

جامعة الأمير  
سليمان بن عبدالعزيز  
PRINCE SAUD BIN ABULAZIZ UNIVERSITY

**Lecture (1)**  
**Electric Circuit Variables and Basic Concepts**

EE2010

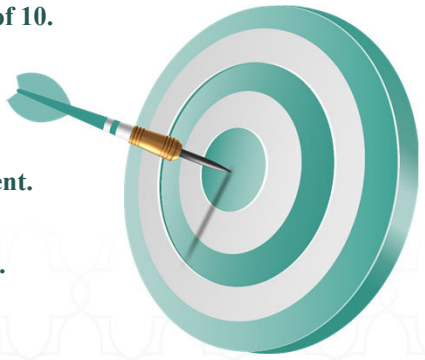
**Abdullah Alharbi**



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**Lecture Objectives**

- 1 Introduction
- 2 Be able to use SI units and the standard prefixes for powers of 10.
- 3 Know the concept of electric charges
- 4 Know and be able to use the definitions of voltage and current.
- 5 Know and be able to use the definitions of power and energy.
- 6 Identify the electrical circuit elements
- 7 Be able to use the passive sign convention to calculate the power.



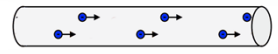
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### Introduction

#### What is Electricity?

Electricity is the physical flow of electrons, referred to as an electrical current.

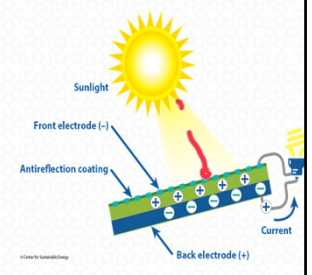
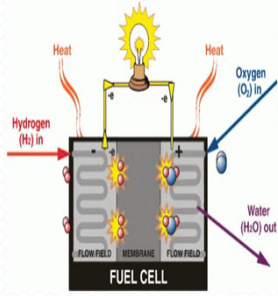
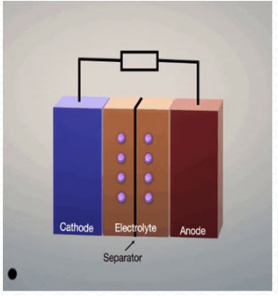
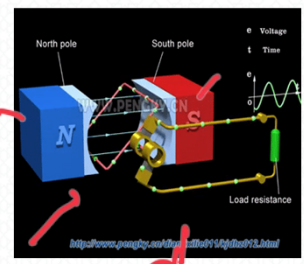


#### How is Electricity Generated?

By electro-magnetic conversion, (electric generator)

By chemical reaction, (battery or fuel cell).

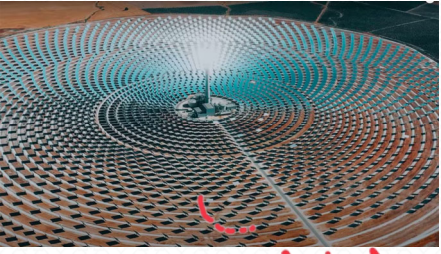
By solid-state conversion, (solar cell).



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### Introduction



wind turbine



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## The Pivotal Role of Electricity in Modern Society

**Overview** Electricity is fundamental to the functionality of modern society, influencing numerous aspects of our daily activities and the broader social infrastructure.

### Ubiquity of Electrical Systems

Electrical systems are integral to our daily existence, embedded in every facet from residential to commercial spaces, educational institutions, and transportation networks, ensuring seamless operation across various platforms.

### Comprehensive Classification of Electrical Systems:

1. **Communication Systems:** Enabling global connectivity and information exchange.
2. **Computer Systems:** Central to data processing, storage, and digital services.
3. **Control Systems:** Crucial for automated and precision control in industrial and domestic applications.
4. **Power Systems:** Concerned with the generation, distribution, and management of electric power.
5. **Signal-Processing Systems:** Fundamental for enhancing, manipulating, and interpreting various signals for better accuracy and performance.

