EE 220

CHAPTER 1 – CIRCUIT TERMINOLOGY

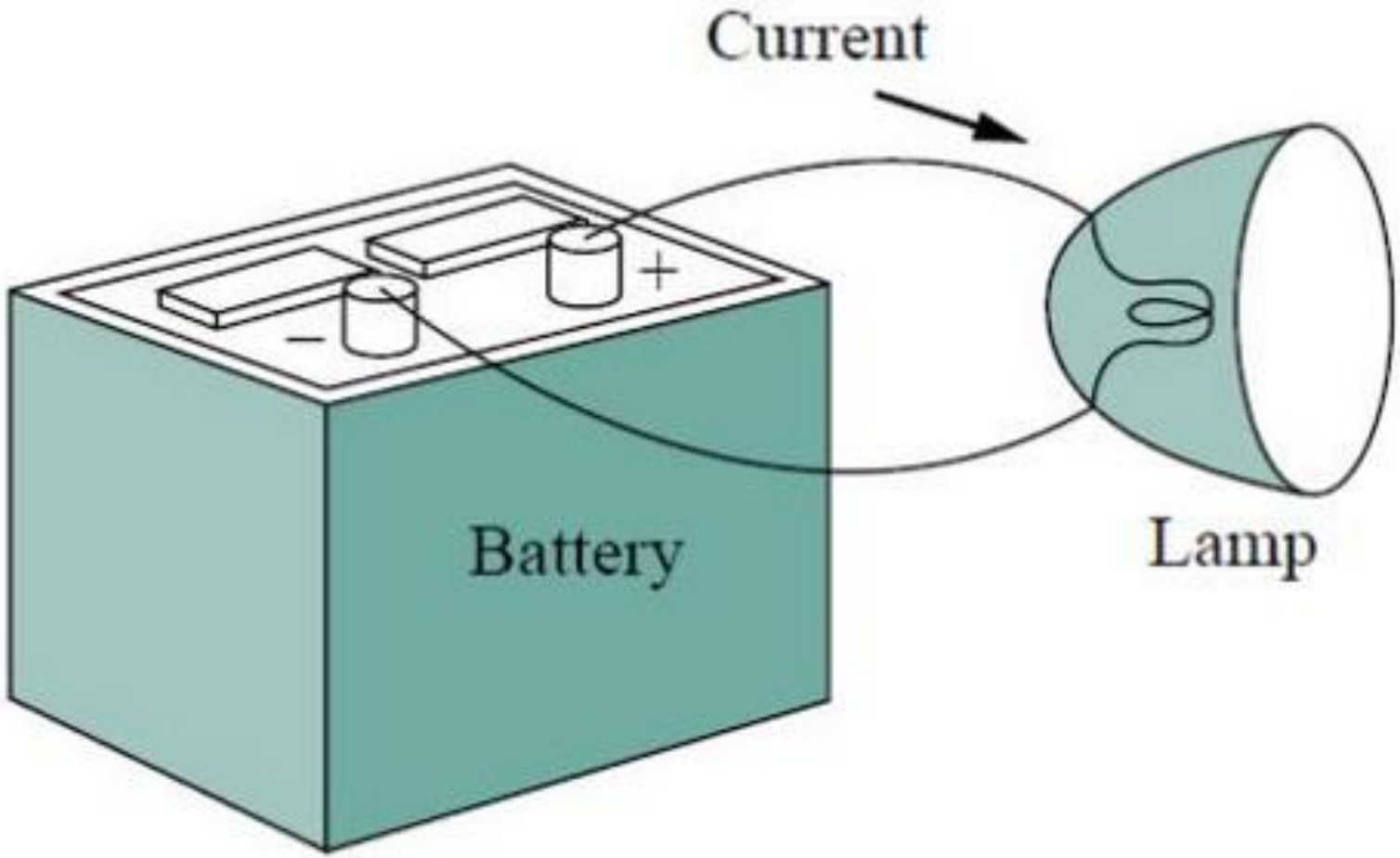
OVERVIEW

- Definition of Electrical Circuits
- Historical Timeline
- Analog vs. Digital Circuits
- Electric vs. Electronic Circuits
- Common Circuit Elements and Terminology
- Planar vs. Nonplanar Circuits
- Charge, Current, Voltage, Power, Energy
- Open Circuit and Short Circuit
- Independent and Dependent Sources
- Circuit Analysis vs. Circuit Synthesis

Introduction

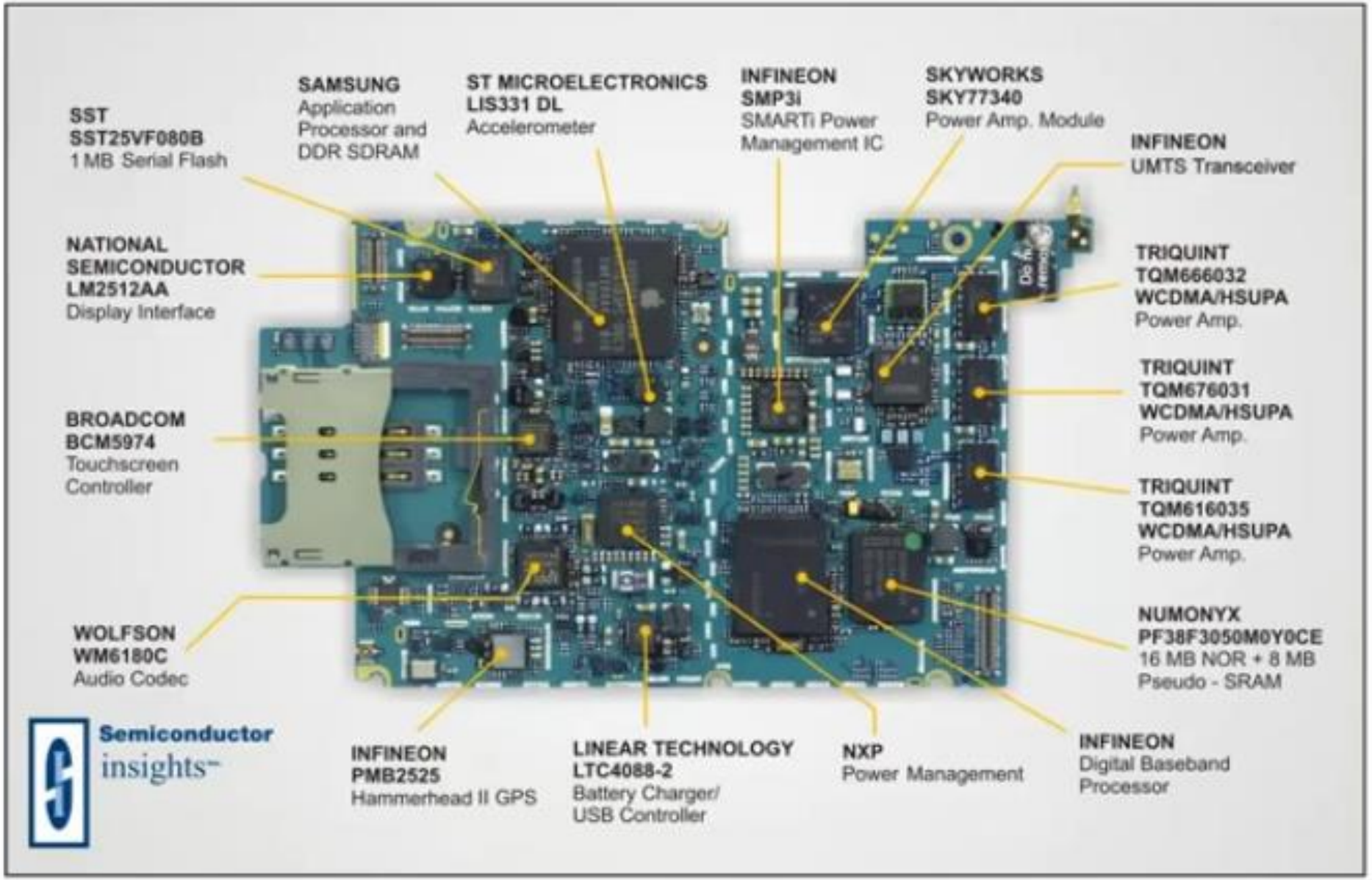
- Electrical circuit and Electromagnetic theory are two fundamental theories for all branches of electrical engineering
- In electrical engineering, we are often interested in communicating or transferring energy from one point to another
- To do this we require an interconnection of electrical devices

Simplest Circuit: Battery & Lamp



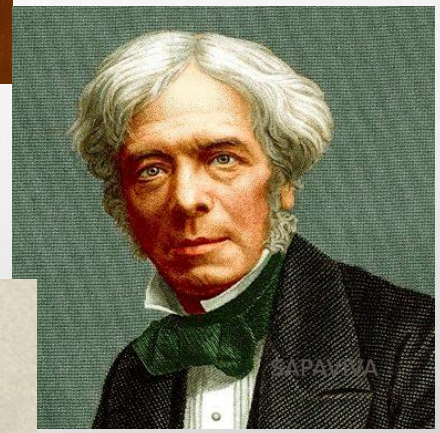
Complex Circuit: Photovoltaic Inverter

Complicated Circuit: Inside a Cellular Phone



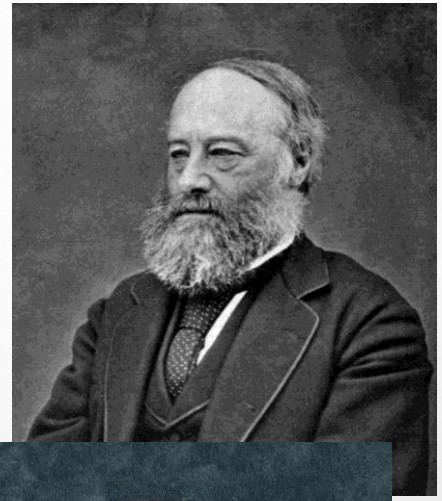
HISTORY OF ELECTRICITY – A TIMELINE

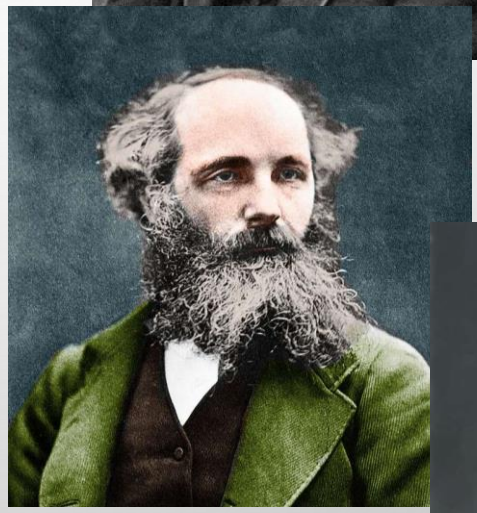
- 1733 Electric charge: Charles Francois du Fay (French) discovers that charges are of two forms and that like charges repel and unlike charges attract.
- 1752 Ben Franklin , proved that static electricity and lightning were the same. His correct understanding of the nature of electricity paved the way for the future.
- 1800 First electric battery invented by Alessandro Volta. The “volt” is named in his honor.
- 1808 Humphry Davy invented the first effective “arc lamp.” The arc lamp was a piece of carbon that glowed when attached to a battery by wires.
- 1821 The first electric motor was invented by Michael Faraday.
- 1826 Georg Ohm defined the relationship between power, voltage, current and resistance in “Ohms Law.”
- 1827 Inductance: introduced by Joseph Henry (American), who built one of the earliest electric motors.
- 1832 Using Faraday built the first “dynamo,” an electric generator capable of delivering power for industry.

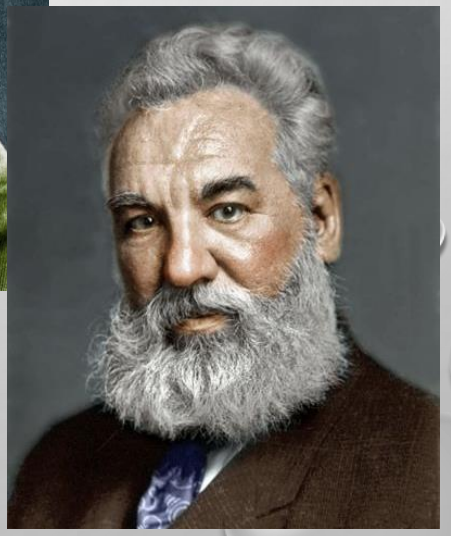


HISTORY OF ELECTRICITY – A TIMELINE

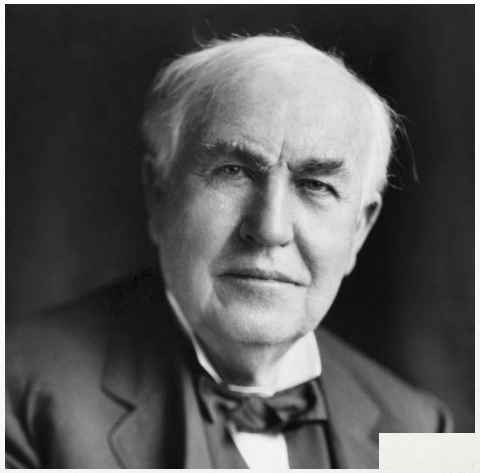
- 1835 Joseph Henry invented the electrical relay, used to send electrical currents long distances.
- 1837 Thomas Davenport invented the electric motor, an invention that is used in most electrical appliances today.
- 1841 James Prescott Joule showed that energy is conserved in electrical circuits involving current flow, thermal heating, and chemical transformations.
- 1844 Samuel Morse invented the electric telegraph, a machine that could send messages long distances across wire.
- 1860's Mathematical theory of electromagnetic fields published. J.C. Maxwell created a new era of physics when he unified magnetism, electricity and light.
- 1876 Alexander Graham Bell invented the rotary telephone which became available in 1890.



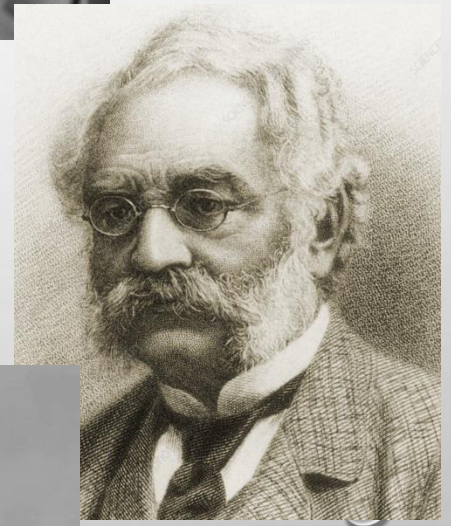


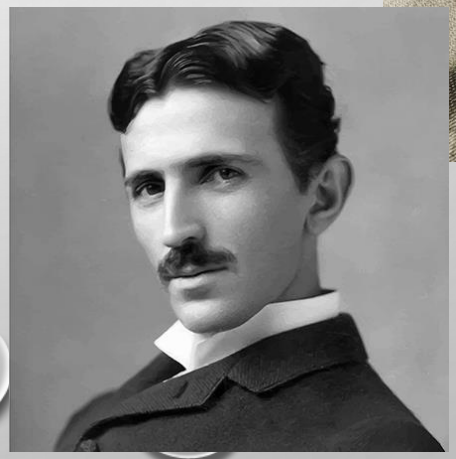


HISTORY OF ELECTRICITY – A TIMELINE



- 1878Thomas Edison founded the Edison Electric Light Co. (US), in New York City. He began experiments to develop a practical, long-lasting light bulb.
- 1879 Thomas Edison invented an incandescent light bulb that could be used for about 40 hours. By 1880 his bulbs could be used for 1200 hours.
- 1879 Electric lights were first used for public street lighting, in Cleveland, Ohio. California Electric Light Company, Inc. in San Francisco was the first electric company to sell electricity to customers.
- 1881 The electric streetcar was invented by E.W. V. Siemens
- 1882 Thomas Edison opened Pearl Street Power Station in New York City. The Pearl Street Station was one of the world's first central electric power plants and could power 5,000 lights. The Pearl Street Station was a direct current (DC) power system.
- 1883 Nikola Tesla invented the "Tesla coil", a transformer that changes electricity from low voltage to high voltage making it easier to transport over long distances..



