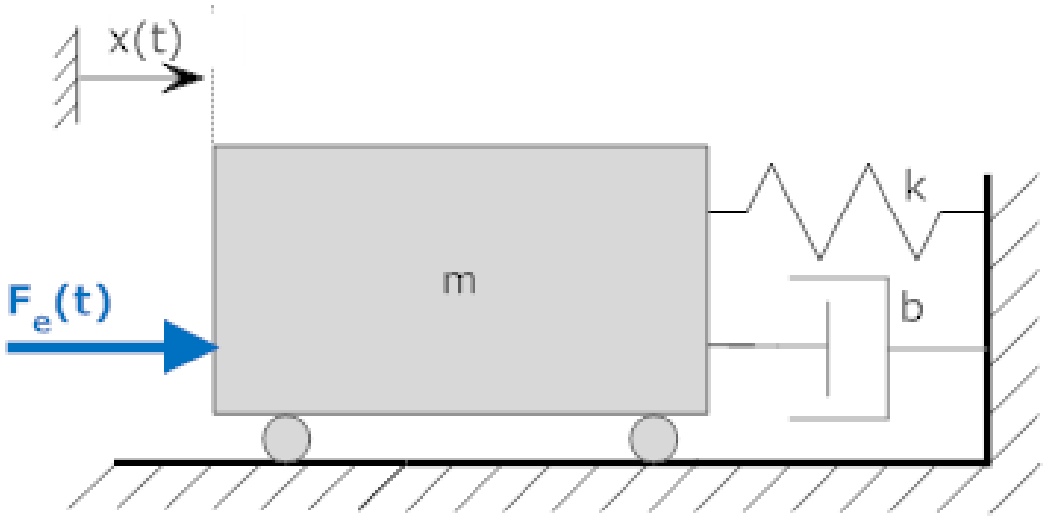
Examples: Resistive Circuit, Mass Spring Systems

Linear Resistor and Light Bulb



v-i characteristics

Spring Mass Damper System



Spring Mass Damper System

Governing Equation

$$F_e = m\frac{d^2x}{dt} + b\frac{dx}{dt} + kx$$

Is the system linear?

Spring Mass Damper System

Input to the system is external force (Fe) & the output is the displacement (x)

Apply linearity test to check.

Spring Mass Damper System

Input to the system is external force (Fe) & the output is the displacement (x)

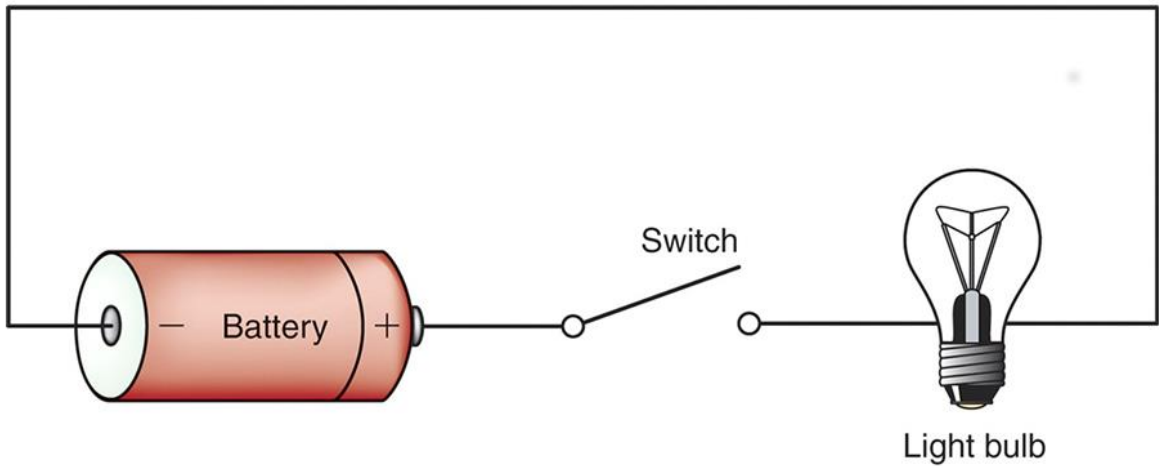
Since both additivity and homogeneity are satisfied the system is linear.

Introduction to Electric Circuits

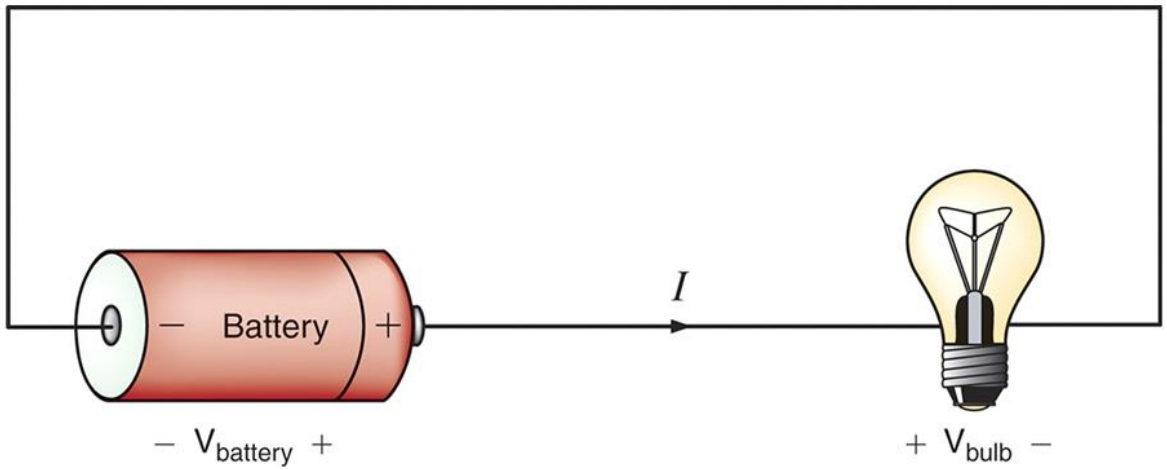
Electric Circuits

An electric circuit is an interconnection of electrical elements.

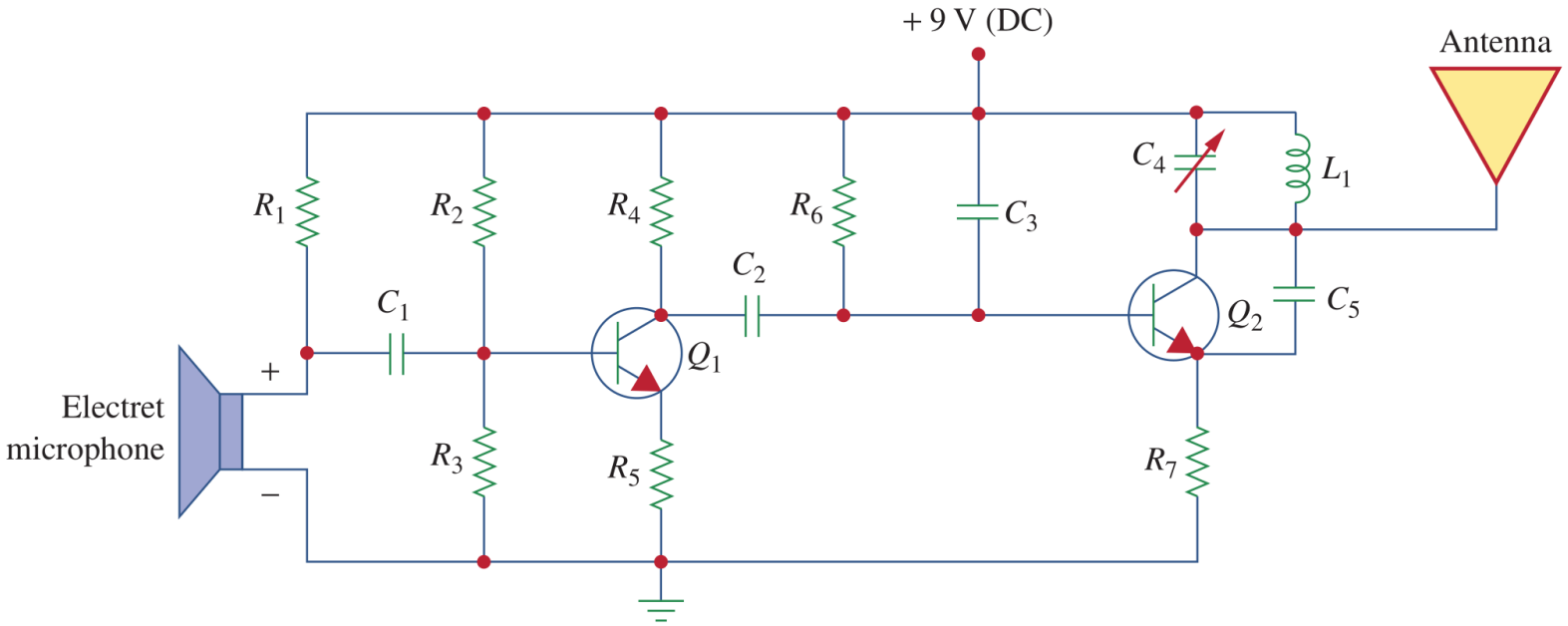
Example (Simple Circuit)



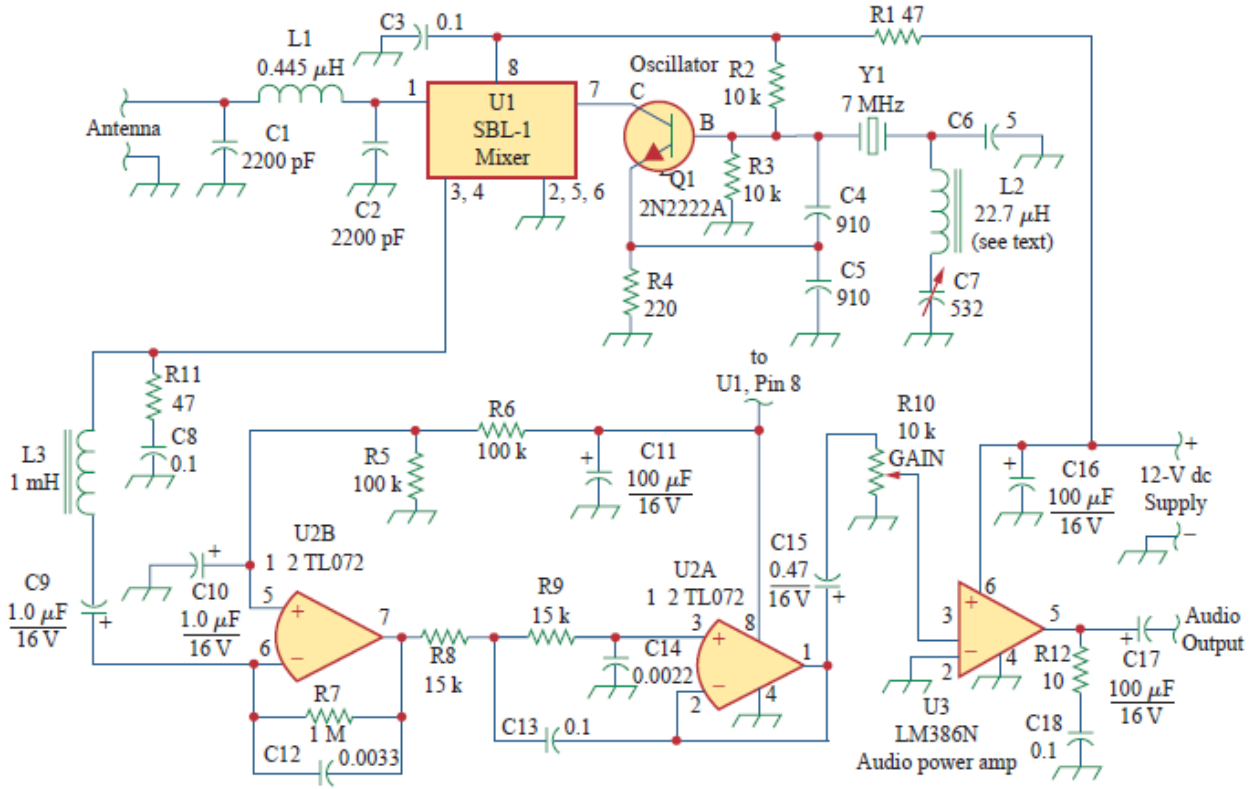
Example (Simple Circuit)



