Tishk International University
Faculty of Engineering
Computer Engineering Department

Chapter Two
DIRECT-CURRENT CIRCUITS

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GENERAL PHYSICS II
Weeks 3-4
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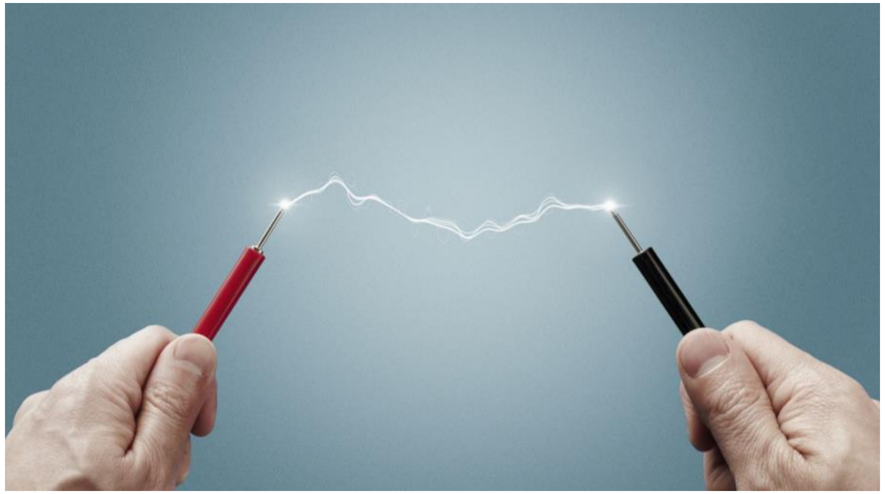
Date



Outline

- **Introduction to DC Circuits**
- **Definition of DC and its components**
- **Characteristics and analysis of Kirchhoff's Laws**
- **KCL and KVL**
- **Examples and Practice**
- **Worked examples and practice problems**
- **Conclusion**

Objectives

- **Understand DC circuits, including basic components and their behavior.**
- **Apply Ohm's Law to calculate voltage, current, and resistance in DC circuits.**
- **Apply Kirchhoff's Laws to solve complex DC circuit problems.**
- **Develop problem-solving skills through examples and practice problems.**
- **Recognize the importance of DC circuits in electrical engineering.**

Introduction

- The laws which determine the currents and voltage drops in DC networks are:

(a) Ohm's law

(b) The laws for resistors in series and in parallel

(c) Kirchhoff's laws

- In addition, there are a number of circuit theorems which have been developed for solving problems in electrical networks. These include:

(i) The superposition theorem

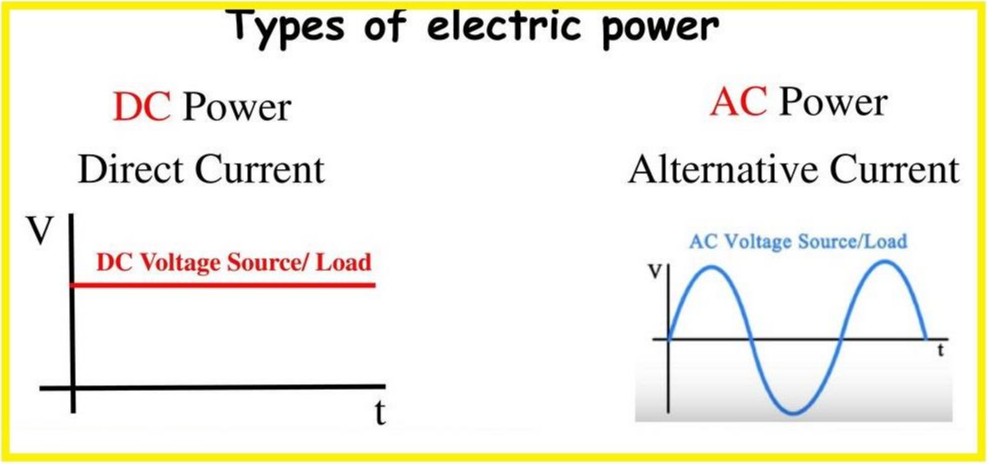
(ii) Th´evenin's theorem

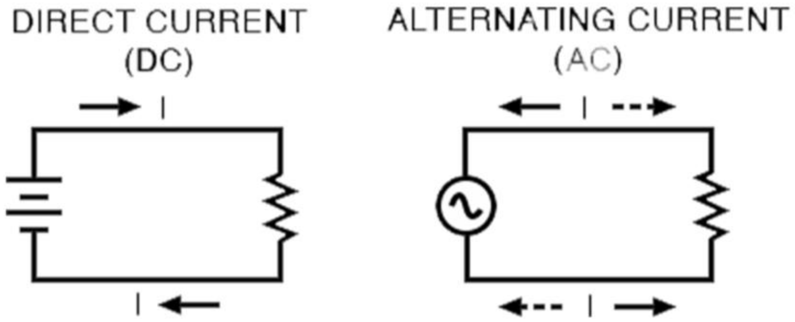
(iii) Norton's theorem, and

(iv) The maximum power transfer theorem.

Types of Electric Current

- **There are 2 types of Electric Current – AC (Alternating Current and DC (Direct Current).**
- **What is an Alternating Current (AC)?**
- In alternating current, the electric charge flow changes its direction periodically. AC is the most commonly used and most-preferred electric power for household equipment, office, buildings, etc.
- Alternating current can be identified in a waveform called a sine wave. In other words, it can be referred to as a curved line. These curved lines represent electric cycles and are measured per second. The measurement is read as Hertz (Hz).
- **What is Direct Current (DC)?**
- Unlike alternating current, the flow of direct current does not change periodically. The current electricity flows in a single direction in a steady voltage. The major use of DC is to supply power to electrical devices and also to charge batteries. Example: mobile phone batteries, flashlights, flat-screen television and electric vehicles. DC has the combination of a plus and a minus sign, a dotted line or a straight line.





Properties of AC and DC

Alternating Current	Direct Current
AC is easy to be transferred over longer distances – even between two cities – without much energy loss.	DC cannot be transferred over a very long distance. It loses electric power.
The rotating magnets cause the change in direction of electric flow.	The steady magnetism makes DC flow in a single direction.
The frequency of AC is dependent upon the country. But, generally, the frequency is 50 Hz or 60 Hz.	DC has no frequency or zero frequency.
In AC the flow of current changes its direction forward and backward periodically.	It flows in a single direction steadily.
Electrons in AC keep changing their directions – backward and forward.	Electrons only move in one direction – forward.

Network analysis

There are two general approaches to network analysis:

- **Direct Method:**

The network is left in its original form while determining its different voltages and currents.

Such methods are usually restricted to fairly simple circuits and include ***Kirchhoff's laws***, ***Loop analysis, Nodal analysis***, *superposition theorem*, *Compensation theorem and Reciprocity theorem* and … etc.

- **Network Reduction Method:**

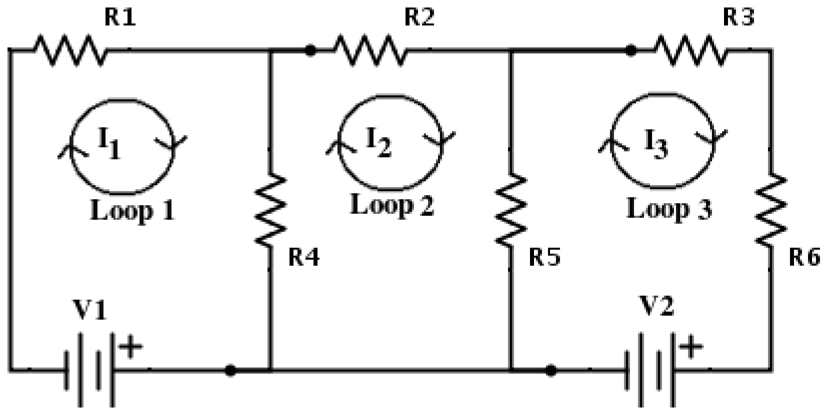
The original network is converted into a much simpler equivalent circuit for rapid calculation of different quantities.

