EN811100
LINEAR CIRCUIT ANALYSIS

Chapter 1

Basic Concepts

Dec 20, 2019

C. K. Alexander – M. N. O. Sadiku
Fundamentals of Electric Circuits, 5th Edition, The McGraw-Hill Companies 2013
J. A. Svoboda – R. C. Dorf
Introduction to Electric Circuits, 9th edition, John Wiley & Sons, Inc. 2014

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Basic Concepts - Chapter 1

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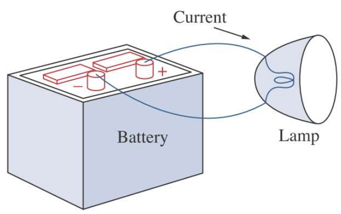
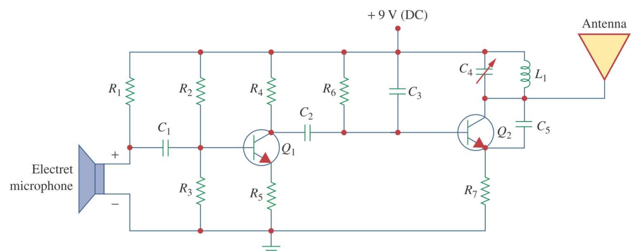
1.1 Introduction

An **electric circuit** is an interconnection of electrical elements.



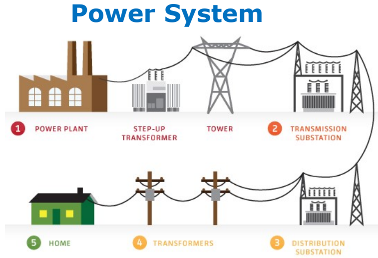
A simple electric circuit.



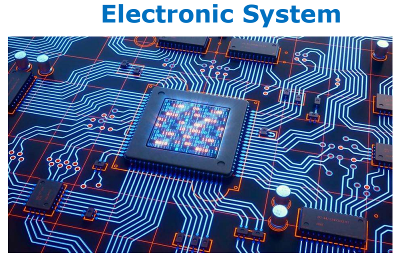
Electric circuit of a radio transmitter.

1.1 Introduction

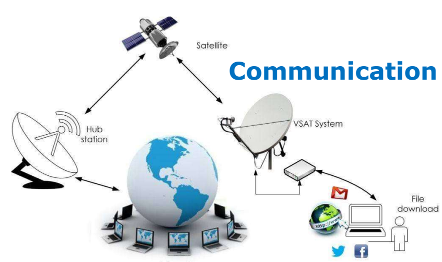
Power System



Electronic System



Communication System



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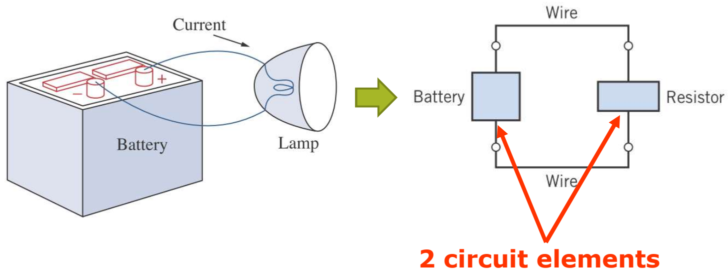
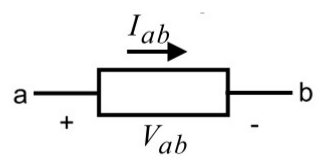
1.1 Introduction



A general two-terminal electrical element



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1.2 System of Units

SI is *Système International d'Unités* or the International System of Units.