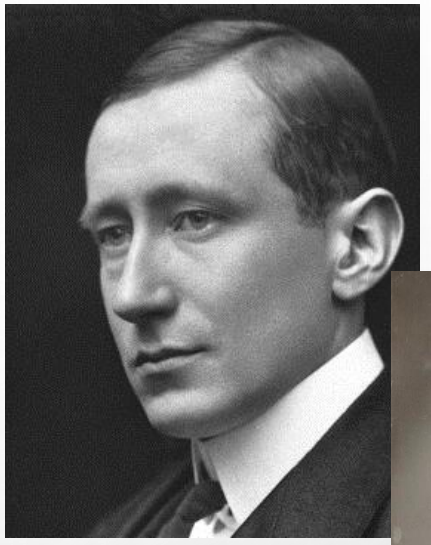


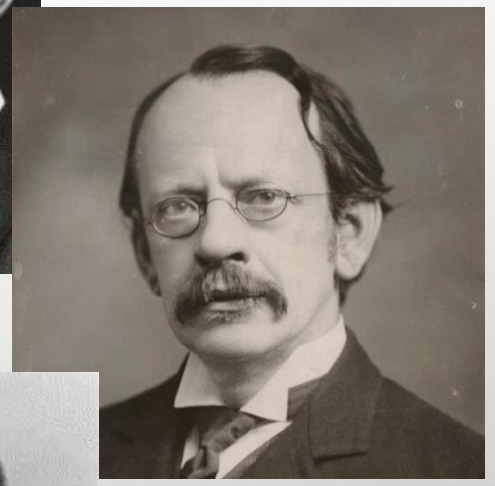
HISTORY OF ELECTRICITY – A TIMELINE

- 1884 Nikola Tesla invented the electric alternator, an electric generator that produces alternating current (AC).
- 1887 Heinrich Hertz (German) built a system that could generate electromagnetic waves (at radio frequencies) and detect them.
- 1888 Nikola Tesla demonstrated the first "poly-phase" alternating current (AC) electrical system.
- 1893 The Westinghouse Electric Company used an alternating current (AC) system to light the Chicago World's Fair. A 22 mile AC power line was opened, sending electricity from Folsom Powerhouse in California to Sacramento.
- 1895 X-rays: discovered by Wilhelm Rontgen (German). One of his first X-ray images was of the bones in his wife's hands
- 1896 Radio wireless transmission: patented by Guglielmo Marconi (Italian). In 1901, he demonstrated radio telegraphy across the Atlantic Ocean

HISTORY OF ELECTRICITY – A TIMELINE

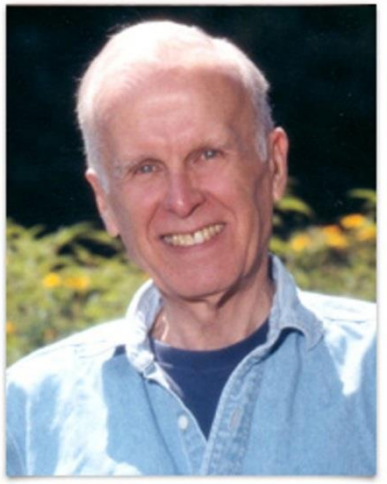
- 1896 An AC power line that transmits power 20 miles from Niagara Falls to Buffalo, New York was opened.
- 1897 Electron discovered by Joseph John Thomson.
- 1903 First successful gas turbine (France).World's first all turbine station (Chicago).
- 1911 Electric air conditioning – W. Carrier.
- 1920 Commercial radio broadcasting: Westinghouse Corporation established radio station KDKA in Pittsburgh, Pennsylvania
- 1923 Television: invented by Vladimir Zworykin (Russian-American). In 1926, John Baird (Scottish) transmitted TV images over telephone wires from London to Glasgow.
- 1930 Analog computer: developed by Vannevar Bush (American) for solving differential equations.
- 1935 Radar: invented by Robert Watson-Watt (Scottish).

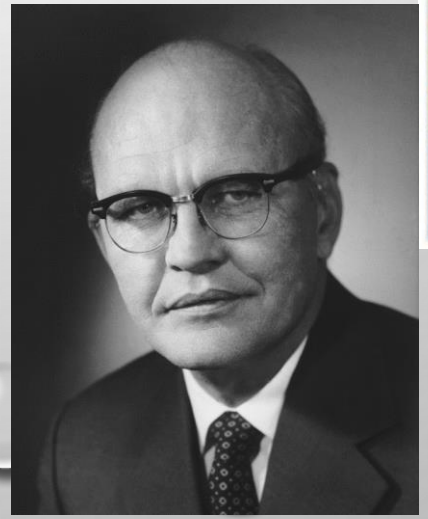




HISTORY OF ELECTRICITY – A TIMELINE

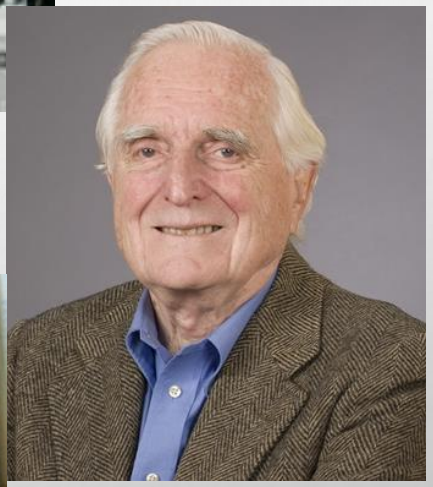
- 1945 ENIAC: The first all-electronic computer was developed by John Mauchly and J. Presper Eckert (both Americans)
- 1947 Transistor invented by William Shockley, Walter Brattain, and John Bardeen (all Americans) at Bell Labs.
- 1950 Floppy disk: invented by Yoshiro Nakama (Japanese) as a magnetic medium for storing data.
- 1954 First AM transistor radio (Texas Instruments)
- 1955 Optical fiber: demonstrated by Narinder Kapany (Indian-American) as a low-loss, light-transmission medium.
- 1956 FORTRAN: developed by John Backus (American), the first major programming language.
- 1958 Modem: developed by Bell Labs.
- 1958 Integrated circuit (IC): Jack Kilby (American) built the first IC on germanium, and independently, Robert Noyce (American) built the first IC on silicon.

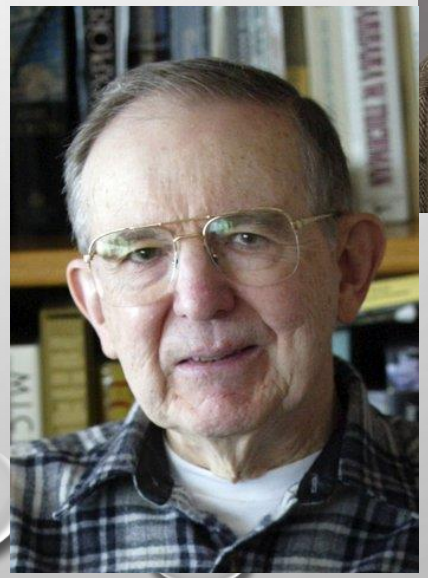




HISTORY OF ELECTRICITY – A TIMELINE

- 1960 Microcomputer: introduced by Digital Equipment Corporation as the PDP-1, which was followed with the PDP-8 in 1965.
- 1962 MOSFET: invented by Steven Hofstein and Frederic Heiman (both American), which became the workhorse of computer microprocessors.
- 1964 IBM's 360 mainframe: became the standard computer for major businesses.
- 1965 BASIC computer language: developed by John Kemeny and Thomas Kurtz (both American).
- 1968 Word processor: demonstrated by Douglas Engelbart (American), followed by the mouse pointing device and the use of a Windows-like operating system
- 1970 CD-ROM: patented by James Russell (American), as the first system capable of digital-to-optical recording and playback.



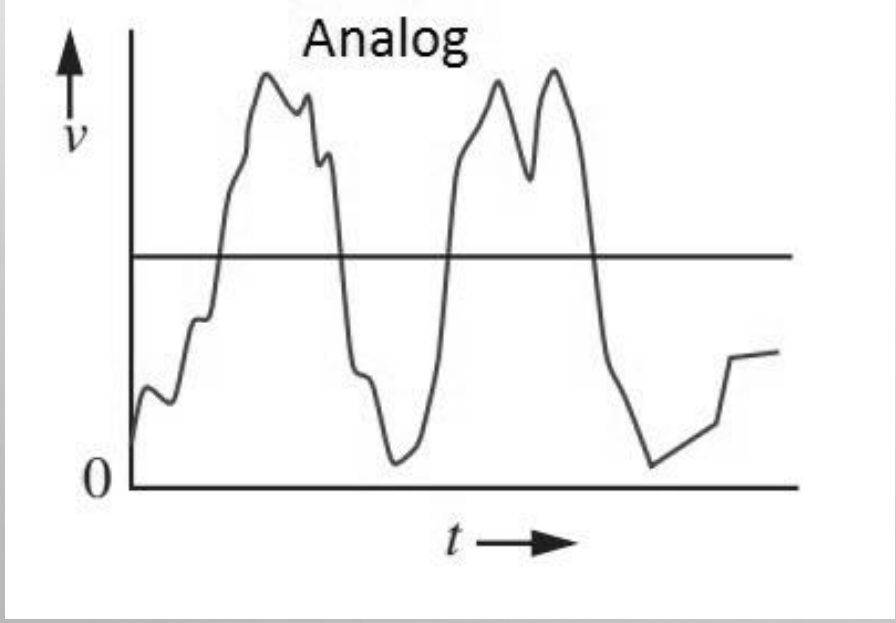


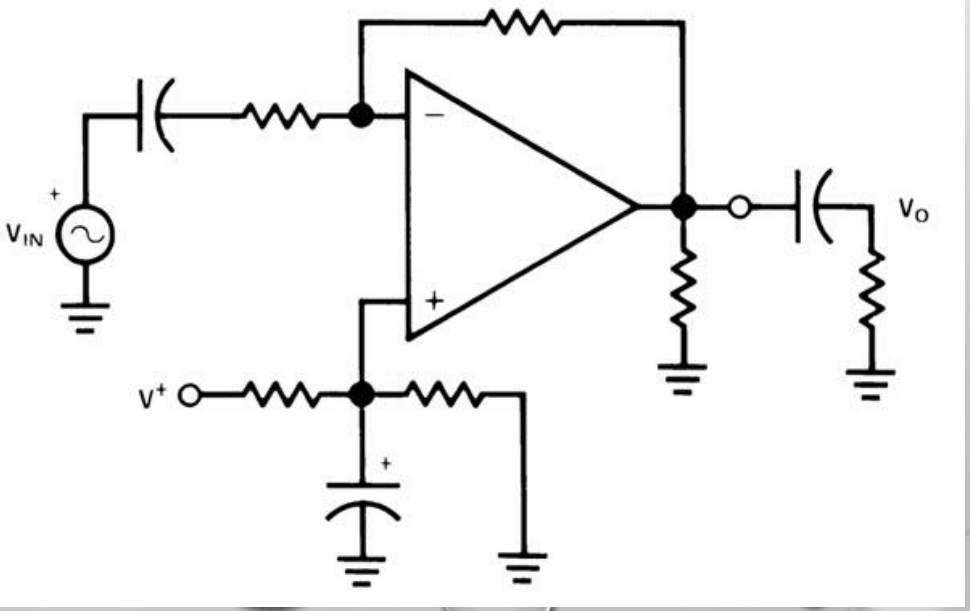
HISTORY OF ELECTRICITY – A TIMELINE

- 1976 Laser printer: introduced by IBM.
- 1976 Apple I: sold by Apple Computer in kit form, followed by the fully assembled Apple II in 1977, and the Macintosh in 1984.
- 1979 First cellular telephone network: built in Japan.
- 1980 MS-DOS computer disk operating system: introduced by Microsoft: Windows marketed in 1985.
- 1981 PC - introduced by IBM.
- 1984 Internet became operational worldwide.
- 1988 First transatlantic optical fiber cable: installed between the U.S. and Europe.
- 1989 World Wide Web: invented by Tim Berners-Lee (British) by introducing a networking hypertext system.
- 1996 Hotmail: launched by Sabeer Bhatia (Indian-American) and Jack Smith (American) as the first webmail service.
- 2007 White LED: invented by Shuji Nakamura (Japanese). iPhone: released by Apple.
- 2009 Cloud computing: went mainstream.
- 2011 Text messages: 8×1012 (8 trillion) text messages sent worldwide. 2014 Mobile subscribers: Approximately 96% of the world population is a mobile phone subscriber (7 billion people).

ANALOG VS. CIRCUITS

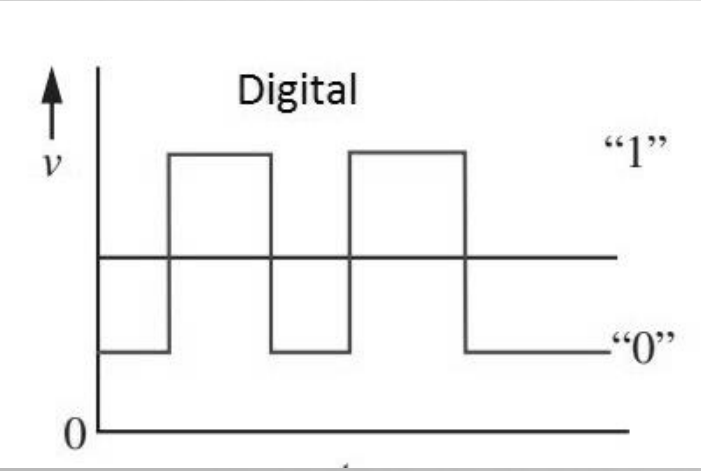
- Analog circuits deals with continuous analog signals.
- An analog circuit is a type of electronic circuit which processes analog signals using analog components like resistors, capacitors, diodes, transistors etc. (e.g., see amplifier circuit below).