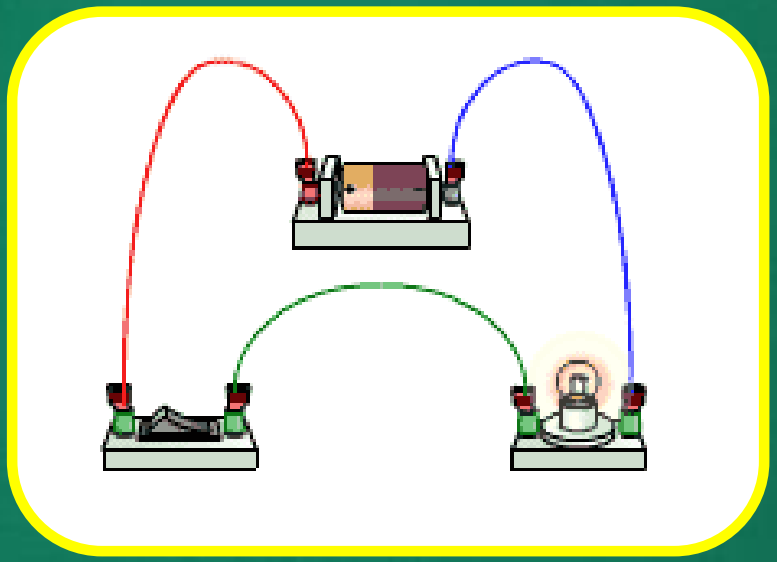
Example (Radio Transmitter Circuit)



Example (Radio Receiver Circuit)



Circuit Representation (Symbols)



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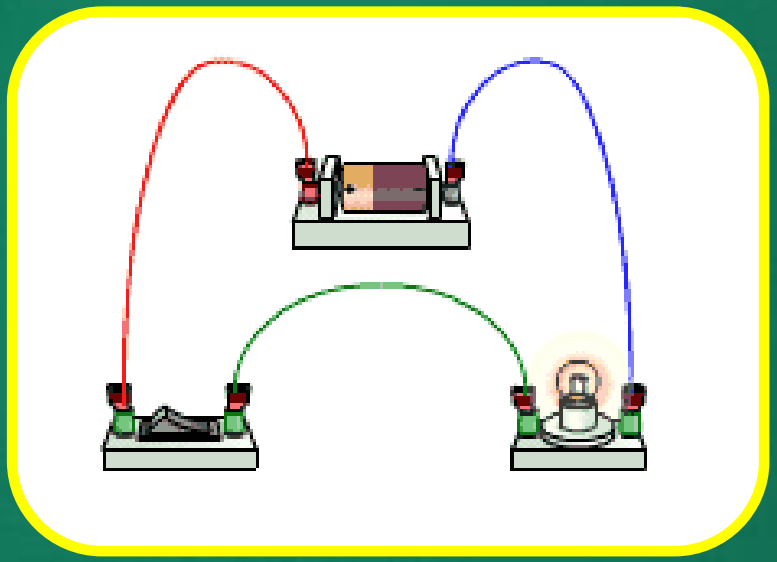

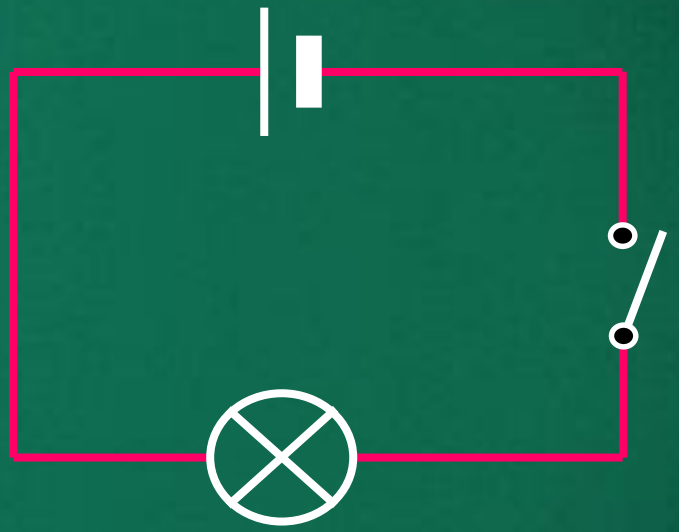

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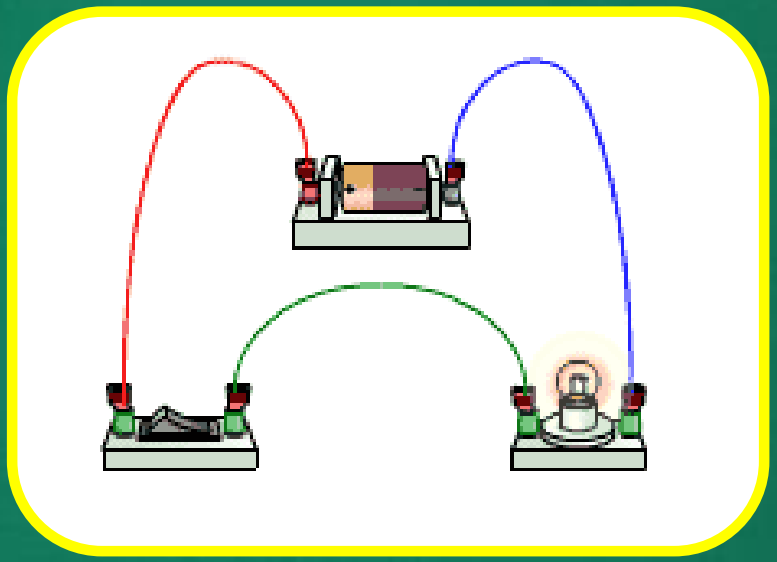

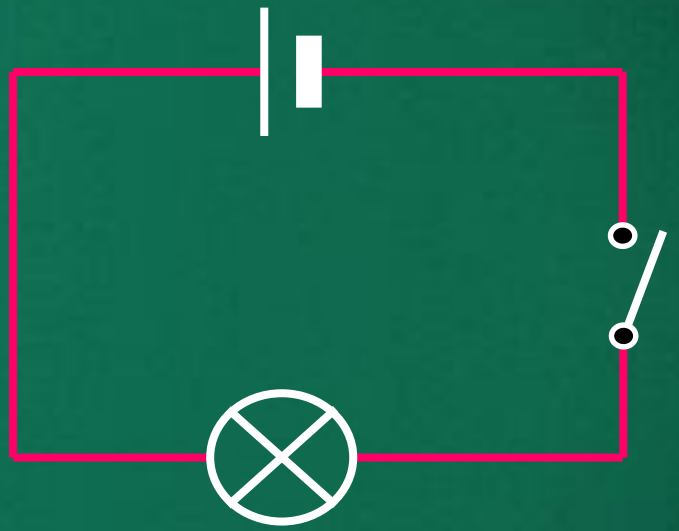

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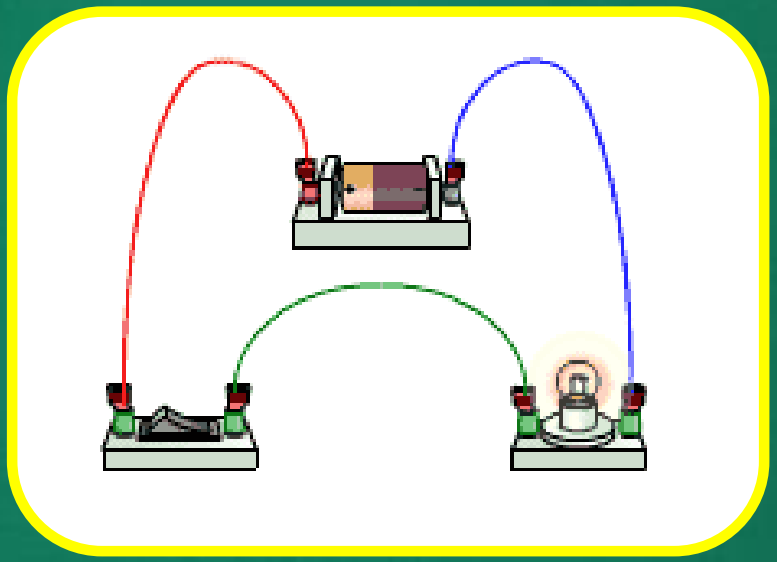
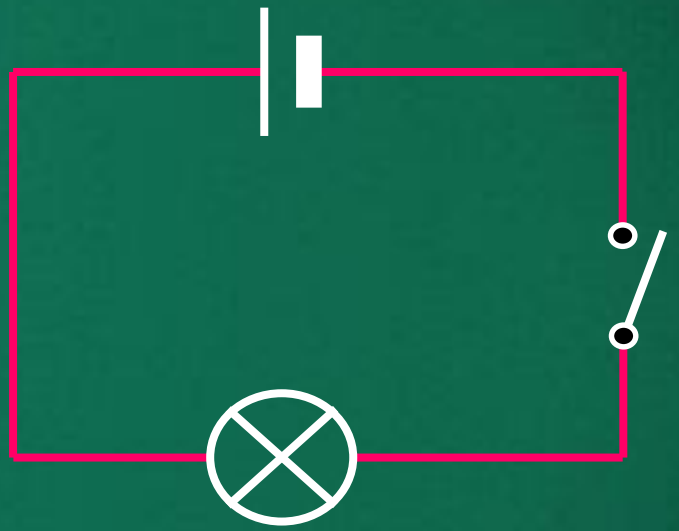