Table 1.3-1 SI Base Units

QUANTITY	SI UNIT NAME	SI UNIT SYMBOL
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

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1.2 System of Units

Table 1.3-2 Derived Units in SI

QUANTITY	UNIT NAME	FORMULA	SYMBOL
Acceleration — linear	meter per second per second	m/s^2	
Velocity — linear	meter per second	m/s	
Frequency	hertz	s^{-1}	Hz
Force	newton	$kg \cdot m/s^2$	N
Pressure or stress	pascal	N/m^2	Pa
Density	kilogram per cubic meter	kg/m^3	
Energy or work	joule	$N \cdot m$	J
Power	watt	J/s	W
Electric charge	coulomb	$A \cdot s$	C
Electric potential	volt	W/A	V
Electric resistance	ohm	V/A	Ω
Electric conductance	siemens	A/V	S
Electric capacitance	farad	C/V	F
Magnetic flux	weber	$V \cdot s$	Wb
Inductance	henry	Wb/A	H

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1.2 System of Units

Table 1.3-3 SI Prefixes

MULTIPLE	PREFIX	SYMBOL
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f

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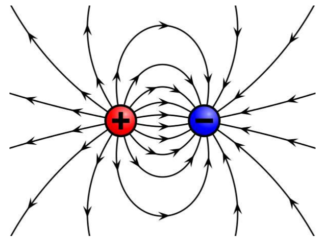
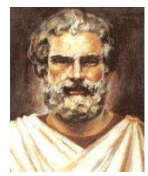
1.3 Electric Charges



- Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).
- The charge e on one electron is negative and equal in magnitude to 1.602×10^{-19} C which is called as *electronic charge*. The charges that occur in nature are integral multiples of the electronic charge.



Thales of Miletus (640 – 546 B.C.)

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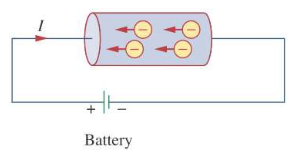
1.4 Current



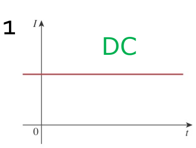
ค่ากระแสไฟฟ้าคือปริมาณประจุที่เคลื่อนที่ผ่านแท่งตัวนำในระยะเวลา 1 วินาที

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

- Electric current

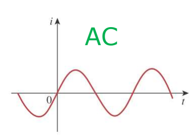
$$i(t) = \frac{dq}{dt}$$

1.1



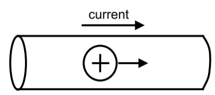
The unit of ampere can be derived as 1 A = 1C/s.

- A direct current (dc) is a current that remains constant with time.
- An alternating current (ac) is a current that varies sinusoidally with time. (reverse direction)

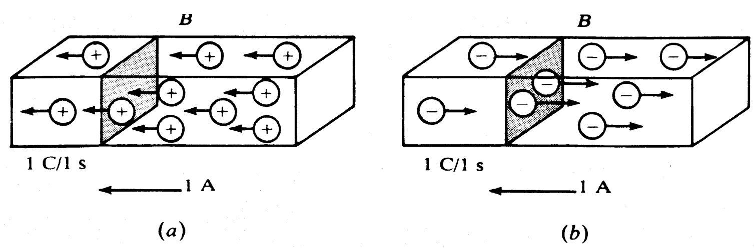


1.4 Current

The flow of current is conventionally represented as a flow of positive charges.



- The direction of current flow



Positive ions

Negative ions

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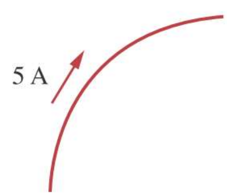
1.4 Current



Example 1

A conductor has a constant current of 5 A.

How many electrons pass a fixed point on the conductor in one minute?

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1.4 Current

Solution

Total no. of charges pass in 1 min is given by
5 A = (5 C/s)(60 s/min) = 300 C/min

Total no. of electrons pass in 1 min is given

$$\frac{300 \text{ C/min}}{1.602x10^{-19} \text{ C/electron}} = 1.87x10^{21} \text{ electrons/min}$$

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Example 2 Charge from Current

Find the charge that has entered the terminal of an element from $t = 0$ s to $t = 3$ s when the current entering the element is as shown in Figure 1.2-6.