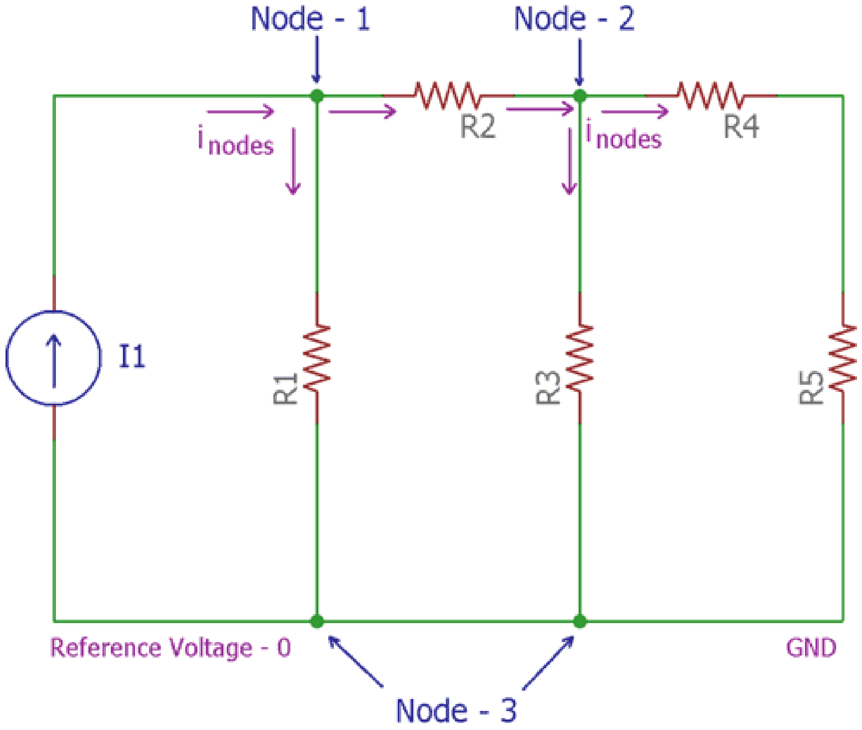
This method can be applied to simple as well as complicated networks. **Examples of this method are:** ***Delta/Star and Star/Delta conversions***, ***Thevenin's theorem and Norton's Theorem*** **etc.**

Terminology

- **Circuit**: ***A circuit is a closed conducting path through which an electric current either flows or is intended flow***.
- **Parameters**: ***The various elements of an electric circuit are called its parameters like resistance, inductance and capacitance***. These parameters may be **lumped** or **distributed**.
- Electric Network: *A combination of various electric elements, connected in any manner whatsoever, is called an electric network*.
- Electromotive force, also called emf is the voltage developed by any source of electrical energy such as a battery or dynamo. It is generally defined as the electrical potential for a source in a circuit.
- **Passive Network**: ***It is one which contains no source of e.m.f. in it***.
- **Active Network**: ***It is one which contains one or more than one source of e.m.f.***
- **Branch**: ***It is that part of a network which lies between two junctions***.
- **Loop**: ***It is a close path in a circuit in which no element or node is encountered more than once***.
- **Node**: ***It is a junction in a circuit where two or more circuit elements are connected together***.

Loops and nodes





Kirchhoff's Rules

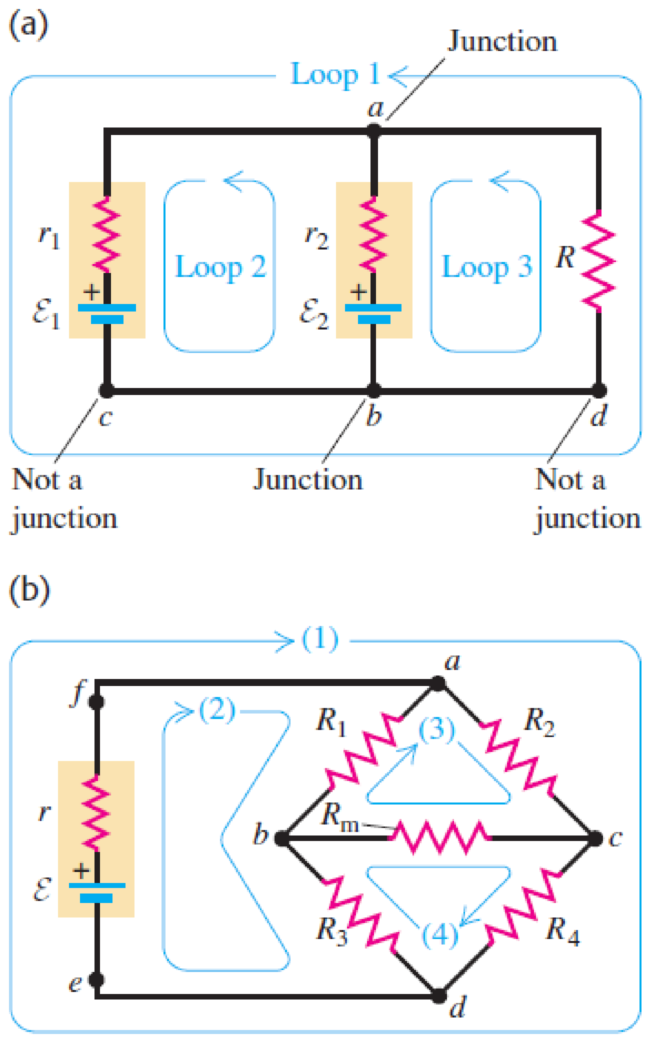
- **Many practical resistor networks cannot be reduced to simple series-parallel combinations**. Figure a shows a dc power supply with emf ε_1 charging a battery with a smaller emf ε_2 and feeding current to a light bulb with resistance *R*. Figure b is a "bridge" circuit, used in many different types of measurement and control systems. To compute the currents in these networks, we'll use the techniques developed by the German physicist **Gustav Robert Kirchhoff.**

- First, here are two terms that we will use often. A **junction** in a circuit is a point where three or more conductors meet. A **loop** is any closed conducting path. In Fig. a points *a* and *b* are junctions, but points *c* and *d* are not; in Fig. b the points *a*, *b*, *c*, and *d* are junctions, but points *e* and *f* are not.

- ***The blue lines in Figs. a and b show some possible loops in these circuits.***

- The junction rule is based on *conservation of electric charge.* No charge can accumulate at a junction, so the total charge entering the junction per unit time must equal the total charge leaving per unit time. if we consider the currents entering a junction to be positive and those leaving to be negative, the algebraic sum of currents into a junction must be zero. It's like a T branch in a water pipe.

- *Suppose we go around a loop, measuring potential differences across successive circuit elements as we go. When we return to the starting point, we must find that the algebraic sum of these differences is zero;*



Kirchhoff's Laws

- Kirchhoff's rules are the following two statements:
- **Kirchhoff's junction rule (also called Kirchhoff's current law –KCL):** *The algebraic sum of the currents into any junction is zero.* That is,

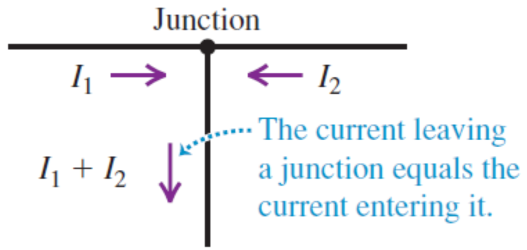
$$\sum I = 0 \qquad \text{(junction rule, valid at any junction)}$$

- **Kirchhoff's loop rule (also called Kirchhoff's voltage law –KVL): :** *The algebraic sum of the potential differences in any loop,* including those associated with emfs and those of resistive elements, *must equal zero.* That is,

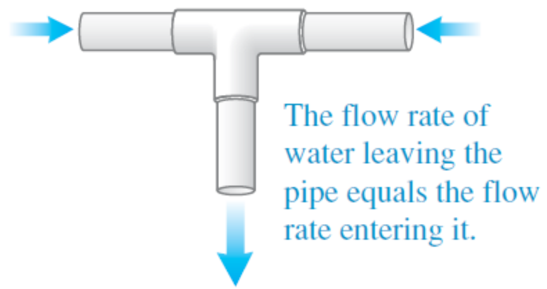
$$\sum V = 0 \qquad \text{(loop rule, valid for any closed loop)}$$

Kirchhoff's junction rule states that as much current flows into a junction as flows out of it.