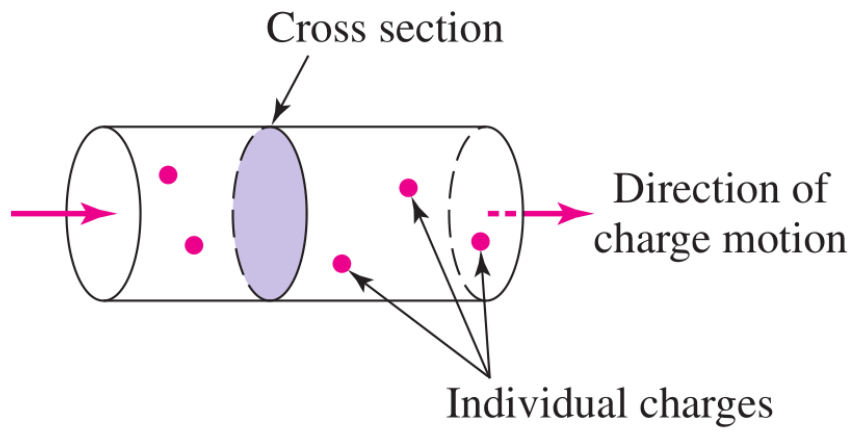
cell

lamp

switch

wires

Current

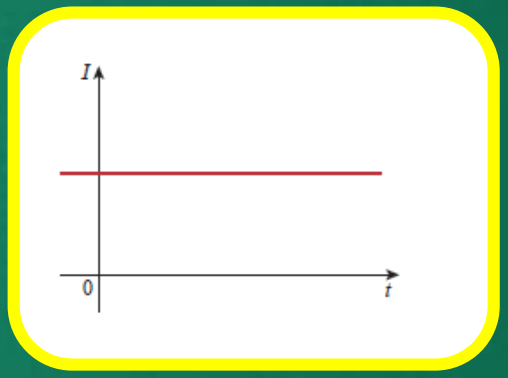


$$i(t) = \frac{dq(t)}{dt}$$

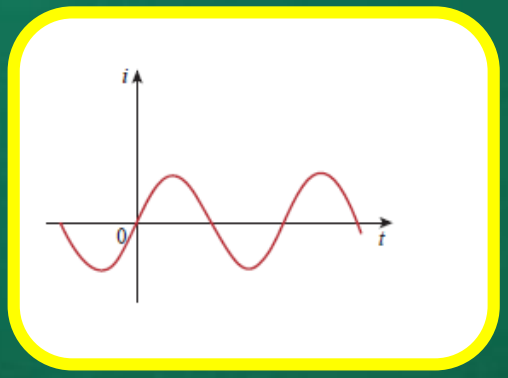
- Unit : Ampere (A)
- Conventional Current – Opposite to electron current
- Through variable
- Associated with direction

DC and AC

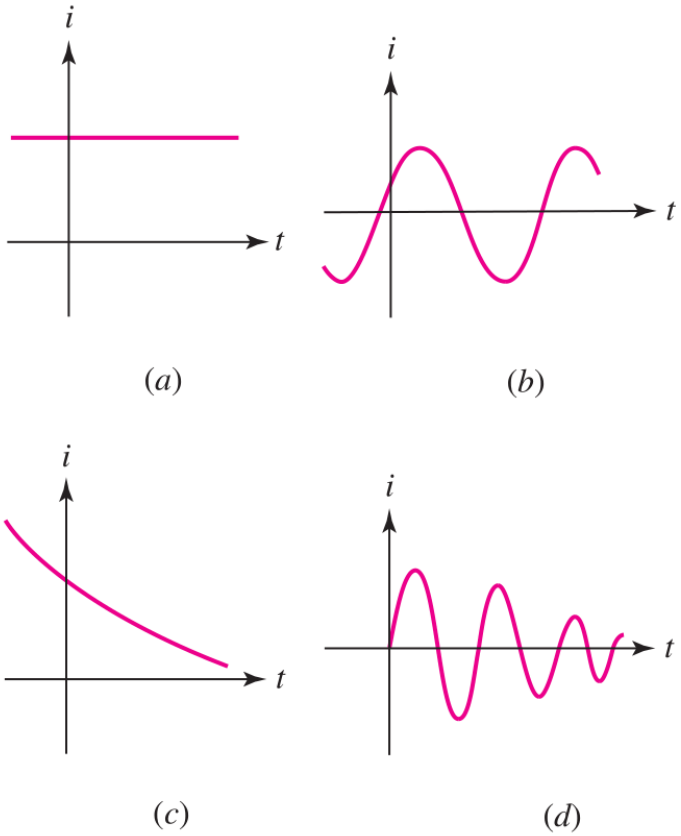
- Direct Current – Current that remains constant with time



- Alternating Current – Current that varies sinusoidally with time

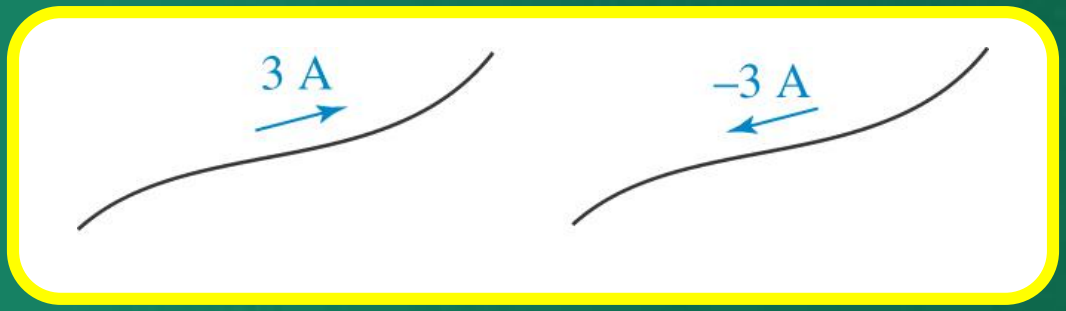


Example

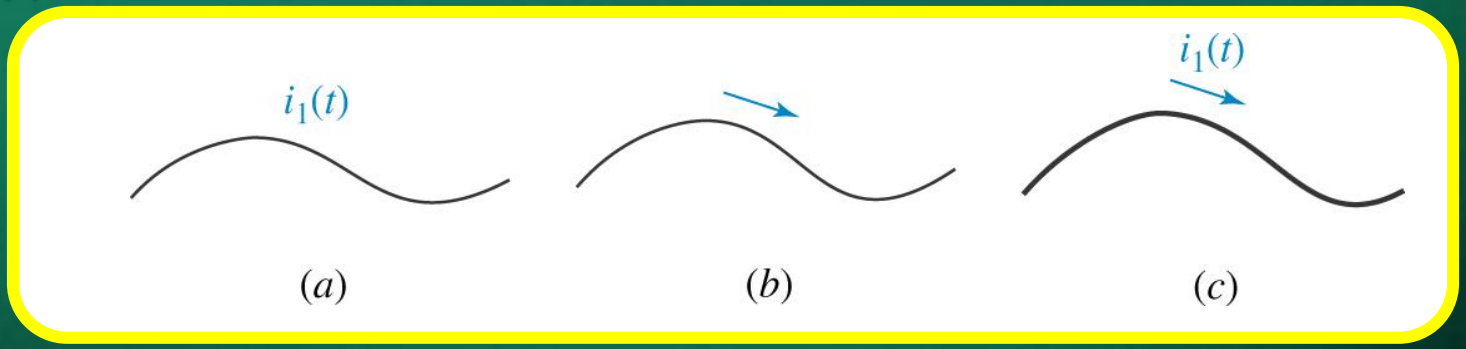


Labelling of Currents

Two different methods of labeling the same current.



(a, b) Incomplete, improper, and incorrect definitions of a current. (c) the correct definition of $i_1(t)$.

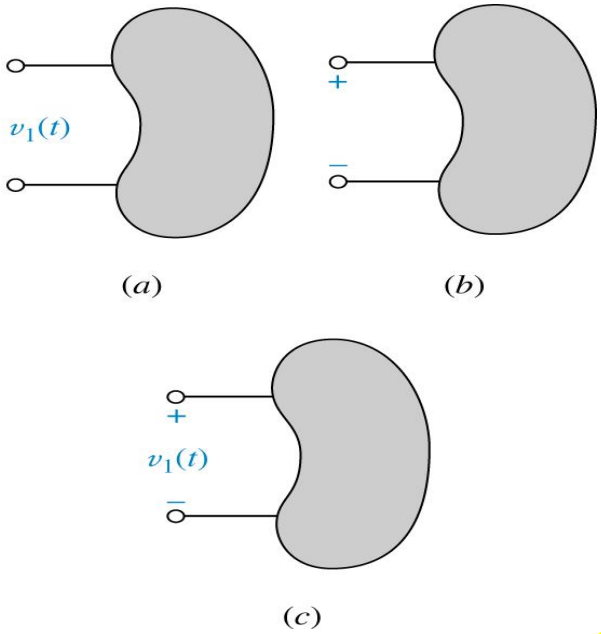


Voltage

$$v_{ab} \triangleq \frac{dw}{dq}$$

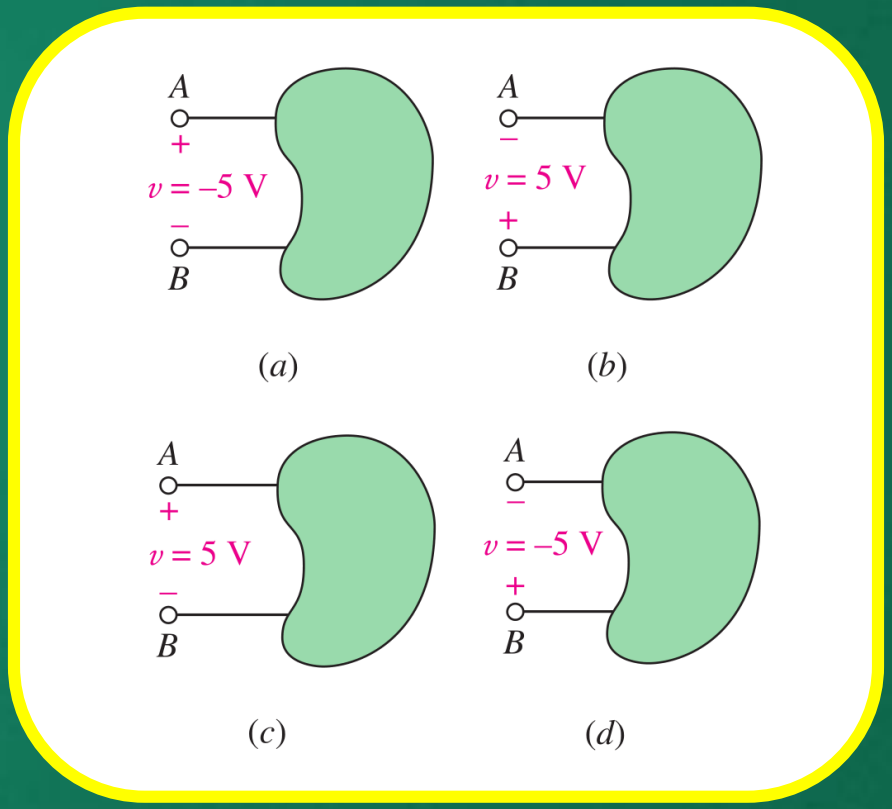
- Voltage or potential difference is the energy required to move a unit charge through an element
- Unit : Volt (V)
- Across variable
- Associated with polarity

Labelling of Voltages



(a, b) These are inadequate definitions of a voltage.
(c) A correct definition includes both a symbol for the variable and a plus-minus symbol pair.

Labelling of Voltages



(a, b) Terminal B is 5 V positive with respect to terminal A; (c, d) terminal A is 5 V positive with respect to terminal B.