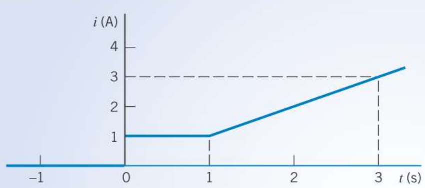

FIGURE 1.2-6 Current waveform for Example 1.2-2.

Solution
From Figure 1.2-6, we can describe $i(t)$ as

$$i(t) = \begin{cases} 0 & t < 0 \\ 1 & 0 < t \le 1 \\ t & t > 1 \end{cases}$$

Using Eq. 1.2-2, we have

$$q = \int_{-\infty}^{t} i\, d\tau = \int_{0}^{t} i\, d\tau + q(0)$$

$$q(3) - q(0) = \int_0^3 i(t)dt = \int_0^1 1\, dt + \int_1^3 t\, dt$$

$$= t\Big|_0^1 + \frac{t^2}{2}\Big|_1^3 = 1 + \frac{1}{2}(9-1) = 5\,\text{C}$$

Alternatively, we note that integration of $i(t)$ from $t = 0$ to $t = 3$ s simply requires the calculation of the area under the curve shown in Figure 1.2-6. Then, we have

$$q = 1 + 2 \times 2 = 5\,\text{C}$$

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1.5 Voltage

ค่าแรงดันไฟฟ้าคือพลังงานที่ต้องใช้ในการเคลื่อนที่ประจุ 1 หน่วย ผ่านจากขั้วต้นทางไปยังขั้วปลายทาง

- Voltage (or potential difference) is the energy required to move a unit charge through an element, measured in volts (V).
- Mathematically,

$$v_{ab} = \frac{dw}{dq} \qquad 1.2$$

W=Work

  - w is energy in joules (J) and q is charge in coulomb (C).

- Electric voltage, v_{ab}, is always across the circuit element or between two points in a circuit.
  - $v_{ab} > 0$ means the potential of a is higher than potential of b.
  - $v_{ab} < 0$ means the potential of a is lower than potential of b.

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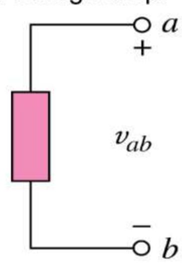
1.5 Voltage

- The plus (+) and minus (-) sign are used to define voltage polarity.
- The assumption is that the potential of the terminal with (+) polarity is higher than the potential of the terminal with (-) polarity by the amount of voltage drop.



- The polarity assignment is somewhat arbitrary! Is this a scientific statement?!! What do you mean by arbitrary?!!!

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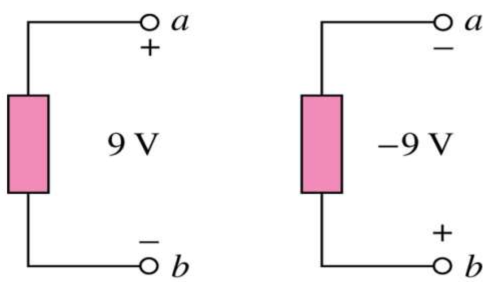
1.5 Voltage

- Figures (a) and (b) are two equivalent representation of the same voltage:

V_{ab} = 9V



(a) (b)

V_{ba} = -9V

- Both show that the potential of terminal a is 9V higher than the potential of terminal b.

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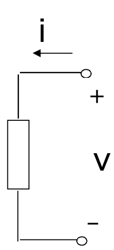
1.6 Power and Energy

- Power is the time rate of expending or absorbing energy, measured in watts (W).
- Mathematical expression: $$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi \qquad 1.3$$

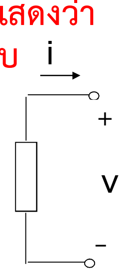
ปกติเรากำหนดให้กระแสไหลจากแรงดันบวกไปแรงดันลบ