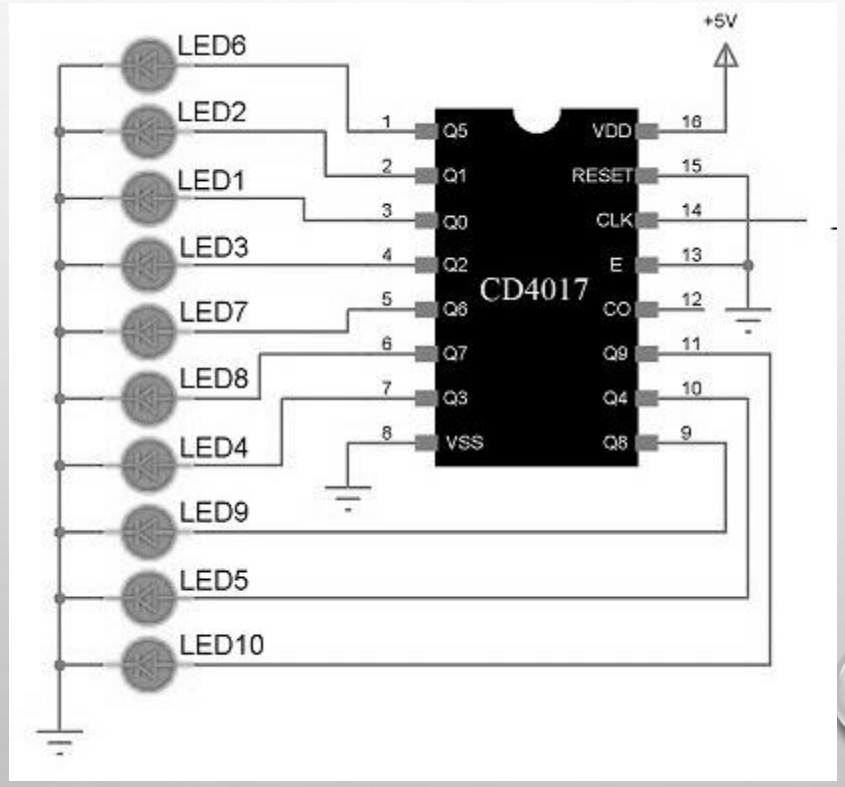


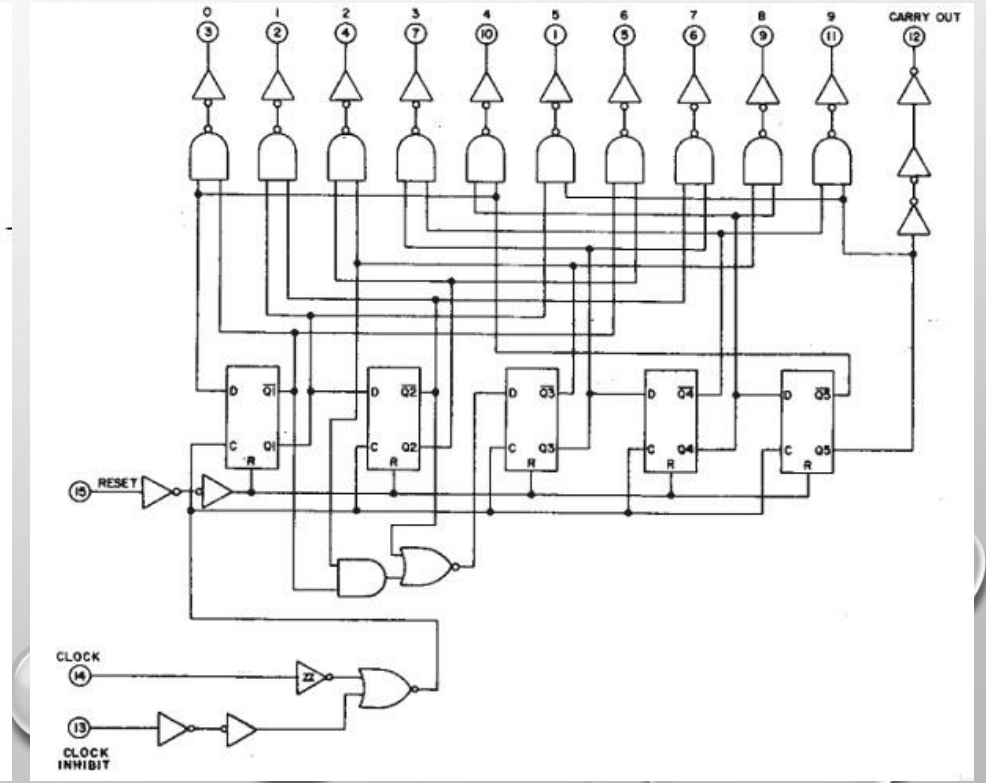


ANALOG VS. CIRCUITS

- Digital circuits deals with discrete digital signals.
- a digital circuit is predominantly built using digital electronic components to process digital signals. At low level, the digital circuits consist of a combination of transistors, logic gates (AND, NAND, NOT etc.) and at high level, microcontrollers and processors (e.g., see counter below)







ELECTRICAL VS. ELECTRONIC CIRCUITS

- An ***electric circuit*** is one composed of passive devices (RLC), in addition to voltage and current sources, and switches. In contrast, the term ***electronic*** has become synonymous with transistors and other active devices.
- **Main difference:** An electric circuit simply powers machines with electricity. However, an electronic circuit can interpret a signal or an instruction, and perform a task to suit the circumstance.
- Most modern appliances use a combination of electronic and electrical circuitry. For example, a washing machine has an electrical circuit comprising a plug socket, fuse, on/off switch, heater and motor, which rotates the drum. The desired wash cycle and temperature are interpreted by electronic circuits.

UNITS, MULTIPLES, NOTATION

Table 1-1: Fundamental SI units.

Dimension	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol

Table 1-2: Multiple and submultiple prefixes.

Prefix	Symbol	Magnitude
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

As a general rule, we shall use:

- A lowercase letter, such as *i* for current, to represent the general case:

  i *may or may not be time varying*

- A lowercase letter followed with (t) to emphasize time:

  $i(t)$ *is a time-varying quantity*

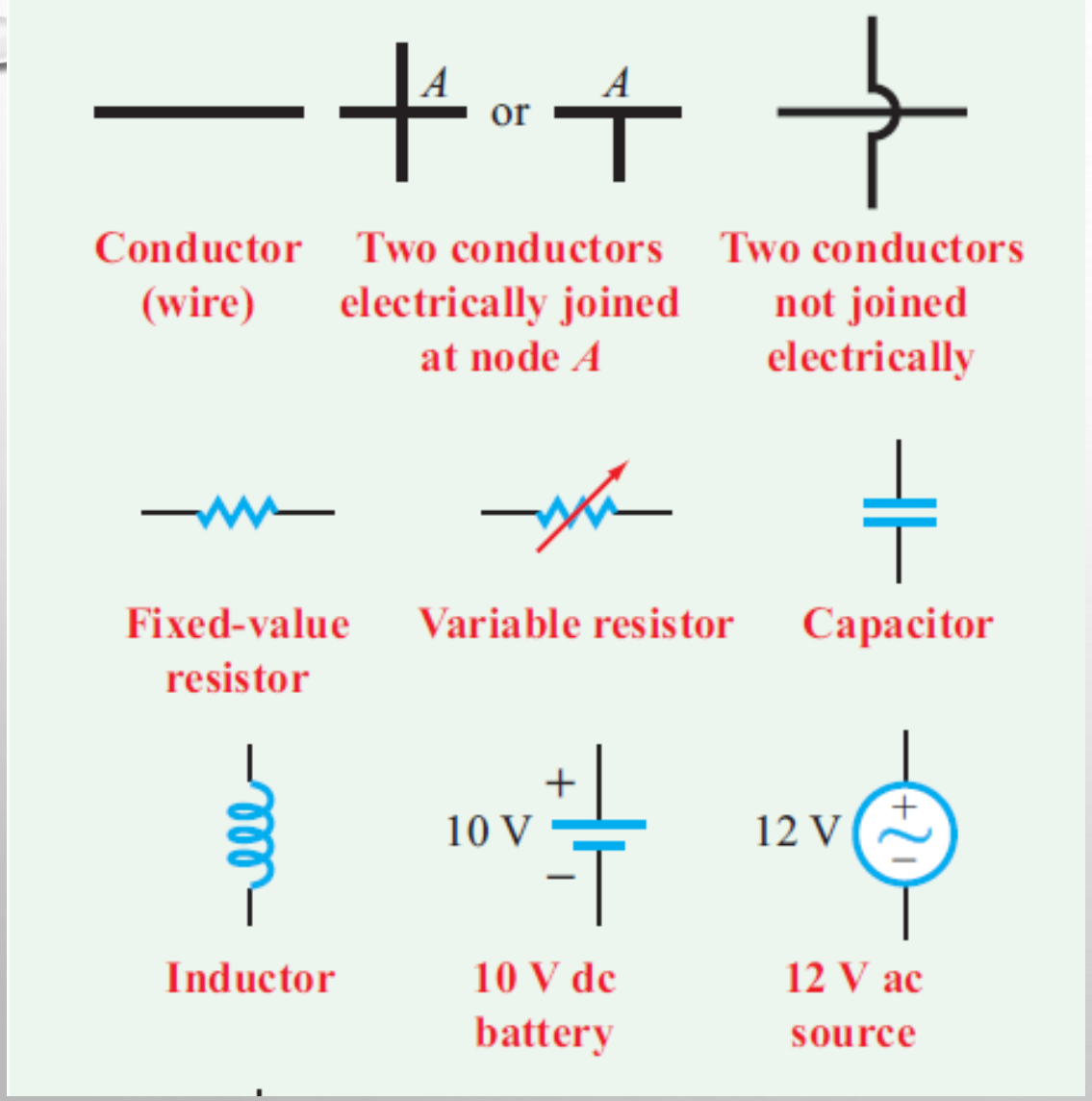
- An uppercase letter if the quantity is not time varying; thus:

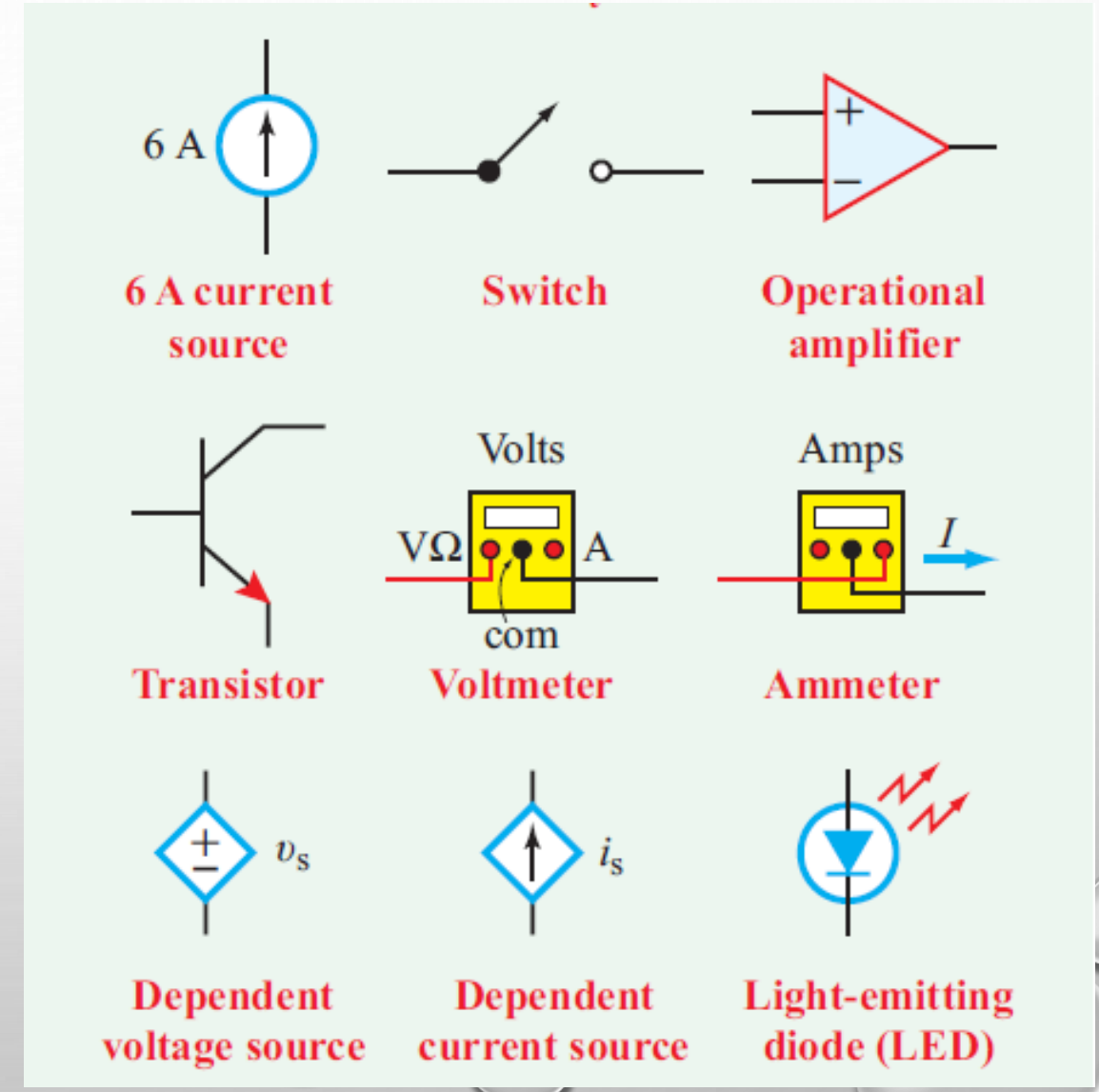
  I *is of constant value (dc quantity)*

- A letter printed in boldface to denote that:

  $\mathbf{I}$ *has a specific meaning, such as a vector, a matrix, the phasor counterpart of* $i(t)$*, or the Laplace or Fourier transform of* $i(t)$

