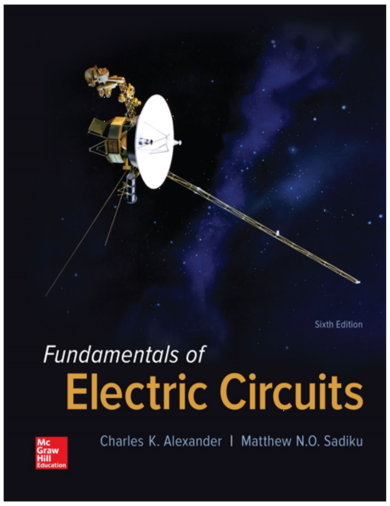


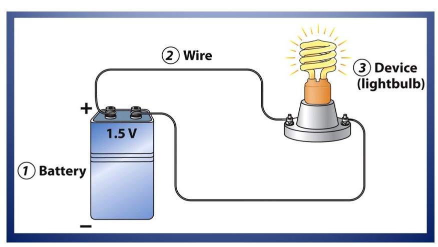
Chapter 1 - Basic Concepts

- **This chapter introduces the concept of voltage and current.**
- **The concept of a circuit will be introduced.**
- **Sources will be introduced.**
- **These can provide either a specified voltage or current.**
- **Dependent and independent sources will be discussed.**
- **Also a strategy for solving problems will be introduced.**

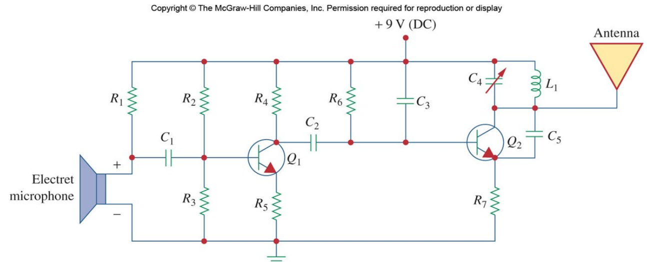
1.1 Introduction

Many engineering disciplines are interested in transmitting energy from one point to another. In the case of electrical engineering, an interconnection of electrical devices or elements is required, and this interconnection is known as an *electric circuit*.

Every electric circuit consists of three basic elements: (1) a source of energy such as a battery, (2) a closed path made up of a conducting material through which the electric current can flow, and (3) a device or load that uses the electrical energy or converts it into a more useful form of energy.



Electrical circuits can be very simple, like the one shown above or much more complicated.



1.2 Systems of Units

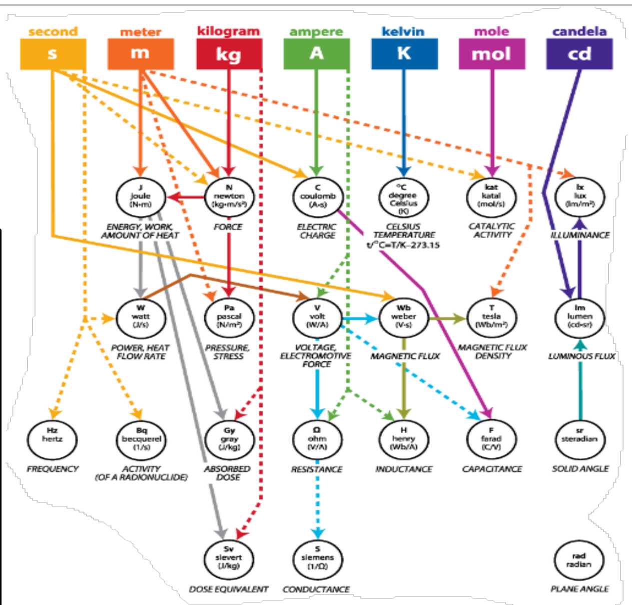
What do you think the countries colored in red on this map have in common?

Ch 1, p3

The SI system has 7 base units that define 22 derived units.

SI Base Units			
Base quantity		**Base unit**	
Name	**Typical symbol**	**Name**	**Symbol**
time	*t*	second	s
length	*l, x, r*, etc.	meter	m
mass	*m*	kilogram	kg
electric current	*I, i*	ampere	A
thermodynamic temperature	*T*	kelvin	K
amount of substance	*n*	mole	mol
luminous intensity	I_v	candela	cd

Source: NIST Special Publication 330:2019, Table 2.