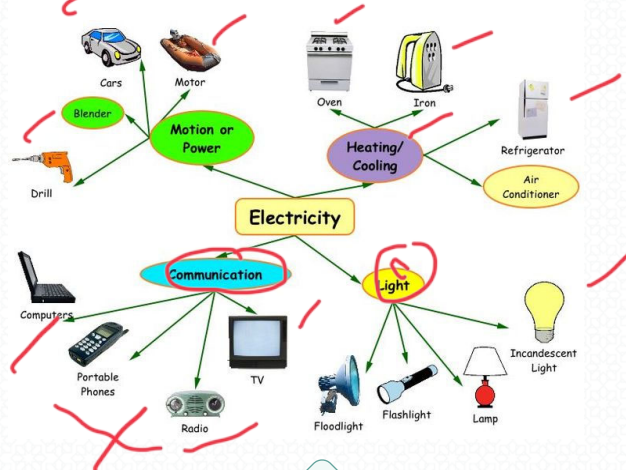
### Applications and Implications

The design and implementation of these systems are facilitated through advanced electrical circuits, which underscore the innovation and efficiency in managing and utilizing electrical energy effectively

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## Uses Of Electricity In Our Daily Life



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### Electrical Engineering and Electric Circuits

**Electrical engineering** primarily focuses on the communication or transfer of energy from one point to another. Achieving this requires an interconnection of electrical elements, forming what we call an electric circuit.

**An electric circuit** is essentially a mathematical model that approximates the behavior of an actual electrical system. While the term "electric circuit" often refers to the real-world electrical system, it also describes the model that represents it.

In this course, our main objective is to analyze circuits. Circuit analysis involves studying the behavior of a circuit, including:

**Response to Input:** How does the circuit respond to a given input?  
**Element Interaction:** How do the interconnected elements and devices within the circuit interact?

Understanding these aspects is crucial for mastering the principles of electrical engineering.

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### The International System of Units (SI)

- As electrical engineers, we deal with measurable quantities.
- The language of measurement must be understood and known throughout the world.
- So, an international measurement language is the International System of Units (SI).
- The SI units are based on seven defined quantities:

Quantity	Basic Unit	Symbol	Prefix	Symbol	Power
Length	meter	m	atto	a	$10^{-18}$
Mass	kilogram	kg	femto	f	$10^{-15}$
Time	second	s	pico	p	$10^{-12}$
Electric current	ampere	A	nano	n	$10^{-9}$
Thermodynamic temperature	degree kelvin	K	micro	$\mu$	$10^{-6}$
Amount of substance	mole	mol	milli	m	$10^{-3}$
Luminous intensity	candela	cd	centi	c	$10^{-2}$
			deci	d	$10^{-1}$
			deka	da	10
			hecto	h	$10^2$
			kilo	k	$10^3$
			mega	M	$10^6$
			giga	G	$10^9$
			tera	T	$10^{12}$

Handwritten red notes include:  $3 \times 10^{-6} \dots 5 \times 10^6 \text{ m}$ ,  $5 \text{ Mm} = 3 \text{ MF} \rightarrow 3 \times 10^{-6} \text{ F}$ , and various checkmarks and arrows.

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شحنة

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### Understanding Electric Charges (q)

**Fundamental Concepts:**

**Charge:** An electrical property of atomic particles, measured in coulombs (C).

**Electron Charge (e):** Each electron carries a negative charge of  $1.602 \times 10^{-19} C$  termed as electronic charge.

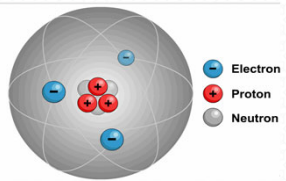
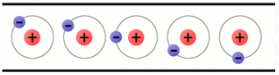
**Charge Multiplicity:** Natural charges occur as integral multiples of the electronic charge.

**Conservation Principle:**

**Law of Conservation of Charge:** This fundamental law states that charges can neither be created nor destroyed, only transferred between bodies

**Particle Charges:**  
**Electrons and Protons:** Electrons bear a negative charge, while protons have an equivalent positive charge.