Power

Power – Time rate of expending or absorbing energy

$$p \triangleq \frac{dw}{dt}$$

It is measured in watts (W)

Power in terms of v & i

$$p \triangleq \frac{dw}{dt}$$

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$$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt}$$

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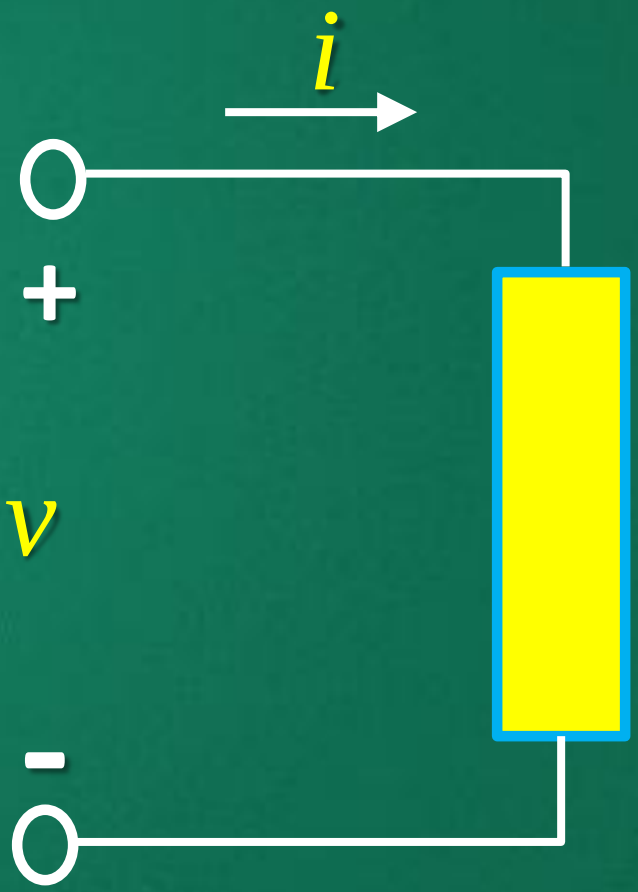
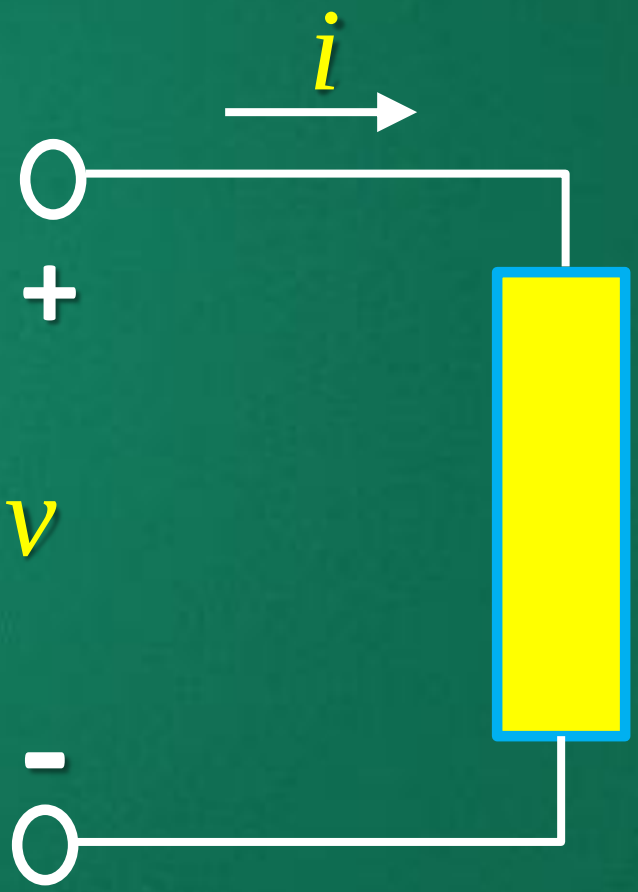
$$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt}$$

$$\Longrightarrow \quad p = v \cdot i$$

Reference Polarities for Power

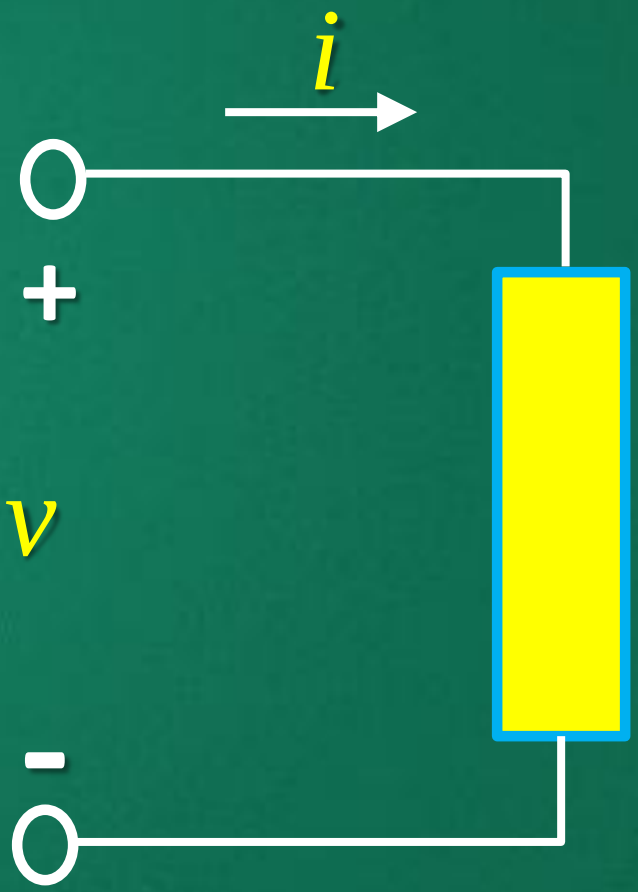


Reference Polarities for Power



Power absorbed by the element $p = vi$

Reference Polarities for Power



Power absorbed by the element $p = vi$

Power supplied by the element $p = -vi$

Passive Sign Convention

Passive sign convention is satisfied when the current enters through the positive terminal of an element and $p = +vi$. If the current enters the negative terminal, $p = -vi$.

+Power absorbed = -Power supplied

Energy

Energy – Capacity to do work

Energy

Energy – Capacity to do work

Measured in joules (J)

Energy

Energy – Capacity to do work

Measured in joules (J)

$$w = \int_{t_0}^{t} p(t)\,dt = \int_{t_0}^{t} v(t)i(t)\,dt$$

Tellegen's Theorem

Algebraic sum of power in a circuit at any instant of time is zero.

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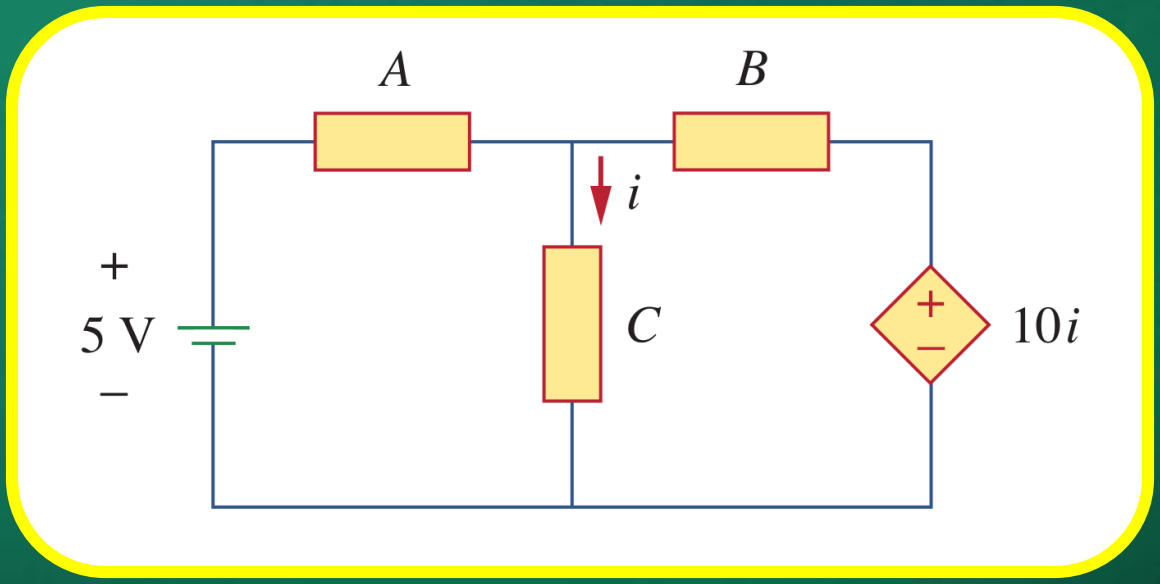
Algebraic sum of power in a circuit at any instant of time is zero.

$$\sum p(t) = 0$$

Circuit Analysis

An electric circuit is an interconnection of elements and circuit analysis is the process of determining voltages across (or currents through) the elements of the circuit.



Circuit Elements

Two types of elements

- Passive elements
- Active elements

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An active element is capable of generating energy whereas a passive element is not.

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Examples of passive elements – Resistors, Capacitors, and inductors.

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Two types of elements

- Passive elements
- Active elements

An active element is capable of generating energy whereas a passive element is not.

Examples of passive elements – Resistors, Capacitors, and inductors.

Examples of active elements – generators, batteries, and operational amplifiers.

Active Elements (Sources)

Most important active elements are voltage sources and current sources.

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Most important active elements are voltage sources and current sources.

Two kinds of sources

- ❑ Independent sources
- ❑ Dependent sources

Ideal Independent Source

An ideal independent source is an active element that provides a specified voltage or current that is completely independent of other circuit elements.

Independent Voltage Source

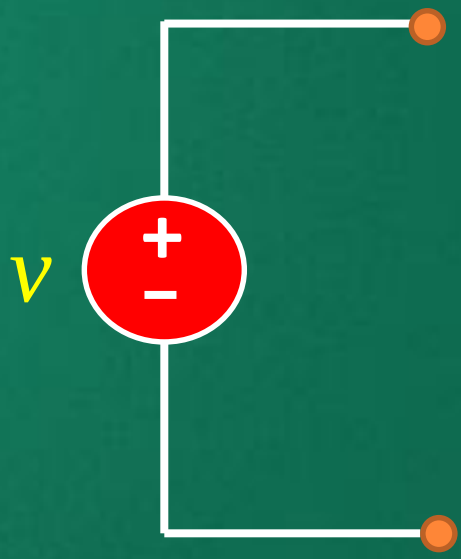
It maintains its rated terminal voltage irrespective of the current it delivers to other part of the circuit.

Independent Voltage Source

It maintains its rated terminal voltage irrespective of the current it delivers to other part of the circuit.

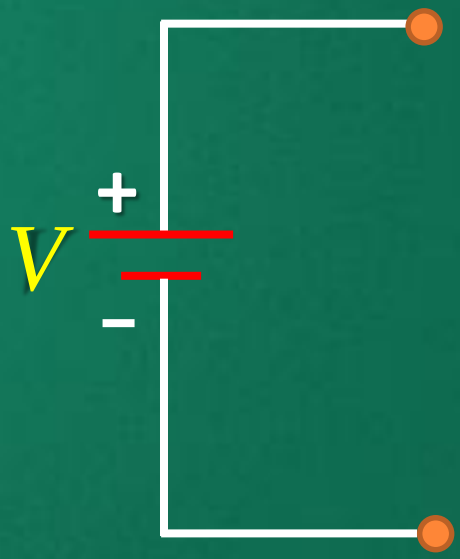
Physical sources such as batteries and generators may be regarded as approximations to independent voltage sources.

Symbols for Independent Voltage Sources



Constant or time varying independent voltage source

Symbols for Independent Voltage Sources



Constant voltage source

Independent Current Source

An ideal independent current source is an active element that provides a specified current completely independent of the voltage across the source.