(a) Kirchhoff's junction rule



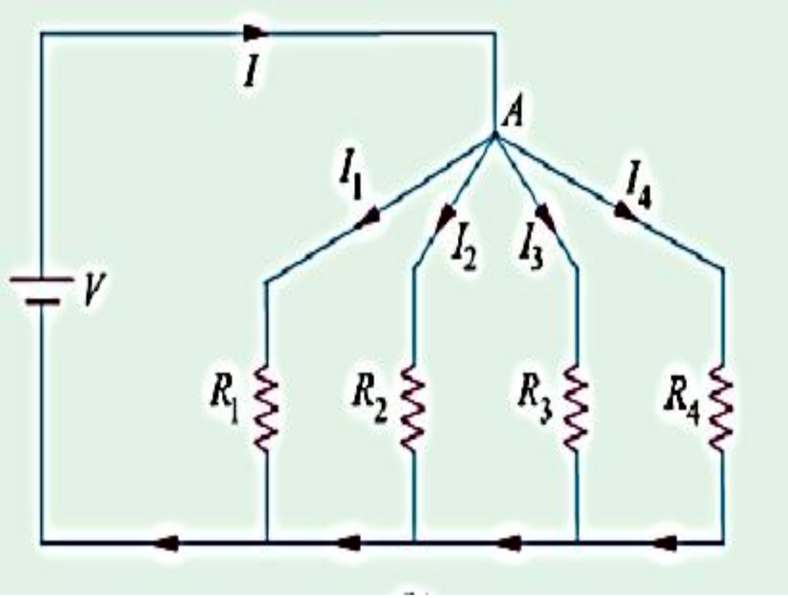
(b) Water-pipe analogy



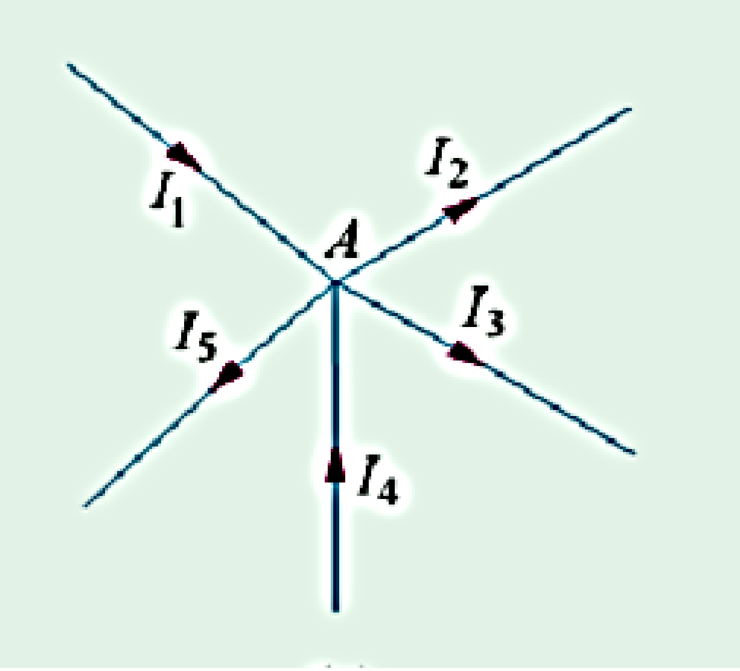
Kirchhoff's Current Law (KCL)

"In any electrical network, the algebraic sum of the currents meeting at a point (or junction) is zero"

$$\sum I = 0 \qquad \ldots \textit{at a junction}$$



$$+I + (-I_1) + (-I_2) + (-I_3) + (-I_4) = 0 \quad \text{or} \quad I = I_1 + I_2 + I_3 + I_4$$



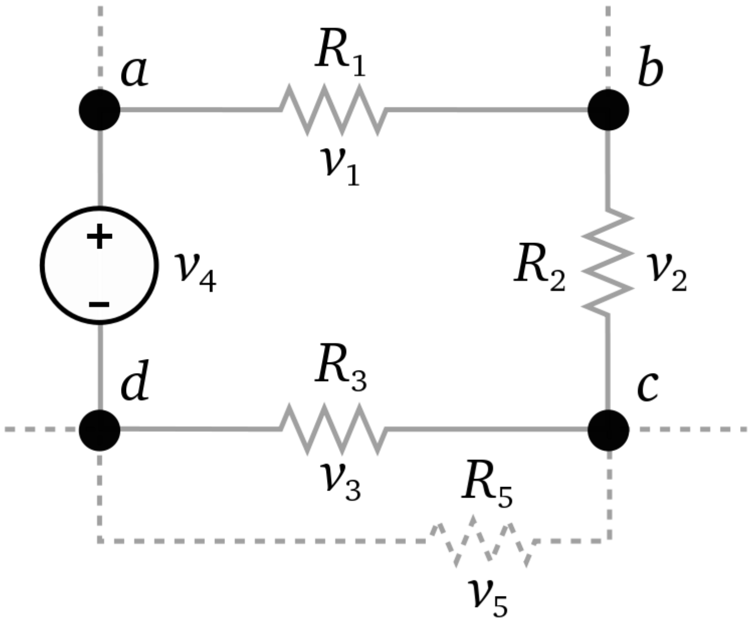
$$I_1 + (-I_2) + (-I_3) + (+I_4) + (-I_5) = 0$$

$$I_1 + I_4 - I_2 - I_3 - I_5 = 0 \;\; or \;\; I_1 + I_4 = I_2 + I_3 + I_5$$

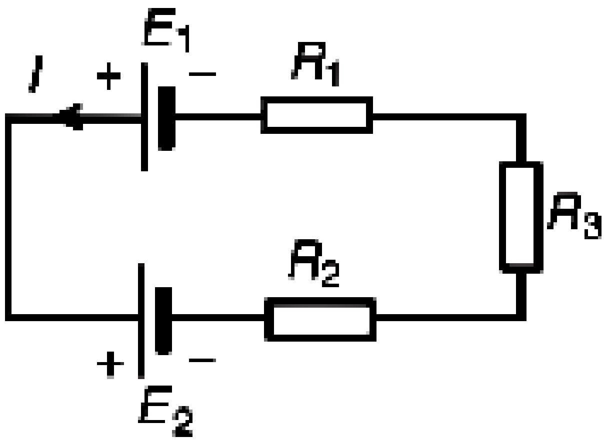
Or incoming currents = outgoing currents

Kirchhoff's Voltage Law (KVL)

- The algebraic sum of the products of currents and resistances in each of the conductors in any closed path (or mesh) in a network plus the algebraic sum of the e.m.f. in that path is zero.
- $\sum \mathrm{IR} + \sum \mathrm{e.m.f.} = 0 \quad \boldsymbol{around\,a\,mesh}$



v1 + v2 + v3 - v4 = 0

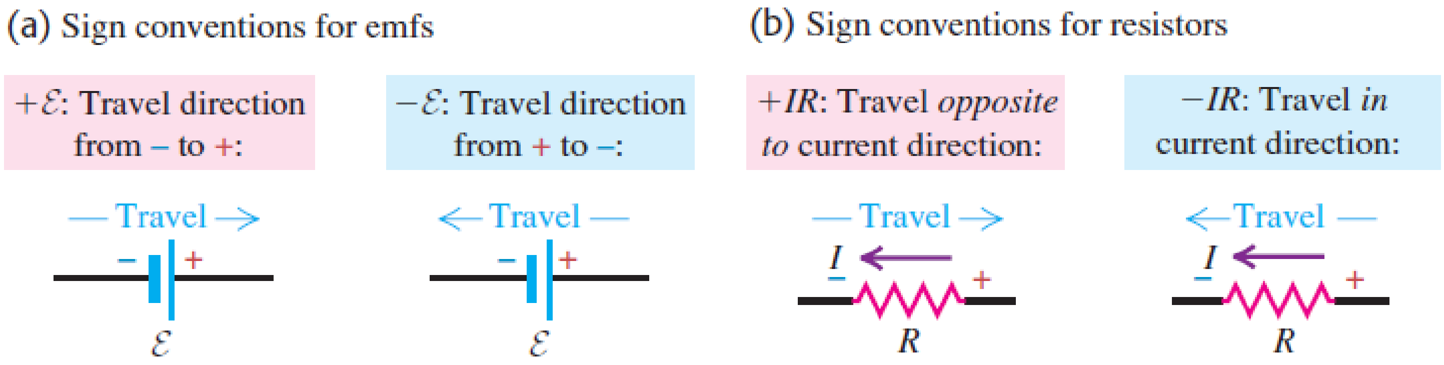


$$E_1 - E_2 = IR_1 + IR_2 + IR_3$$

Sign Conventions for the Loop Rule

- We first assume a direction for the current in each branch of the circuit and mark it on a diagram of the circuit. Then, starting at any point in the circuit, we imagine traveling around a loop, adding emfs and *IR* terms as we come to them. When we travel through a source in the direction from – to + the emf is considered to be *positive;* when we travel from + to - the emf is considered to be *negative*. When we travel through a resistor in the *same* direction as the assumed current, the *IR* term is *negative* because the current goes in the direction of decreasing potential. When we travel through a resistor in the direction *opposite* to the assumed current, the *IR* term is *positive* because this represents a rise of potential.
- Kirchhoff's two rules are all we need to solve a wide variety of network problems. Usually, some of the emfs, currents, and resistances are known, and others are unknown. We must always obtain from Kirchhoff's rules a number of independent equations equal to the number of unknowns so that we can solve the equations simultaneously. Often the hardest part of the solution is not understanding the basic principles but keeping track of algebraic signs!

