EECS 42 Introduction to Electronics for Computer Science
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Corrections Slide 3 and 9

Lecture #2

- **Charge, Current, Energy, Voltage**
- **Power**
- **Kirchhoff's Current Law**
- **Kirchhoff's Voltage Law**

Oldham & Schwarz: 1.3-1.4; HW 1.2, 1.3

http://inst.EECS.Berkeley.EDU/~ee42/

REVIEW OF ELECTRICAL QUANTITIES AND BASIC CIRCUIT ELEMENTS

Free Charge

Most matter is macroscopically electrically neutral most of the time. Exceptions: clouds in thunderstorm, people on carpets in dry weather, plates of a charged capacitor, etc.

Microscopically, of course, matter is full of charges. Consider solids:

- Solids in which all charges are bound to atoms are called *insulators*.
- Solids in which outer-most atomic electrons are free to move around are called *metals*.
  - Metals typically have ~ 1 "free electron" per atom (~ 5 $X10^{22}/cm^3$)
  - Charge on a free electron is –"e" or "q", where |e| = 1.6 x 10^{-19} C ← **C stands for the units of charge called Coulomb**
- *Semiconductors* are insulators in which electrons are not tightly bound and thus can be easily "promoted" to a free state (by heat or even by "doping" with a foreign atom).

Al or Cu – good metallic conductor – great for wires

Si or GaAs – classic semiconductors

Quartz – good insulator – great for dielectric

CHARGE (cont.)

Charge flow ➠ Current **Charge storage** ➠ Energy, information

Definition of current i (or I)

i (in Amperes) = flow of 1 coulomb per second

$$i\,(A) = \frac{dq}{dt}\left(\frac{C}{S}\right)$$

where **q** is the charge in coulomb and t is the time in sec

Note: Current has ***sign***

Examples:

(a) 10^5 positive unit charges of value $e = 1.6\times10^{-19}C$ flow to right (+ x direction) every nanosecond

$$i = \frac{10^5 \times 1.6\times10^{-19}}{10^{-9}} = 1.6\times10^{-5}A = 16\mu A \text{ (left to right)}$$

(b) 10^{10} electrons flow to right in a wire every microsecond

$$i = \frac{-10^{10}\times1.6\times10^{-19}}{10^{-6}} = -1.6\times10^{-3} = -1.6mA \text{ (left to right)}$$

Units and mulitpliers

We use metric ("SI") units in electrical engineering.
The important ones are:

Energy -	E	Joules	(J)	
Power -	P	Watts	(W)	
Charge -	Q	Coulomb	(C)	
Current -	I	Ampere	(A)	
Potential -	V	Volt	(V)	
Resistance -	R	Ohm	(Ω)	(V/I)
Capacitance -	C	Farad	(F)	(C/V)
Inductance -	L	Henry	(H)	(Vsec/A)

PREFIX

femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	m	10^{-6}
milli	m	10^{-3}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}

POSSIBLE CONCEPTUAL ISSUES

1 How does charge move through the wire?

Remember a wire has a huge number of free carriers moving very fast but randomly (because of thermal energy)

$\langle v \rangle \sim C/1000$ at 20°C

Drift concept: Now add even a modest electric field

Carriers "feel" an electric field along the wire and tend to drift with it (+ sign charge) or against it (– charge carrier). This drift is still small compared to the random motion.

2 Sign of the charge carriers: It is often negative (for metals); in silicon, it can be either negative or positive.

Ben Franklin: Picked/guessed that carriers in wires have a positive sign and move with the electric field. In fact electrons have a negative charge and go the other way (in a positive field). But of course the current is the same for either + or – Q since they move in opposite directions in a given field.

POSSIBLE CONCEPTUAL ISSUES (con't)

3. Modern Definition re signs: Electric field is in the direction positive charge carriers move. Thus if we have an electrical field in the Z direction, positive charges (ions, positrons, whatever) will experience a force in the positive Z direction. Negatively charged particles will experience the force in the –Z direction.