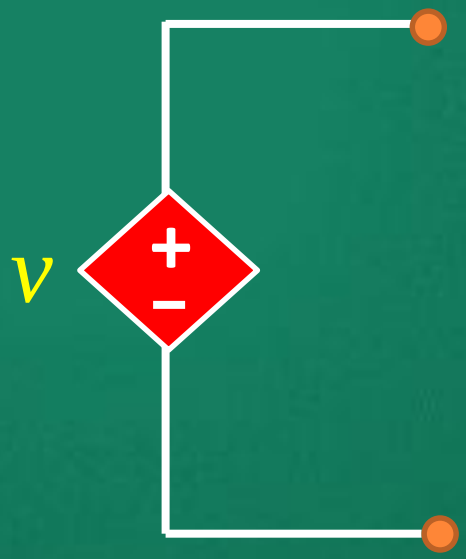
Symbol for Independent Current Source

Independent current source

Ideal Dependent Source

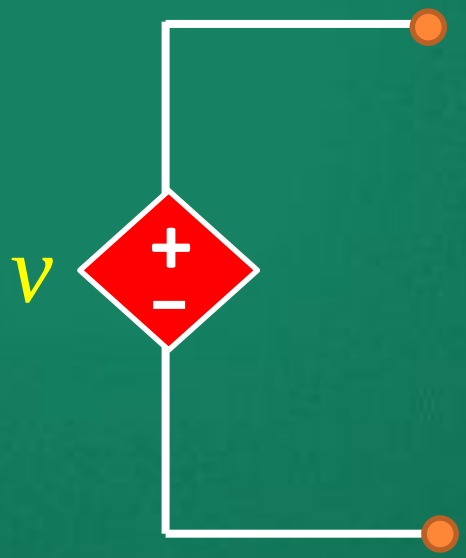
An ideal dependent (or controlled) source is an active element in which the source quantity is controlled by another voltage or current.

Symbols for Dependent Sources

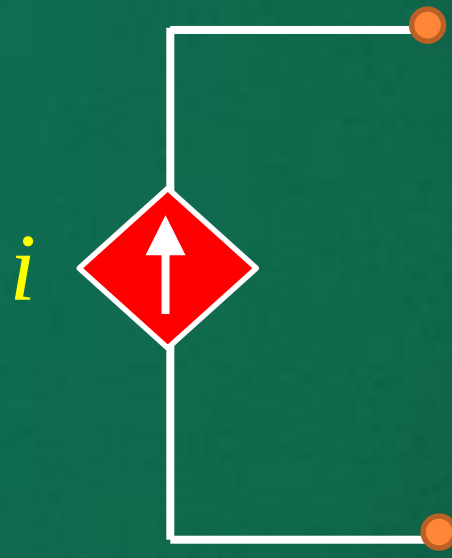


Dependent voltage source

Symbols for Dependent Sources



Dependent voltage source



Dependent current source

Types of Dependent Source

4 types of dependent sources

1. **Voltage-controlled voltage source** (VCVS)
2. **Current-controlled voltage source** (CCVS)
3. **Voltage-controlled current source** (VCCS)
4. **Current-controlled current source** (CCCS)

Types of Dependent Source

4 types of dependent sources

1. **Voltage-controlled voltage source** (VCVS)
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3. **Voltage-controlled current source** (VCCS)
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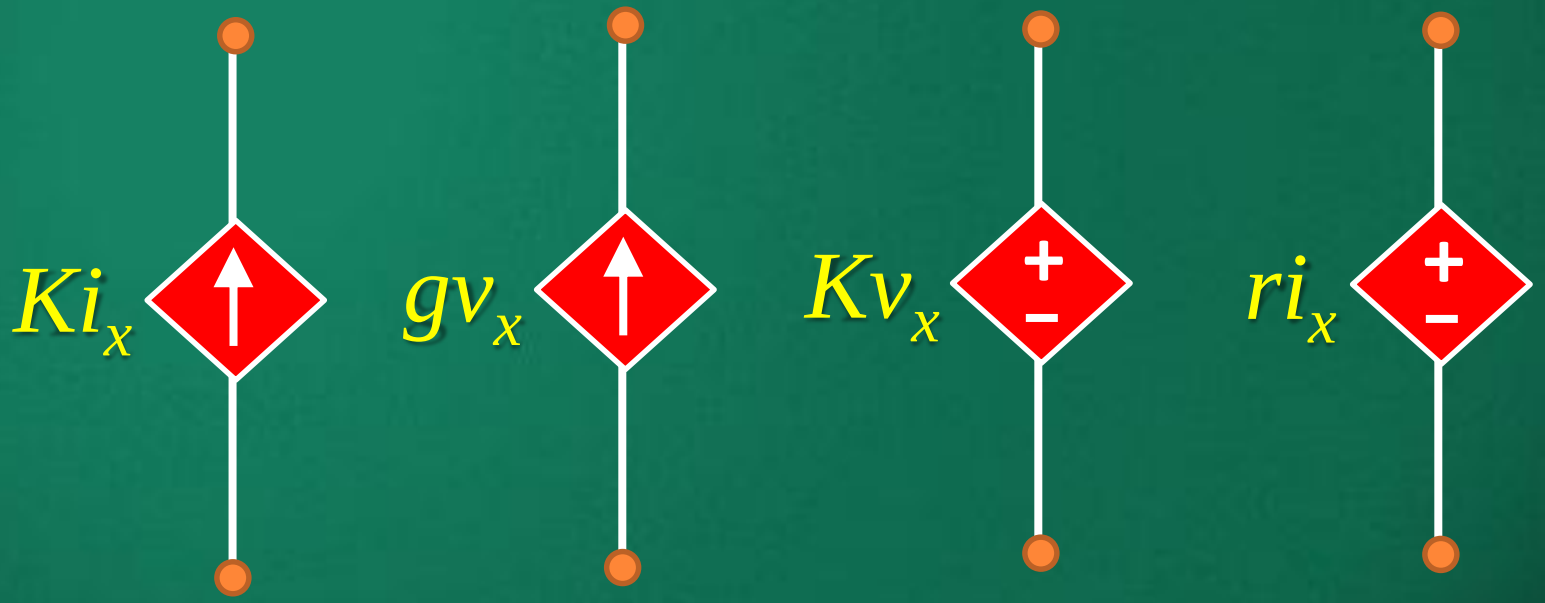
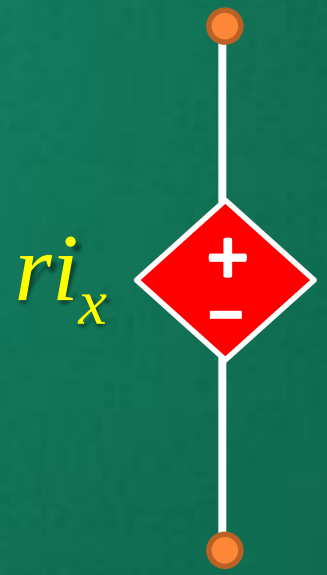
Dependent sources are useful in modeling transistors, operational amplifiers, and integrated circuits.

Dependent Sources



Voltage Controlled Voltage Source (VCVS)

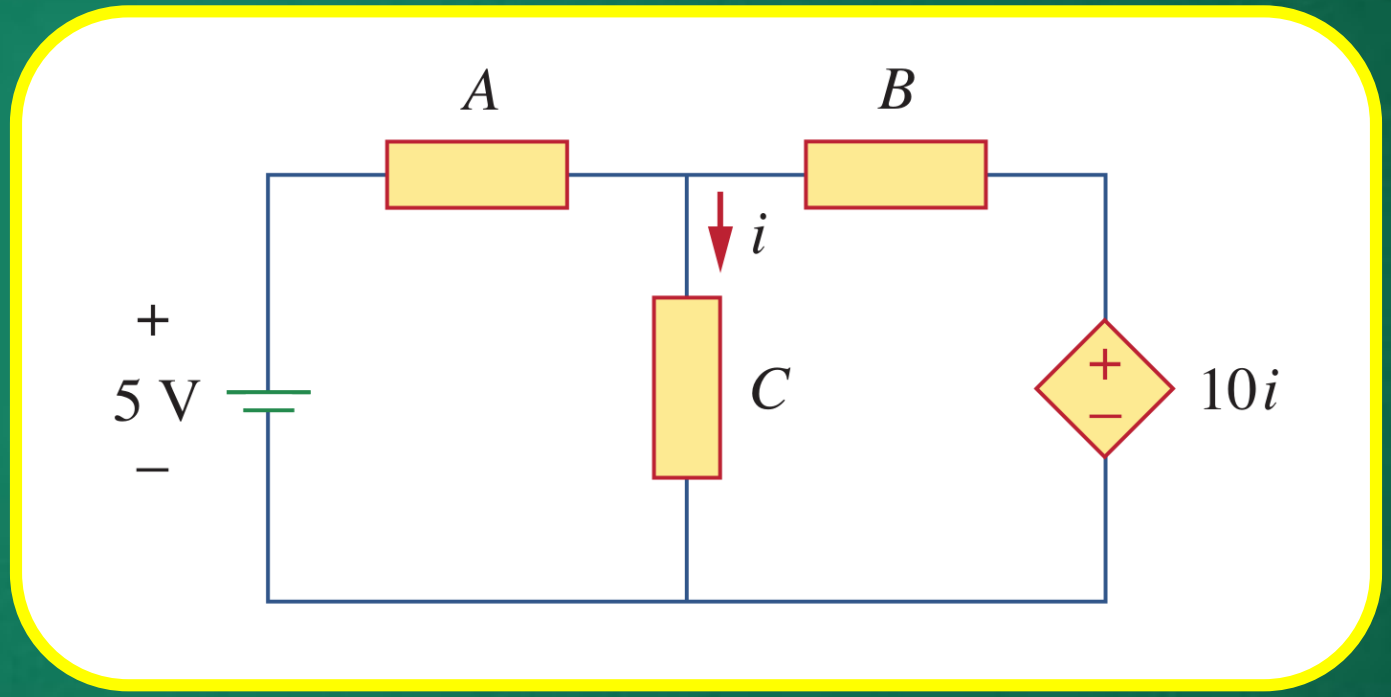
Current Controlled Voltage Source (CCVS)