**Neutrality in Atoms:** Atoms remain neutrally charged when they have equal numbers of protons and electrons.

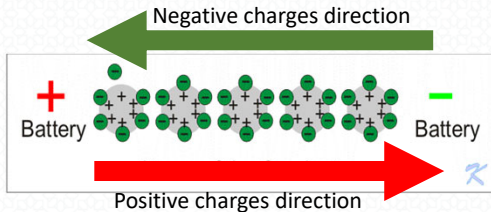

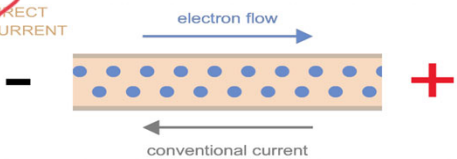



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$\frac{dq}{dt} \rightarrow I$

### Electric Current

- When a conducting wire (consisting of several atoms) is connected to a source of electromotive force, the charges are compelled to move; positive charges move in one direction while negative charges move in the opposite direction.
- The electrical effects caused by charges in motion depend on the rate of charge flow. The rate of charge flow is known as the **electric current**.
- Electric current** is the time rate of change of charge.  $i = \frac{dq}{dt}$
- The unit of electric current is ampere (A), which is  $1 A = \frac{1 C}{sec}$ .
- The direction of current flow is conventionally taken as the direction of positive charge movement.

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$\frac{q}{t} \rightarrow \text{time}$        $\frac{100}{60 \times 60} \dots 0$

$$i = \frac{dq}{dt} \rightarrow q = \int i dt$$

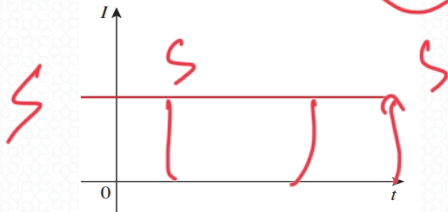
## Types of Electric Current

- The charge transferred between time  $t_0$  and  $t$

$$i = \frac{dq}{dt} \Rightarrow dq = i dt \Rightarrow \int_0^t dq = \int_0^t i dt \Rightarrow Q = \int_0^t i dt$$

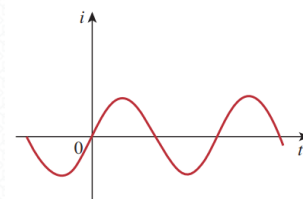
**Direct current (DC)** is a current that remains constant with time.

$$Q = \int_0^t i dt = I \int_0^t dt = I t \quad \text{and} \quad I = \frac{Q}{t}$$



**Alternating current (AC)** is a current that varies sinusoidally with time. (reverse direction)

$$Q = \int_0^t i dt$$



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## Relating Current and Charge

### Example (1):

The total charge entering a terminal is given by  $q = 5t \sin 4\pi t$  mC. Calculate the current at  $t = 0.5$  sec.

Solution:

$$i = \frac{dq}{dt} = \frac{d}{dt}(5t \sin 4\pi t) = (5 \sin 4\pi t + 20\pi t \cos 4\pi t) \text{ mA}$$

$$\text{At } t = 0.5 \text{ sec.} \quad i = 5 \sin 2\pi + 10\pi \cos 2\pi = 10\pi = 31.42 \text{ mA}$$

### Example (2):

Determine the total charge entering a terminal between  $t = 1$  sec. and  $t = 2$  sec. if the current passing the terminal is  $i = (3t^2 - t)$  A.

Solution:

$$Q = \int_{t=1}^2 i dt = \int_1^2 (3t^2 - t) dt = \left( t^3 - \frac{t^2}{2} \right) \Big|_1^2 = (8 - 2) - \left( 1 - \frac{1}{2} \right) = 5.5 \text{ C}$$