ถ้ากระแสไหลจากแรงดันลบไปแรงดันบวก แสดงว่ากระแสมีค่าติดลบ



ตัวรับ Power

ตัวจ่าย Power



Passive sign convention

P = +vi
absorbing power

p = −vi
supplying power

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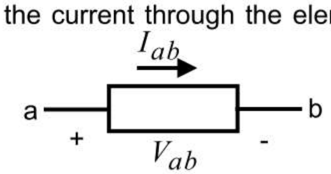
1.6 Power and Energy

Passive Sign Convention

- For calculating absorbed power: The power absorbed by any circuit element with terminals A and B is equal to the voltage drop from A to B multiplied by the current through the element from A to B, i.e., $P = V_{ab} \times I_{ab}$



- With this convention if $P \geq 0$, then the element is absorbing (consuming) power. Otherwise (i.e., $P < 0$) is absorbing negative power or actually generating (delivering) power.

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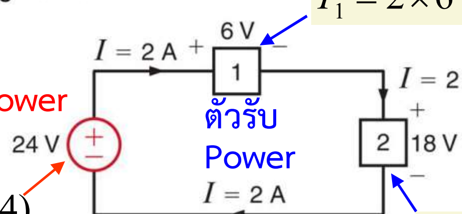
1.6 Power and Energy

Exercise

Determine the power absorbed or supplied by the elements of the following network:

$P_1 = 2 \times 6 = 12$ Watts

ตัวจ่าย Power



ตัวรับ Power

ตัวรับ Power

$P = 2(-24)$
$= -48$ Watts

$P_2 = 2 \times 18 = 36$ Watts

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

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1.6 Power and Energy

- The law of conservation of energy must be obeyed in any electric circuit. For this reason, the algebraic sum of power in a circuit, at any instant of time, must be zero

$$\sum p = 0$$

- Energy is the capacity to do work, measured in joules (J).
- Mathematical expression $w = \int_{t_0}^{t} pdt = \int_{t_0}^{t} vidt$ 1.4

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Side note

The Three Laws of Thermodynamics

The first law, also known as Law of Conservation of Energy, states that energy cannot be created or destroyed in an isolated system.

The second law of thermodynamics states that the entropy of any isolated system always increases.

The third law of thermodynamics states that the entropy of a system approaches a constant value as the temperature approaches absolute zero.

src: https://courses.lumenlearning.com/introchem/chapter/the-three-laws-of-thermodynamics

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1.6 Power and Energy

Tellegan’s Theorem

- **Principle of Conservation of the Power:** The algebraic sum of the powers absorbed by all elements in a circuit is zero at any instance of time **($\Sigma P=0$)**. That is, the sum of absorbed powers is equal to the sum of generated powers at each instance of time.

- This principle is also known as Tellegan’s theorem. (Bernard D.H. Tellegan (1900-1990), a Dutch electrical engineer)

- Similarly, one can write the principle of conservation of energy.

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Example 3 Power, Energy, and the Passive Convention

Consider the circuit shown in Figure 1.5-4 with $v(t) = 12e^{-8t}$ V and $i(t) = 5e^{-8t}$ A for $t \geq 0$. Both $v(t)$ and $i(t)$ are zero for $t < 0$. Find the power supplied by this element and the energy supplied by the element over the first 100 ms of operation.

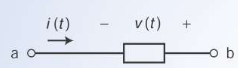

FIGURE 1.5-4 The element considered in Example 1.5-3.

Solution

The power

$$p(t) = v(i)\, i(t) = \left(12e^{-8t}\right)\left(5e^{-8t}\right) = 60e^{-16t} \text{ W}$$

is the power *supplied* by the element because $v(t)$ and $i(t)$ do not adhere to the passive convention. This element is supplying power to the charge flowing through it.