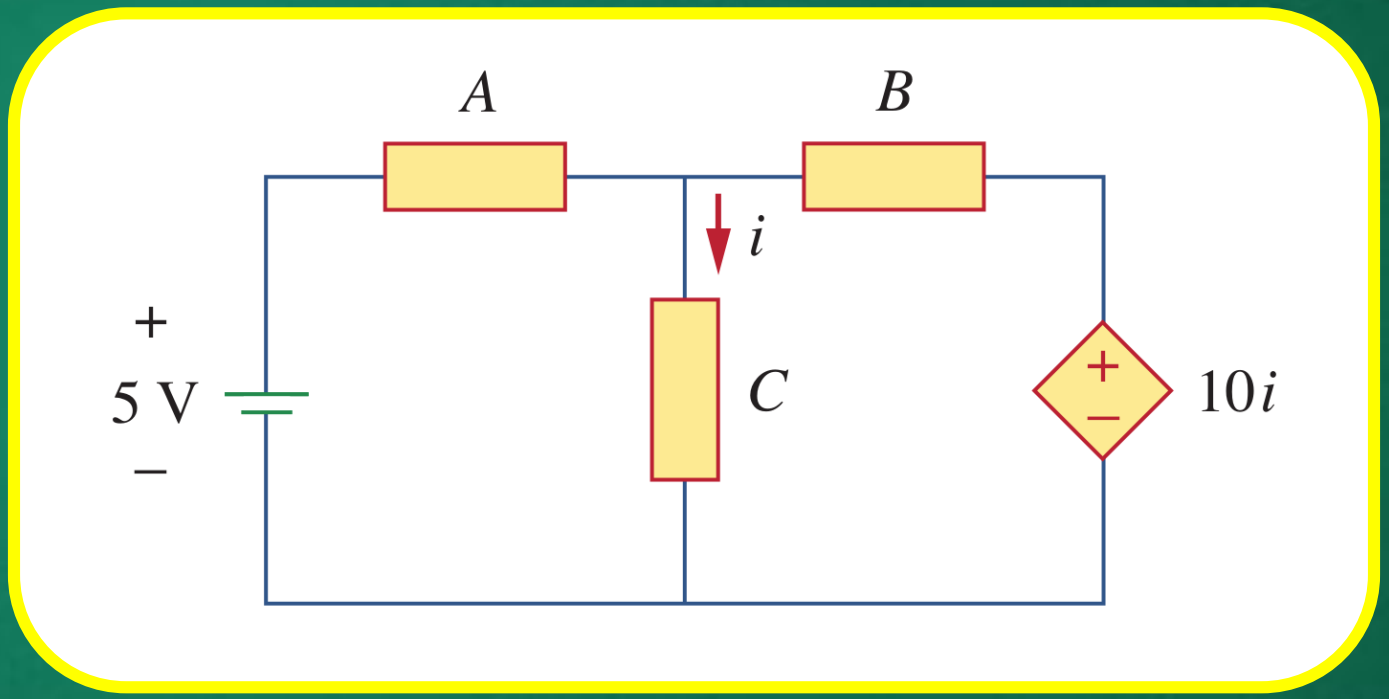
Voltage Controlled Current Source (VCCS)

Current Controlled Current Source (CCCS)

Circuit containing CCVS



Circuit containing CCVS



The voltage in the dependent voltage source is controlled by the current through the element 'C'.

Passive Elements

Circuit elements which can either dissipate or store energy are called passive elements.

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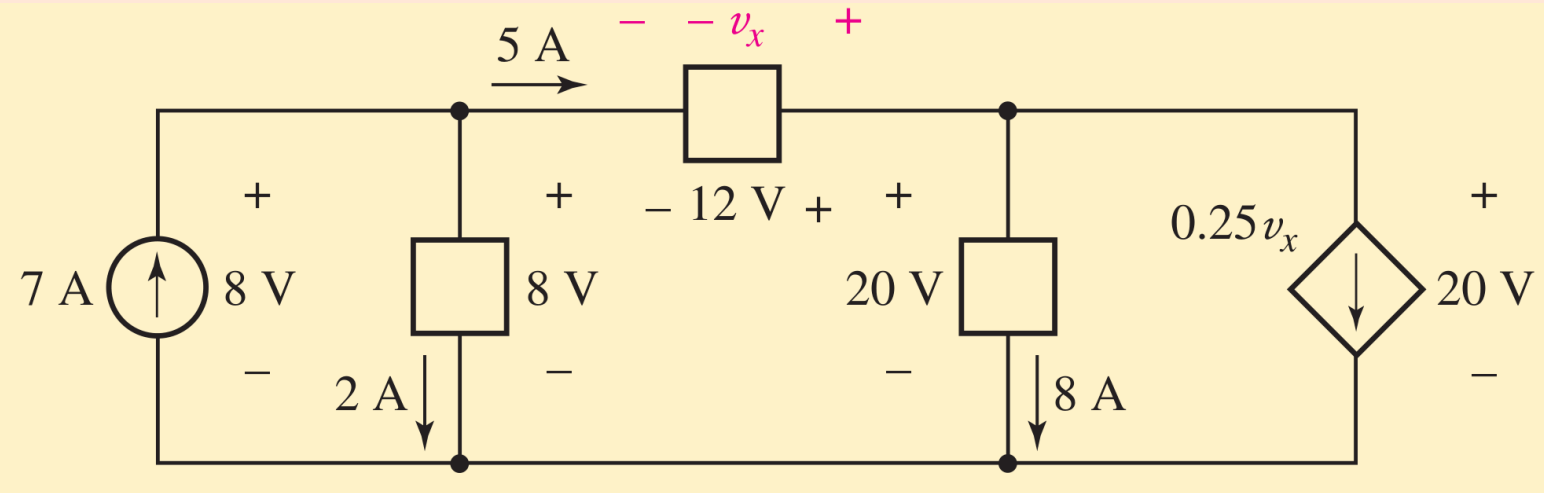
Example: Resistors, Capacitor, and Inductors.

Problem

Find power absorbed in each element of the circuit.



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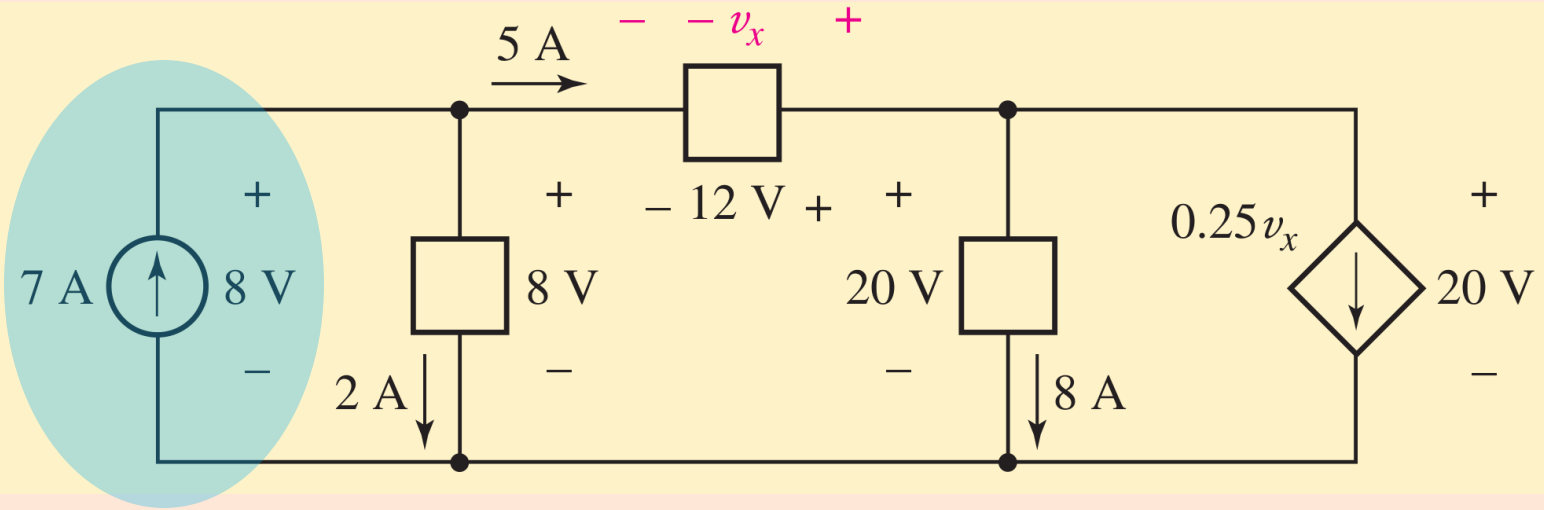
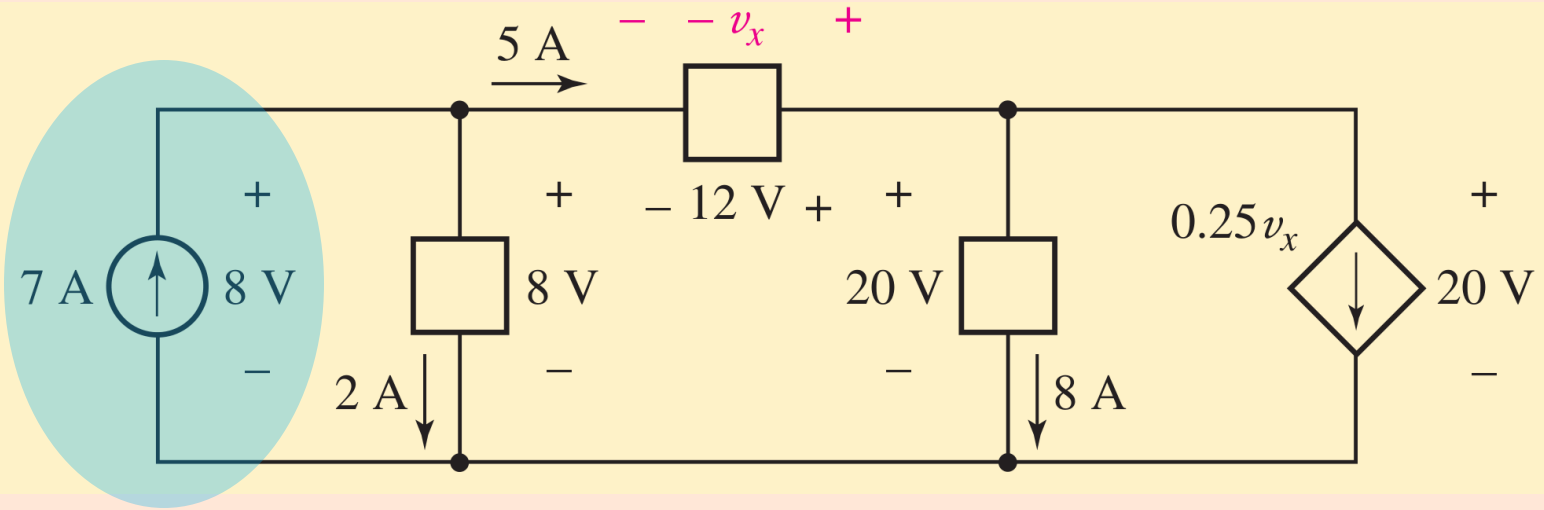


Ans: (From left to right)

Problem

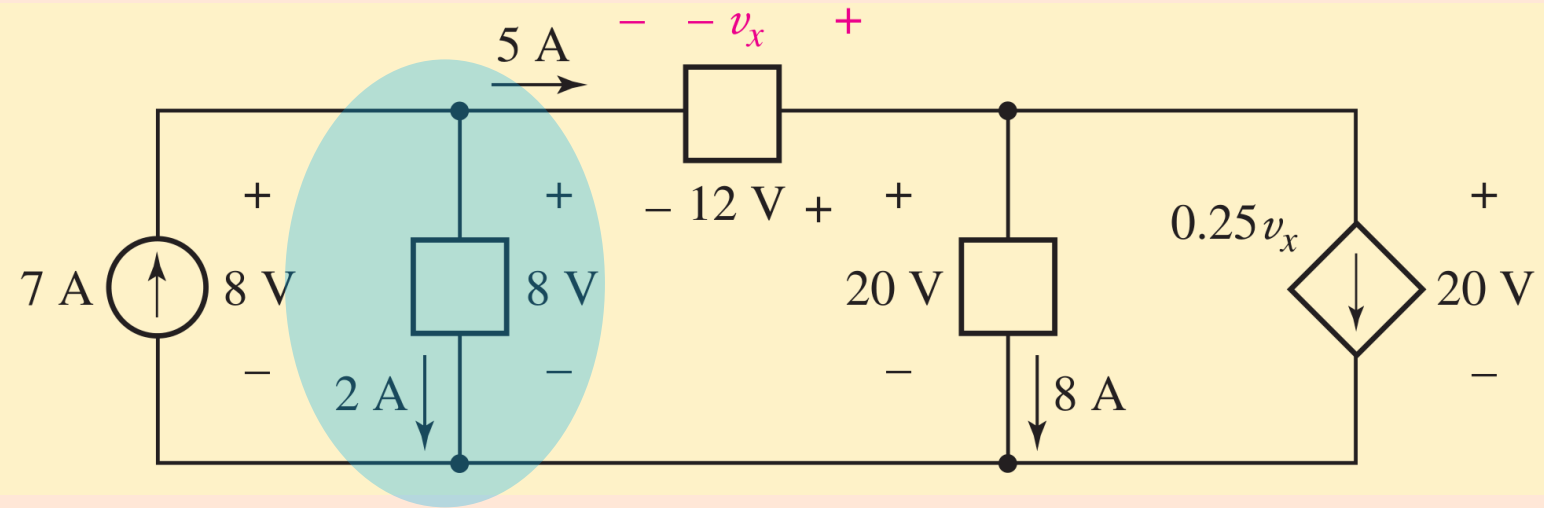
Find power absorbed in each element of the circuit.