The basic unit of electric current is the ampere, and is defined as the constant current that, if maintained in two infinitely long straight parallel conductors with a negligible circular cross-section and placed 1 m apart in a vacuum, would produce a force between the conductors equal to 2×10^{-7} newtons per meter of length.

The derived units that will apply to this course are:

energy/work	joule	J
electric charge	coulomb	C
power	watt	W
voltage (emf)	volt	V
frequency	hertz	Hz
resistance	ohm	
inductance	henry	H
capacitance	farad	F
conductance	siemens	S

Ch 1, p4

One of the key features and great advantages of the SI system of units is that it uses prefixes based on the power of 10 to relate larger and smaller units to the base units.

unit handout?

Prefixes

Purpose	Name	Symbol	Factor	Name
larger quantities or whole units	yotta	Y	10^{24}	Septillion
	zetta	Z	10^{21}	Sextillion
	exa	E	10^{18}	Quintillion
	peta	P	10^{15}	Quadrillion
	tera Example: terahertz	T	10^{12}	Trillion
	giga Example: gigawatt	G	10^{9}	Billion
	mega	M	10^{6}	Million
	kilo Example: kiloliter	k	10^{3}	Thousand
	hecto Example: hectare	h	10^{2}	Hundred
	deka Example: dekameter	da	10^{1}	Ten
			10^{0}	One
smaller quantities or sub units	deci Example: decimeter	d	10^{-1}	Tenth
	centi Example: centigram	c	10^{-2}	Hundredth
	milli Example: milliliter	m	10^{-3}	Thousandth
	micro Example: microgram	μ	10^{-6}	Millionth
	nano Example: nanometer	n	10^{-9}	Billionth
	pico Example: picogram	p	10^{-12}	Trillionth
	femto Example: femtosecond	f	10^{-15}	Quadrillionth
	atto	a	10^{-18}	Quintillionth
	zepto Example: zeptosecond	z	10^{-21}	Sextillionth
	yocto Example: yoctosecond	y	10^{-24}	Septillionth

Ch 1, p5

1.3 Charge and Current

The most basic quantity in an electric circuit is the ***electric charge***. Charge is an electrical property of the atomic particles that make up matter and is measured in **coulombs (C)**.

The concept of charge is somewhat mystical in nature since it is an inherent property of matter, similar to the concept of mass in physics.

Atoms are the fundamental building blocks of matter and consist of electrons, protons, and neutrons. The charge (e) on an electron is negative and has a magnitude of 1.602 x 10^{-19} C while a proton has a positive charge of the same magnitude. Since atoms have the same number or electrons as protons, every atom is electrically neutral.

Some points that should be noted about electric charge:

1. the coulomb is a derived SI unit and reflects the number of electrons (or protons) present.
2. the coulomb is a large unit. 1 C represents 6.24 x 10^{18} electrons. As a result, realistic or laboratory values of charge are on the order of picocoulombs, nanocoulombs, or microcoulombs.
3. according to experimental observations the only charges that occur in nature are integral multiples of the electronic (or protonic) charge of1.602 x 10^{-19} C.
4. The *law of conservation of charge* states that charge can be neither created nor destroyed and can only be transferred. Thus, the algebraic sum of the electric charges in a system does not change.

Ch 1, p6

A unique feature of electric charge is the fact that it is mobile and can move from one place to another where it can be converted into another form of energy.

Some preliminary vocabulary:

- An ***electric current*** is the flow of charges through a material. The charges that move in a current are called *charge carriers*.
    - In one of the more confusing aspects of studying, analyzing and using electrical circuits, is the convention that: **current is the flow of positive charges** (even if the charge carriers may actually be actually negatively-charged electrons* flowing in the opposite direction).
- A *conductor* is a material through which charge easily moves. In contrast, an *insulator* does not readily permit the flow of charges and does not permit a current.
    - The most common conductors are metals and the charge carriers in a metal are electrons, which are known as *conduction electrons.*
    - Materials other than metals may also contain charge carriers. For example, the charge carriers in ionic materials are ions*, both positive and negative.

  * Since electrons and ions are particles, another useful definition of electric current may the idea that it is the flow of charged particles.

