EECE251

Circuit Analysis I

Set 1: Basic Concepts and Resistive Circuits

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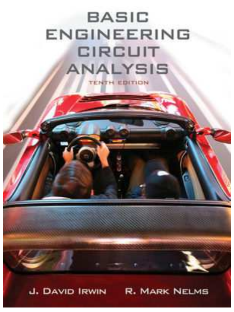
Course Material

- Lecture notes (http://www.ece.ubc.ca/~shahriar/eece251.html)
- Textbook:
  Basic Engineering Circuit Analysis, 10th edition
  by J. David Irwin and R. Mark Nelms,
  John Wiley & Sons, 2011.



- Must purchase WileyPlus edition:
- Binder Ready version from UBC Bookstore includes access to electronic version online.
- Link to our section on WileyPlus:
  http://edugen.wileyplus.com/edugen/class/cls295775/
- Another good reference:
  - Fundamentals of Electric Circuits, 4th Edition
    by Charles Alexander and Matthew Sadiku, McGraw Hill, 2009

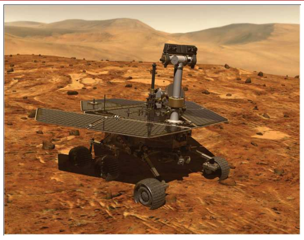
Evaluation

- Assignments 10%
- Midterms 40%
- Final Exam 50%

Motivation

Electrical circuits seem to be everywhere!




Overview

In this slide set we will review basic concepts, electrical quantities and their units, circuit elements, and basic circuit laws.

Reading Material: Chapters 1 and 2 of the textbook.

Note: Some of the figures in this slide set are taken from the books (R. Decarlo and P.-M. Lin, *Linear Circuit Analysis*, Second Edition, 2001, Oxford University Press) and (C.K. Alexander and M.N.O Sadiku, *Fundamentals of Electric Circuits*, Second Edition, 2004, McGraw Hill)

What is an Electric Circuit?

- In electrical engineering, we are usually interested in transferring energy or communicating signals from one point to another.

  To do this, we often require an interconnection of electrical components.

  "An electric circuit is an interconnection of electrical components."

- Typical circuit or electrical components that we will see in this year:

  batteries or voltage sources, current sources, resistors, switches, capacitors, inductors, diodes, transistors, operational amplifiers, …

What is an Electric Circuit?

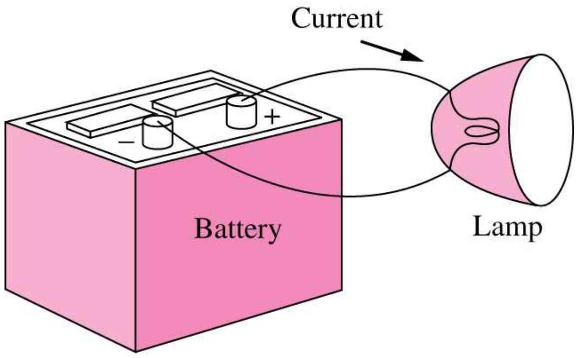
- According to Merriam-Webster Dictionary:
  "The complete path of an electric current including usually the source of electric energy."

- According to Encyclopedia Britannica:

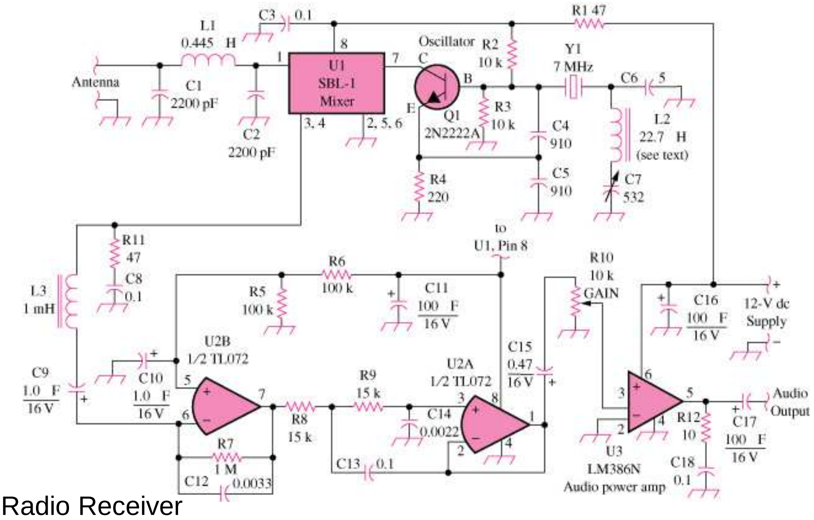
  "Path that transmits electric current."