COMMON CIRCUIT ELEMENTS

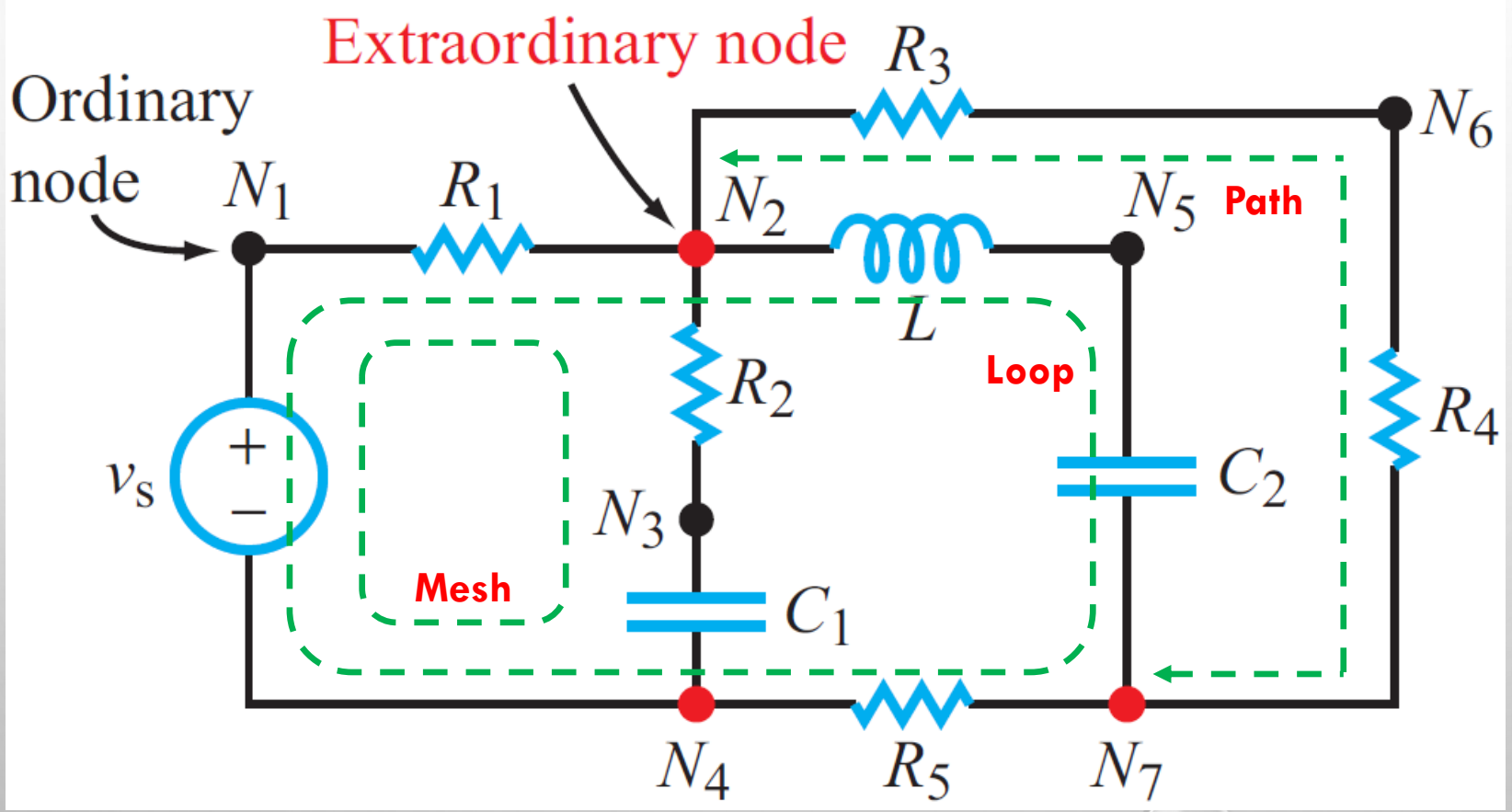




CIRCUIT TERMINOLOGY

- ***Node:*** An electrical connection between two or more elements (including wires).
- ***Branch:*** Trace between two consecutive nodes with only one element between them.
- ***Path:*** Continuous sequence of branches with no node encountered more than once.
- ***Loop:*** Closed path with the same start and end node.
- ***Mesh:*** Loop that encloses no other loops within it.
- ***Supermesh:*** Loop created from two meshes that have an independent or dependent current source in common.
- ***In series:*** Elements that share the same current. They have only ordinary nodes between them.
- ***In parallel:*** Elements that share the same voltage. They share two extraordinary nodes.

ILLUSTRATION



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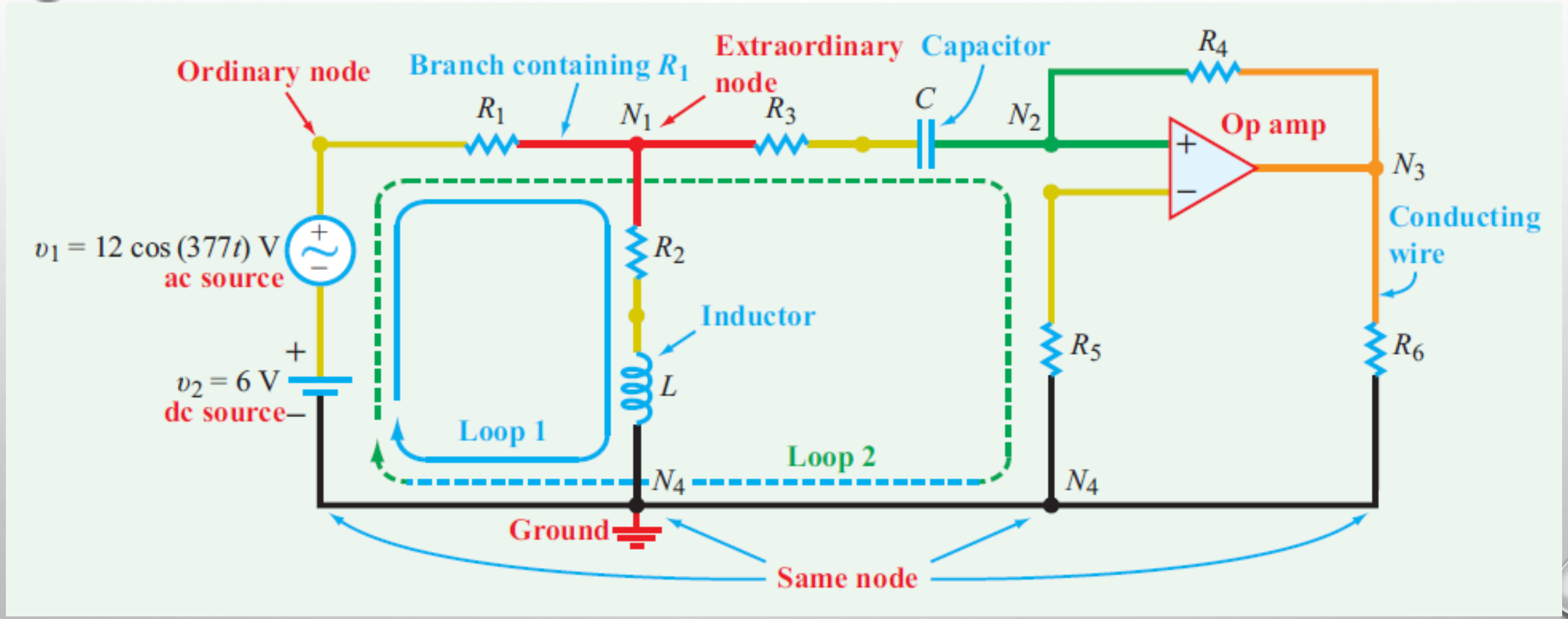

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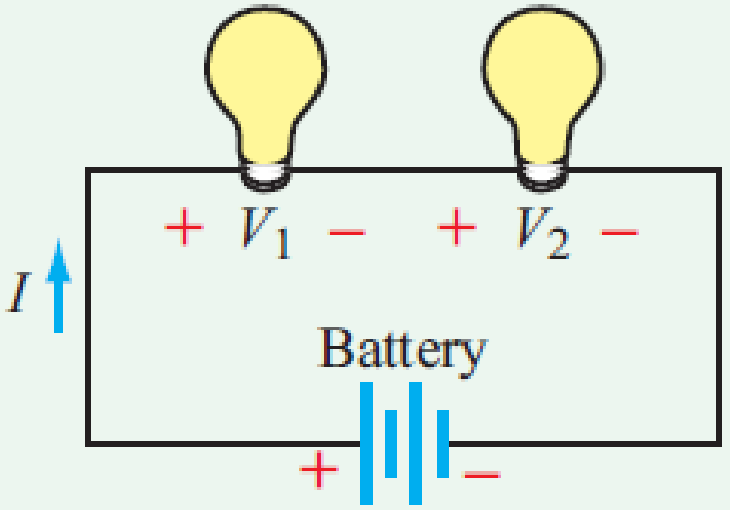
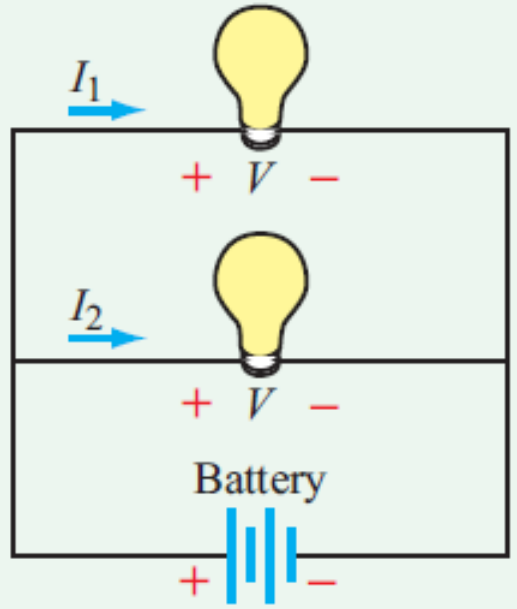


(a) Series circuit

Same Current

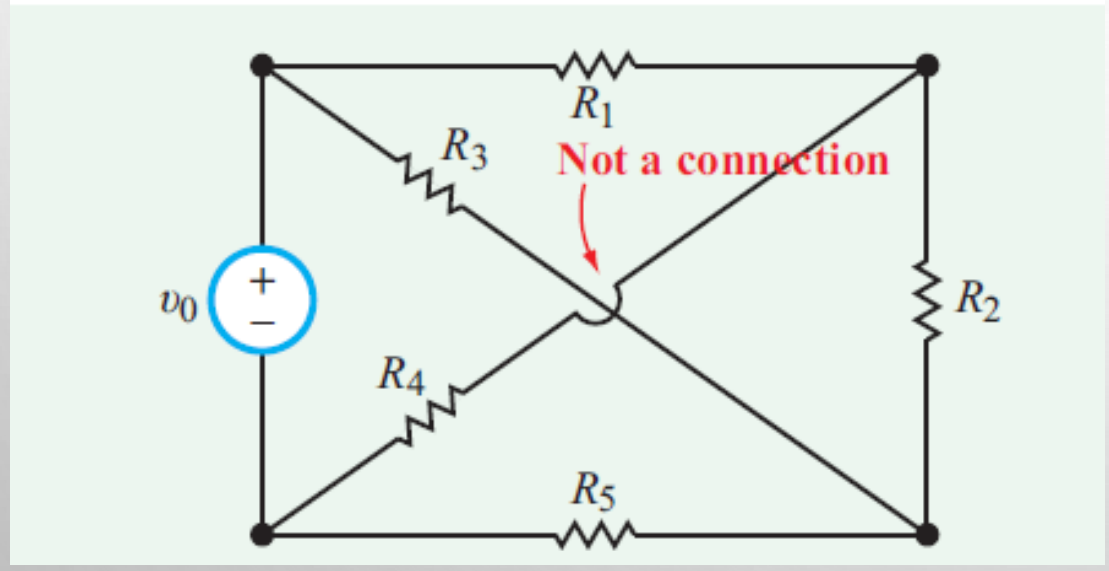


(b) Parallel circuit

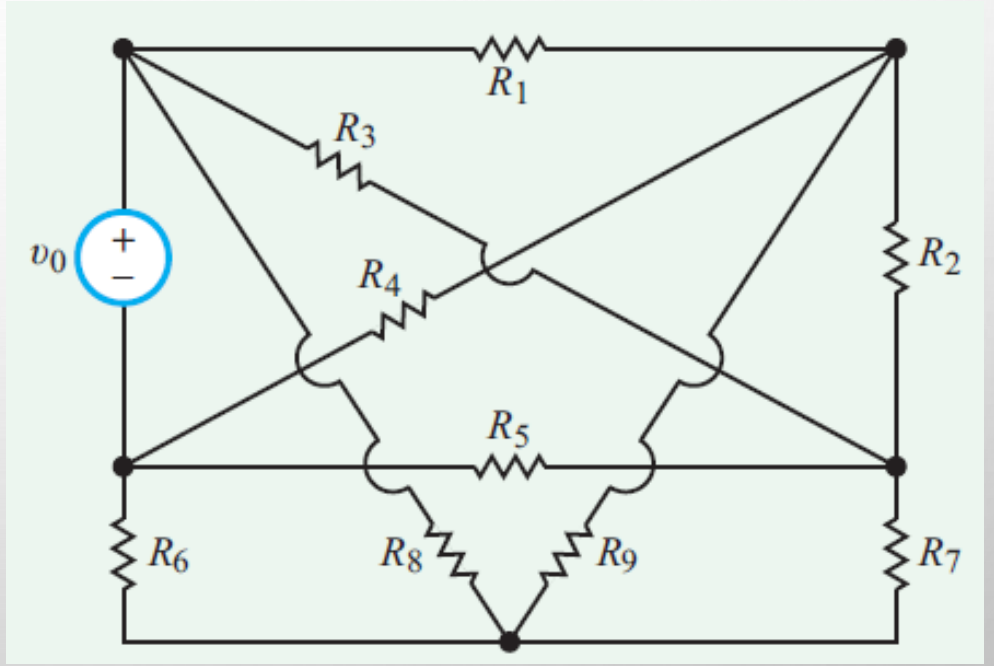
Same Voltage

PLANAR VS. NONPLANAR CIRCUITS

- A circuit is ***planar*** if it is possible to draw it on a two dimensional plane without having any two of its branches cross over or under one another.
- If such a crossing is unavoidable, then the circuit is ***nonplanar***.



Planar Circuit



Nonplanar Circuit

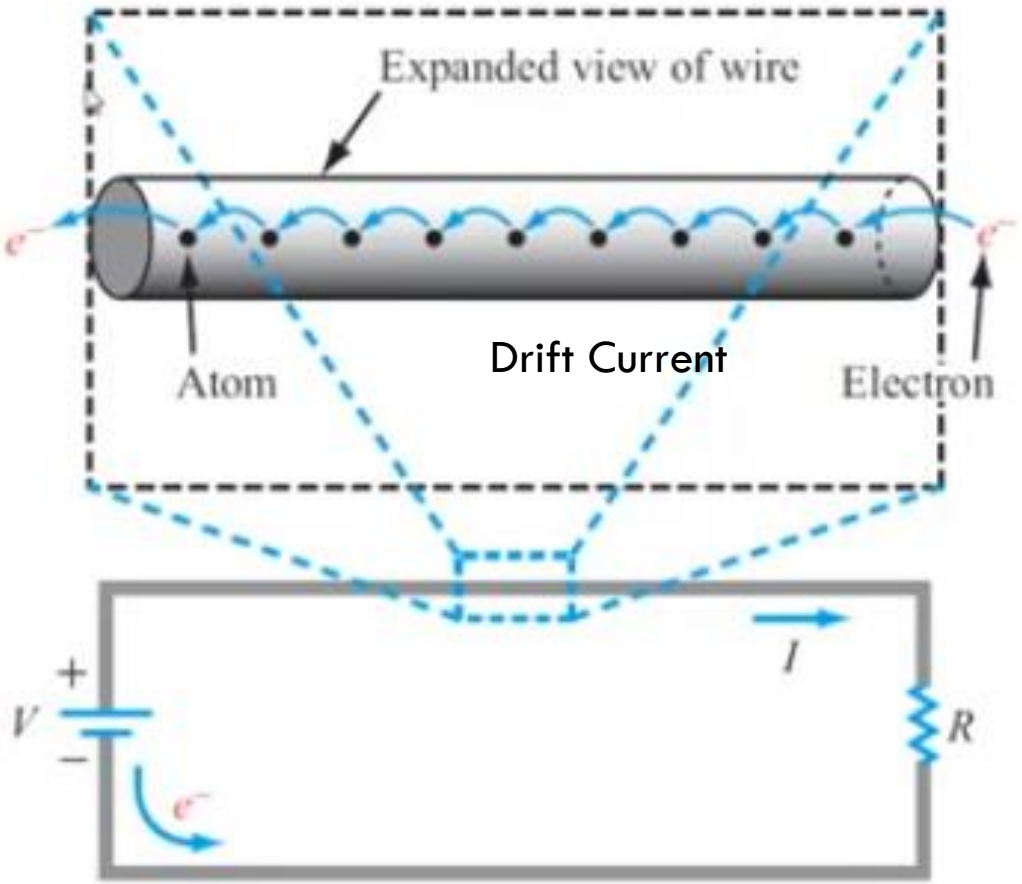
CHARGE

Unit of charge = coulomb

- Charge can be either positive (+) or negative (-)
- The fundamental quantity of charge is that of a single electron or proton.
  - Charge magnitude is usually denoted by the letter *e*.

