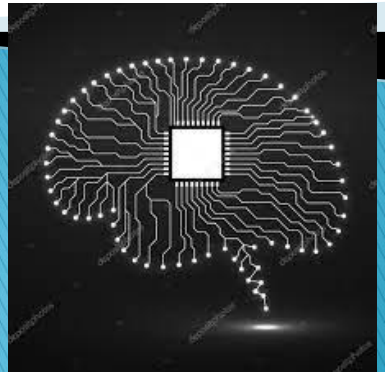
AYDIN
ADNAN MENDERES UNIVERSITY
FACULTY OF ENGINEERING
Department of Electrical and Electronics Engineering

EE201 – Circuit Theory I





1. **Basic Concepts (Chapter 1 of Nilsson – Week 1)**

   Introduction, Current and Voltage, Power and Energy

2. **Basic Laws (Chapter 2&3 of Nilsson – Week 2)**

   Voltage and Current Sources, Ohm's Law,

   Kirchhoff's Laws, Resistors in parallel and in series, Voltage and Current Division

3. **Techniques of Circuit Analysis (Chapter 4 of Nilsson – Weeks 3-6)**

   Node Analysis, Node-Voltage Method and Dependent Sources, Mesh Analysis, Mesh-Current Method and Dependent Sources, Source Transformations, Thevenin and Norton Equivalents, Maximum Power Transfer, Superposition Theorem

   MIDTERM (Weeks 7&8)

4. **Operational Amplifier (Chapter 5 of Nilsson – Weeks 9-10)**

   Op-Amp Terminals & Ideal Op-Amp, Basic Op-Amp Circuits, Buffer circuit, Inverting and Non-inverting Amplifiers, Summing Inverter, Difference Amplifier, Cascade Op-Amp Circuits

5. **Capacitors and Inductors (Chapter 6 of Nilsson – Weeks 11)**

   Inductors, Capacitors, Series and Parallel Combinations of them

6. **First Order Circuits (Chapter 7 of Nilsson – Weeks 12 & 13)**

   The Natural Response of an RL & RC Circuits, The Step Response of RL and RC Circuits, A General Solution for Step and Natural Responses, Integrating Amplifier Circuit

7. **Second Order Circuits (Chapter 8 of Nilsson – Weeks 14 & 15)**

   The Natural Response of a Parallel RLC Circuit, The Forms of Natural Response of a Parallel RLC Circuit, The Step Response of a Parallel RLC Circuit, Natural and Step Responses of a Series RLC Circuit

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Chapter 1: Basic Concepts

- **Alessandro Giuseppe Antonio Anastasio Volta** (1745 – 1827), an Italian physicist, invented the electric battery-which provided the **first continuous flow of electricity**-and the capacitor.



- The publication of his work in 1800 marked the **beginning of electric circuit theory**. Volta received many honors during his lifetime. **The unit of voltage or potential difference, the volt**, was named in his honor.

- **Andre-Marie Ampere** (1775–1836), a French mathematician and physicist, laid the foundation of electrodynamics. He **defined the electric current and developed a way to measure it** in the 1820s.



- He formulated the laws of electromagnetics. He invented the electromagnet and the ammeter. **The unit of electric current, the ampere**, was named after him.

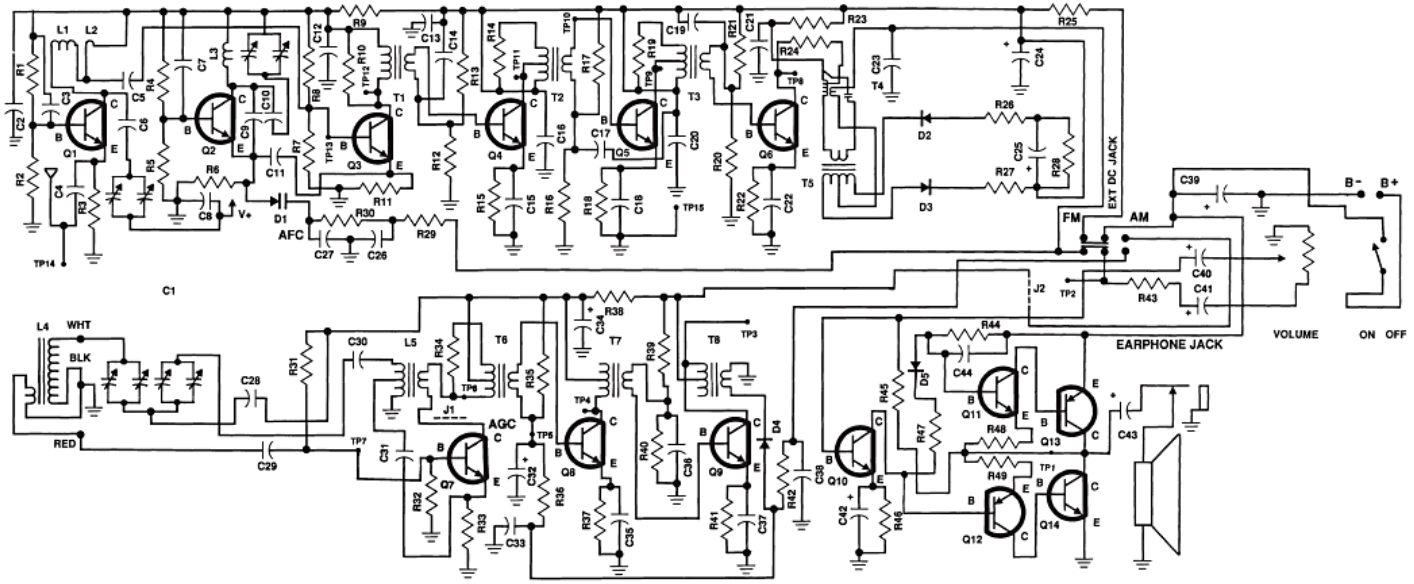
Ch1: Basic Concepts – Introduction

- This course deals with the analysis design of linear electric circuits.
- **Electric circuit theory** and **electromagnetic theory** are the two fundamental theories upon which all branches of electrical engineering are built.
- Many branches of electrical engineering, such as power, electric machines, control, electronics, communications, and instrumentation, are based on electric circuit theory.
- **Circuit theory is also valuable to students specializing in other branches of the physical sciences because circuits are a good model for the study of energy systems in general, and because of the applied mathematics, physics, and topology involved.**

WHAT IS AN ELECTRIC CIRCUIT?

- An electric circuit is an interconnection of electrical elements that process **energy** or **information**.

- An electric circuit is a mathematical **model** that **approximates** the behavior of an actual electrical system.