Thus the free carriers we will be concerned with (electrons with negative charge and "holes" with positive charge) will move against and with the electric field respectively.

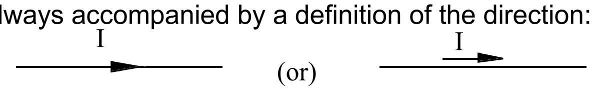
4. Field or Current can have positive or negative sign.

Examples: I = 0.2 mA → same as I = –0.2 mA ←

(Think about hooking up an ammeter and then reversing its connection. The sign of the current it reads must change.)

POSSIBLE CONCEPTUAL ISSUES (con't)

5. When we have unknown quantities such as current or voltage, we of course do not know the sign. A question like "Find the current in the wire" is always accompanied by a definition of the direction:

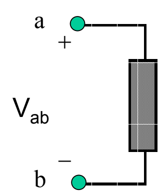


In this example if the current turned out to be 1mA, but flowing to the left we would merely say I = -1mA.

6. Thus there is no need to guess the reference direction so that the answer comes out positive….Your guess won't affect what the charge carriers are doing! Of course you will find that your intuition and experience will often guide you to define a current direction so that the answer comes out positive.

THINKING ABOUT VOLTAGE ("electrical potential")

Definition: Voltage (electrical potential) is the electrical energy per unit positive charge.
The Units are Volts = Joules/Coulomb



"V_{ab}" means the potential at a minus the potential at b.

Generalized circuit element with two terminals (wires) a and b, with a potential difference v across the element

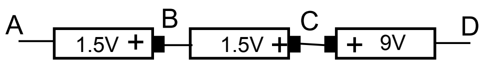
Potential is always referenced to some point (V in the example; V is measured with respect to V_b)

Sign Convention

SIGN CONVENTIONS (cont.)

Lets put a bunch of batteries, say 1.5V and 9V in series to see what we already know about sign conventions:

Example 1



V_{AB} = -1.5V

V_{BC} = -1.5V

V_{CD} = +9V

What is V_{AD} ?

Math Approach: Factor into known steps

$V_{AD} = V_{AB} + V_{BC} + V_{CD}$ = **(+1.5) + (+1.5V) - 9V** = **+6V**

Physical Approach: Add the voltage (potential) drops

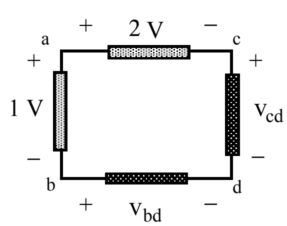
V_{AD} = **(1.5)** + **1.5V** + **(-9V)** = **-6V**

KEEPING THE VOLTAGE SIGNS STRAIGHT

Labeling Conventions

- Indicate + and – terminals clearly; or label terminals with letters
- The + sign corresponds to the first subscript; the – sign to the second subscript. Therefore, $V_{ab} = -V_{ba}$

Note: The labeling convention has nothing to do with whether or not v > 0 or v < 0



Using sign conventions:

$$V_{ab} = 1;\ V_{ca} = -2, \text{ thus}$$
$$V_{cb} = -2 + 1 = -1V$$

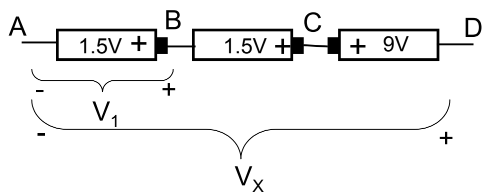
Obviously $V_{cd} + V_{db} = V_{cb}$ too. Then if V_{bd} = 5V, what is V_{cd}?

SIGN CONVENTIONS (cont.)