$$e = 1.6 \times 10^{-19} \qquad (\mathrm{C})$$

- Law of conservation of charge:
  - (net) charge in a closed region can neither be created nor destroyed



CURRENT

- A conductor is a material where charges are free to move about.
- Typical charge carriers include:
  - electrons
  - ions
  - "holes" (in semiconductors)

Current is charge in motion.

$$I = \frac{\text{Net charge crossing surface in time } \Delta t}{\Delta t}$$

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

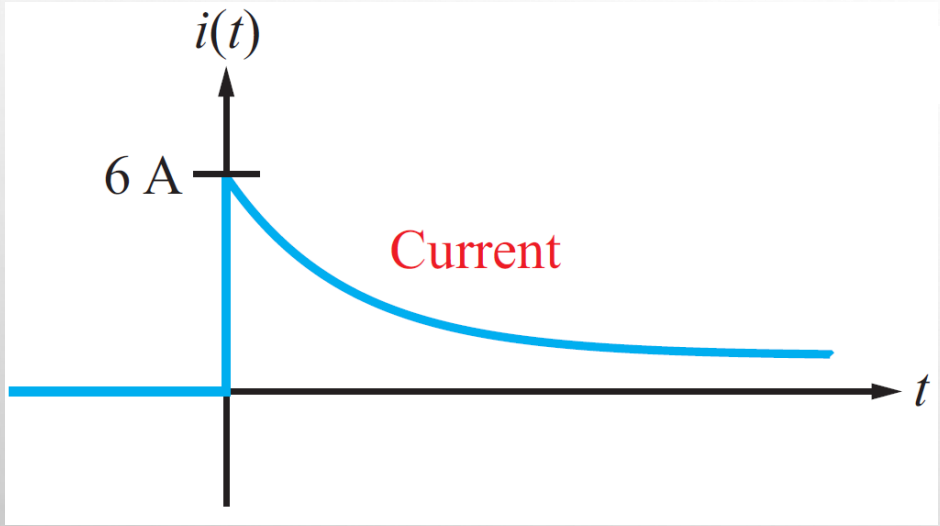
where Δt is a small time interval. The units of current are [I] = [C/s] = [A], or ampere (after André-Marie Ampère).

1 A = 1 C/s

Charge transfer within a given time period: $\Delta Q = q(t_2) - q(t_1) = \int_{t_1}^{t_2} i \, dt$

EXAMPLE

$$i(t) = \begin{cases} 0 & \text{for } t < 0, \\ 6e^{-0.2t} \text{ A} & \text{for } t \geq 0. \end{cases}$$

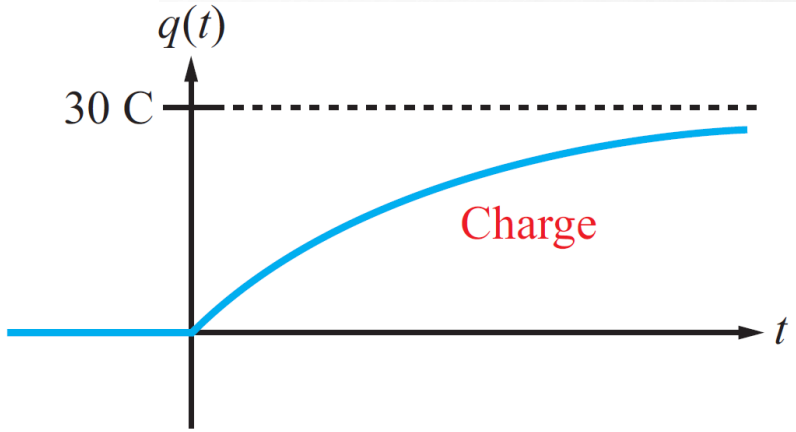


Determine: (a) $q(t)$

(b) $\Delta Q(1, 2)$

Solution:

$$q(t) = \int_0^t 6e^{-0.2t}\, dt = \frac{-6}{0.2}\, e^{-0.2t}\Big|_0^t = 30[1 - e^{-0.2t}] \text{ C}.$$

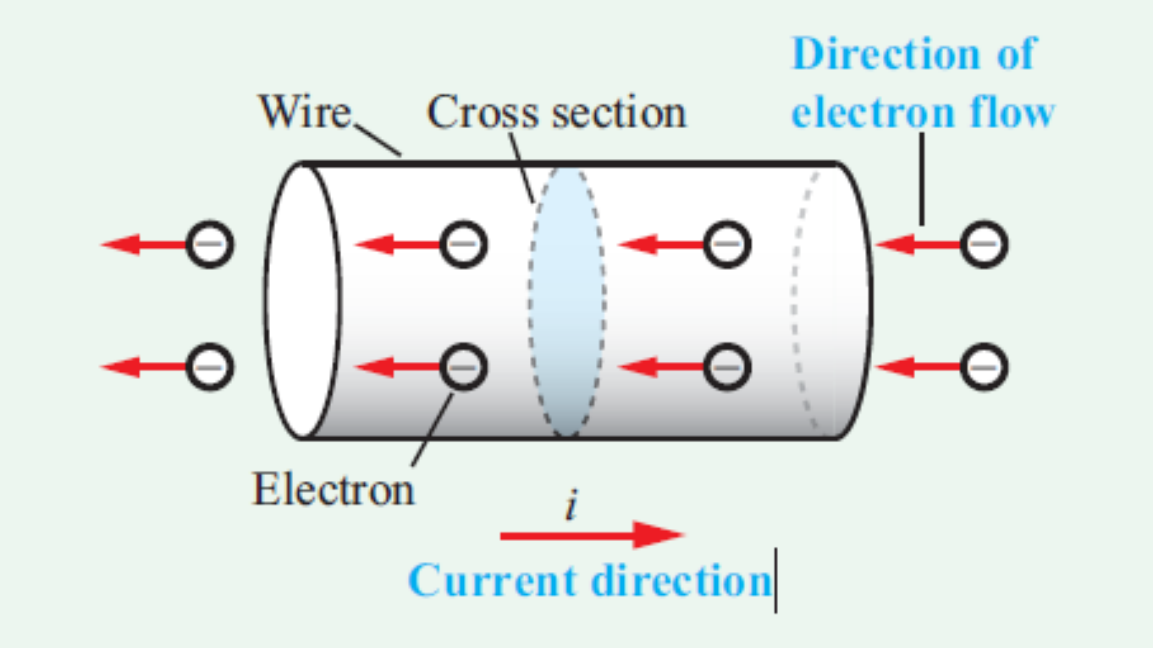


$$\Delta Q(1, 2) = \int_1^2 6e^{-0.2t}\, dt = \frac{6e^{-0.2t}}{-0.2}\Big|_1^2$$

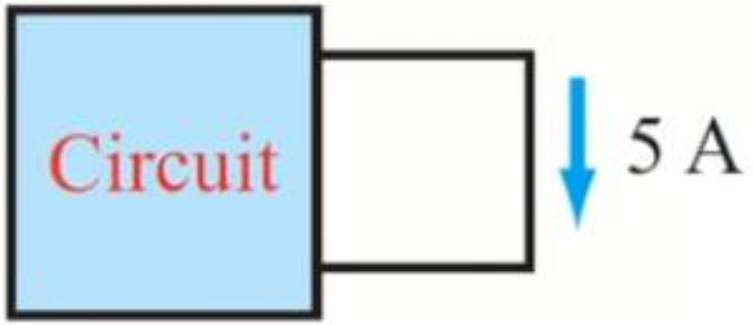
$$= -30(e^{-0.4} - e^{-0.2}) = 4.45 \text{ C}.$$

DIRECTION OF CURRENT FLOW

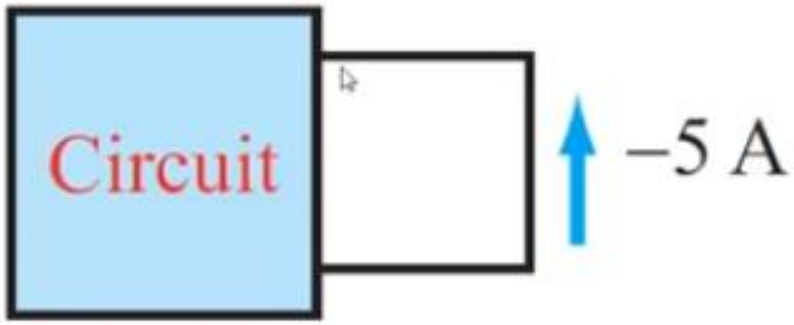
- The current flows from the positive (+) terminal of the battery to its negative (−) terminal, along the path ***external*** to the battery.
- The direction of electric current *I* is defined to be the same as the direction of flow that positive charges would follow, which is opposite to the direction of flow of electrons.



CURRENT MAGNITUDE AND SIGN

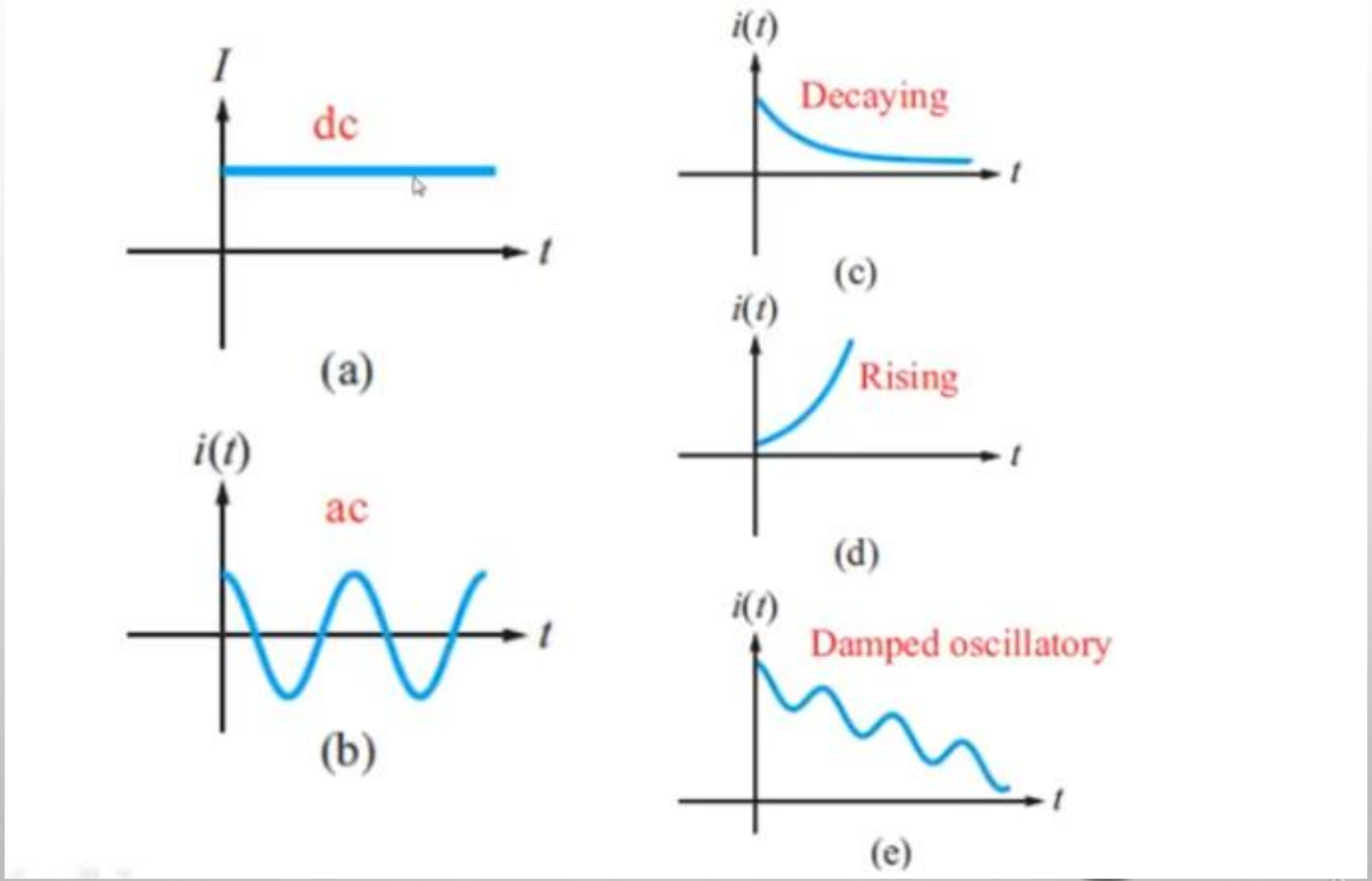


(a)



(b)

CONSTANT AND TIME-VARYING CURRENTS



VOLTAGE

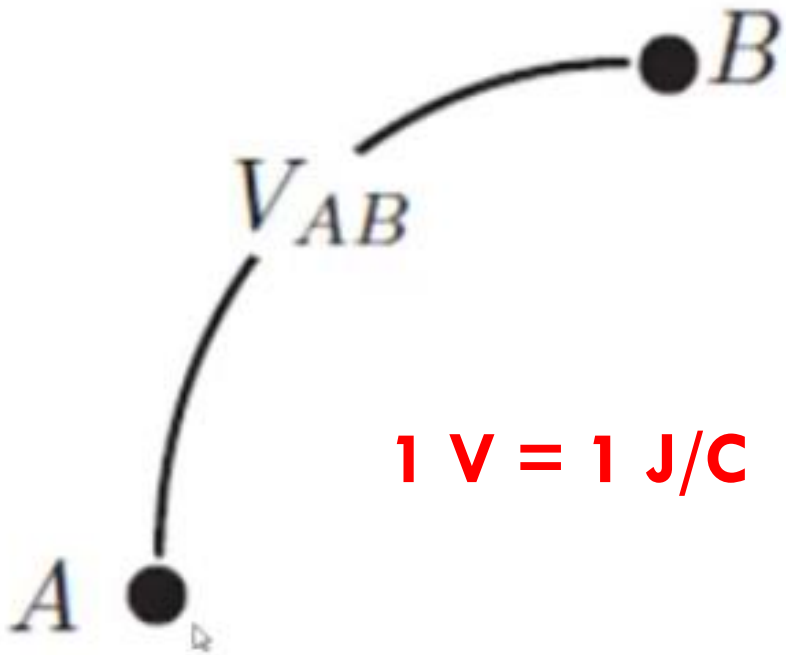
- V_{AB} is the voltage difference between point A and point B
- V_{AB} is the amount of energy gained or lost per unit charge in moving between A and B