Symbol of Units (SI)

- As electrical engineers, we deal with measurable quantities.
- Our measurement, however, must be communicated in a standard language that virtually all professionals can understand, irrespective of the country where the measurement is conducted.
- Such an international measurement language is the **International System of Units (SI)**, adopted by the General Conference on Weights and Measures in 1960.
- In this system, **there are seven principal units** from which the units of all other physical quantities can be derived.

Ch1: Basic Concepts

Symbol of Units (SI)

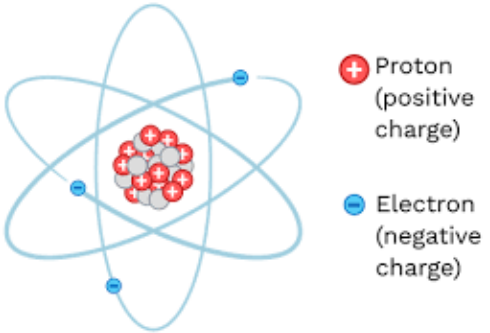
Fundamental Quantities	SI Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	Ampere	A
Temperature	Kelvin	K
Amount of subtance	mol	mol
Luminous Intensity	candela	cd

Prefix	Symbol	Multiply Base Unit by	Example
tera	T	1,000,000,000,000	teragram = Tg = 10^{12} g
giga	G	1,000,000,000	gigaliter = GL = 10^{9}L
mega	M	1,000,000	megagram = Mg = 10^{6} g
kilo	k	1,000	kilogram = kg = 10^{3} g
hecto	h	100	hectogram = hm = 10^{2} m
deka	da	10	decagram = dag = 10 g
deci	d	1/10	deciliter = dL = 10^{-1} L
centi	c	1/100	centimeter = cm = 10^{-2} g
milli	m	1/1000	millimeter = mm = 10^{-3} m
micro	μ	1/1,000,000	microgram = μg = 10^{-6} g
nano	n	1/1,000,000,000	nanoliter = nL = 10^{-9} L
pico	p	1/1,000,000,000,000	picogram = pg = 10^{-12}g
femto	f	1/1,000,000,000,000,000	femtomole = fmol= 10^{-15} mol

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Electric Charge

- The most basic quantity in an electric circuit is the electric charge.
- The concept of **electric charge** is the underlying principle for explaining all electrical phenomena.
- Charge is an electrical property of the atomic particles of which matter consists, measured in **coulombs** (**C**).
- The symbol "**q**" is used to represent charge.
  - One electron has a charge of **-1.602×10^{-19} C**



$1 / 1.602 \times 10^{-19} = 6.25 \times 10^{18}$ electrons in 1 Coulomb of charge

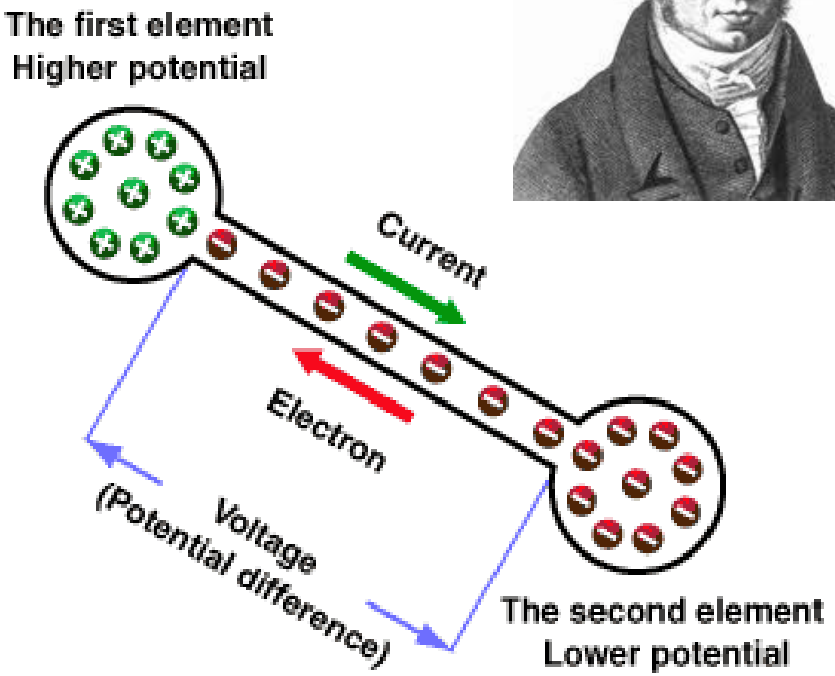
Ch1: Basic Concepts

Voltage , Current

- Andre Ampere was the first to recognize the importance of distinguishing between the electrical effects now called **voltage** and **current**.

- In circuit theory, the **separation** of charge creates an electric force (voltage), and the **motion** of charge creates an electric fluid (current).





Voltage and Current

Ch1: Basic Concepts

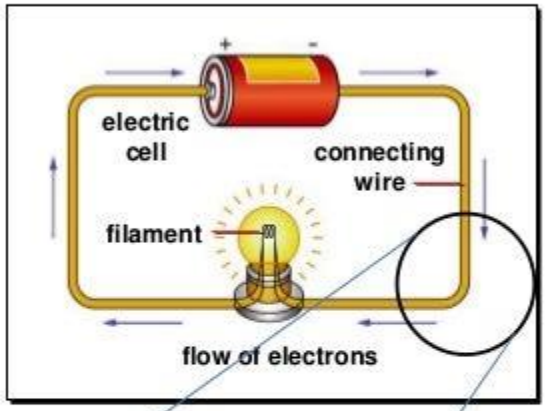
Current

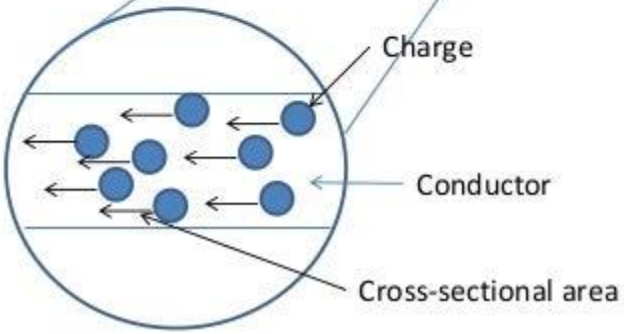
- The **motion** of charge creates an electric fluid (current).

Electric Current

Definition:

An electric current is the rate of flow of electric charges in a circuit.





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Ch1: Basic Concepts

Current

- The **motion** of charge creates an electric fluid (current).