  "A circuit includes a battery or a generator that gives energy to the charged particles; devices that use current, such as lamps, motors, or electronic computers; and connecting wires or transmission lines. Circuits can be classified according to the type of current they carry (see alternating current, direct current) or according to whether the current remains whole (series) or divides to flow through several branches simultaneously (parallel). Two basic laws that describe the performance of electric circuits are Ohm's law and Kirchhoff's circuit rules."

A Simple Circuit



A More Complicated Circuit



A Radio Receiver

System of Units

The International System of Units, or Système International des Unités (**SI)**, also known as **metric** system uses 7 mutually independent base units. All other units are *derived* units.

Base quantity	SI base unit Name	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

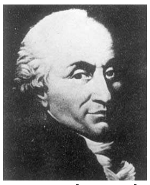
SI Base Units

SI Prefixes

Factor	Name	Symbol	Factor	Name	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deka	da	10^{-24}	yocto	y

Review of Basic Circuit Concepts

- Electric Charge is the basis for describing all electrical phenomena .
- **Charge** is an electrical property of the atomic particles of which matter consists and is measured in coulombs (Charles Augustin de Coulomb (1736-1806) a French Scientist)



- Inside an atom, there is negative charge on electrons, positive charge on protons and no charge on neutrons.
- The charge of an electron is equal to that of an proton and is: $e = 1.602 \times 10^{-19}$ C

Charge

- Note that in 1C of charge there are:
  $1/ 1.602 \times 10^{-19} = 6.24 \times 10^{18}$ electrons

- Laboratory values of charges are more likely to be a fraction of a Coulumb (e.g., pC, nC, μC, or mC).

- *Law of conservation of charge*: charge can neither be created nor destroyed, only transferred. (This is a law in classical physics and may not be true in some odd cases!. We are not dealing with those cases anyway.)

- Electrical effects are attributed to both separation of charges and/or charges in motion!

A Material Classification

- **Conductor:** a material in which charges can move to neighboring atoms with relative ease.
  - One measure of this relative ease of charge movement is the electric resistance of the material
  - Example conductor material: metals and carbon
  - In metals the only charged particles that can move are electrons
- **Insulator:** a material that opposes the charge movement (ideally infinite opposition, i.e., no charge movement)
  - Example insulators: Dry air and glass
- **Semi-conductor:** a material whose conductive properties are somewhat in between those of conductor and insulator
  - Example semi-conductor material: Silicon with some added impurities

Electric Current (Charges in Motion!)

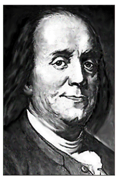
- **Current:** net flow of charge across any cross section of a conductor, measured in Amperes (Andre-Marie Ampere (1775-1836), a French mathematician and physicist)

- Current can be thought of as the rate of change of charge:

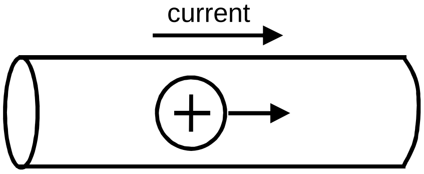
$$i = \frac{dq}{dt}$$

Electric Current

- Originally scientists (in particular Benjamin Franklin (1706-1790) an American scientist and inventor) thought that current is only due to the movement of positive charges.

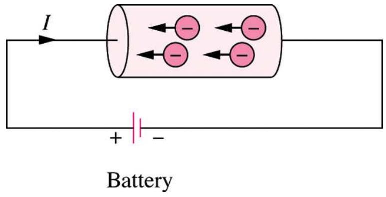


- Thus the direction of the current was considered the direction of movement of positive charges.

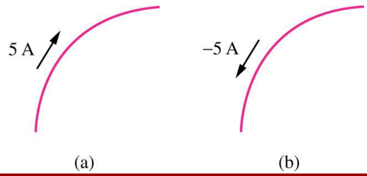


Electric Current

- In reality in metallic conductors current is due to the movement of **electrons**, however, we follow the universally accepted convention that current is in the direction of positive charge movement.