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$$q = 5t \sin(4\pi t) \text{ mC}$$

at  $t=0, 5$

$$I = 5 \sin(4\pi t) + 5t \cos(4\pi t) \times 4\pi$$

$$I = 5 \sin(4\pi t) + 20\pi t \cos(4\pi t)$$

$$I = 5 \sin(2\pi) + 20\pi \cos(2\pi)$$

$0 + 10\pi =$   
 $10\pi$

$$I = (3t^2 - t) \text{ A} \quad t=1 \rightarrow t=2$$

$$Q = \int_1^2 i = \int_1^2 (3t^2 - t) dt$$

$$= \left[ t^3 - \frac{t^2}{2} \right]_1^2 = (8 - 2) - \left( \frac{1}{2} - \frac{1}{2} \right) = 6 - \frac{1}{2} = 5.5$$

$$\frac{40}{3} \text{ A}$$

### To Do at Home

**Problem (1):**  
 The current flowing through an element is

$$i = \begin{cases} 4 \text{ A} & 0 < t < 1 \\ 4t^2 \text{ A} & t > 1 \end{cases}$$

Calculate the charge entering the element from  $t = 0$  to  $t = 2$  sec.

*Handwritten solution:*  
 $Q = \int i dt = \int_0^1 4 dt + \int_1^2 4t^2 dt = 4t \Big|_0^1 + \frac{4t^3}{3} \Big|_1^2 = 4(1-0) + \frac{4}{3}(2^3 - 1^3) = 4 + \frac{4}{3}(8-1) = 4 + \frac{28}{3} = \frac{12}{3} + \frac{28}{3} = \frac{40}{3}$


**Problem (2):**  
 A lightning bolt with 10 kA strikes an object for 15 sec. How much charge is deposited on the object?

*Handwritten solution:*  
 $q = it = 10 \times 10^3 \times 15 = 150000 \text{ C} = 150 \text{ kC}$

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### Summary

- > The International System of Units (SI) enables engineers to communicate in a meaningful way about quantitative results.
- > An electric circuit consists of electrical elements connected together.
- > A circuit model is a mathematical representation of an electrical system. Circuit analysis, used to predict the behaviour of a circuit model, is based on the variables of voltage and current.
- > Current is the rate of charge flow and has the SI unit of ampere  $i = \frac{dq}{dt} \text{ A}$ .




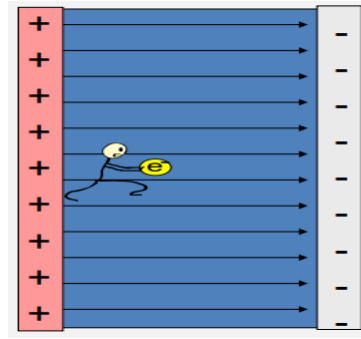
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### Potential Difference or Voltage

- Force is required to move a charge against the electric field.
- When force is applied over a distance, work is done.
- This work is performed by an external electromotive force (emf), which is also known as voltage or potential difference.
- Voltage (or potential difference) : is the energy (or work) required to move a unit charge through an element, measured in volts (V).

$$v = \frac{dw}{dq}$$


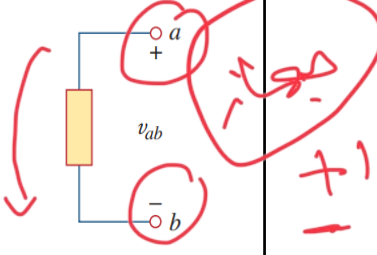
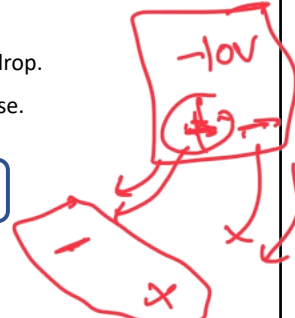
- One volt is the voltage between two points when one joule of energy is used to move one coulomb of charge from one point to the other.

$$1 \text{ volt} = \frac{1 \text{ joule}}{\text{coulomb}} = \frac{1 \text{ newton} \cdot \text{meter}}{\text{coulomb}}$$