- If "**q**" is the cumulative charge passing **through** a point, we define a signal variable "**i**" called current as follows;

$$i = \frac{dq}{dt}$$

- Current is a measure of the flow of the electrical charge and it's direction is universally accepted as the flow of the **positive/negative (???)** charges.

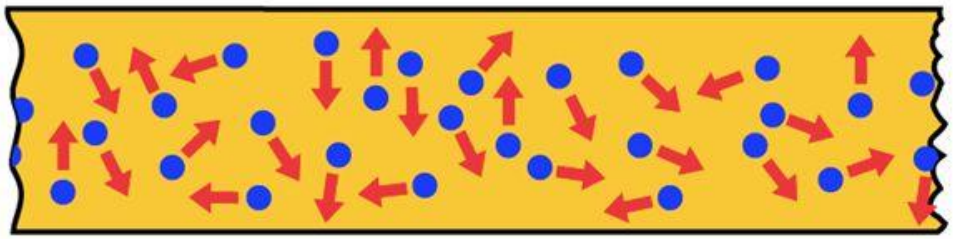
POSITIVE…..

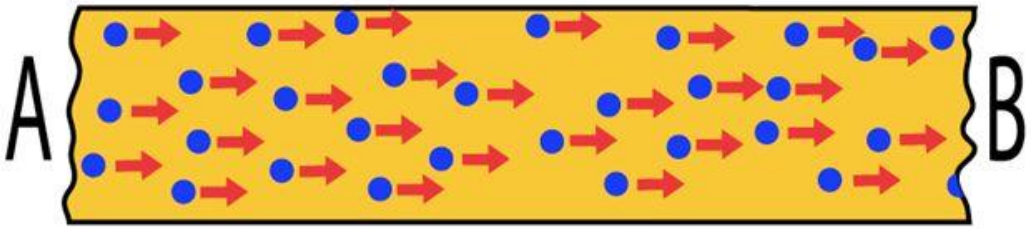
- Electric current is the time rate of change of charge, measured in amperes (A).

(1 ampere = 1 coulomb/second)

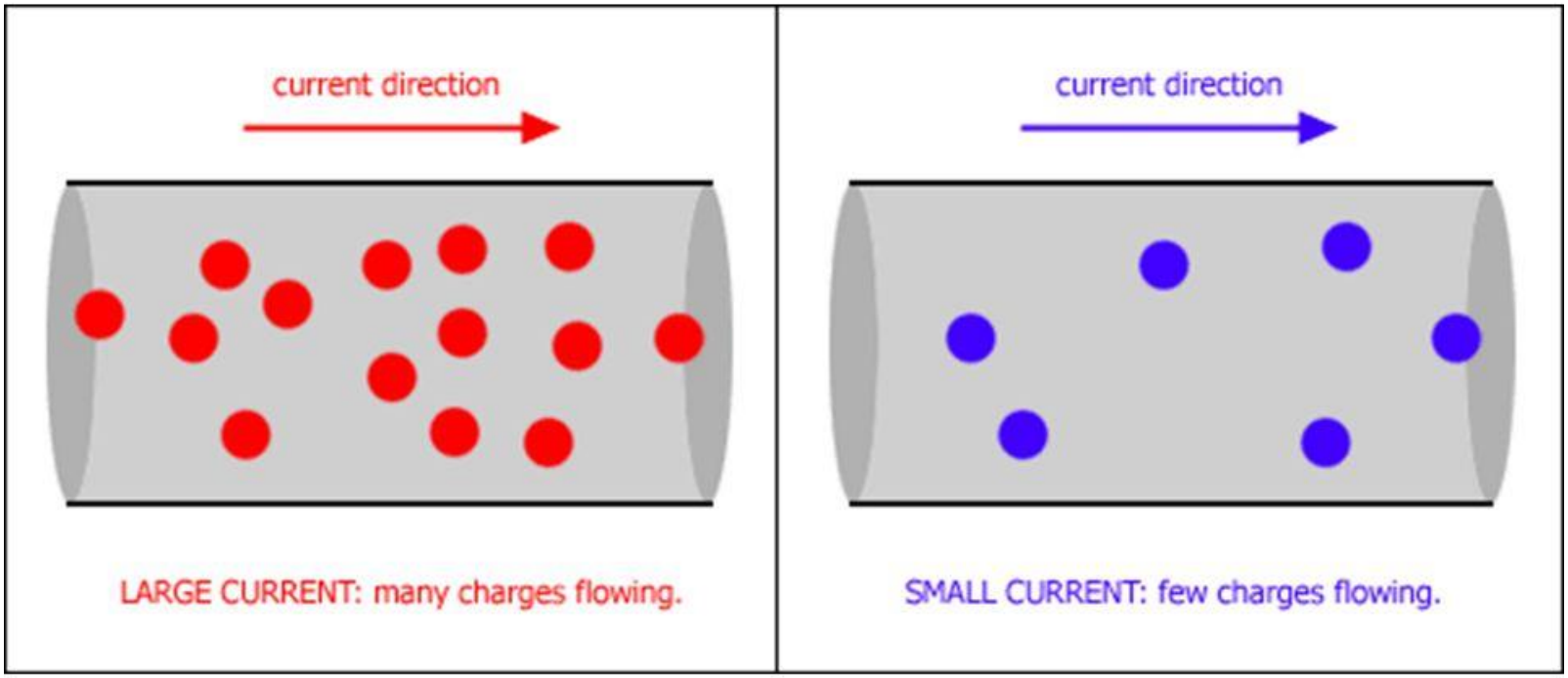
$$q = \int_{t_o}^{t} i.dt$$

CURRENT ELECTRICITY: THE CONTROLLED FLOW OF ELECTRONS THROUGH A CONDUCTOR





Electric Current



Current – AC/DC

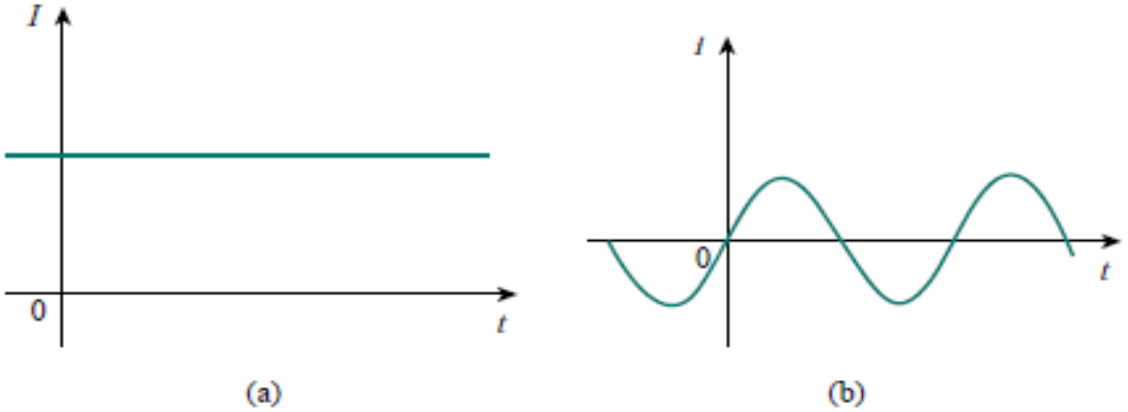
- Current can be time-varying (ac) or time-invarying (dc).