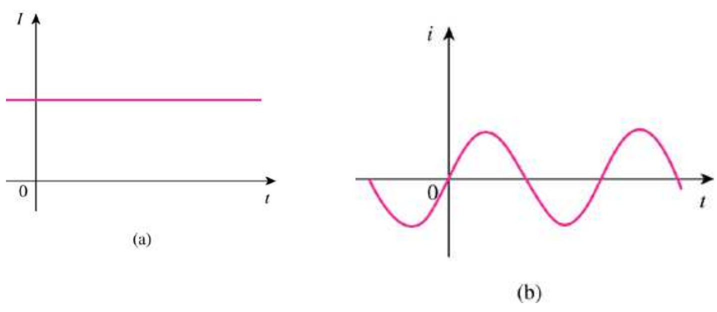


- Two ways of showing the same current:

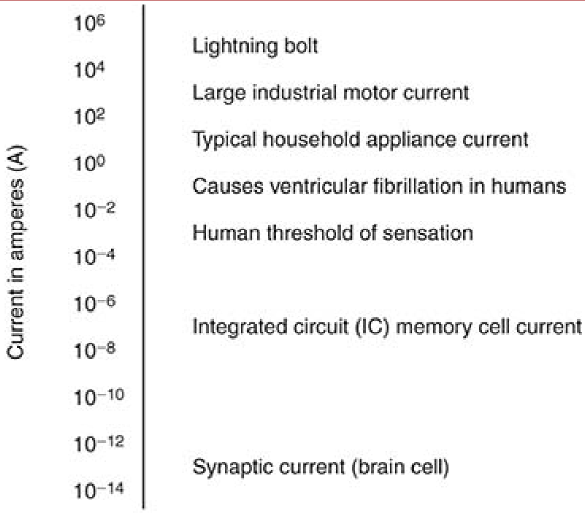


Two Important Types of Current

- Direct current (DC) is a current that remains constant with time.
- Alternating current (AC) is a current that varies sinusoidally with time.



Magnitude of Some Typical Currents



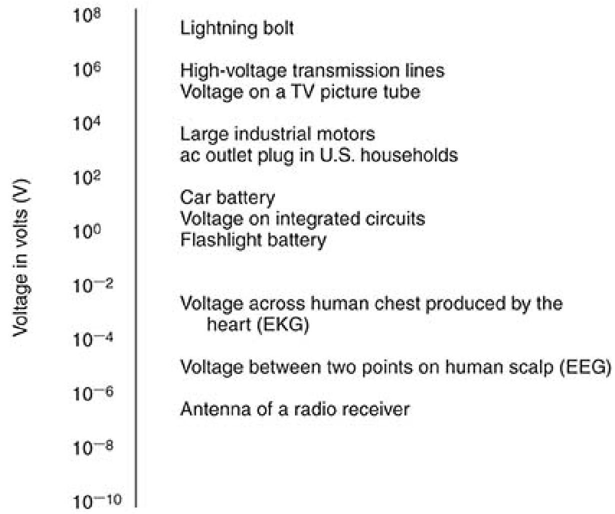
Voltage (Separation of Charge)

- **Voltage** (electromotive force, or potential) is the energy required to move a unit charge through a circuit element, and is measured in Volts (Alessandro Antonio Volta (1745-1827) an Italian Physicist).

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

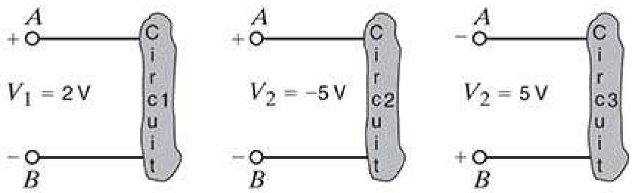
- Similar to electric current, there are two important types of voltage: DC and AC

Typical Voltage Magnitudes



Voltage

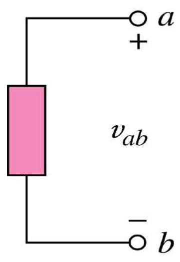
- "*Voltage* between two points in a circuit is the difference in energy level of a unit charge located at each of the two points.
- Voltage is very similar to a gravitational force.
- Some examples:



(a) (b) (c)