- Voltage is a relative quantity.
  - An absolute voltage is meaningless!
- If a charge q is moved from A to B, the energy required is

$$E = qV_{AB}$$

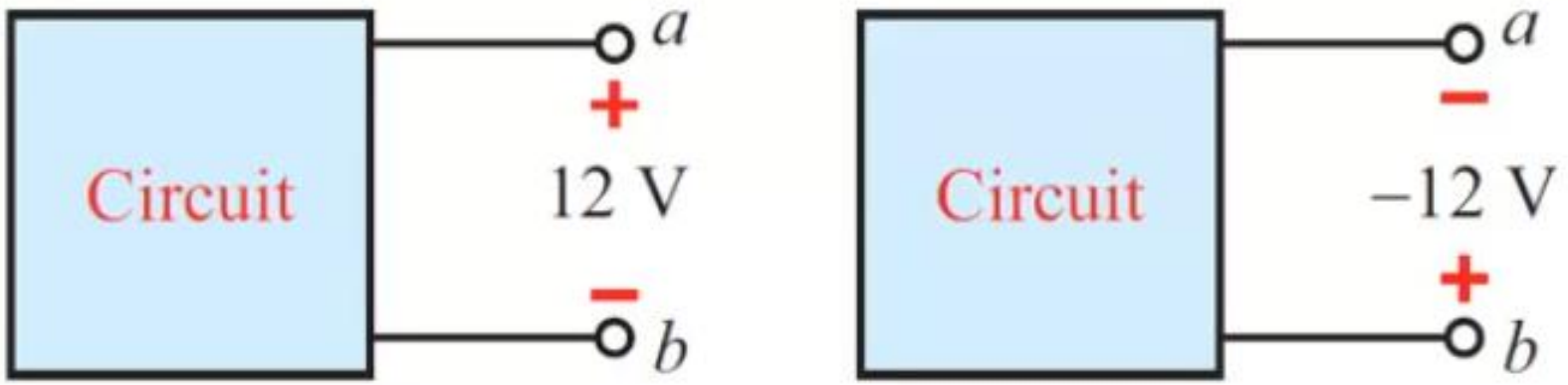
- Positive energy value →
  - energy is lost by the charge

- Negative energy value →
  - energy is gained by the charge



1 V = 1 J/C

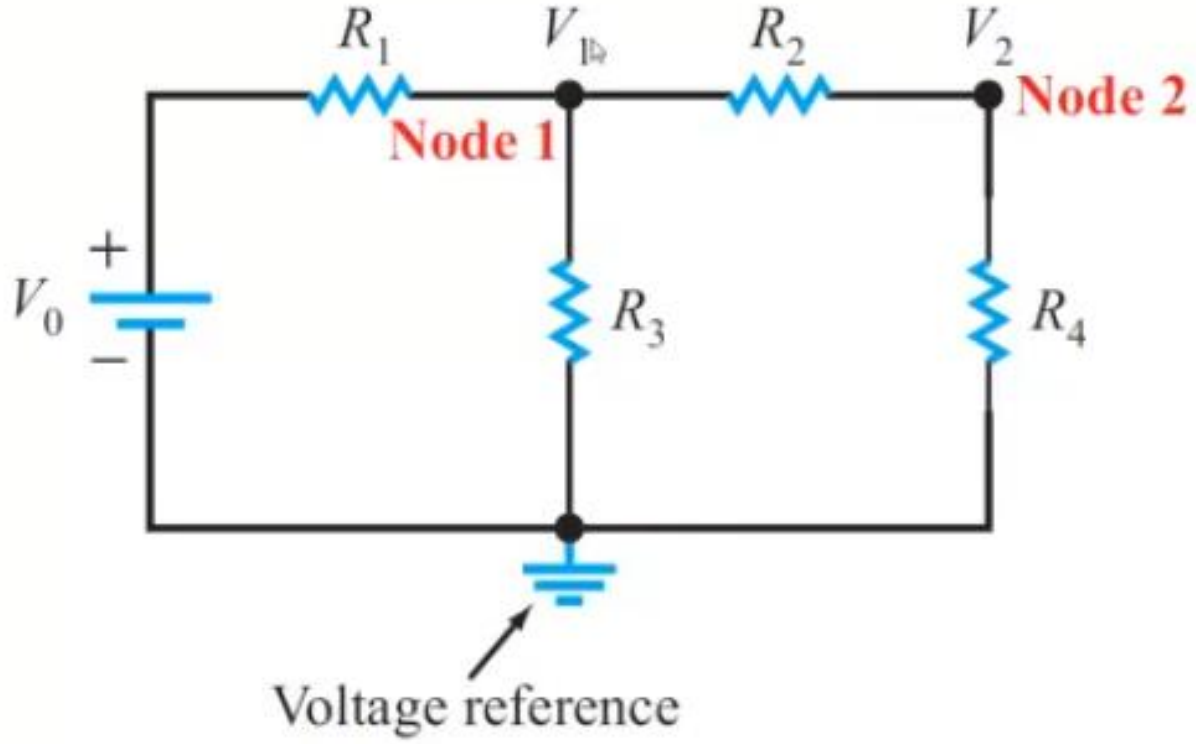
VOLTAGE MAGNITUDE AND SIGN



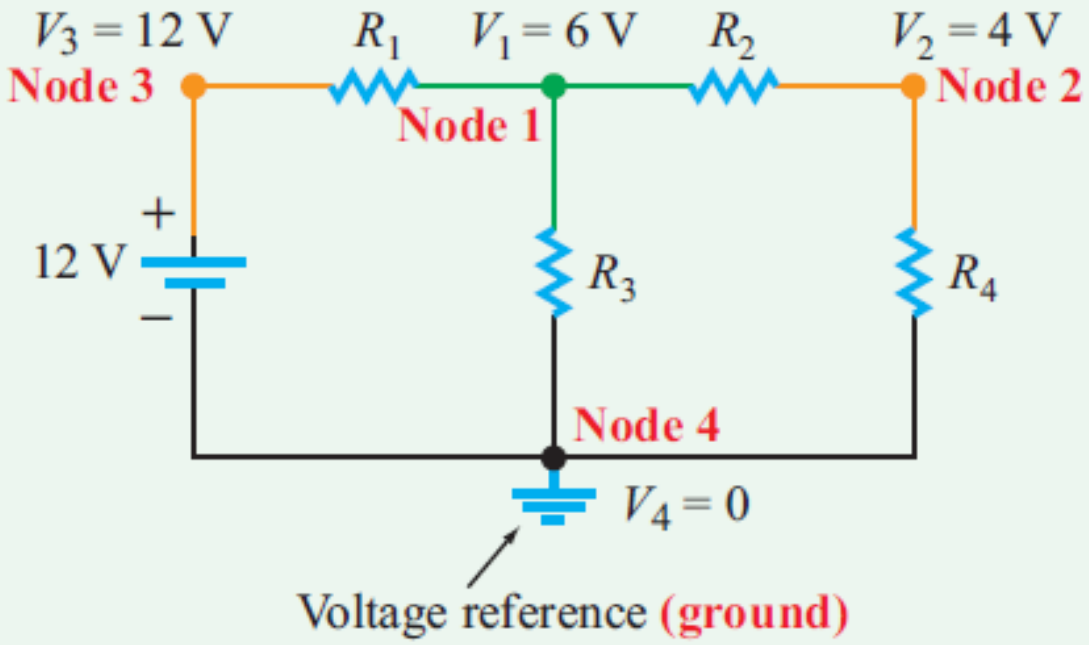
$$V_{ab} = -V_{ba}$$

REFERENCE NODE & GROUND

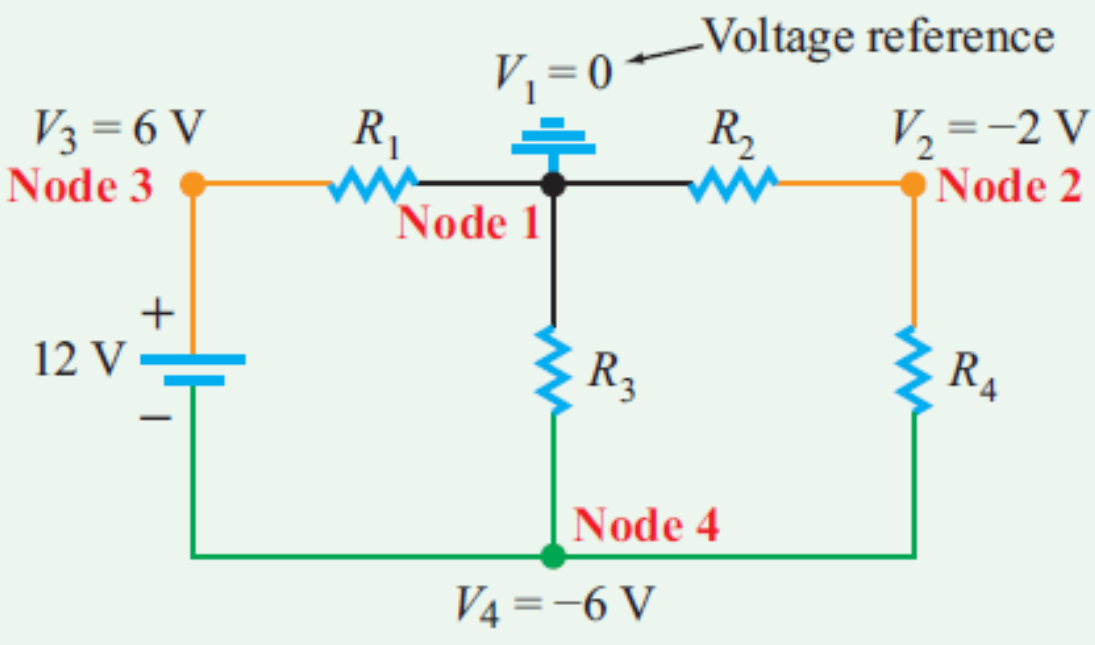
- Choose reference point for potential
- Assign potential at reference = 0, called ground
- Now all potentials are relative to ground terminal



ILLUSTRATION



(a) Ground = Node 4

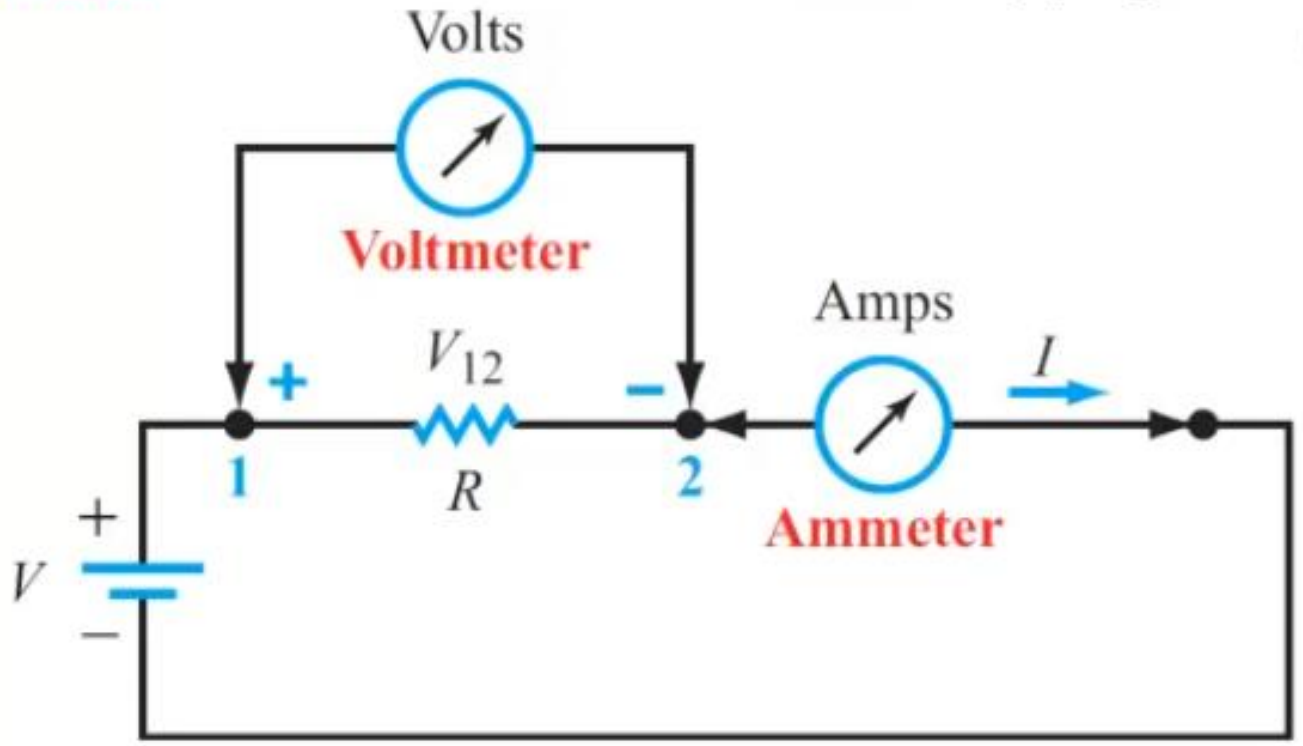


(b) Ground = Node 1

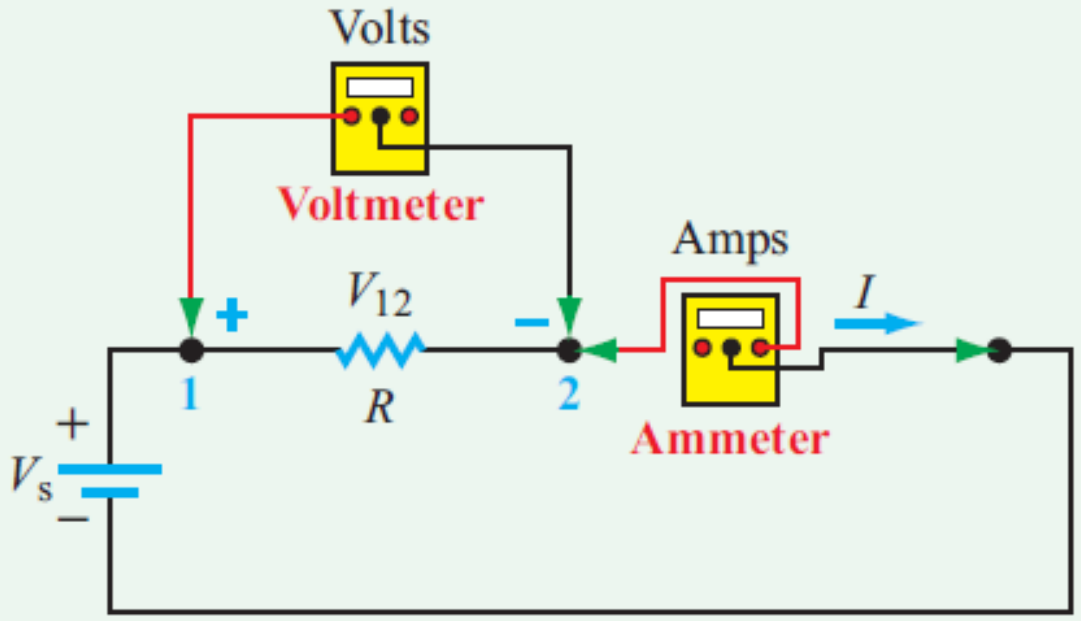
MEASURING VOLTAGE AND CURRENT

Voltmeter: measures voltage without drawing current

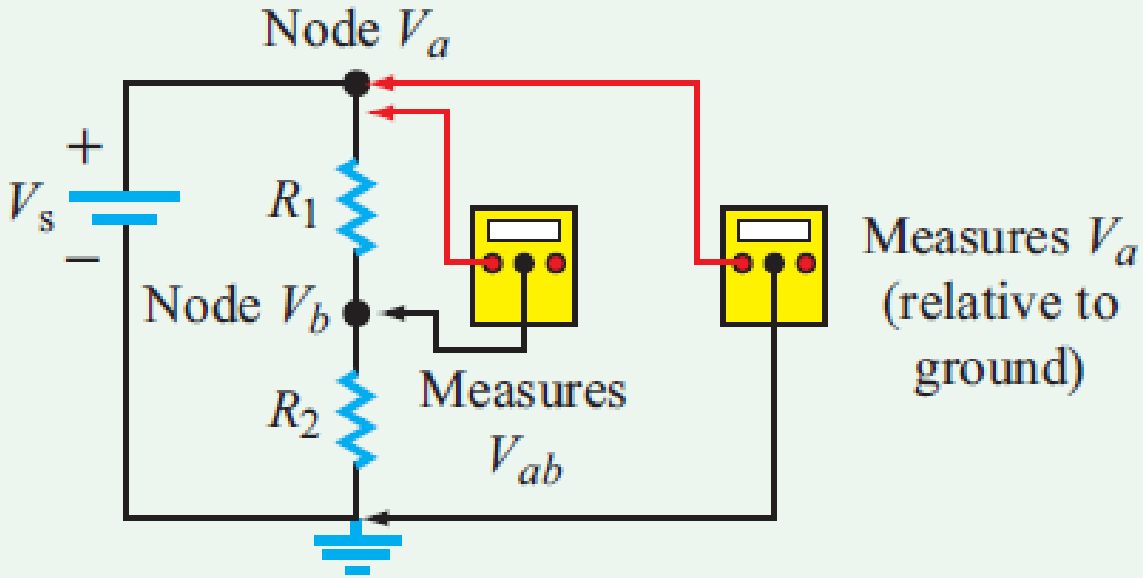
Ammeter: measures current without dropping voltage