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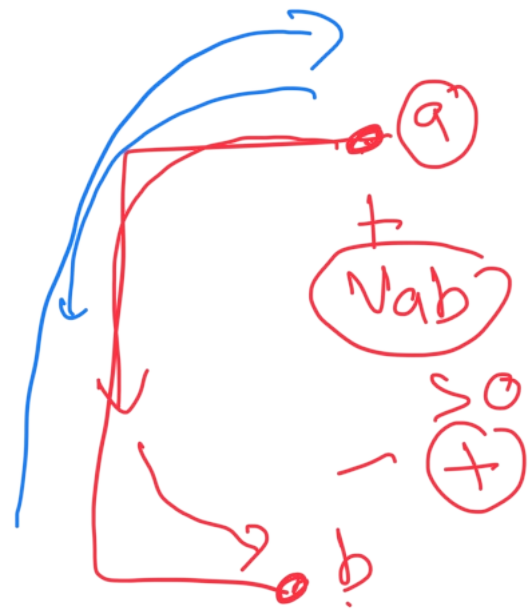
### Voltage Polarity and Passive Sign Convention

- Voltage ( $v_{ab}$ ) is always across the circuit element or between two points (a) and (b) in a circuit.
- The plus (+) and minus (-) signs are used to define reference direction or voltage polarity.
- The  $v_{ab}$  can be interpreted in two ways:
  - Point (a) is at a potential of  $v_{ab}$  volts higher than point (b).
  - The potential at point (a) with respect to point (b) is  $v_{ab}$ .
- $v_{ab} > 0$  (+ve) means the potential of (a) is higher than potential of (b), and known as a voltage drop.
- $v_{ab} < 0$  (-ve) means the potential of (a) is lower than potential of (b), and known as a voltage rise.
- A voltage drop from (a) to (b) is equivalent to a voltage rise from (b) to (a), where  $v_{ab} = -v_{ba}$

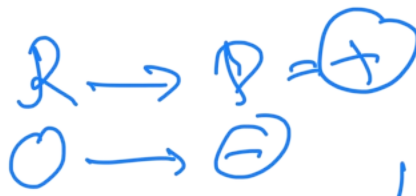




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$$\ominus v_{ba} = v_{ab}$$







### Electric Power and Passive Sign Convention

$p = 4 * 3 = +12 W$        $p = 4 * 3 = +12 W$        $p = -4 * 3 = -12 W$        $p = -4 * 3 = -12 W$

**The element is absorbing power of 12 W**      **The element is supplying power of 12 W**

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### Power Balance

- The law of conservation of energy must be obeyed in any electric circuit.
  - ✓ The total power supplied to the circuit must balance the total power absorbed.
    - i.e. The algebraic sum of power in a circuit, at any instant of time, must be zero:
 
$$+ \text{Power absorbed} = - \text{Power supplied}$$

$$\sum p = 0$$
- The energy absorbed or supplied by an element from time to time t is;
 
$$w = \int_{t_0}^t p dt = \int_{t_0}^t vi dt$$
  - i.e. Energy is the capacity to do work, measured in joules (J).

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واحد يتبع والآخر ياخذ

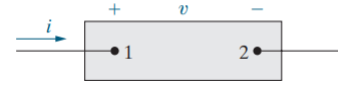
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### Relating Voltage, Current, Power, and Energy

**Example (3):** Assume that the voltage and current at the terminals of the element in the figure are

$$v = 0, \quad i = 0, \quad t < 0;$$

$$v = 10e^{-5000t} \text{ kV}, \quad i = 20e^{-5000t} \text{ A}, \quad t \geq 0;$$



- Calculate the power supplied to the element at 1 ms.
- Calculate the total energy (in joules) delivered to the circuit element.

**Solution:**

- Since the current is entering the (+) terminal of the voltage drop;

$$p = +vi = +(10,000e^{-5000})(20e^{-5000t})$$

$$= 200,000e^{-10,000t} \text{ W}$$

at  $t = 1 \text{ ms}$

$$p(0.001) = 200,000e^{-10} = 9.08 \text{ W}$$

- From the definition of power, the expression for energy is:

$$w(t) = \int_0^t p(t) dt$$

To find the total energy delivered:

$$w_{total} = \int_0^{\infty} (200,000e^{-10,000t}) dt = \left( \frac{200,000e^{-10,000t}}{-10,000} \right) \Big|_0^{\infty}$$

$$= -20(e^{-\infty} - e^0) = 20 \text{ J}$$

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### Relating Voltage, Charge and Energy

**Example (4):**

An energy source forces a constant current of 2 A for 10 s to flow through a light bulb.