26.8 Use these sign conventions when you apply Kirchhoff's loop rule. In each part of the figure "Travel" is the direction that we imagine going around the loop, which is not necessarily the direction of the current.



Problem 1. (a) Find the unknown currents marked in Figure 13.3(a). (b) Determine the value of e.m.f. E in Figure 13.3(b).

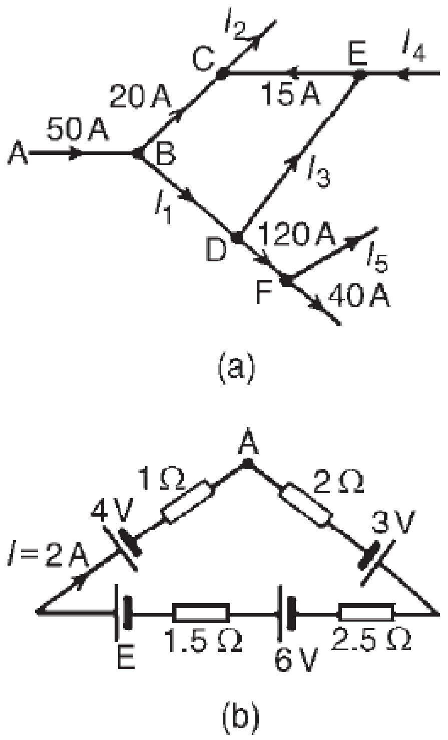


Figure 13.3

(a) Applying Kirchhoff's current law:

For junction B: $50 = 20 + I_1$. Hence $\mathbf{I_1 = 30\ A}$

For junction C: $20 + 15 = I_2$. Hence $\mathbf{I_2 = 35\ A}$

For junction D: $I_1 = I_3 + 120$

i.e. $30 = I_3 + 120$. Hence $\mathbf{I_3 = -90\ A}$

(i.e. in the opposite direction to that shown in Figure 13.3(a))

For junction E: $I_4 + I_3 = 15$

i.e. $I_4 = 15 - (-90)$. Hence $\mathbf{I_4 = 105\ A}$

For junction F: $120 = I_5 + 40$. Hence $\mathbf{I_5 = 80\ A}$

(b) Applying Kirchhoff's voltage law and moving clockwise around the loop of Figure 13.3(b) starting at point A:

$$3 + 6 + E - 4 = (I)(2) + (I)(2.5) + (I)(1.5) + (I)(1)$$

$$= I(2 + 2.5 + 1.5 + 1)$$

i.e. $5 + E = 2(7)$, since $I = 2$ A

Hence $E = 14 - 5 = \mathbf{9\ V}$

- Problem 2. Use Kirchhoff's laws to determine the currents flowing in each branch of the network shown in Figure 13.4.

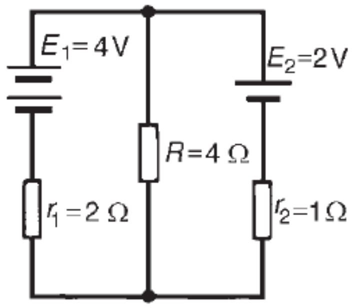


Figure 13.4

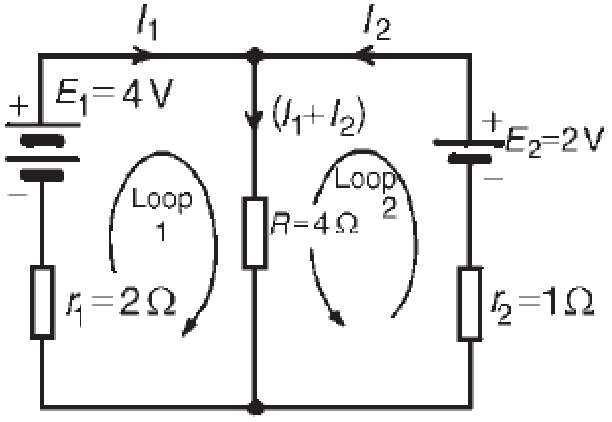


Figure 13.5

Procedure

1 Use Kirchhoff's current law and label current directions on the original circuit diagram. The directions chosen are arbitrary, but it is usual, as a starting point, to assume that current flows from the positive terminals of the batteries. This is shown in Figure 13.5 where the three branch currents are expressed in terms of I_1 and I_2 only, since the current through R is $I_1 + I_2$.

2 Divide the circuit into two loops and apply Kirchhoff's voltage law to each. From loop 1 of Figure 13.5, and moving in a clockwise direction as indicated (the direction chosen does not matter), gives

$$E_1 = I_1 r_1 + (I_1 + I_2)R, \text{ i.e. } 4 = 2I_1 + 4(I_1 + I_2),$$

$$\text{i.e. } 6I_1 + 4I_2 = 4 \qquad (1)$$

From loop 2 of Figure 13.5, and moving in an anticlockwise direction as indicated (once again, the choice of direction does not matter; it does not have to be in the same direction as that chosen for the first loop), gives:

$$E_2 = I_2 r_2 + (I_1 + I_2)R, \text{ i.e. } 2 = I_2 + 4(I_1 + I_2),$$

$$\text{i.e. } 4I_1 + 5I_2 = 2 \quad (2)$$

3 Solve equations (1) and (2) for I_1 and I_2.

$2 \times (1)$ gives: $12I_1 + 8I_2 = 8$ (3)

$3 \times (2)$ gives: $12I_1 + 15I_2 = 6$ (4)

$(3) - (4)$ gives: $-7I_2 = 2$ hence $I_2 = -\frac{2}{7} = \mathbf{-0.286\ A}$

(i.e. I_2 is flowing in the opposite direction to that shown in Figure 13.5.)

From (1) $6I_1 + 4(-0.286) = 4$

$$6I_1 = 4 + 1.144$$

Hence $I_1 = \frac{5.144}{6} = \mathbf{0.857\ A}$

Current flowing through resistance R is

$$I_1 + I_2 = 0.857 + (-0.286) = \mathbf{0.571\ A}$$

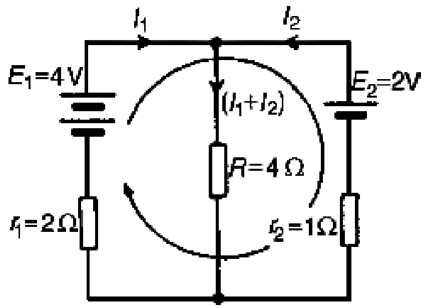


Figure 13.6

Note that a third loop is possible, as shown in Figure 13.6, giving a third equation which can be used as a check:

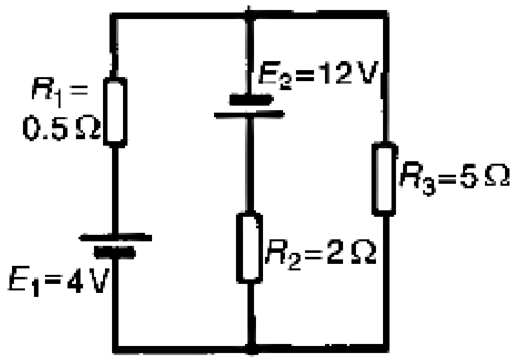
$$E_1 - E_2 = I_1 r_1 - I_2 r_2$$

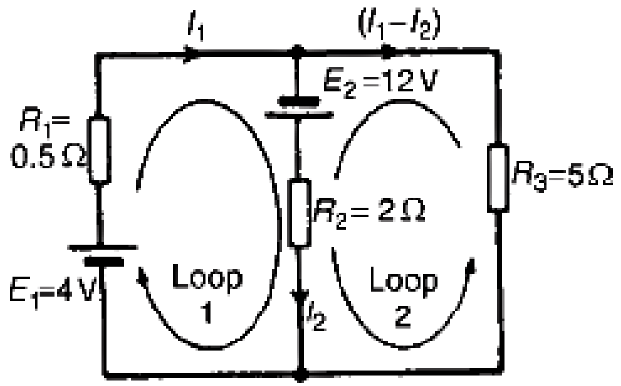
$$4 - 2 = 2I_1 - I_2$$

$$2 = 2I_1 - I_2$$

[Check: $2I_1 - I_2 = 2(0.857) - (-0.286) = 2$]

- Problem 3. Determine, using Kirchhoff's laws, each branch current for the network shown in Figure below,





For loop 1:

$$E_1 + E_2 = I_1R_1 + I_2R_2$$

i.e. $16 = 0.5I_1 + 2I_2$ (1)

For loop 2:

$$E_2 = I_2R_2 - (I_1 - I_2)R_3$$

Note that since loop 2 is in the opposite direction to current$(I_1 - I_2)$, the volt drop across R_3 (i.e. $(I_1 - I_2)(R_3)$ is by convention negative).