Voltage Polarity

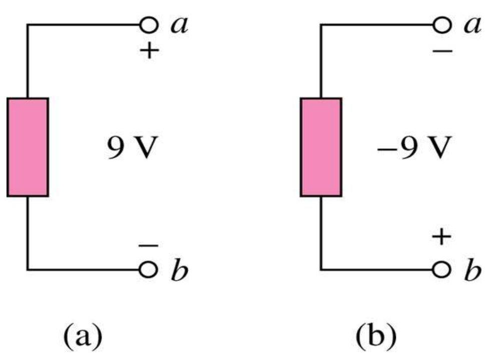
- The plus (+) and minus (-) sign are used to define voltage polarity.
- The assumption is that the potential of the terminal with (+) polarity is higher than the potential of the terminal with (-) polarity by the amount of voltage drop.



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

Voltage Polarity

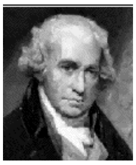
- Figures (a) and (b) are two equivalent representation of the same voltage:



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

Power

- The rate of change of (expending or absorbing) energy per unit time, measured in Watts (James Watt (1736-1819) a Scottish inventor and mechanical engineer)



$$p = \frac{dW}{dt} = \frac{dW}{dq} \times \frac{dq}{dt} = vi$$

A Classification of Circuit Components

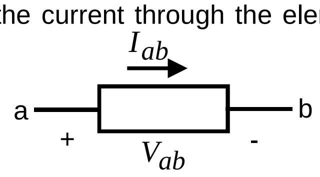
- One common classification for circuit components is to group them in two major groups:

1) Passive components or passive elements
   Components or elements that absorb power.

2) Active components or active elements
   Components that are not passive! that is, components that deliver power.

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.

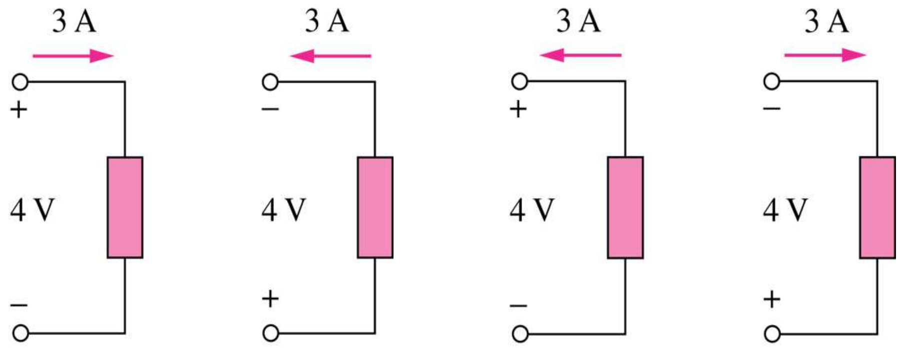
Tellegan's Theorem

- **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 **(ΣP=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.

Passive Sign Convention

- Calculate the power absorbed or supplied by each of the following elements:

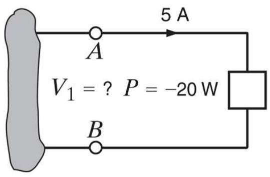


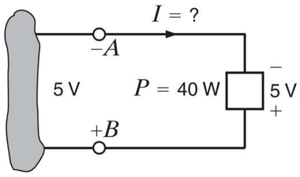
Example

- Given the two diagrams shown below, determine whether the element is absorbing or supplying power and how much.

Example

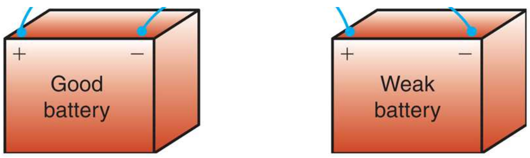
- Determine the unknown voltage or current in the following figures:





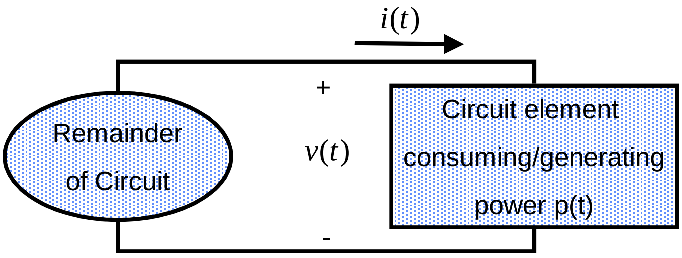
Example

- Suppose that your car is not starting. To determine whether the battery is faulty, you turn on the light switch and find that the lights are very dim, indicating a weak battery. You borrow a friend's car and a set of jumper cables. However, how do you connect his car's battery to yours? What do you want his battery to do?