If 2.3 kJ is given off in the form of light and heat energy, calculate the voltage drop across the bulb.

**Solution:**

The total charge is

$$\Delta q = i \Delta t = 2 * 10 = 20 \text{ C}$$

The voltage drop is

$$v = \frac{\Delta w}{\Delta q} = \frac{2300}{20} = 115 \text{ V}$$

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a)  $P = +Vi$

$P = 200000 \text{ e}$   
 $t = 1 \text{ ms}$   
 $W = 10000 \times 10^{-3}$

$P = 200000 \text{ e}$   
 $= 9,07 \text{ a a w}$

# Total Energy

$$E = \int_0^{\infty} p$$

$$\int_0^{\infty} \rightarrow 0$$

$$E = \int_0^{\infty} 2000000 e^{-10000t} dt$$

$$E = \frac{2000000}{-10000}$$

~~$0 \neq (2000000)$~~

~~$10000$~~

$10000$

$2000000$

$$\frac{2000000}{10000}$$
$$\frac{2000000}{10000}$$
$$\frac{2000000}{10000}$$



### Relating Voltage, Charge and Energy

#### Example (5):

find the power delivered to an element at  $t = 3ms$  if the current entering its positive terminal is;

$$i = 5 \cos 60\pi t \text{ A}$$

and the voltage is: a)  $v = 3i$  ,    b)  $v = 3 \frac{di}{dt}$

#### Solution:

a) The voltage is     $v = 3i = 15 \cos 60\pi t \text{ V}$

and The power is     $p = vi = 75 \cos^2 60\pi t \text{ W}$

$$\text{At } t = 3ms \quad p = 75 \cos^2(60\pi * 3 * 10^{-3}) = 75 \cos^2(0.18\pi) = 53.48 \text{ W}$$

b) The voltage is     $v = 3 \frac{di}{dt} = 3(-60\pi) 5 \sin 60\pi t$

$$= -900\pi \sin 60\pi t \text{ V}$$

and The power is     $p = vi = -4500\pi \sin(60\pi t) \cos(60\pi t) \text{ W}$

$$\text{At } t = 3ms \quad p = -4500\pi \sin(0.18\pi) \cos(0.18\pi) = -6.396 \text{ kW}$$

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### Relating Voltage, Charge and Energy

#### Example (6):

How much energy does a 100 – W electric bulb consume in *two hours*?

#### Solution:

$$p = 100 \text{ W}, \quad t = 2 \text{ h}$$

$$w = pt = 100 * 2 = 200 \text{ Wh}$$

or

$$w = pt = 100(w) * 2(h) * 60 \left( \frac{\text{min}}{h} \right) * 60 \left( \frac{s}{\text{min}} \right) = 720,000 \text{ J} = 720 \text{ kJ}$$

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$$l = (5 \cos 60\pi t) \text{ m} \leftarrow$$

$$t = 3 \text{ ms}$$

$$p = v \cdot i$$

$$m = 10^{-3}$$

$$v = a) \quad 3 \dot{l}$$

$$p = 3 \dot{l} \cdot \dot{l} = \dot{l}^2$$

$$= 3 \left( 5 \cos(60\pi t) \right)^2 \cdot 3 \times 10^{-3}$$

$$75 \cos^2(60\pi t)$$

$$= 53,4667 \text{ W}$$

$$b) \quad v = 3 \frac{\partial l}{\partial t}$$

$$3 \left[ 5 (-\sin(60\pi t) \cdot 60\pi) \right]$$

$$\underline{-900\pi \sin(60\pi t)} = v$$

$$p = v \cdot i = -4500\pi \cos(60\pi t) \cdot \sin(60\pi t)$$

$$= -6395,8455 \text{ W}$$

$$= -6,3958 \text{ kW}$$

$$V = \frac{dw}{dq} = \frac{W}{q}$$

### To Do at Home

**Problem (3):**

To move charge  $q$  from point  $a$  to point  $b$  requires  $-30$  J. Find the voltage drop  $v_{ab}$  if: (a)  $q = 6$  C, (b)  $q = -3$  C.