Ans: (From left to right) -56 W;

Problem

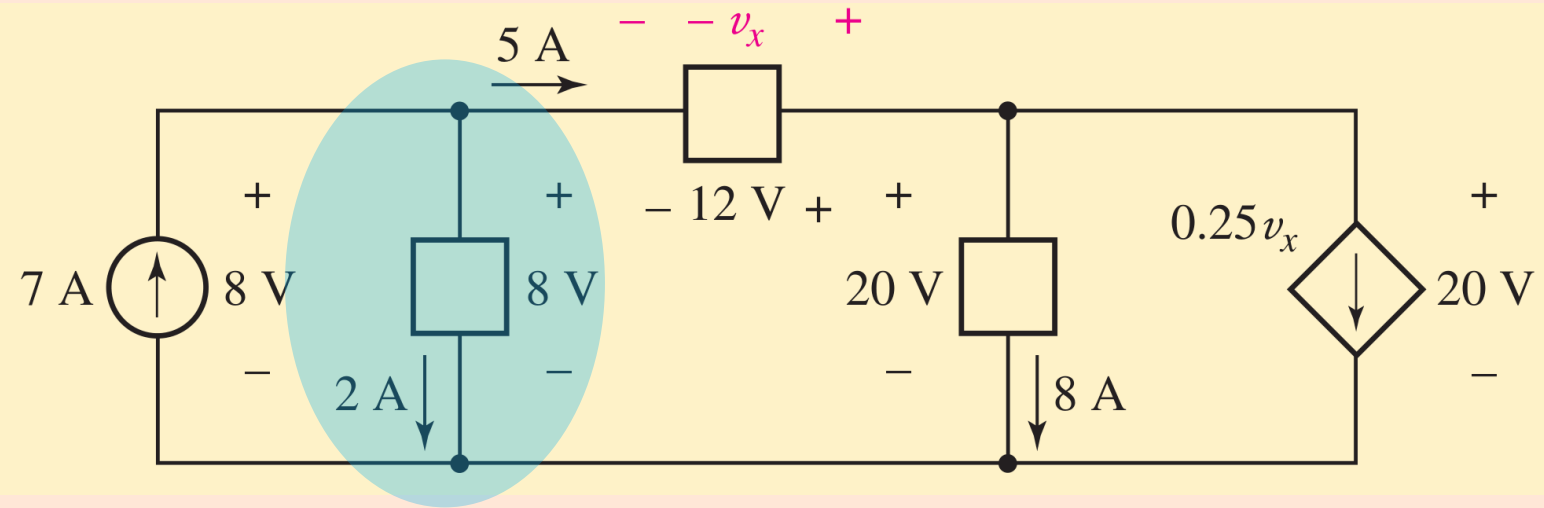
Find power absorbed in each element of the circuit.



Ans: (From left to right) -56 W;

Problem

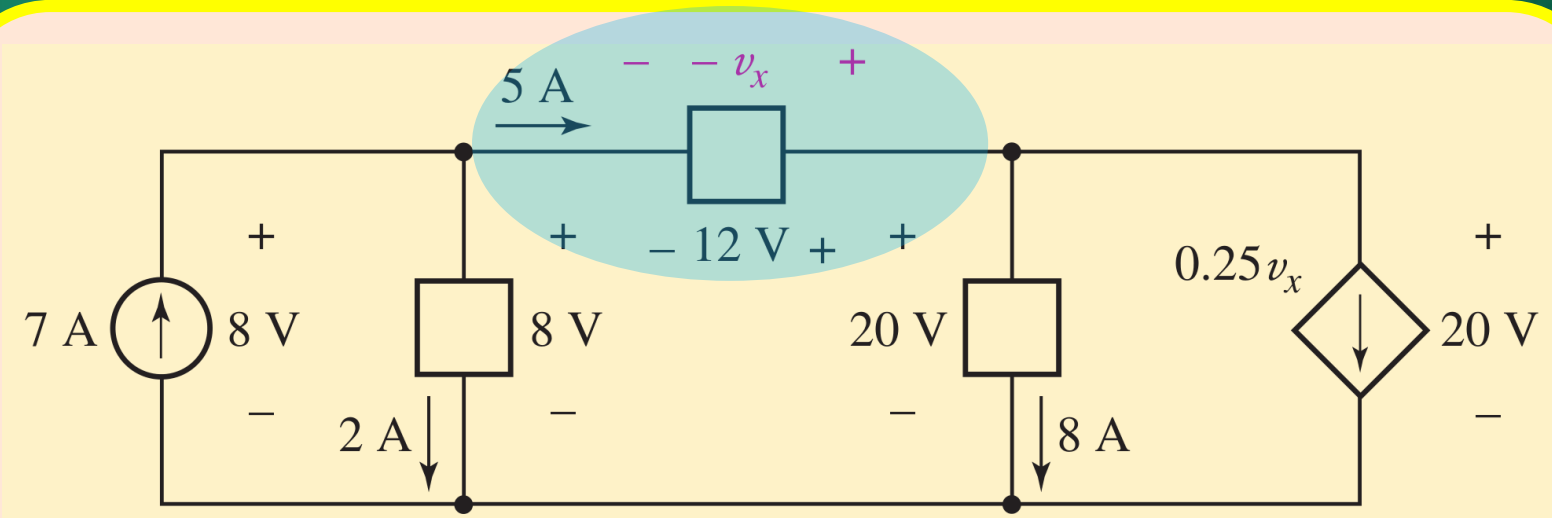
Find power absorbed in each element of the circuit.



Ans: (From left to right) -56 W; 16 W;

Problem

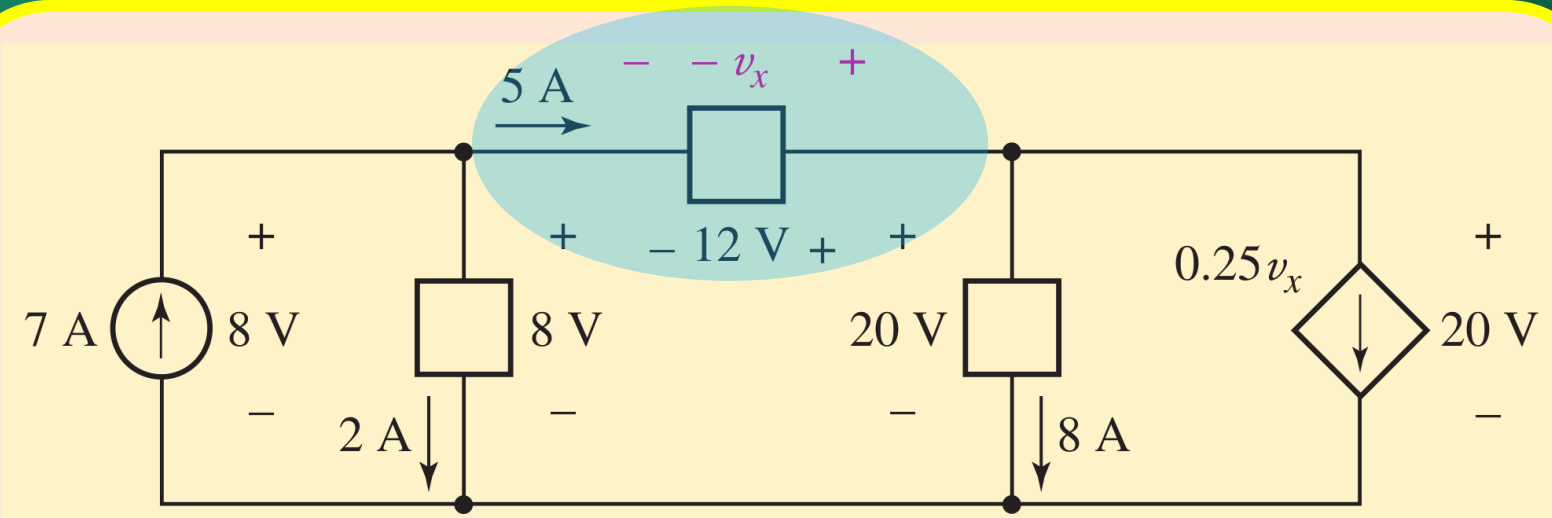
Find power absorbed in each element of the circuit.



Ans: (From left to right) -56 W; 16 W;

Problem

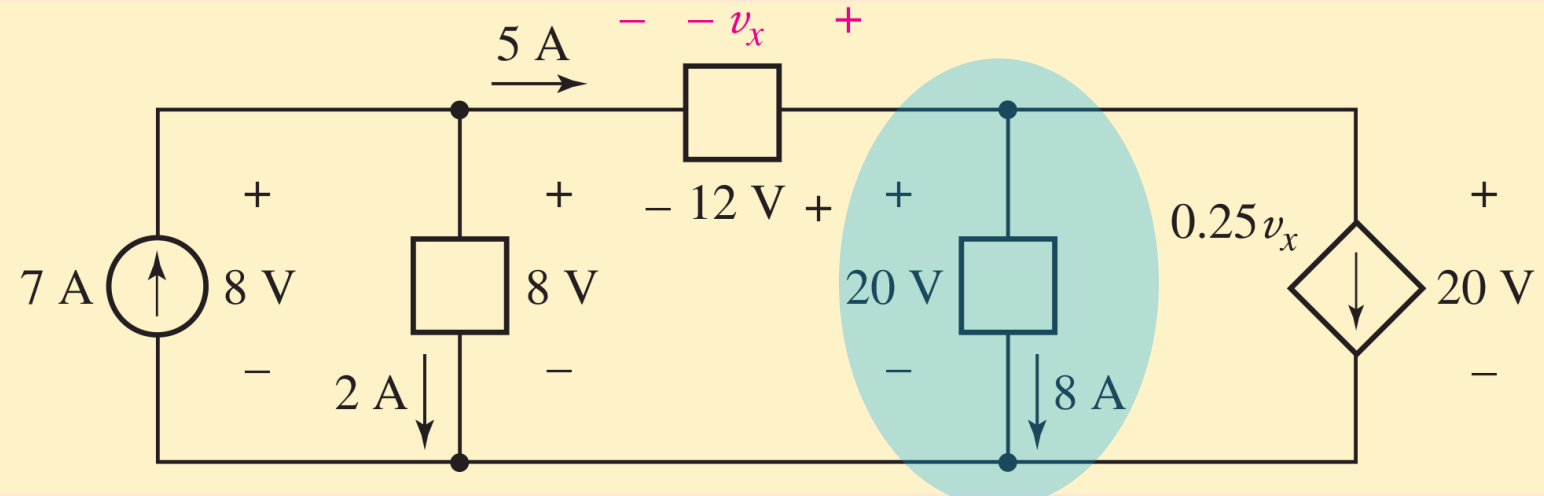
Find power absorbed in each element of the circuit.