- A **direct current (DC)** is a current that remains **constant with time**.

  By convention the symbol **I** is used to represent such a constant current.

- An **alternating current (AC)** is a current that varies **sinusoidally with time**.

  A time-varying current is represented by the symbol ***i***.

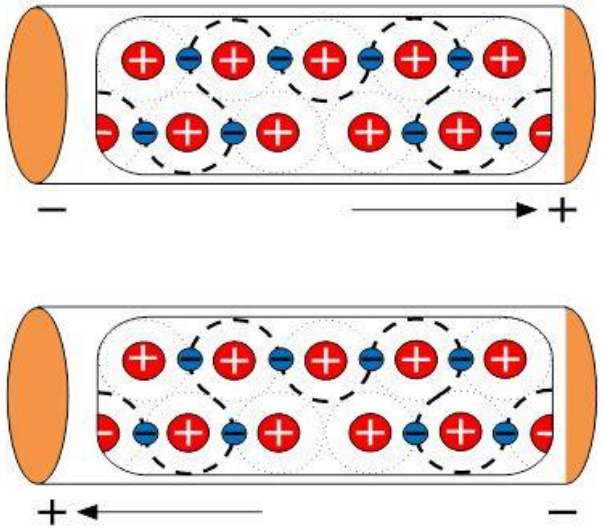


Two common types of current:
(a) direct current (dc), (b) alternating current (ac).

Ch1: Basic Concepts

The supply of current for electrical devices may come from

1. **Direct current (DC)** , source electrons flow continuously in one direction from the source of power through a conductor to a load and back to the source of power.
2. **Alternating current (AC)** , source electrons flow first in one direction then in another. AC generator reverses its terminal polarities many times a second.



Example : The total charge entering a terminal is given by *q = 5t sin(4πt) mC. Calculate* the current at *t = 0.5 s.*

(Answer : 31,42 mA)

$$i = \frac{dq}{dt}$$

- **Example :** Determine the total charge entering a terminal between *t = 1 s and t = 2 s* if the current passing the terminal is $i(t) = 3t^2 - t$ *A.*
- (Answer : 5,5 C)

$$q = \int_{t_o}^{t} i.dt$$

Voltage

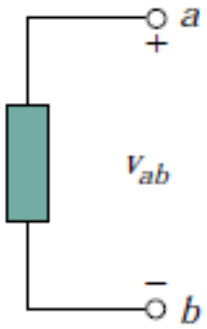
- The **separation** of charge creates an electric force (voltage).

- **Voltage** (or potential difference) is the energy per unit charge created by the separation.

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

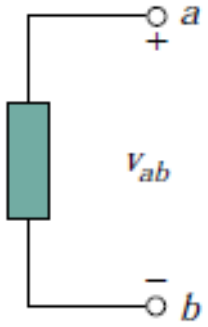
(1 volt= 1 Joule/coulomb)

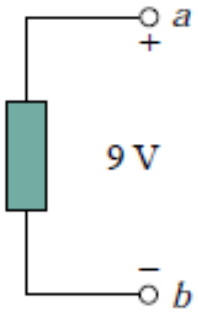
- Voltage must be defined between two points like “a” and “b”. (v_{ab})

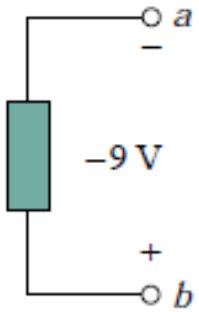


Voltage

- v_{ab} can be interpreted in two ways;
  - ✓ **point *a*** *is at a potential of* v_{ab} volts higher than **point *b***
  - ✓ **point *b*** *is at a potential of* v_{ab} volts lower than **point *a***
  - ✓ the potential at **point *a*** *w.r.t.* **point *b*** *is* $v_{ab} = -v_{ba}$







Like electric current, voltage (or potential difference) can be ac (*v*) or dc (V)!!!!! (constant or varying sinusoidally)

Electric current is always through an element.
Electric voltage is always across the element or between two points.

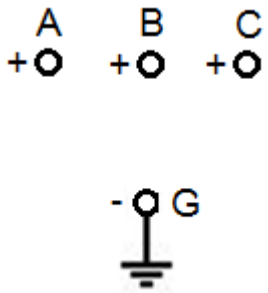
Voltage

- Since the voltage (or potential difference) is defined between two points, it is useful to define a **common voltage reference** point.

GROUND !!!!



- The voltages at all other points in a circuit are then defined w.r.t. this common reference point (or GROUND).



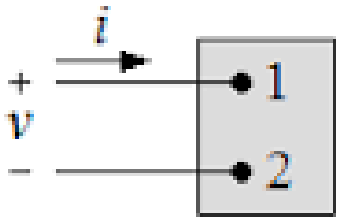
$$v_{AG} = v_A$$

$$v_{BG} = v_B$$

$$v_{CG} = v_C$$

The Ideal Basic Circuit Element

- The IBCE has three attributes
  - it has only two terminals, which are points of connection to other circuit components,
  - it is described mathematically in terms of current and/or voltage,
  - it cannot be subdivided into other elements.



- Once you have assigned the references, you must write all subsequent equations to agree with the chosen references.

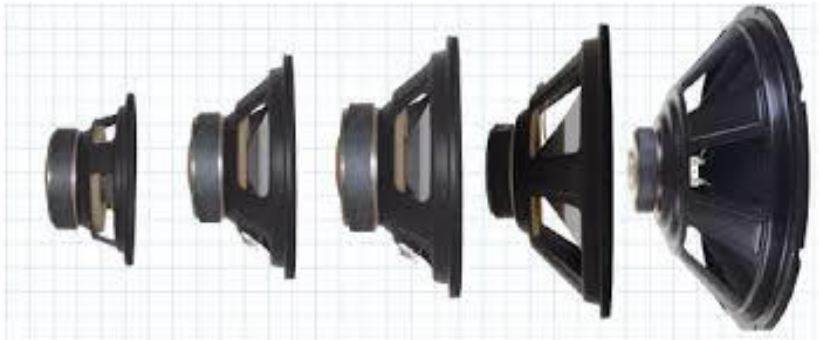
- The most widely used sign convention applied to these references is called the **passive sign convention**.