ILLUSTRATION



(a) Voltmeter and ammeter connections



(b) Voltmeters connected to measure voltage difference V_{ab} and node voltage V_a (relative to ground)

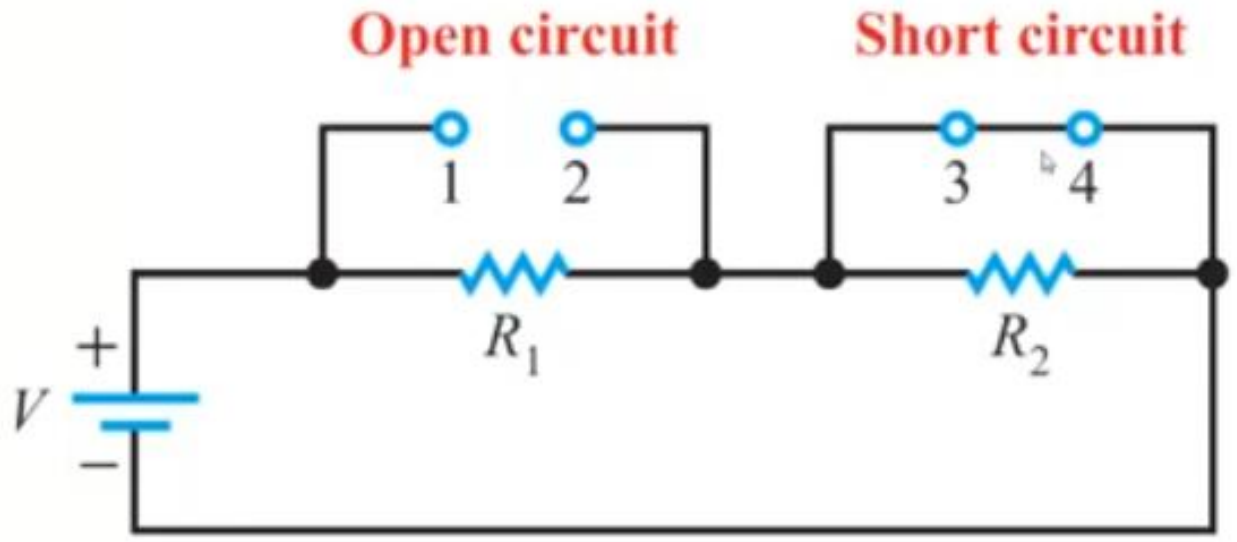
OPEN CIRCUIT & SHORT CIRCUIT

Open circuit: no path for current flow

$R = \infty$

Short circuit: no voltage drop

$R = 0$

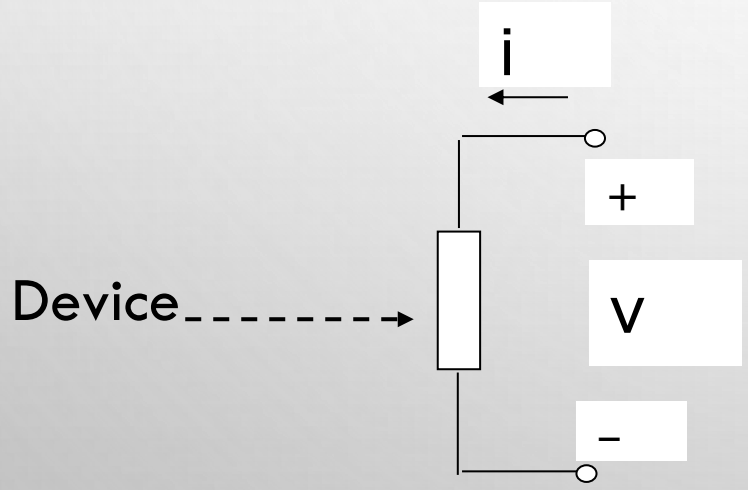


POWER

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

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

- The power delivered to a device is equal to the voltage across it multiplied by the current entering through its (+) voltage terminal.



1 W = 1 J/s = 1 VA

Power delivered to (or absorbed by) device: P = VI

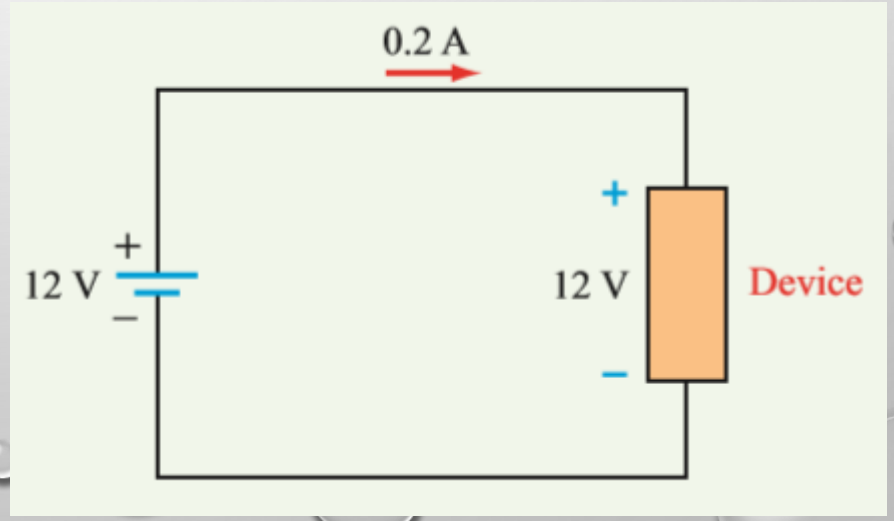
CONSERVATION OF POWER

- For an isolated electric circuit composed of multiple elements, the law of conservation of power requires that the algebraic sum of power for the entire circuit be always zero.

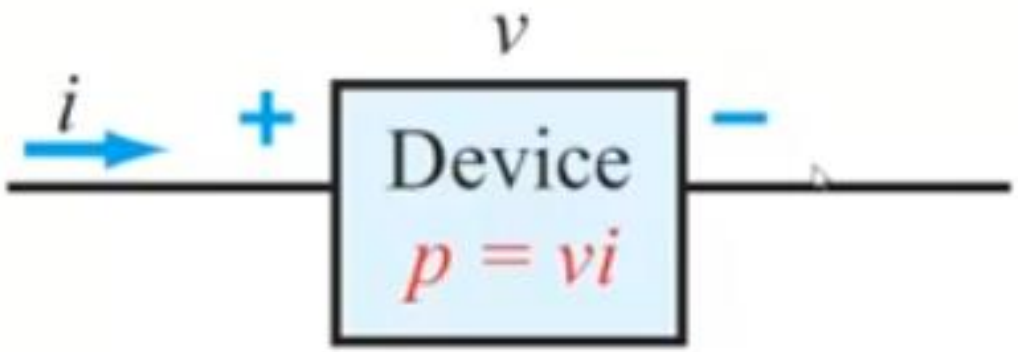
$$\sum P = 0$$

which means that the total power supplied by the circuit always must equal the total power absorbed by it.

- Example: Power generated by the 12 V battery must equal the power absorbed by the device.



!!!!!Passive Sign Convention!!!!!

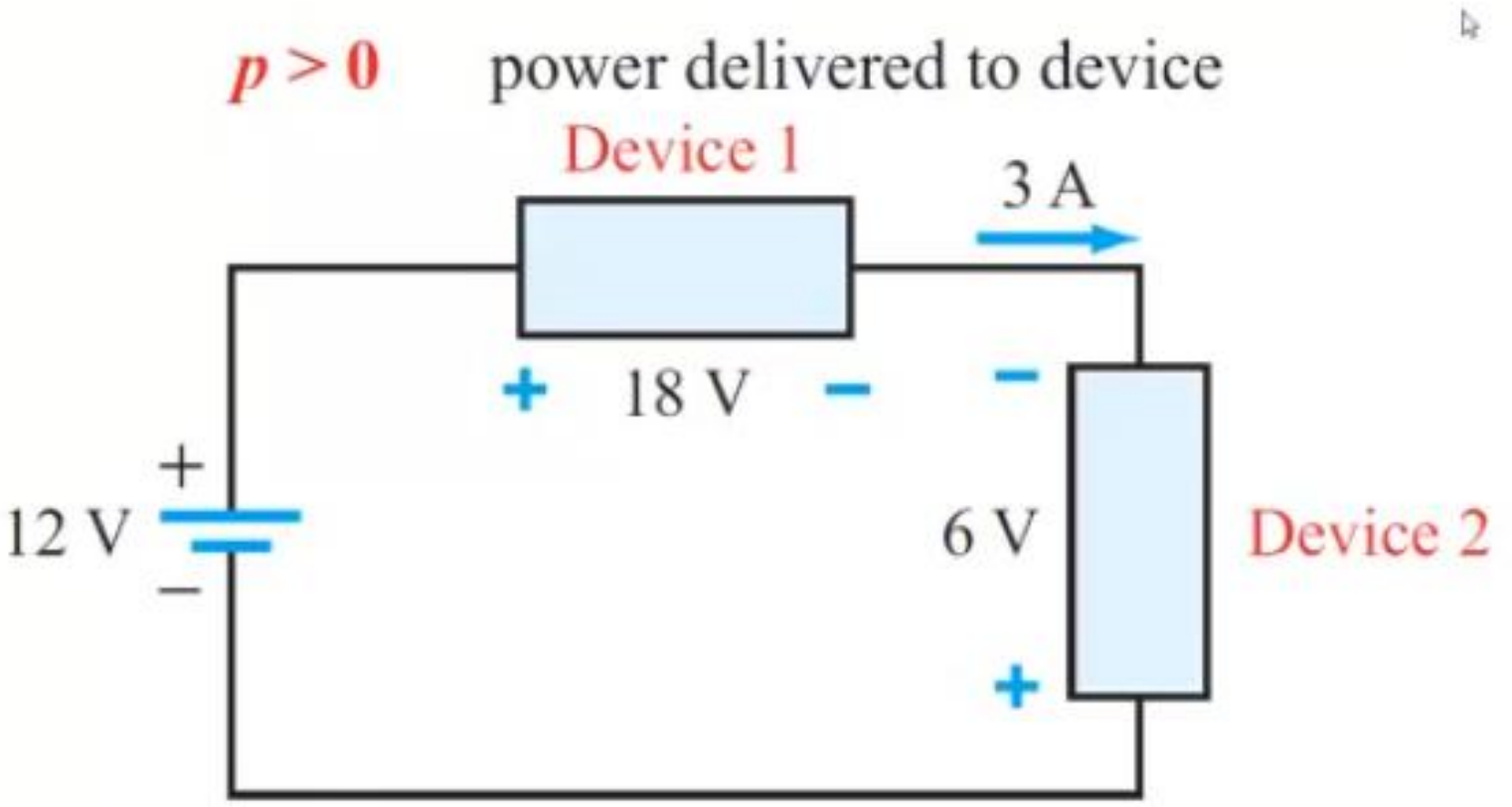


$p > 0$ power delivered to device

$p < 0$ power supplied by device

*Note that i direction is defined as entering (+) side of v.

!!!!!Passive Sign Convention!!!!!



ENERGY

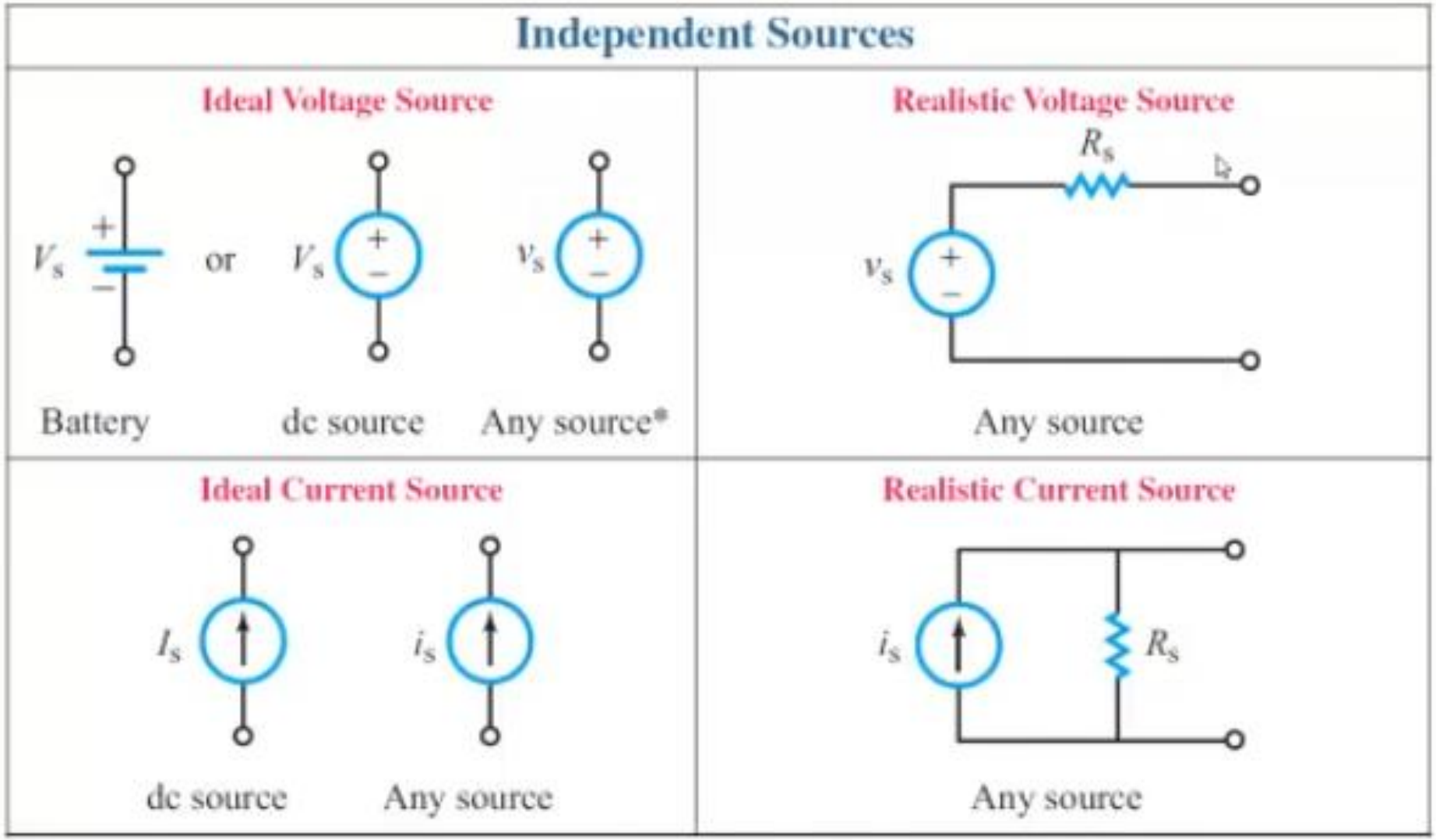
- Energy is the capacity to do work, measured in joules (J). Mathematically,