Thus $12 = 2I_2 - 5(I_1 - I_2)$ i.e. $12 = -5I_1 + 7I_2$ (2)

Solving equations (1) and (2) to find I_1 and I_2:

$10 \times (1)$ gives $160 = 5I_1 + 20I_2$ (3)

$(2) + (3)$ gives $172 = 27I_2$ hence $I_2 = \frac{172}{27} = \mathbf{6.37\ A}$

From (1): $16 = 0.5I_1 + 2(6.37)$

$$I_1 = \frac{16 - 2(6.37)}{0.5} = \mathbf{6.52\ A}$$

Current flowing in $R_3 = I_1 - I_2 = 6.52 - 6.37 = \mathbf{0.15\ A}$

- Problem 4. For the bridge network shown in Figure below, determine the currents in each of the resistors.
- Solution

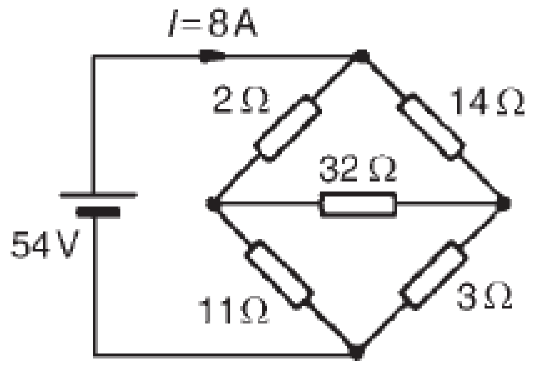
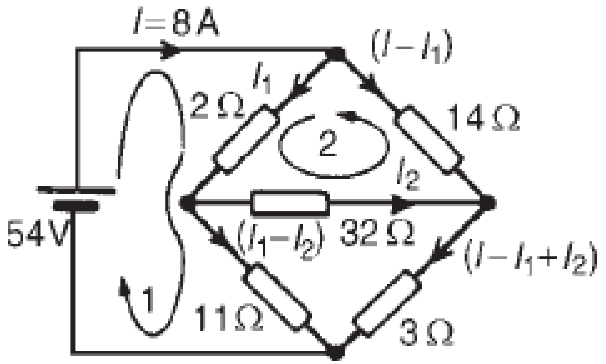


Figure 13.9

Let the current in the 2 Ω resistor be I_1, then by Kirchhoff's current law, the current in the 14 Ω resistor is $(I - I_1)$. Let the current in the 32 Ω resistor be I_2 as shown in Figure 13.10. Then the current in the 11 Ω resistor is $(I_1 - I_2)$ and that in the 3 Ω resistor is $(I - I_1 + I_2)$. Applying Kirchhoff's voltage law to loop 1 and moving in a clockwise direction as shown in Figure 13.10 gives:

$$54 = 2I_1 + 11(I_1 - I_2)$$

i.e. $13I_1 - 11I_2 = 54$ (1)



Applying Kirchhoff's voltage law to loop 2 and moving in an anticlockwise direction as shown in Figure 13.10 gives:

$$0 = 2I_1 + 32I_2 - 14(I - I_1)$$

However $I = 8$ A

Hence $0 = 2I_1 + 32I_2 - 14(8 - I_1)$

i.e. $16I_1 + 32I_2 = 112$ (2)

Equations (1) and (2) are simultaneous equations with two unknowns, I_1 and I_2.

$$16 \times (1) \text{ gives:} \quad 208I_1 - 176I_2 = 864 \qquad (3)$$

$$13 \times (2) \text{ gives:} \quad 208I_1 + 416I_2 = 1456 \qquad (4)$$

$$(4) - (3) \text{ gives:} \quad 592I_2 = 592$$

$$I_2 = 1 \text{ A}$$

Substituting for I_2 in (1) gives:

$$13I_1 - 11 = 54$$

$$I_1 = \frac{65}{13} = 5\ A$$

Hence,

the current flowing in the 2 Ω resistor $= I_1 = \mathbf{5\ A}$

the current flowing in the 14 Ω resistor $= I - I_1 = 8 - 5 = \mathbf{3\ A}$

the current flowing in the 32 Ω resistor $= I_2 = \mathbf{1\ A}$

the current flowing in the 11 Ω resistor $= I_1 - I_2 = 5 - 1 = \mathbf{4\ A}$ and

the current flowing in the 3 Ω resistor $= I - I_1 + I_2 = 8 - 5 + 1$

$$= \mathbf{4\ A}$$

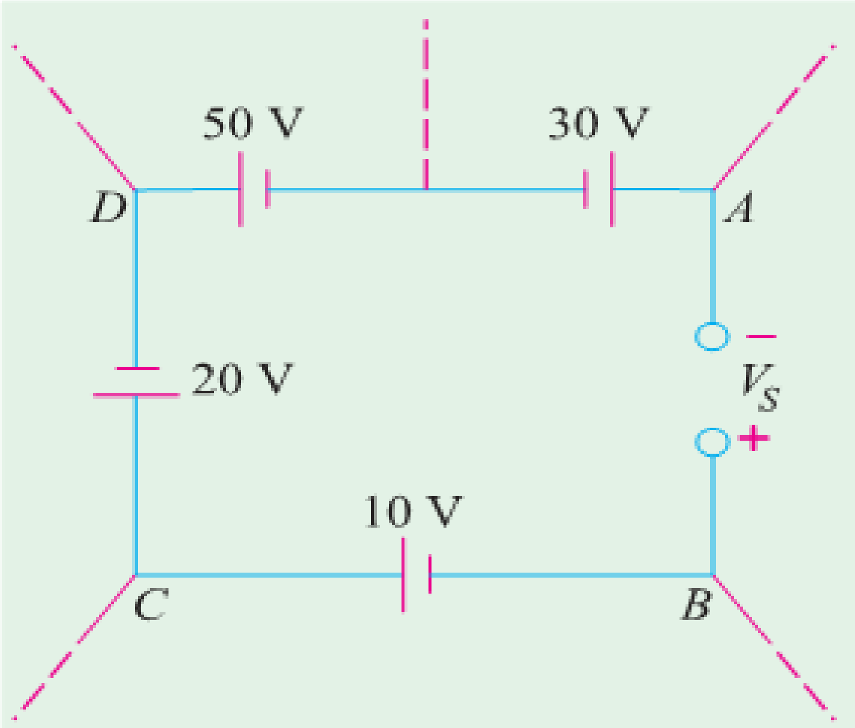
Problem 5: What is the voltage V_s across the open switch in the circuit of this figure?

Solution 1:

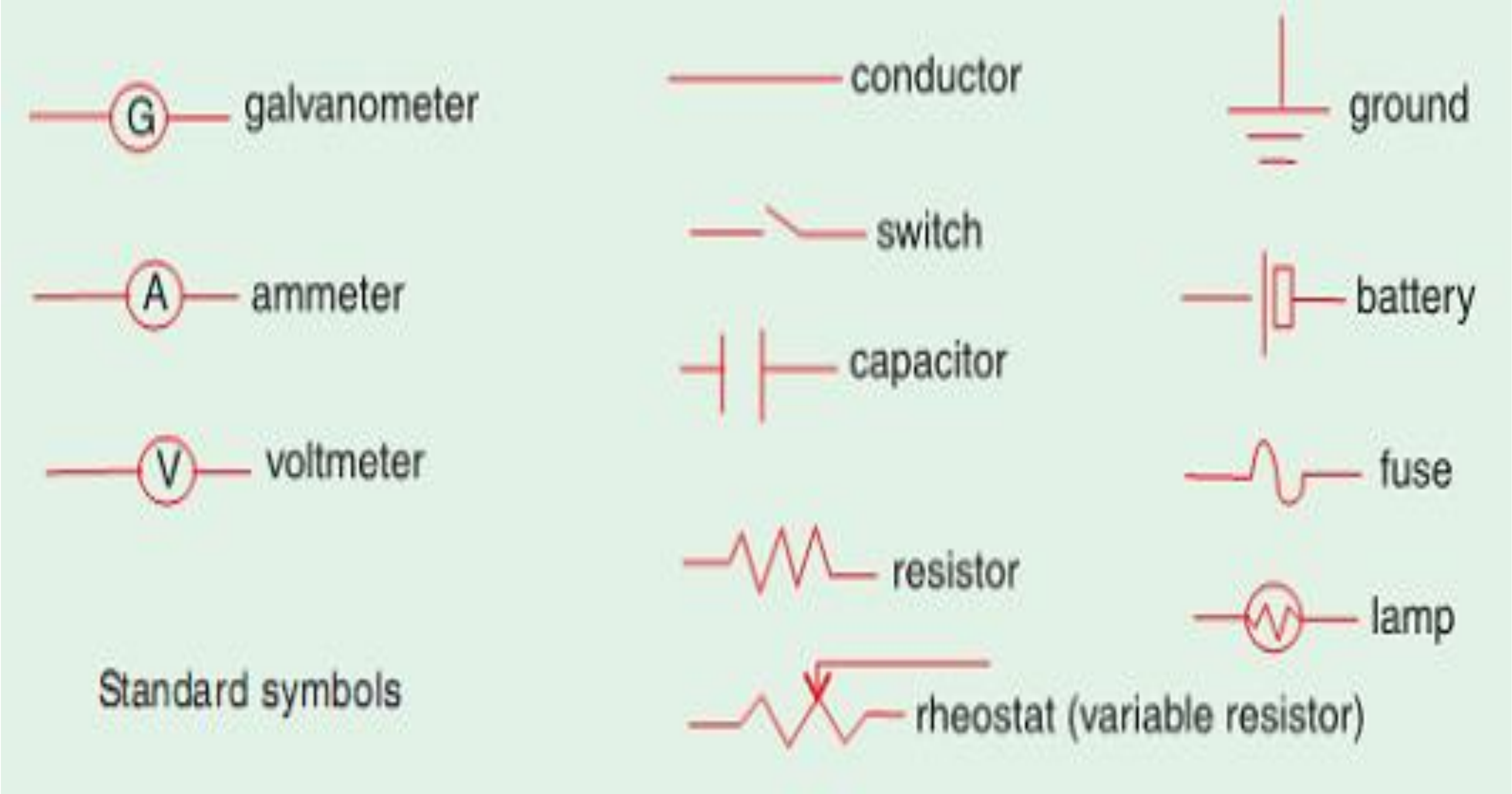
Taking the outer closed loop ABCDA and applying KVL to it, we get:

$$+V_s + 10 - 20 - 50 + 30 = 0$$

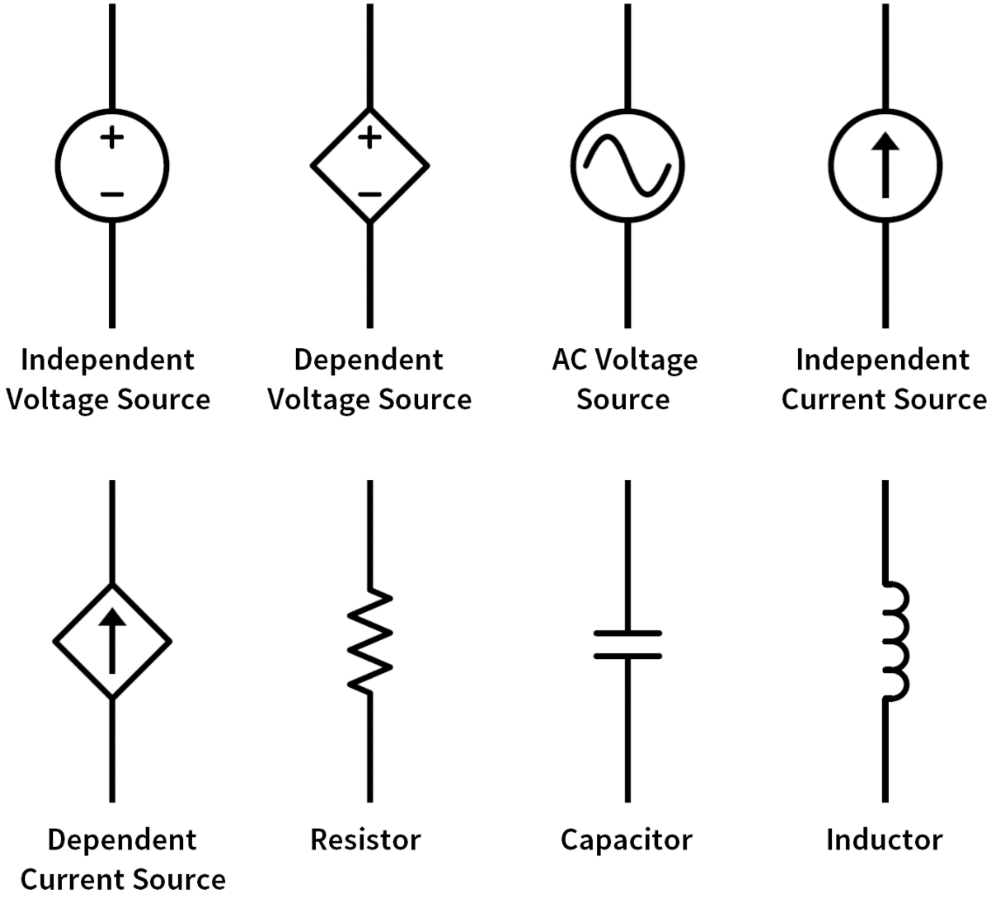
$$\therefore \quad V_s = 30 \text{ V}$$



Circuit Symbols



Circuit Symbols



Voltage source and current source

- **Voltage source**: A voltage source can be defined **as a device that supplies a constant voltage** to a load. A voltage source can produce varying voltage, such as an **AC power supply**, or it can provide a constant voltage like a **battery.**

- **Current source**: it is harder to visualize a current source physically. In theory, it is defined as a device that could source a steady amount of current regardless of the voltage required for a load. A practical current source couldn’t sustain the required current if the voltage across the load rises to a certain level.
- A current source usually **involves transistors**. You do not have a single component that is specifically a current source. A current source is usually derived from transistors.
- For instance, the emitter current of a BJT transistor is defined by the current that flows through the base. By providing a positive voltage at the base-emitter junction, a **constant current will flow through the emitter** which is a direct function of base current.

Dependent and independent sources

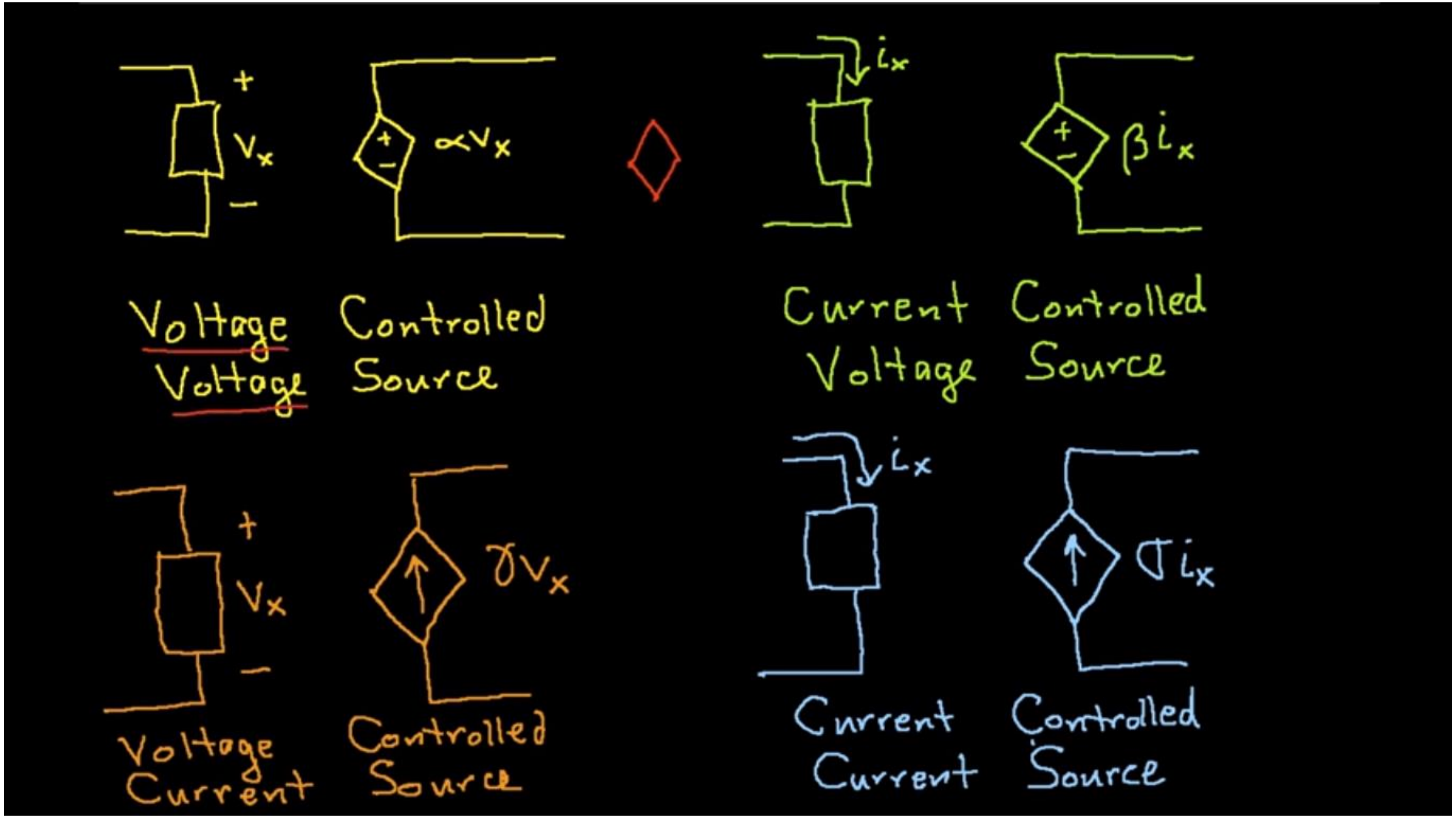
- **Independent sources**: The values of the sources presented are fixed and do not depend on any parameter or element of the surrounding circuit.