Power & Energy

- Although current and voltage are the two basic variables in an electric circuit, they are not sufficient by themselves.

- For practical purposes, we need to know how much power an electric device can handle.







Power

- Power is the time rate of expending or absorbing energy, measured in watts (W).

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

$$p = \frac{dw}{dt} = \frac{dw}{dq}.\frac{dq}{dt} = v.i \qquad \boxed{p = v.i}$$

- Power is a quantity associated with a pair of terminals, and we have to be able to tell from our calculation whether power is being **delivered** to the pair of terminals or **extracted** from it.

USE PSC !!!!

Power

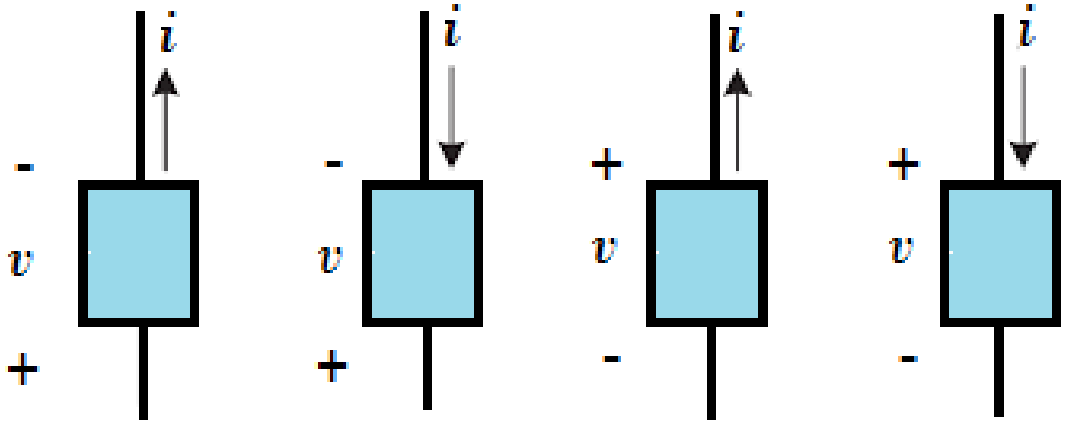
- **Passive Sign Convention (PSC) :** Whenever the reference direction for the current in an element is in the direction of the reference voltage drop across the element , **use a positive sign in any expression** that relates the voltage to the current. Otherwise, use a negative sign.

If PSC is satisfied, then

If PSC is not satisfied, then

$$p = +v.i$$

$$p = -v.i$$



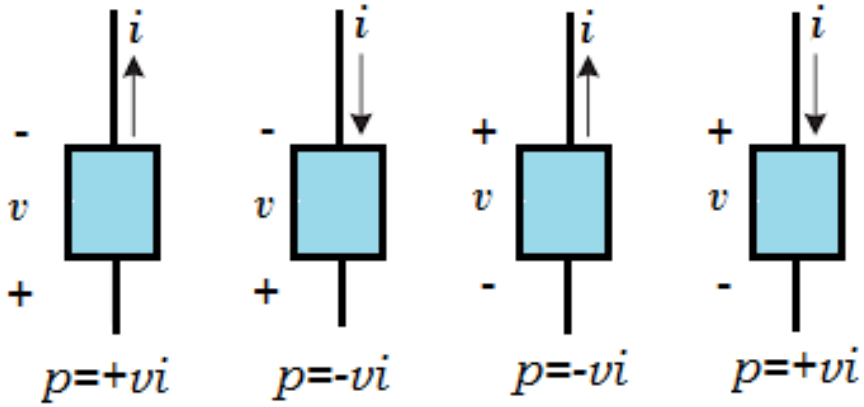
Power

- If the power is positive (p>0), power is being **delivered** to the circuit inside the box. Circuit is **absorbing power.**

- If the power is negative (p<0), power is being **extracted** from the circuit inside the box. Circuit is **releasing or supplying power**.

If PSC is satisfied, then ⟹ $p = +v.i$ **absorbing power.**

If PSC is not satisfied, then ⟹ $p = -v.i$ **supplying power.**



Energy

- **Energy** is the capacity to do work, measured in **joules** (**J**). (1Wh = 3600J)

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

- The energy absorbed or supplied by an element from t_0 to t is;

$$w = \int_{t_o}^{t} p.dt = \int_{t_o}^{t} v.i.dt$$

Summary for PSC

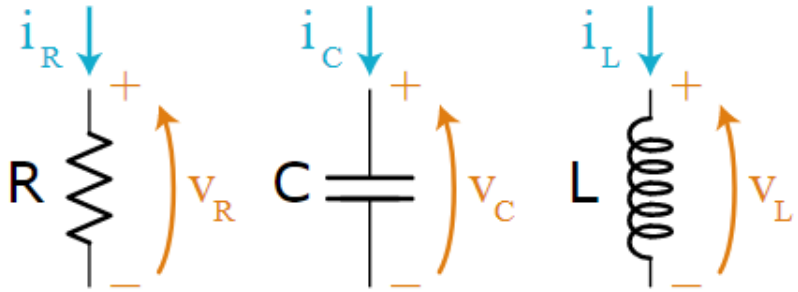
Sign convention for passive components

We need a simple, widely understood way to refer to voltages and currents in a circuit. The purpose of the sign convention developed here is to define what we mean by positive and negative voltages and currents.

Ch1: Basic Concepts

Summary for PSC

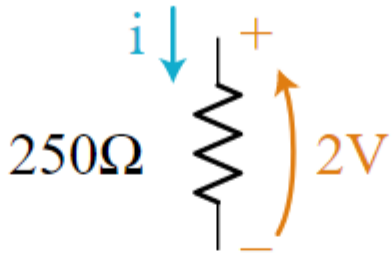
Why do we need a sign convention? Passive components (resistors, capacitors, inductors) have a defining equation (Ohm's Law and others). These equations establish a relationship between voltage and current. We can't just assign voltage polarity and current direction any which way. Voltage polarity and current direction have to be consistent with each other. The universal convention for voltage polarity and current direction for two-terminal components is shown below:



This is called the *sign convention for passive components*.