Normally we do not need two subscripts for voltages because:

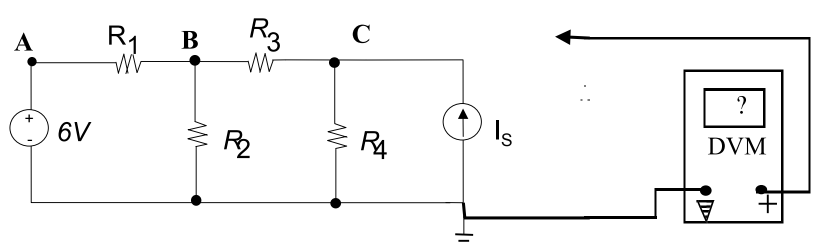
1) We have defined a point in the circuit to the reference node (common or "ground"), I.e. the place where we will atttach the common wire of the voltmeter. Thus all voltages are measured with respect to this point. OR
2) We use "brackets" with signs to indicate the polarity and symbol:

Example How are single-subscript voltages related to double-subscript voltages?



EXAMPLE OF SINGLE-SUBSCRIPT NODE VOLTAGES

Choose a reference (ground) and define the circuit voltages with respect to this point. This is equivalent to attaching common node of voltmeter to the reference node.



Thus we can connect the + lead of the DVM to point (Node) A and call the potential of point A "V_A", similarly at points (Nodes) B, C.

Of course what V_A means is the potential of point (Node) A with respect the point connected to the common lead of the DVM . What is V_A?

POWER IN ELECTRIC CIRCUITS

Power: Transfer of energy per unit time (Joules per second = Watts)
Concept: in falling through a positive potential drop V, a positive charge q gains energy

- potential energy change = qV for each charge q
- Rate is given by # charges/sec

Power = P = V (dq/dt) = VI

$P = V \times I$ Volt × Amps = Volts × Coulombs/sec = Joules/sec = Watts

Circuit elements can *absorb* or *release* power (i.e., from or to the rest of the circuit); power can be a function of time.

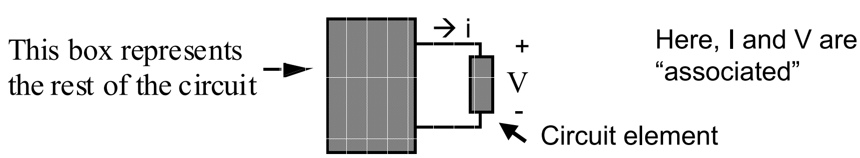
How to keep the signs straight for absorbing and releasing power?

+ Power ≡ absorbed into element

– Power ≡ delivered from element

"ASSOCIATED REFERENCE DIRECTIONS"

It is often convenient to define the current *through* a circuit element as positive when entering the terminal associated with the + reference for voltage



For positive current and positive voltage, positive charge "falls down" a potential "drop" in moving through the circuit element: it *absorbs* power

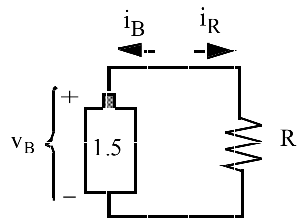
- P = VI > 0 corresponds to the element absorbing power if the definitions of I and V are associated.

How can a circuit element absorb power?

By converting electrical energy into heat (resistors in toasters); light (light bulbs); acoustic energy (speakers); by storing energy (charging a battery).

Negative power ⇒ releasing power to rest of circuit

"ASSOCIATED REFENCE DIRECTIONS" (cont.)



Suppose i_R = 1mA

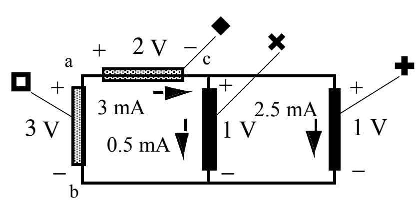
therefore i_B = -1mA

A) Resistor: P = i_B v_B = +1.5mW

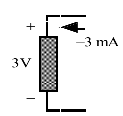
B) Battery: i_B and v_B are associated, therefore P= i_B v_B . Thus

EXAMPLES OF CALCULATING POWER

Find the power absorbed by each element



Element ◘ : flip current direction:



$$= 3V(-3\,mA) = -9\,mW$$

Element ◆ :

Element ✖ :

Element ✚ :