The energy supplied during the first 100 ms = 0.1 seconds is

$$w(0.1) = \int_0^{0.1} p\, dt = \int_0^{0.1} \left(60e^{-16t}\right) dt$$

$$= 60 \left.\frac{e^{-16t}}{-16}\right|_0^{0.1} = -\frac{60}{16}\left(e^{-1.6} - 1\right) = 3.75\left(1 - e^{-1.6}\right) = 2.99 \text{ J}$$

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1.7 Circuit Elements

Circuit Elements

- Circuit components can be broadly classified as being either **active** or **passive**.
- An active element is capable of generating energy.
  - Example: current or voltage sources
- A passive element is an element that does not generate energy, however, they can either consume or store energy.
  - Example: resistors, capacitors, and inductors

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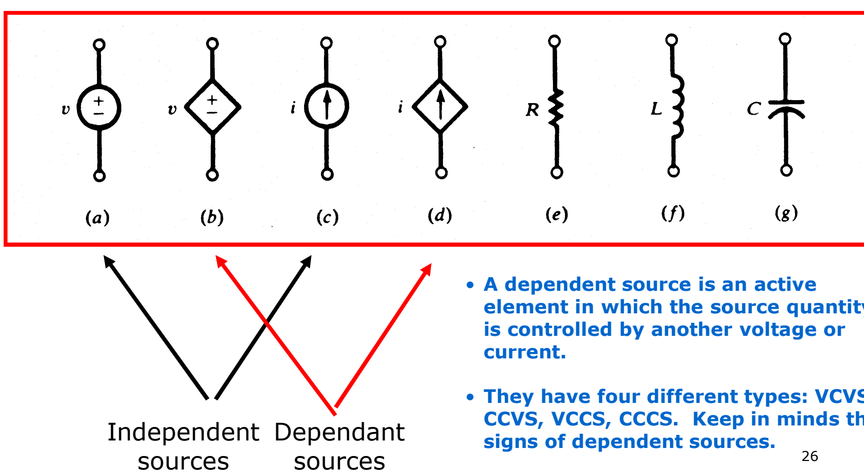
1.7 Circuit Elements

Active Elements **Passive Elements**



- **A dependent source is an active element in which the source quantity is controlled by another voltage or current.**
- **They have four different types: VCVS, CCVS, VCCS, CCCS. Keep in minds the signs of dependent sources.**

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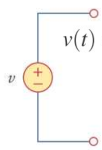
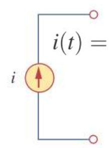
1.7 Circuit Elements

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

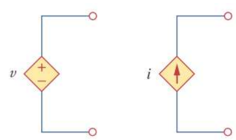


$v(t) = 12 \cos 1000t$ or $v(t) = 9$ or $v(t) = 12 - 2t$



$i(t) = 6 \sin 500t$ or $i(t) = -0.25$ or $i(t) = t + 8$

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



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

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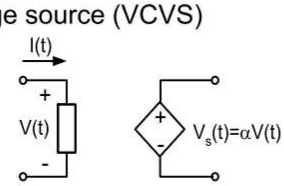
1.7 Circuit Elements

Dependent (Controlled) Source

- There are four types of dependent sources:
- Voltage-controlled voltage source (VCVS)

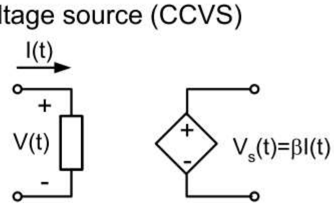
Input V



Output V

- Current-controlled voltage source (CCVS)

Input I



Output V

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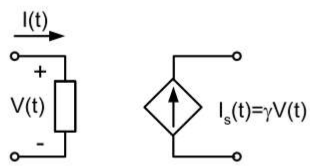
1.7 Circuit Elements

Dependent (Controlled) Source

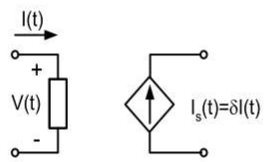
- Voltage-controlled current source (VCCS)



Input V

Output I

- Current-controlled current source (CCCS)