Ch 1, p7

Since it is the movement of electric charges, electric current (i) is measured as the time rate of change of charge:

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

the SI unit for current is the ampere (A):

1 ampere = 1 coulomb/second [1 A = 1 C/s]

Another way you may see this formula (and other formulas in this course) written is:

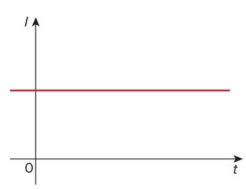
$$I = \frac{\Delta q}{\Delta t}$$

Definition of current

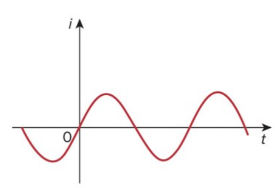
A current that flows in only one direction is called *direct current* (DC).

DC is represented by upper-case *I* while time-varying current uses the lowercase, *i*.

A battery is a common source of DC.



A current that changes direction with time (i.e., sinusoidally) is called *alternating current* (AC)



Ch 1, p8

Since current is defined as the movement of charge (or charged particles), there should be an expected direction of movement.

As a matter of convention, the direction of current flow is taken to be the direction of positive charge movement.

A current of 5A, therefore, can be represented either positively or negatively, i.e., a current of 5A flowing in one direction is the same as a current of -5A flowing in the other direction.

- The sign of the current indicates the direction in which the charge is moving with respect to a direction of interest we have selected or defined.

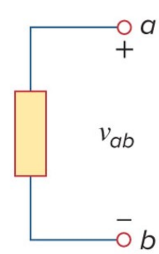
- The direction the charge moves does not have to be used as the selected reference/direction, and there may actually be no choice in the direction the charge moves.

Ch 1, p9

1.4 Voltage

To move a charge carrier through a conductor in a particular direction requires some work or energy transfer.

This work is performed by an external force known as an electromotive force (*emf*) or (more commonly) either as ***voltage*** or *potential difference.*

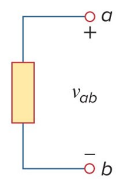


The voltage (or potential difference) is the energy required to move a unit charge from a reference point (-) to another (+), and is measured in volts.

- it is always expressed with reference to two locations.
- a positive charge moving from a higher potential to a lower potential yields energy.
- a positive charge moving from negative to positive requires energy.
- energy (work) is expressed in joules (J), charge is in coulombs (C), and voltages is measured in volts.

1 volt = 1 joule/coulomb = 1 newton-meter/coulomb.

Ch 1, p11



The plus (+) and minus (-) signs in this diagram are used to define what is known as *voltage polarity*.

v_{ab} expresses: the potential of point a with respect to point b

that point a is at a potential of v_{ab} volts higher than point b

$v_{ab} = -v_{ba}$

There is:

a 9 V voltage drop from a to b

a 9 V voltage rise from b to a

A voltage drop from a to b is equivalent to a voltage rise from b to a.

Keep in mind that electric current is always through a circuit element and voltage is always across the element or between two points in the circuit.

Ch 1, p12

1.5 Power and Energy

Current and voltage are the two basic variables in an electric circuit.

Together, they can be used to express another important feature in circuit analysis and that is ***power.***

Power is the amount of work done by or to a system per unit of time:

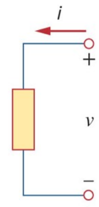
$$p = \frac{dw}{dt} = \frac{dw}{dq} \bullet \frac{dq}{dt} = vi$$

- Power is (or can be) a time-varying quantity and this expression identifies what is known as instantaneous power.
- Power is expressed in watts (*W*) [joules per second ---- 1 W = 1 J/s]
- If *p* is positive, power is being **delivered to or absorbed by** the circuit element.
- If *p* is negative, power is being **supplied** by the element.

Current direction and voltage polarity, therefore, play a major role in determining whether power has a positive or negative sign, and this is addressed by the *passive sign convention*.

Ch 1, p13

The passive sign convention requires that the voltage polarity and current direction conform to the figure shown.

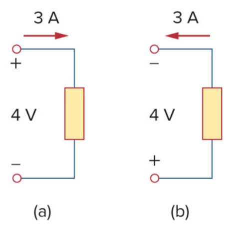


The current enters through the positive terminal of an element and $p = +vi$.

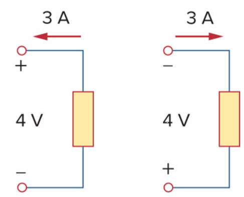
Power is being absorbed by the circuit element.

If the current enters through the negative terminal of an element, p = -vi and power is being supplied by the element.

The element in both these circuits is absorbing power of +12 W



The element in both these circuits is supplying power to the circuit.