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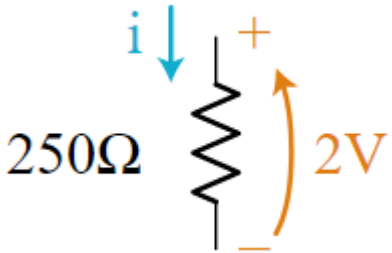
Example :



This $250\,\Omega$ resistor has been labeled using the sign convention for passive components. The voltage polarity (orange signs and arrow) have been assigned with $+$ at the top of the resistor. This direction was an arbitrary choice. The blue current arrow points into the positive terminal. This was not an arbitrary choice. Positive current has to flow into the $+$ sign.

Something (not shown, a voltage source or surrounding circuit) has caused $2\,\text{volts}$ to appear across the resistor.

Example :



What is i?

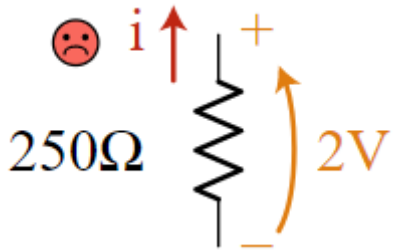
To find the current, apply Ohm's Law: $i = \dfrac{v}{\mathrm{R}}$

$$i = \frac{+2\,\mathrm{V}}{250\,\Omega} \qquad i = +8\,\mathrm{mA}$$

The voltage arrow tells us the top of the resistor is $2\,\mathrm{V}$ above the bottom of the resistor. Ohm's Law tells us the current is $+8\,\mathrm{mA}$. The $+$ sign on current means it is flowing in the direction of the arrow, from top to bottom.

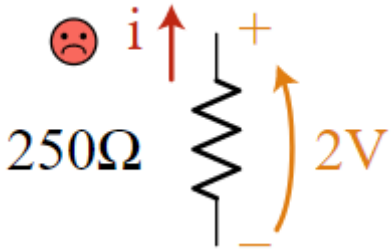
Example : WRONG WAY !!!

What would happen if we labeled the resistor with the wrong sign convention? The diagram below shows the same resistor with the same voltage polarity, but the current arrow points *out* of the positive terminal, so the sign convention for passives is not being used.



Apply Ohm's Law, exactly the same as Example 1, $i = \frac{v}{R}$

Example : WRONG WAY !!!



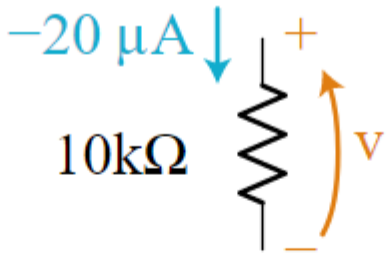
$$i = \frac{v}{\mathrm{R}}$$

$$i = \frac{+2\,\mathrm{V}}{250\,\Omega}$$

$$i = +8\,\mathrm{mA}$$

Ohm's Law is telling us the current is $+8\,\mathrm{mA}$. The $+$ sign on current means it is flowing in the direction of the arrow, from bottom? to top?. What? In a real resistor the current would be flowing the other way. We got the wrong answer. Lesson: use the sign convention for passives.

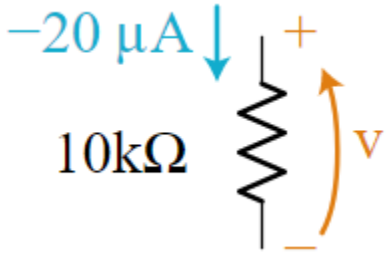
Example :



This $10\,\mathrm{k}\Omega$ resistor has been labeled with the same sign convention as the first example: The orange voltage polarity has $+$ at the top and the blue current arrow points down. This time, the current is specified instead of the voltage. The value of the current is $-20\,\mu\mathrm{A}$. This may look a little odd, to show $-20\,\mu\mathrm{A}$ current flowing in the direction of the arrow. If you like, think of it as a $+20\,\mu\mathrm{A}$ current going in the opposite direction (flowing from bottom to top in the resistor).

Ch1: Basic Concepts

Example :



What is v?

We use Ohm's Law to solve for the unknown voltage. Since we've been careful to use the sign convention, all we have to do is plug in the actual values shown on the schematic. (Avoid the temptation to flip signs around in your head as you write these equations. This often leads to errors.)

$$v = i\,\mathrm{R}$$

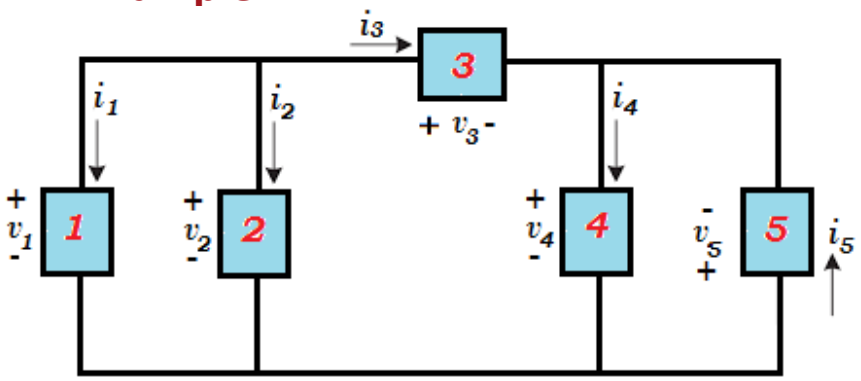
$$v = -20\,\mu\mathrm{A} \cdot 10\,\mathrm{k\Omega}$$

$$v = (-20 \times 10^{-6}) \cdot (10 \times 10^{+3}) \qquad v = -0.2\,\mathrm{V}$$

https://www.khanacademy.org/science/electrical-engineering/ee-circuit-analysis-topic/circuit-elements/a/ee-sign-convention

Ch1: Basic Concepts

Example :



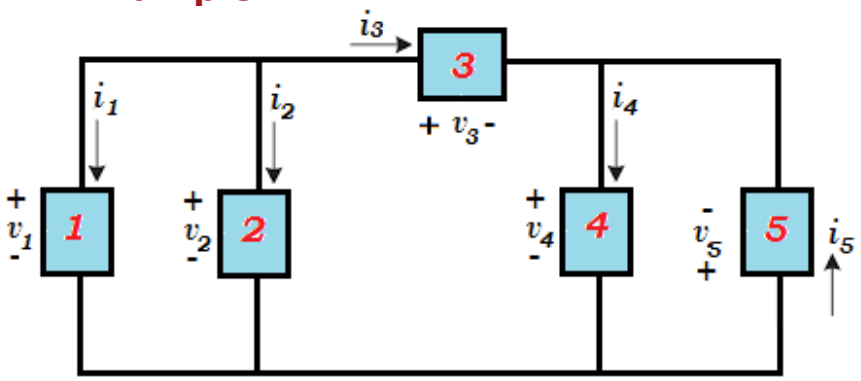
	1	2	3	4	5
v (V)	100	?	25	75	−75
i (mA)	?	5	5	?	5
p(W)	−1	0.5	?	0.75	?

a) Find the missing variables and state whether device is absorbing/delivering power?

b) Check your work by showing that the sum of the device powers is zero?