Input I

Output I

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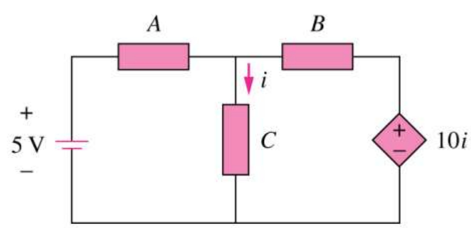
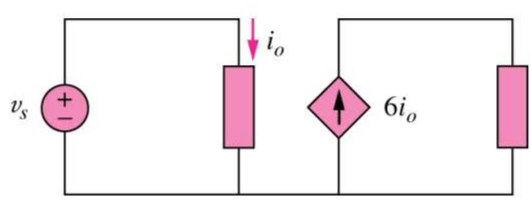
1.7 Circuit Elements

Exercise

In the following circuits, identify the type of dependent sources:





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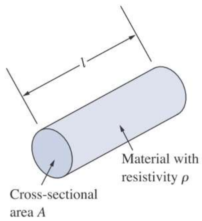
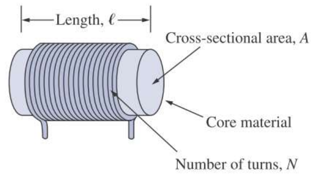
1.7 Circuit Elements

R



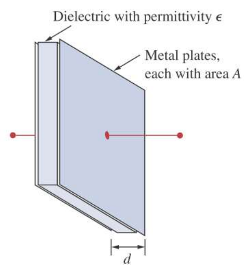
Resistor

L

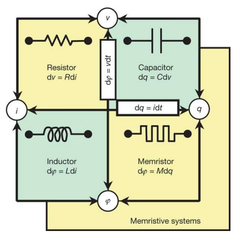


Inductor

C



Capacitor



M

Memristor

Gao et al., A High-Performance Memristor Device and Its Filter Circuit Application. Rapid Research Letters 14(12). 2020.

Fu et al., Bioinspired bio-voltage memristors. Nature Communications 1861 (2020).

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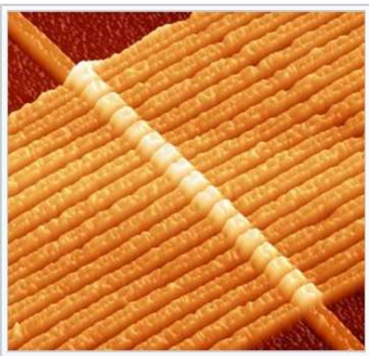
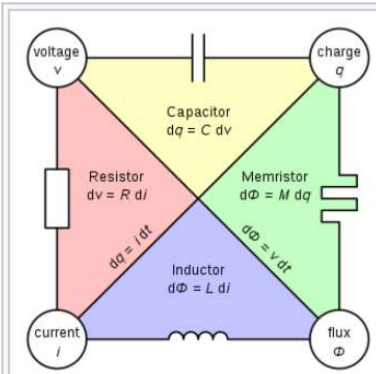
Memristor



An array of 17 purpose-built oxygen-depleted titanium dioxide memristors built at HP Labs, imaged by an atomic force microscope. The wires are about 50 nm, or 150 atoms, wide.[20] Electric current through the memristors shifts the oxygen vacancies, causing a gradual and persistent change in electrical resistance.[21]



Conceptual symmetries of resistor, capacitor, inductor, and memristor.

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1.7 Circuit Elements

Example 4

Obtain the voltage v in the branch shown in Figure 2.1.1P for i_2 = 1A.

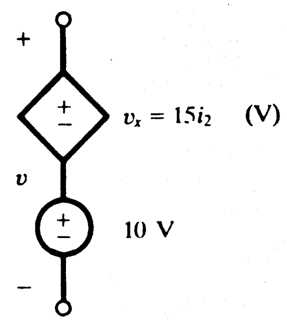

Figure 2.1.1P

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1.7 Circuit Elements

Solution

Voltage v is the sum of the current-independent 10-V source and the current-dependent voltage source v_x.

Note that the factor 15 multiplying the control current carries the units Ω.

Therefore, $v = 10 + v_x = 10 + 15(1) = 25$ V

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