Ch 1, p14

Energy is the capacity or ability to do work, and is measured in joules (*J*).

The law of conservation of energy requires that, in a closed system such as an electric circuit, energy is neither created nor destroyed. Since power is directly related to work and energy, power within an electric circuit must also be conserved.

For an electric circuit, therefore, the sum of all power supplied by circuit elements must be absorbed by the other elements: $\Sigma p = 0$

The energy absorbed or suppled by an element (i.e., the work done to or by an element) from t_o to time t is given by:

$$p = \frac{dw}{dt} = \frac{dw}{dq} \bullet \frac{dq}{dt} = vi \longrightarrow w = \int_{to}^{t} p\ dt = \int_{to}^{t} vi\ dt$$

Ch 1, p15

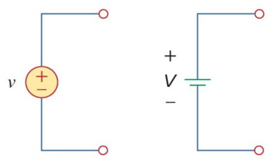
1.6 Circuit Elements

An electric circuit is simply an interconnection of various elements, and there are two basic types of circuit elements: *passive elements* and *active elements*.

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

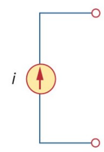
Ideal Voltage Source

- **An ideal voltage source has no internal resistance.**
- **It also is capable of producing any amount of current needed to establish the desired voltage at its terminals.**
- **Thus we can know the voltage at its terminals, but we don't know in advance the current.**



Ideal Current Source

- **Current sources are the opposite of the voltage source:**
- **They have infinite resistance**
- **They will generate any voltage to establish the desired current through them.**
- **We can know the current through them in advance, but not the voltage.**

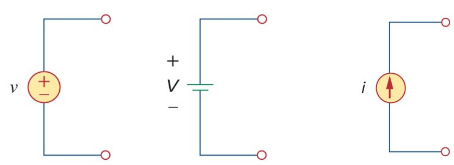


Ideal sources

- **Both the voltage and current source ideally can generate infinite power.**
- **They are also capable of absorbing power from the circuit.**
- **It is important to remember that these sources do have limits in reality:**
  - **Voltage sources have an upper current limit.**
  - **Current sources have an upper voltage limit.**

Ch 1, p17

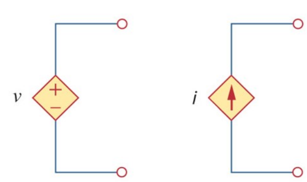
Independent sources are symbolically indicated in circuit diagrams as:



The output of dependent sources, which can be either voltage or current, is controlled by the voltage or current output of some other element of the circuit. As a result, there are four possible types of dependent sources:

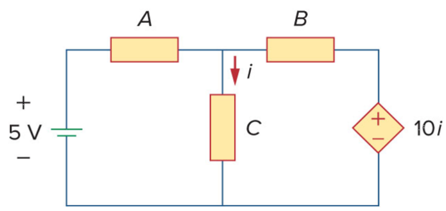
- **A voltage-controlled voltage source (VCVS).**
- **A current-controlled voltage source (CCVS).**
- **A voltage-controlled current source (VCCS).**
- **A current-controlled current source (CCCS).**

Symbolically, dependent sources are indicated in circuit diagrams with diamond shape:



Ch 1, p18

Here's an example of a circuit where the source on the right-hand side is a dependent voltage source whose output depends on the current through it.

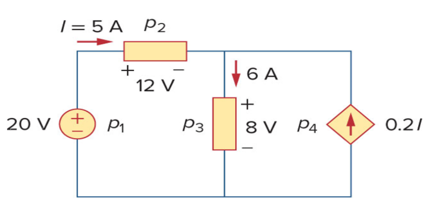


Keep in mind: a voltage source comes with polarity shown in its symbol while a current source comes with an arrow regardless of what the output depends on.

Ch 1, p19

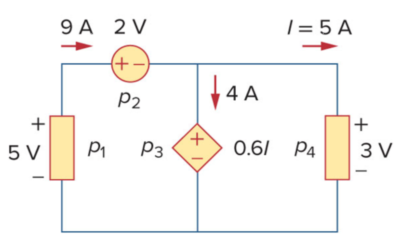
Examples and Practice Problems

E1.7 Calculate the power supplied or absorbed by each element in the circuit shown below:



Check to verify that $\sum p = 0$

P1.7 Calculate the power supplied or absorbed by each element in the circuit shown below:



Check to verify that $\sum p = 0$

Ch 1, p20