**Problem (4):**

Find the power delivered to the element in Example 1.5 at  $t = 5$  ms if the current remains the same but the voltage is: (a)  $v = 2i$  V,

(b)  $v = \left(10 + 5 \int_0^t i dt\right)$  V.

**Problem (5):**

A stove element draws  $15$  A when connected to a  $240$ -V line. How long does it take to consume  $180$  kJ?

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$$P = Vi = \frac{W}{t} \Rightarrow t = \frac{W}{Vi}$$

$$t = \frac{180 \times 10^3}{15 \times 240} = 50$$

### Circuit Elements

- **An element** is the basic building block of an electric circuit.
- **An electric circuit** is simply an interconnection of the elements.
- **Circuit analysis** is the process of determining voltages across (or the currents through) the elements of the circuit.

#### Types of Elements

#### Passive Elements

Not capable of generating energy  
(Resistors, Capacitors, and Inductor)

#### Active Elements

Capable of generating energy  
(Generators, Batteries, and Operational amplifiers)

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### Circuit Elements (Sources)

The most important active elements are voltage or current sources that generally deliver power to the circuit

#### Types of Sources

### Independent

(Voltage source and Current source)

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

voltage source

constant voltage (dc)

current source

### Dependent

(Voltage source and Current source)

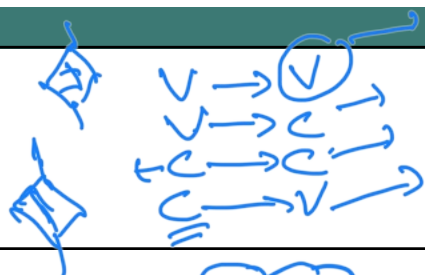
An ideal **dependent** source is an active element that provides a specified voltage or current that is *controlled by another voltage or current*.

voltage source

current source

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### Power Balancing

**Example (7):**  
Calculate the power supplied or absorbed by each element.

**Solution:**

$p_1 = -iv = -5 \times 20 = -100 \text{ W}$  (Supplied power)

$p_2 = +iv = 5 \times 12 = 60 \text{ W}$  (Absorbed power)

$p_3 = +iv = 6 \times 8 = 48 \text{ W}$  (Absorbed power)

$p_4 = -iv = -0.2 \times I \times V = -0.2 \times 5 \times 8 = -8 \text{ W}$  (Supplied power)

Note:

$$p_1 + p_2 + p_3 + p_4 = -100 + 60 + 48 - 8 = 0$$

The total power supplied equals the total power absorbed

$\oint = +$

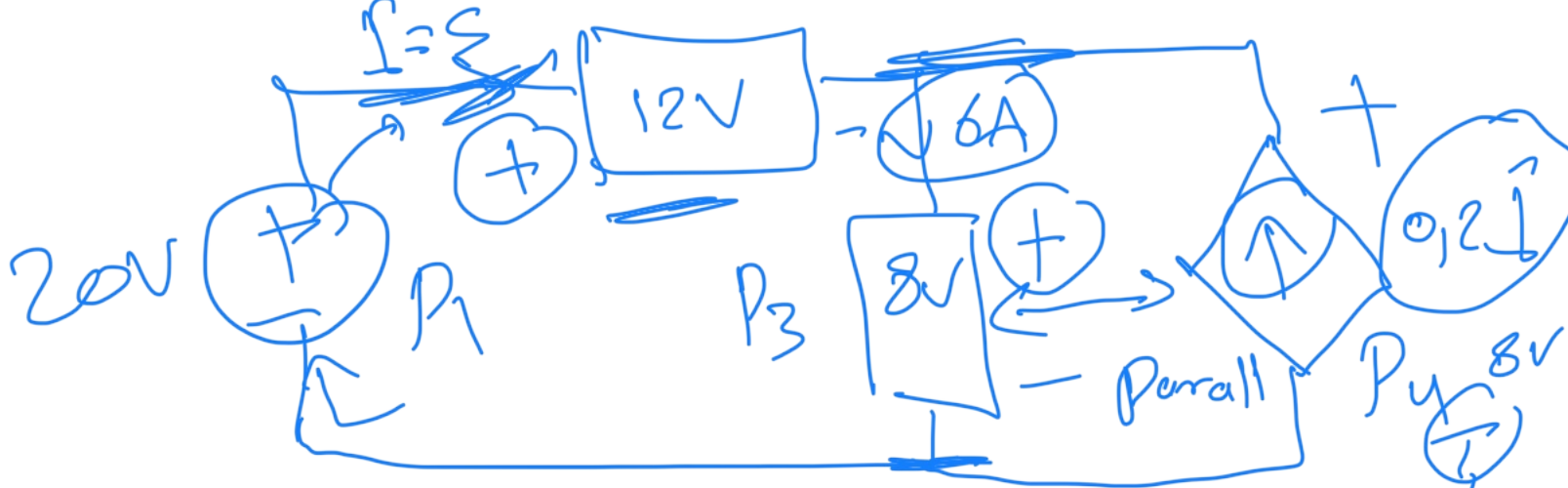
$\oint = +$

EPF

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$$P_1 = Vi = -5 \times 20 = \ominus 100 \text{ W} \text{ supply}$$

$$P_2 = +Vi = +5 \times 12 = \oplus 60 \text{ W} \text{ absorbed}$$

$$P_3 = +Vi = +6 \times 8 = \oplus 48 \text{ W} \text{ parallel}$$

$$P_4 = -Vi \quad U = U$$

$$= -8 \times 0.2 \times 5 = -8 \text{ W}$$

$$\underline{\underline{\sum P = 0}}$$

$$-100 + 60 + 48 - 8 = 0$$

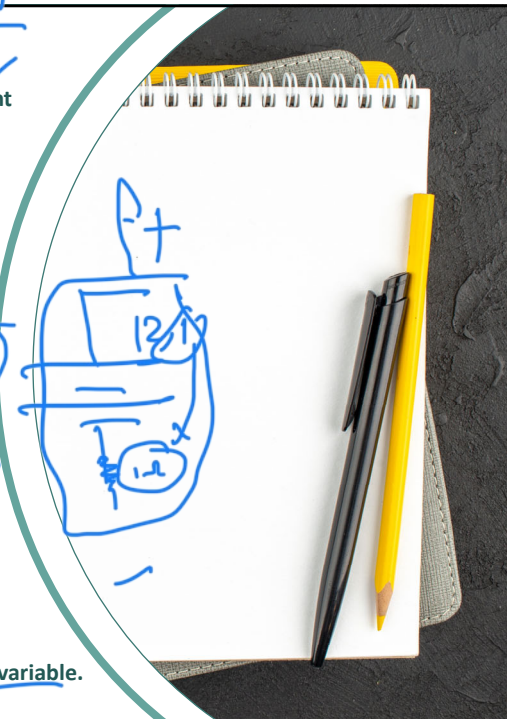
$$-100 + 100 = 0$$

**Summary**

- Voltage is the energy required to move 1 C of charge through an element  

$$v = \frac{dw}{dq}$$
- Power is the energy supplied or absorbed per unit time. It is also the product of voltage and current.  

$$p = \frac{dw}{dt} = vi$$
- According to the passive sign convention, power assumes a positive sign when the current enters the positive polarity of the voltage across an element
- An ideal voltage source produces a specific potential difference across its terminals regardless of what is connected to it.
- An ideal current source produces a specific current through its terminals regardless of what is connected to it.
- Voltage and current sources can be dependent or independent. A dependent source is one whose value depends on some other circuit variable.



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**Use full videos and visual resources**

1. <https://www.youtube.com/watch?v=0LutKTjqE98>
2. <https://www.youtube.com/watch?v=0X67I6HgBO4>
3. <https://www.youtube.com/watch?v=R3gVXdLYaOA>
4. <https://www.youtube.com/watch?v=KMHeivkKKD4>

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## References

[1] J. W. Nilsson and S. Riedel, *Electric Circuits*, 12th ed. Hoboken, NJ, USA: Pearson, 2022.

[2] Charles K. Alexander and Matthew n. o. Sadiku, 5th ed, *Fundamentals of Electric Circuits*, 2012.