Ans: (From left to right) -56 W; 16 W; -60 W;

Problem

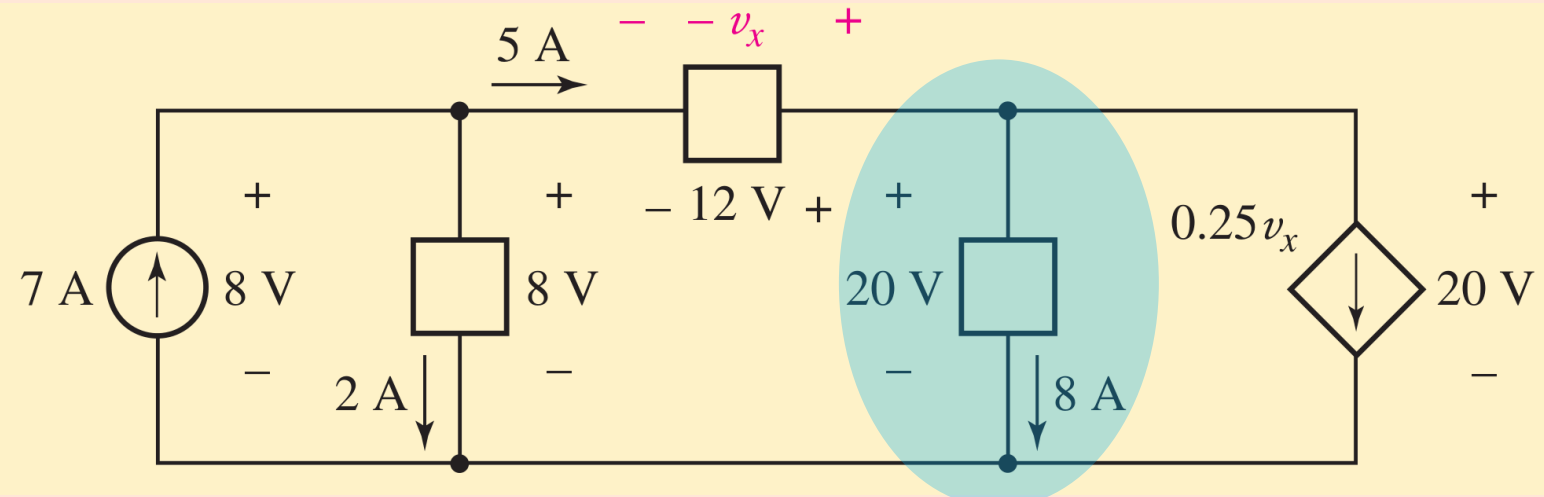
Find power absorbed in each element of the circuit.



Ans: (From left to right) -56 W; 16 W; -60 W;

Problem

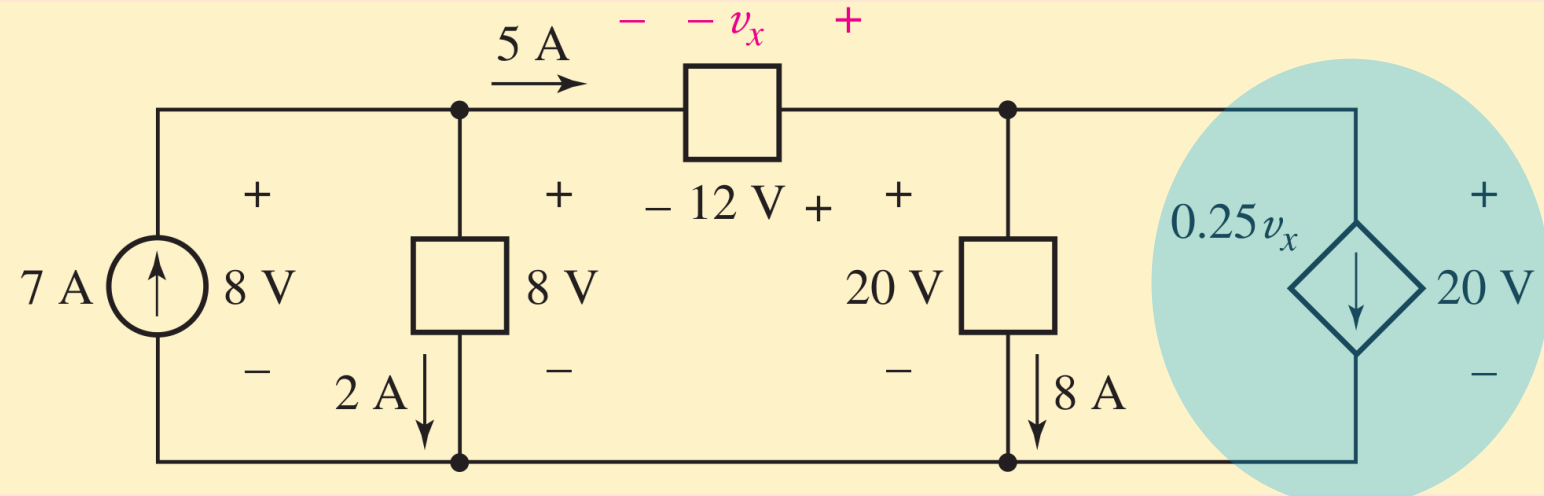
Find power absorbed in each element of the circuit.



Ans: (From left to right) -56 W; 16 W; -60 W; 160 W;

Problem

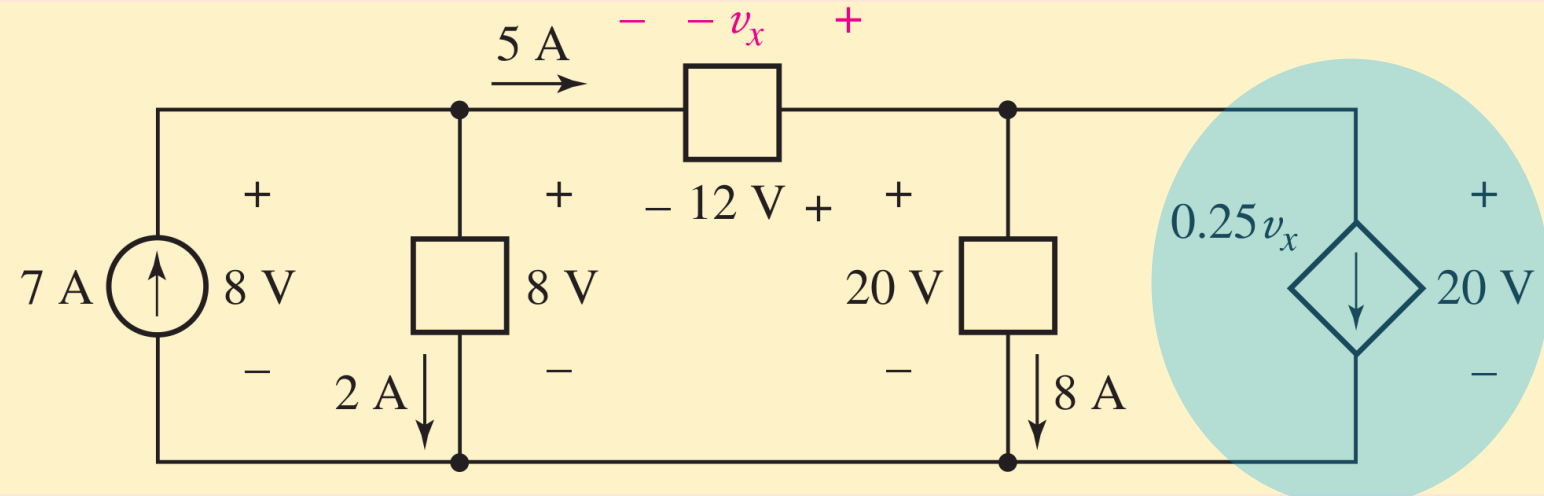
Find power absorbed in each element of the circuit.



Ans: (From left to right) -56 W; 16 W; -60 W; 160 W;

Problem

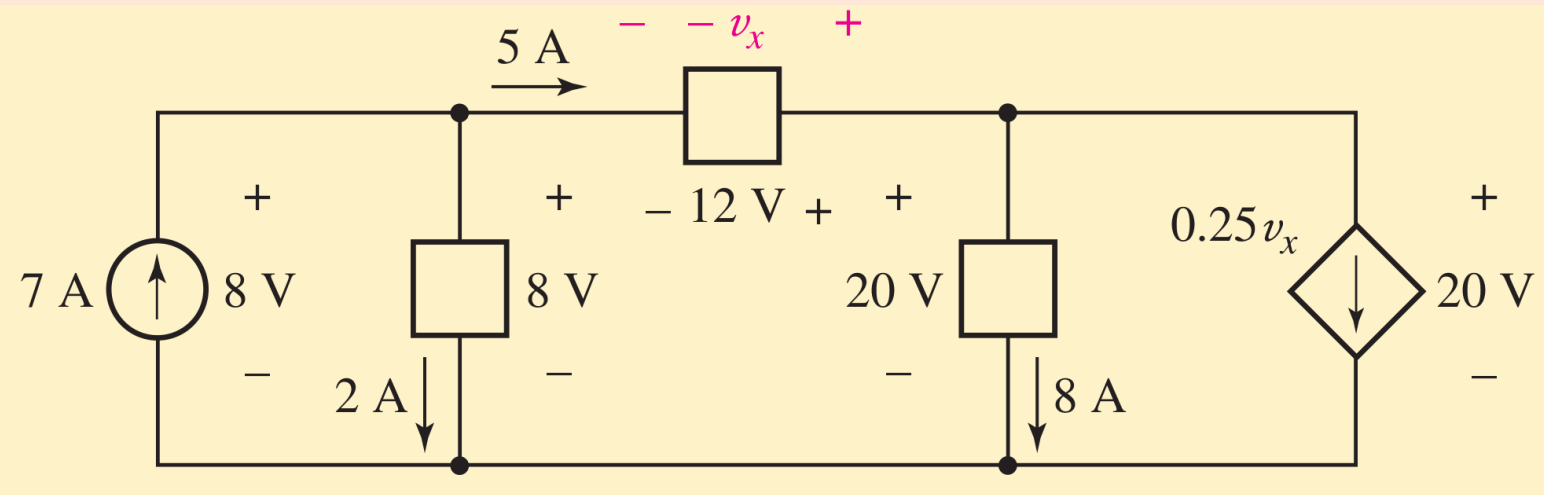
Find power absorbed in each element of the circuit.



Ans: (From left to right) -56 W; 16 W; -60 W; 160 W; -60 W

Problem

Find power absorbed in each element of the circuit.



Ans: (From left to right) -56 W; 16 W; -60 W; 160 W; -60 W

Problem

Check whether Tellegen's Theorem is satisfied for the previous problem.