- **Dependent Source** or controlled source, provides a supply whose magnitude depends on either the voltage across or current flowing through some other circuit element.

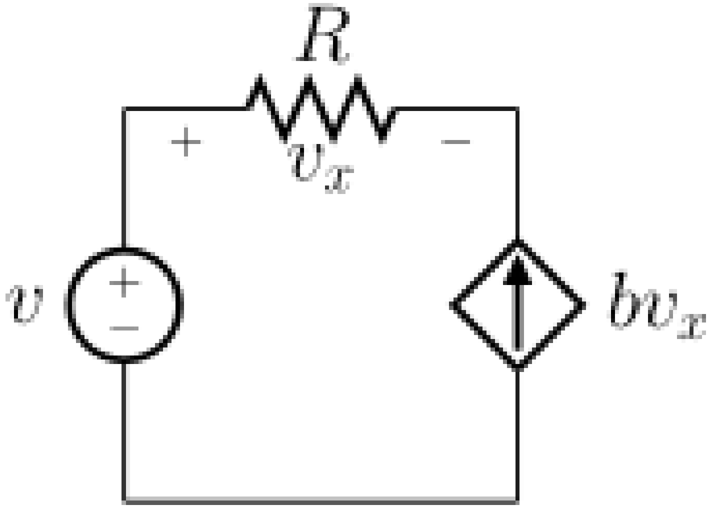
- Types of controlled sources:

1. Voltage controlled voltage source
2. Current controlled voltage source
3. Current controlled current source, and
4. Voltage controlled current source

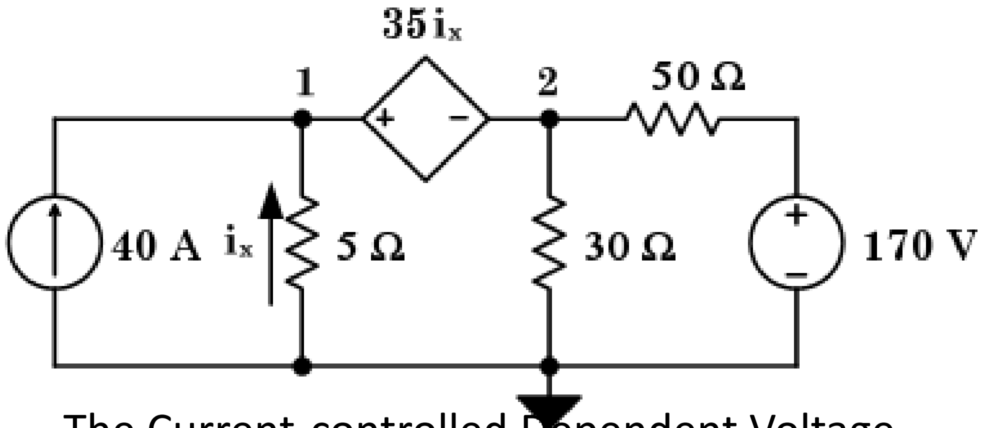
Dependent and independent sources



Dependent and independent sources



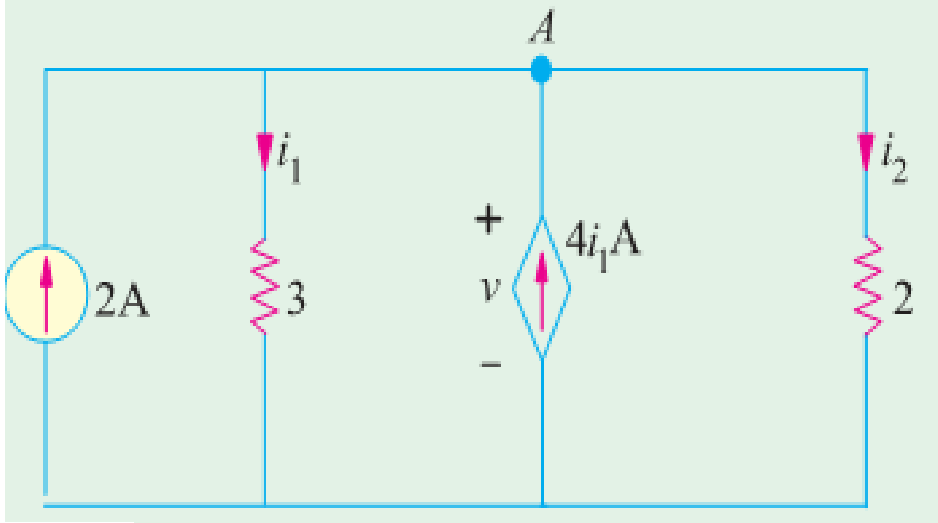
Voltage-controlled Dependent Voltage



The Current-controlled Dependent Voltage

Problem 6

- **Using Kirchhoff's current law. Find the values of the currents i_1 and i_2 in the circuit of this Figure which contains a current-dependent current source. All resistances are in ohms.**



Applying KCL to node A, we get:

$$2 - i_1 + 4\,i_1 - i_2 = 0 \quad \text{or} \quad -3i_1 + i_2 = 2$$

By Ohm's law, $i_1 = v/3$ *and* $i_2 = v/2$

Substituting these values above, we get:

$$-3(v/3) + v/2 = 2 \quad or \quad v = -4\,V$$

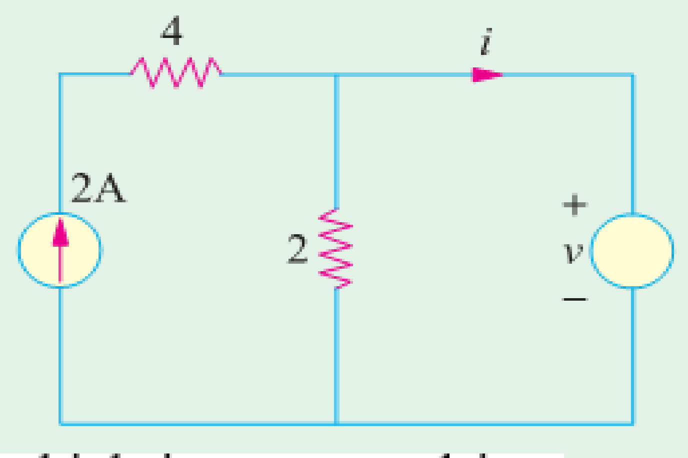
$$\therefore\ i_1 = -4/3\,A \quad and \quad i_2 = -4/2 = -2\,A$$

The value of the dependent current source is

$$= 4i_1 = 4 \times (-4/3) = -16/3A.$$

Problem 7

- **In the circuit shown in this Figure. Apply KCL to find the value of i for the case when (a) $v = 2V$ (b) $v = 4\,V$ (c) $v = 6\,V$. The resistor values are in ohms.**



a: When v =2 V, current through 2 Ω resistor which is connected in parallel with the 2v source = 2/2 =1A. Since the source current is 2 A, $i = 2 - 1 = 1A.$