Ch1: Basic Concepts

Example :



	1	2	3	4	5
v (V)	100	?	25	75	−75
i (mA)	?	5	5	?	5
p(W)	−1	0.5	?	0.75	?

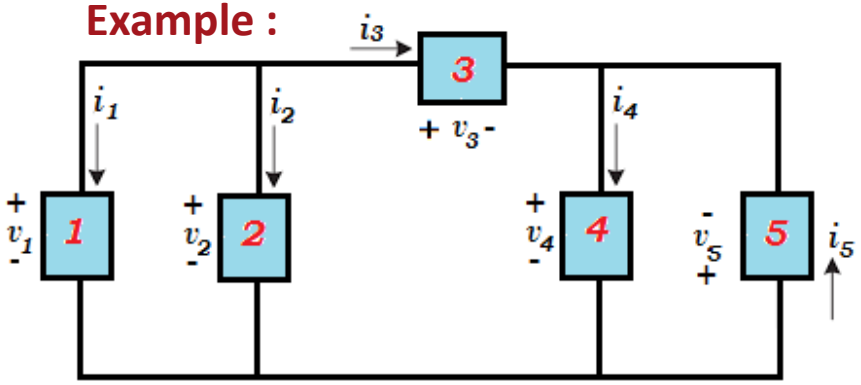
a) Find the missing variables and state whether device is absorbing/delivering power?

$$P = \pm v.i \quad \& \quad v = \pm P/i \quad \& \quad i = \pm P/v$$

But you need to take into account PSC !!!

Ch1: Basic Concepts

Example :



	1	2	3	4	5
v (V)	100	?	25	75	−75
i (mA)	?	5	5	?	5
p(W)	−1	0.5	?	0.75	?

a) Find the missing variables and state whether device is absorbing/delivering power?

For component 1 $i_1 = \pm\frac{P_1}{v1}$ $i_1 = \pm\frac{-1}{100}$ $i_1 = +\frac{-1}{100}$ $i_1 = -0.01A = -10\,mA$

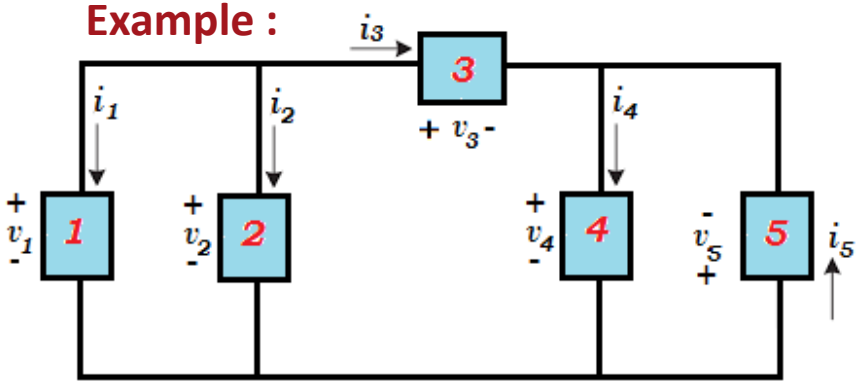
$$P_1 = -1W < 0 \quad hence; delivering\ power$$

For component 2 $v_2 = \pm\frac{P_2}{i2}$ $v_2 = \pm\frac{0.5}{5mA}$ $v_2 = +\frac{0.5}{5mA}$ $v_2 = 0.1KV = 100V$

$$P_2 = 0.5W > 0. \quad hence; absorbing\ power$$

Ch1: Basic Concepts

Example :



	1	2	3	4	5
v (V)	100	?	25	75	−75
i (mA)	?	5	5	?	5
p(W)	−1	0.5	?	0.75	?

a) Find the missing variables and state whether device is absorbing/delivering power?

For component 3 $P_3 = \pm v_3 i_3 \quad P_3 = \pm 25 * 5mA \quad P_3 = +125mW = 0.125W$

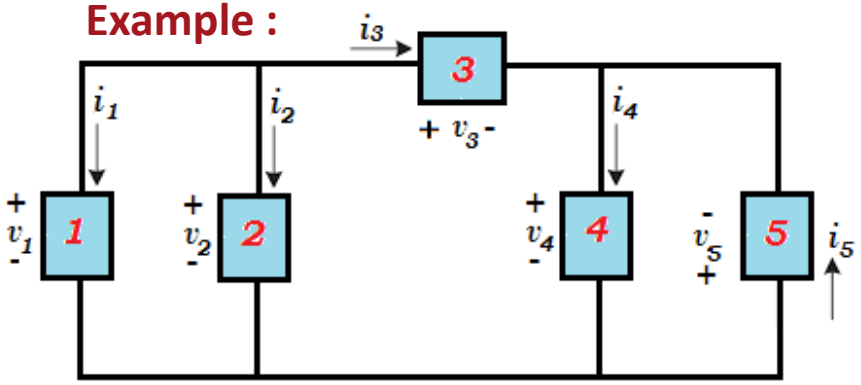
$$P_3 = 0.125W > 0. \quad hence; absorbing\ power$$

For component 4 $i_4 = \pm \frac{P_4}{v4} \quad i_4 = \pm \frac{0.75}{75} \quad i_4 = + \frac{0.75}{75} \quad i_4 = +0.01A = 10\ mA$

$$P_4 = 0.75W > 0. \quad hence; absorbing\ power$$

Ch1: Basic Concepts

Example :



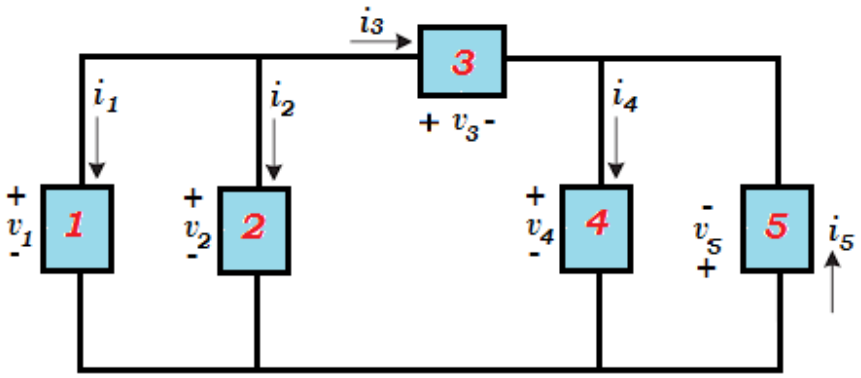
	1	2	3	4	5
v (V)	100	?	25	75	−75
i (mA)	?	5	5	?	5
p(W)	−1	0.5	?	0.75	?

a) Find the missing variables and state whether device is absorbing/delivering power?