$$w = \int_{t_0}^{t} pdt = \int_{t_0}^{t} vidt$$

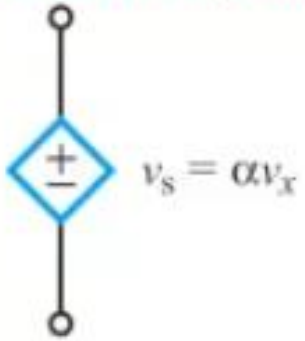
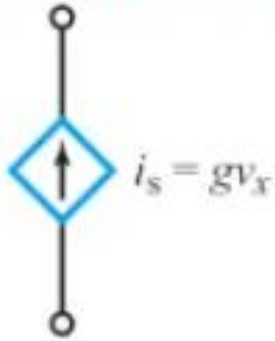
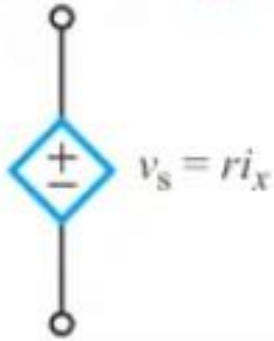
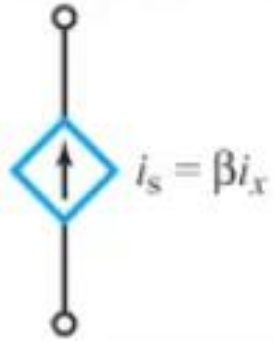
1 J = 1 W.s

- Example: compute the energy consumed by a lamp that draws 40 W over 24 hours (or 86,400 seconds)
  - Answer: 40x86,400 = 3.456 MJ = 960 Wh = 0.96 kWh

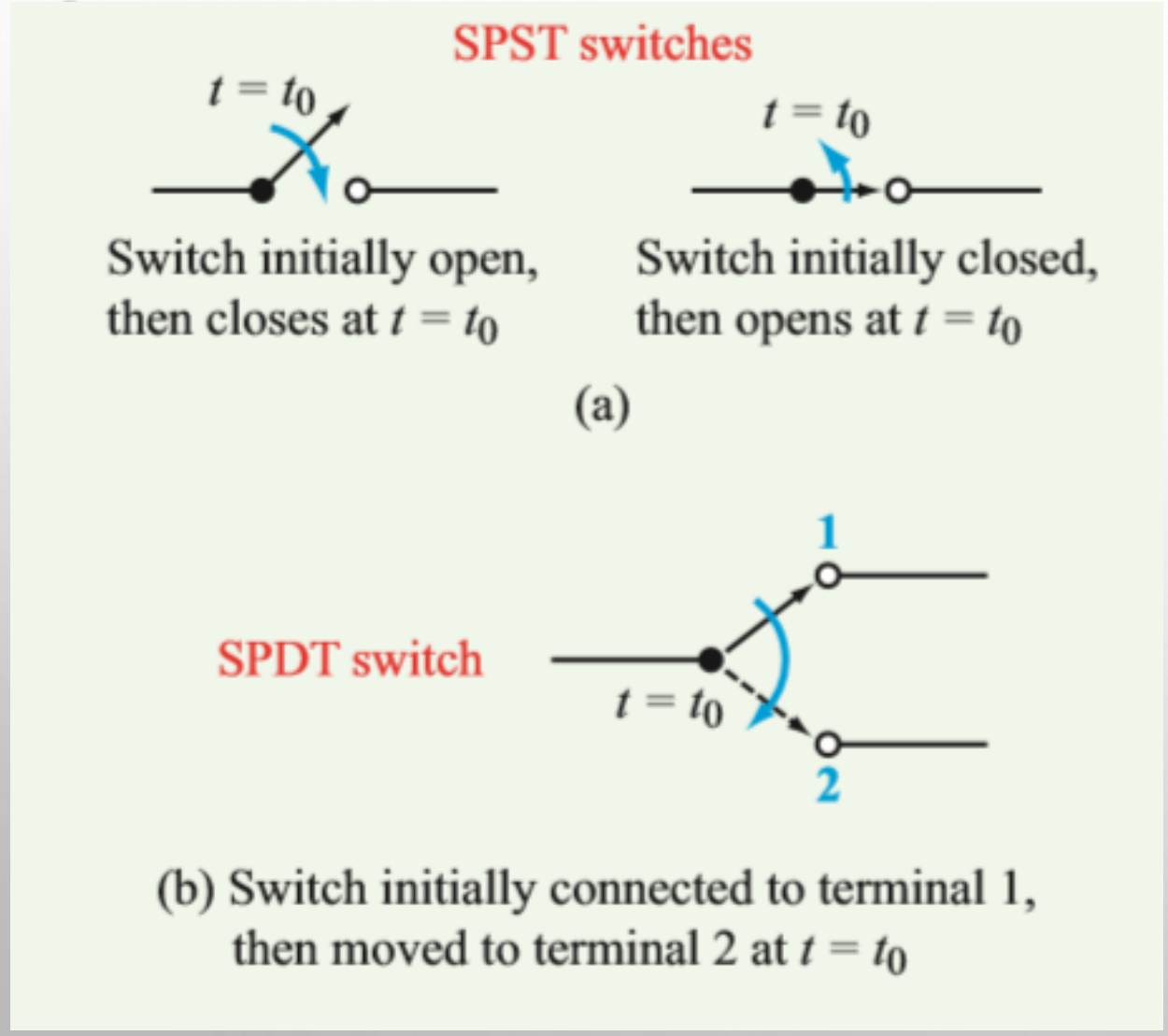
INDEPENDENT SOURCES

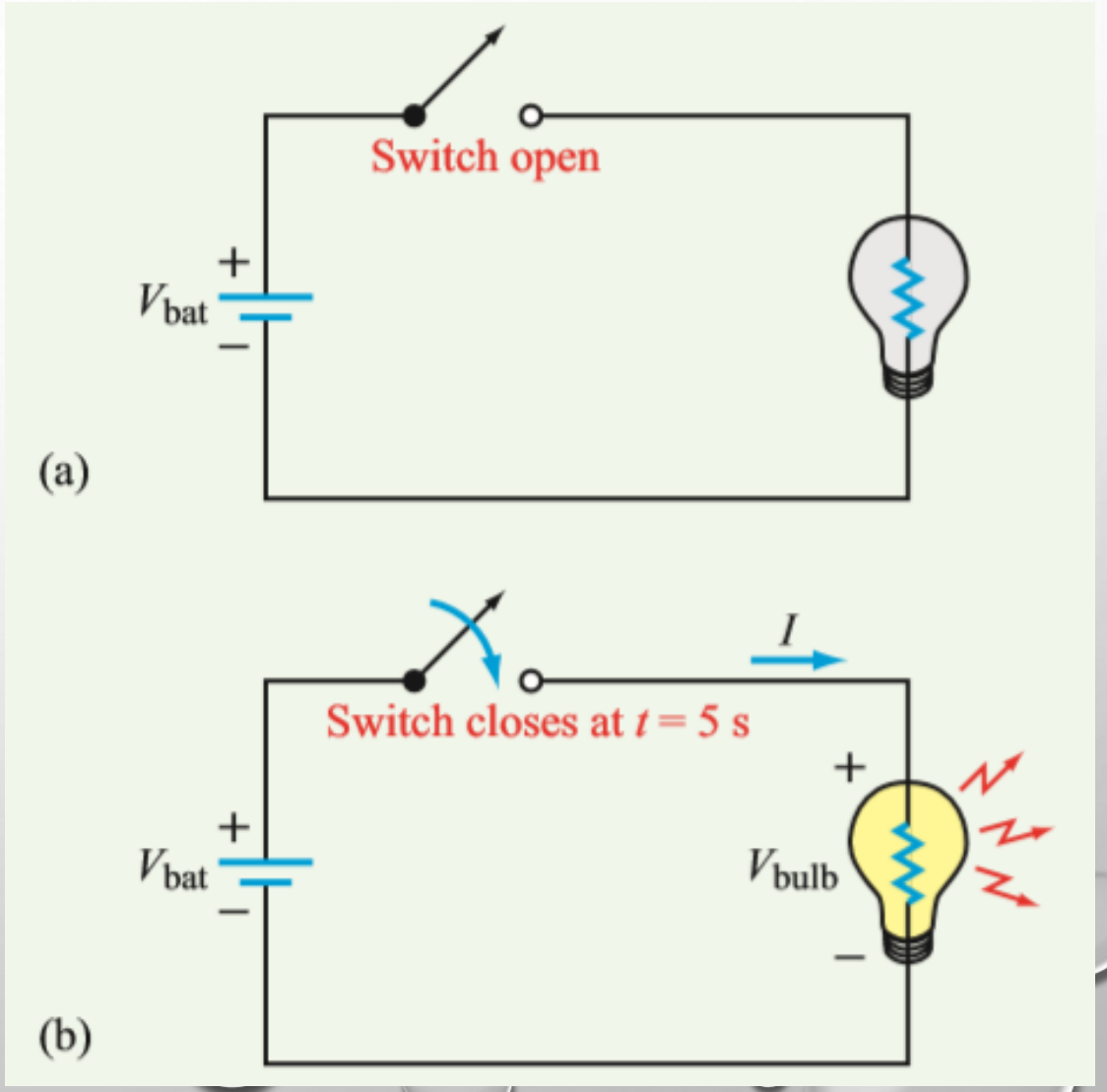


DEPENDENT SOURCES

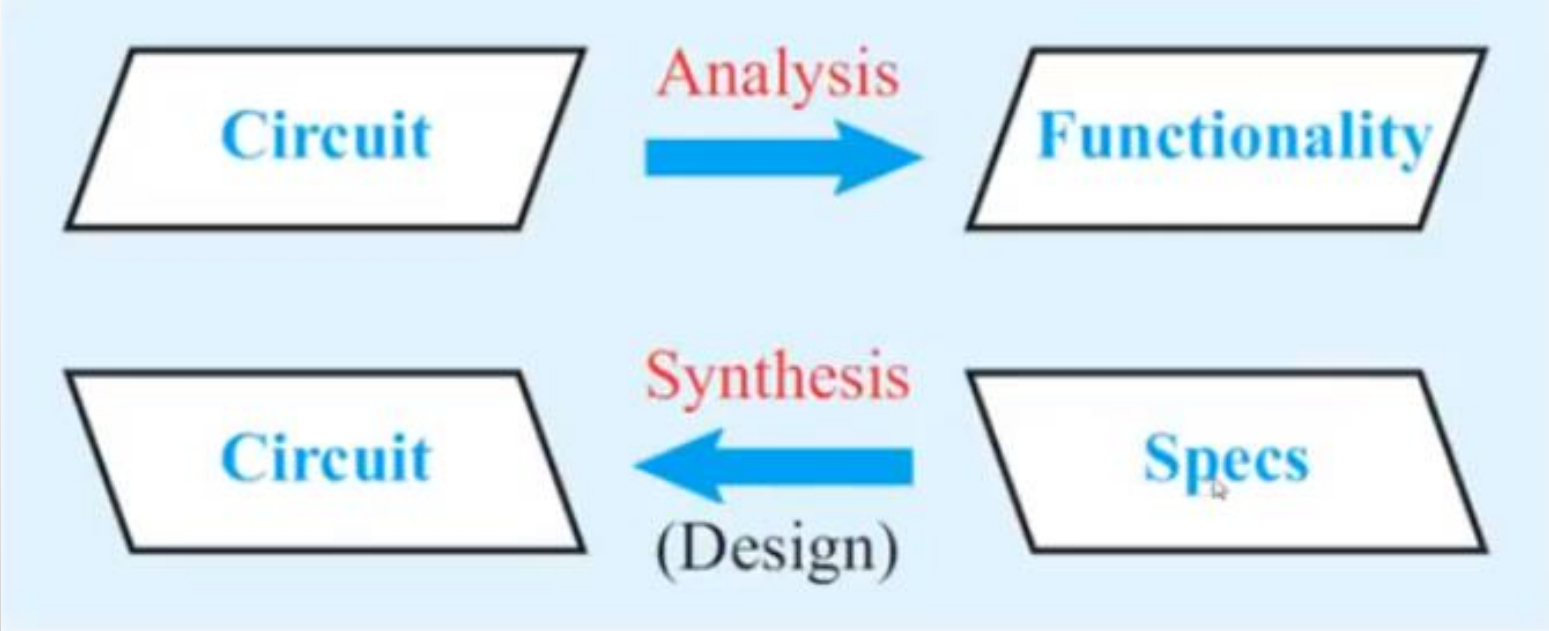
Dependent Sources	
Voltage-Controlled Voltage Source (VCVS)  $v_s = \alpha v_x$	**Voltage-Controlled Current Source (VCCS)**  $i_s = g v_x$
Current-Controlled Voltage Source (CCVS)  $v_s = r i_x$	**Current-Controlled Current Source (CCCS)**  $i_s = \beta i_x$
Note: α, g, r, and β are constants; v_x and i_x are a specific voltage and a specific current elsewhere in the circuit. *Lowercase v and i represent voltage and current sources that may or may not be time varying, whereas uppercase V and I denote dc sources.	

SWITCHES


SPST switches
$t = t_0$
$t = t_0$
Switch initially open, then closes at $t = t_0$
Switch initially closed, then opens at $t = t_0$
(a)
SPDT switch
1
$t = t_0$
2
(b) Switch initially connected to terminal 1, then moved to terminal 2 at $t = t_0$


Switch open
+
V_{bat}
–
(a)
I
Switch closes at $t = 5$ s
+
+
V_{bat}
–
V_{bulb}
–
(b)

CIRCUIT ANALYSIS VS. SYNTHESIS



HOMEWORK ASSIGNMENT

SOLVE THE FOLLOWING PROBLEMS:

7, 9, 15, 17, 19, 23, 25, 27, 29, 31, 33, 37, 41, 43.