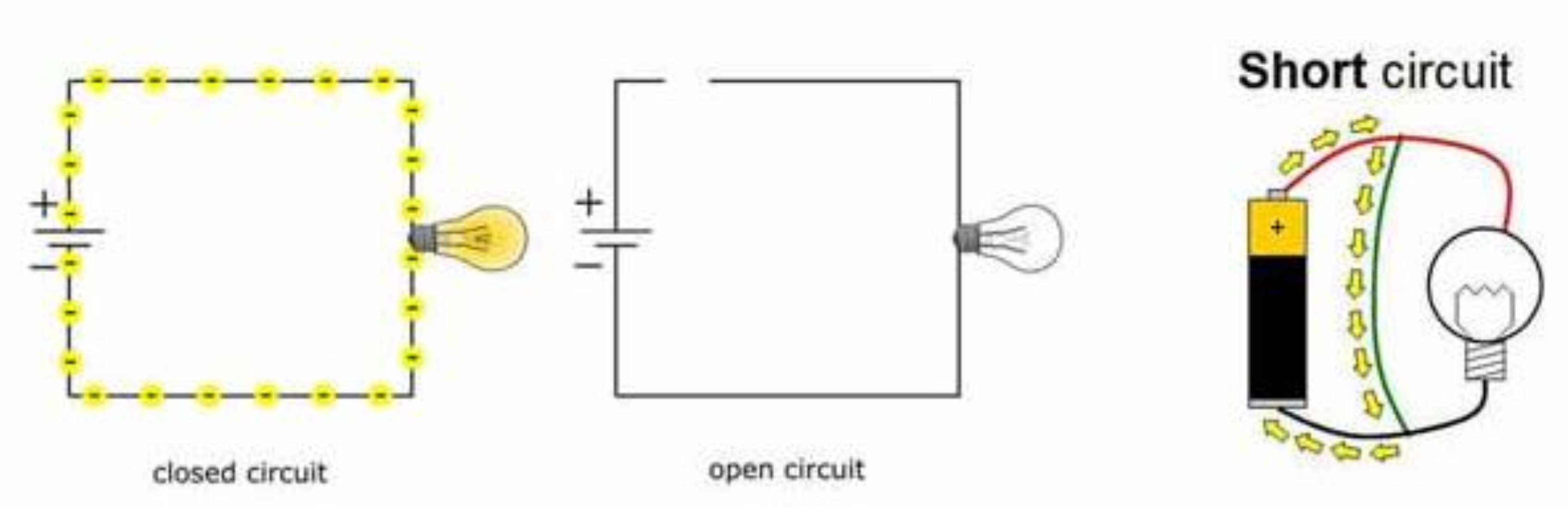
b: When v = 4V, current through the 2Ω resistor = 4/2 =2 A.

Hence $i = 2 - 2 = 0\,A.$

c: When v = 6 V, current through the 2Ω resistor = 6/2 =3 A. Since current source can supply only 2A, the balance of 1 A is supplied by the voltage source. Hence, $i = -1\,A$ i.e. it flows in a direction opposite to that shown in this figure.

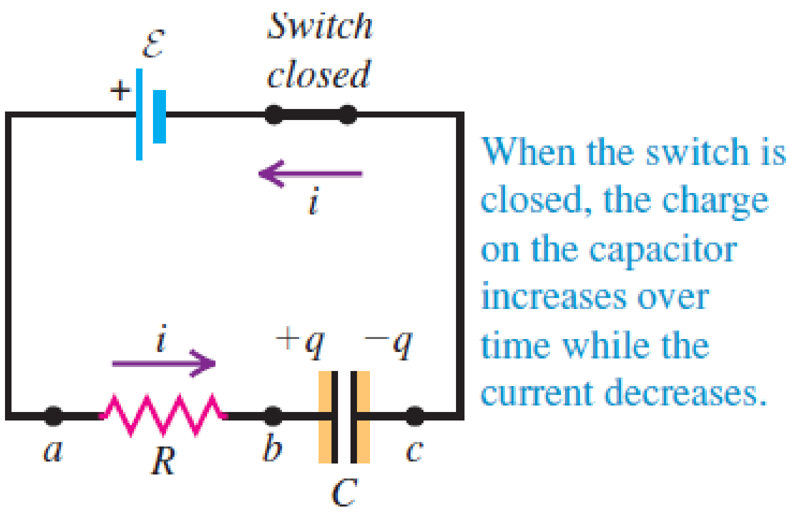
Open circuit, close circuit and short circuit

- Open circuit: no current is drawn or supplied between two terminals.
- A short circuit is an electrical circuit that allows a current to travel along an unintended path with no or very low electrical impedance.
- Closed circuit: current passing naturally around a complete and close loop.

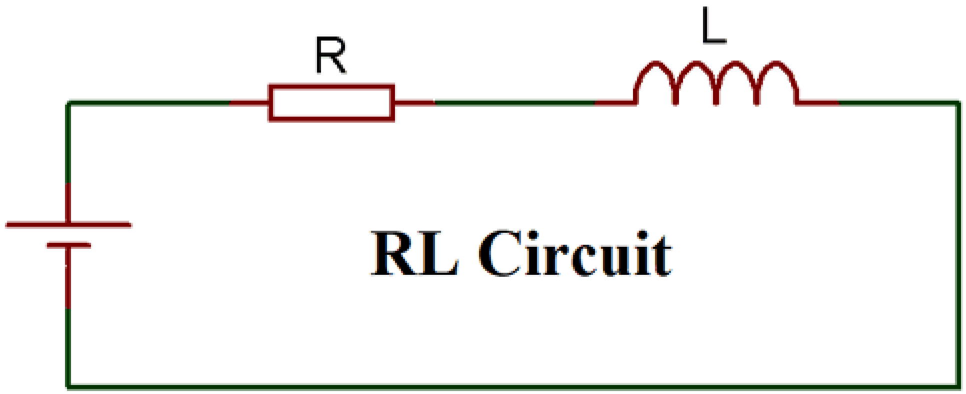


Circuit containing elements

- **RC circuit**
- The **RC circuit** (**Resistor Capacitor Circuit**) will consist of a Capacitor and a Resistor connected either in series or parallel to a voltage or current source. These types of circuits are also called as **RC filters** or **RC networks** since they are most commonly used in filtering applications.
- In the circuits we have analyzed up to this point, we have assumed that all the emfs and resistances are *constant* (time independent) so that all the potentials, currents, and powers are also independent of time. But in the simple act of charging or discharging a capacitor we find a situation in which the currents, voltages, and powers *do* change with time.

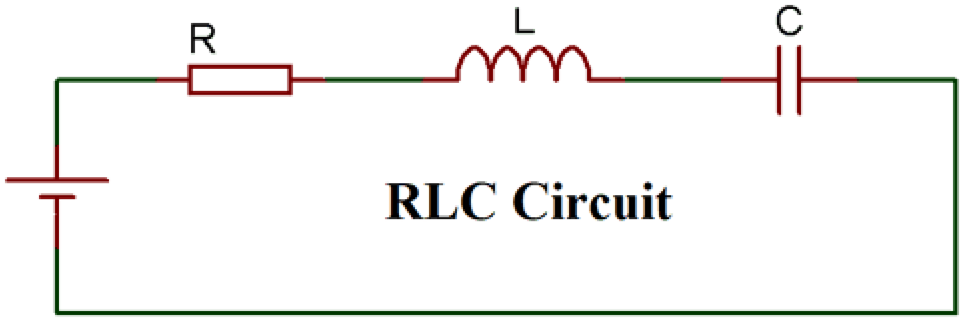


RL Circuit: The **RL Circuit** (**Resistor Inductor Circuit**) will consist of an Inductor and a Resistor again connected either in series or parallel. A series RL circuit will be driven by voltage source and a **parallel RL circuit** will be driven by a current source.



RLC Circuit:

A RLC circuit is a circuit contains resistors, inductors and capacitors, connected in series or parallel. The circuit mostly provide an oscillation in radio transmission circuits.



Conclusion

- Mastery of DC circuits and Kirchhoff's laws is vital for electrical engineering.
- We've covered series circuits, and Kirchhoff's laws.
- These principles enable analysis and solving of complex circuit problems.
- Continued practice will reinforce understanding and application.
- This knowledge forms a strong foundation for advanced electrical engineering topics.

References (in APA style)

- ✓ Alexander, C. K. (2013). Fundamentals of electric circuits. McGraw-Hill,.
- ✓ Young, H. D., Freedman, R. A., & Ford, A. L. (2014). University physics with modern physics (p. 822). New York: Pearson.
- ✓ Bird, J. O. (2007). *Electrical circuit theory and technology*. Routledge.