For component 5 $P_5 = \pm v_5 i_5$ $P_5 = \pm(-75) * 5mA$ $P_3 = +(-75) * 5mA$=-0.375W

$$P_5 = -0.375W < 0 \quad hence; delivering\ \ power$$

Ch1: Basic Concepts



	1	2	3	4	5
v (V)	100	?	25	75	−75
i (mA)	?	5	5	?	5
p(W)	−1	0.5	?	0.75	?

a) Check your work by showing that the sum of the device powers is zero?

For component 1 $P_1 = -1W$

For component 2 $P_2 = +0.5W$

For component 3 $P_3 = +0.125W$

For component 4 $P_4 = +0.75W$

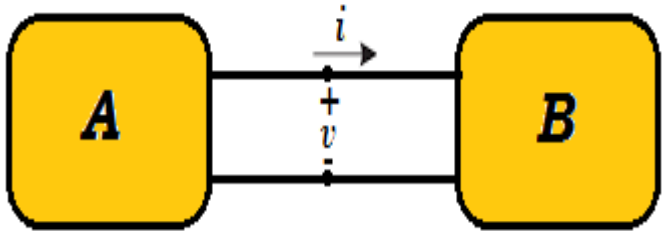
For component 5 $P_5 = -0.375W$

$$\sum P = P_1 + P_2 + P_3 + P_4 + P_5$$

$$= -1 + 0.5 + 0.125 + 0.75 - 0.375$$

$$= 0$$

Example : Two electrical devices are connected at an interface, as shown in figure. Find the power transferred and state whether the power is transferred from A to B or B to A for four cases given in table below.



	(a)	(b)	(c)	(d)
v (V)	+12 V	-33 V	+15 V	-35 mV
i(A)	-2 A	-1.1mA	+40 mA	+200 mA

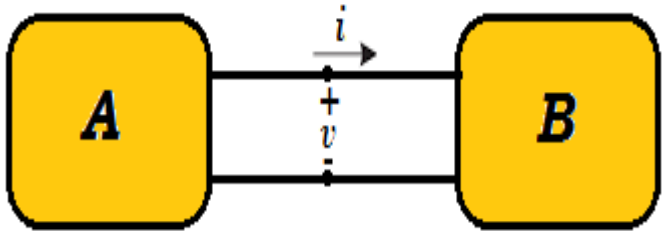
$$\boldsymbol{P = \pm v.i}$$

For Device A, PSC is NOT satisfied ⇨ $\boldsymbol{P = -v.i}$

For Device B, PSC is satisfied ⇨ $\boldsymbol{P = +v.i}$

Ch1: Basic Concepts

Example : Two electrical devices are connected at an interface, as shown in figure. Find the power transferred and state whether the power is transferred from A to B or B to A for four cases given in table below.



	(a)	(b)	(c)	(d)
v (V)	+12 V	-33 V	+15 V	-35 mV
i(A)	-2 A	-1.1mA	+40 mA	+200 mA

For Device A, PSC is NOT satisfied ⇨ $P_A = -v.i$

For Device B, PSC is satisfied ⇨ $P_B = +v.i$

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a)

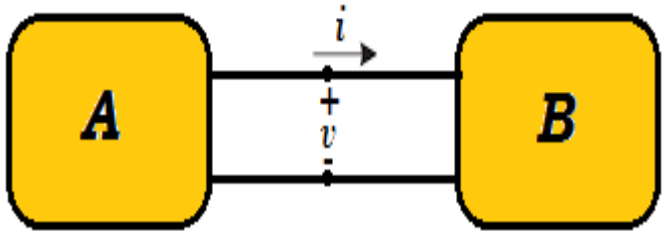
$$P_A = -v.i = -(12)(-2) = 24\text{W, absorbing power}$$

$$P_B = +v.i = (12)(-2) = -24\text{W, delivering power}$$

24W power is transferred from B to A

Ch1: Basic Concepts

Example : Two electrical devices are connected at an interface, as shown in figure. Find the power transferred and state whether the power is transferred from A to B or B to A for four cases given in table below.



	(a)	(b)	(c)	(d)
v (V)	+12 V	-33 V	+15 V	-35 mV
i(A)	-2 A	-1.1mA	+40 mA	+200 mA

For Device A, PSC is NOT satisfied ⇨ $P_A = -v.i$

For Device B, PSC is satisfied ⇨ $P_B = +v.i$

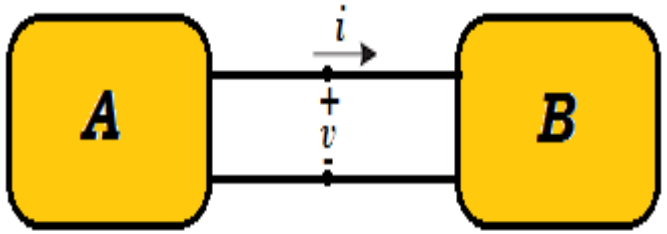
b) $P_A = -v.i = -(-33)(-1.1\text{mA}) = -36.3\text{mW}$, **delivering power**

$P_B = +v.i = (-33)(-1.1) = 36.3\text{mW}$, **absorbing power**

36.3 mW power is transferred from A to B

Ch1: Basic Concepts

Example : Two electrical devices are connected at an interface, as shown in figure. Find the power transferred and state whether the power is transferred from A to B or B to A for four cases given in table below.



	(a)	(b)	(c)	(d)
v (V)	+12 V	-33 V	+15 V	-35 mV
i(A)	-2 A	-1.1mA	+40 mA	+200 mA

For Device A, PSC is NOT satisfied ⇨ $P_A = -v.i$

For Device B, PSC is satisfied ⇨ $P_B = +v.i$

c & d) ???

Calculate and interpret 'c and d' by yourselves.

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END OF CHAPTER 1

Dr. Yılmaz KALKAN