Energy Calculation

- Instantaneous power: $p(t) = v(t)i(t)$



- Energy absorbed or supplied by an element from time t_0 to time $t>t_0$

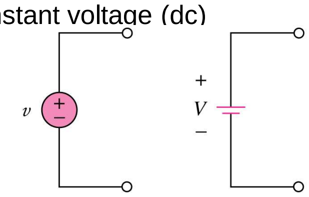
$$W = W(t_0,t) = \int_{t_0}^{t} p(\tau)d\tau = \int_{t_0}^{t} v(\tau)i(\tau)d\tau$$

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

(Ideal) Voltage and Current Sources

- Independent sources: An (ideal) independent source is an active element that provides a specified voltage or current that is independent of other circuit elements and/or how the source is used in the circuit.
- Symbol for independent voltage source
  (a) Used for constant or time-varying voltage
  (b) Used for constant voltage (dc)

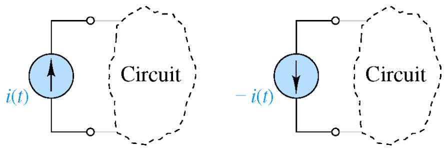


(a) (b)

Question: Plot the v-i characteristic of the above dc source.

Ideal Voltage and Current Sources

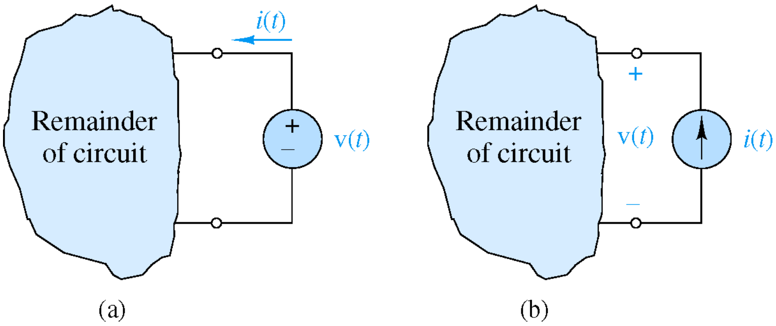
- Equivalent representation of ideal independent current sources whose current *i(t)* is maintained under all voltage requirements of the attached circuit:



(a) (b)

- What is the equivalent of the ideal voltage source shown on the previous slide (Figure (a))?

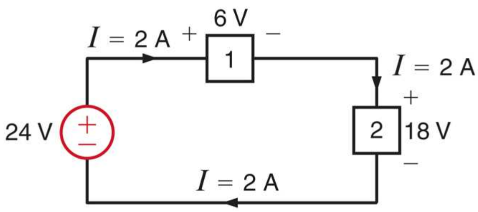
Common Voltage and Current Source Labeling



- Is this different from passive sign convention?
- Can we use the passive convention for sources

Example

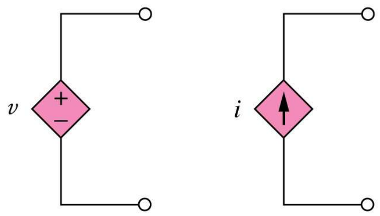
- Determine the power absorbed or supplied by the elements of the following network:



Ideal Dependent (Controlled) Source

- An ideal dependent (controlled) source is an active element whose quantity is controlled by a voltage or current of another circuit element.

- Dependent sources are usually presented by diamond-shaped symbols:

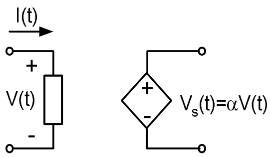


(a) (b)

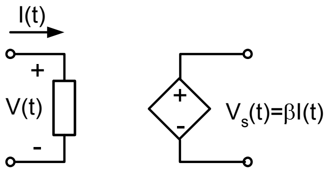
Dependent (Controlled) Source

- There are four types of dependent sources:

- Voltage-controlled voltage source (VCVS)

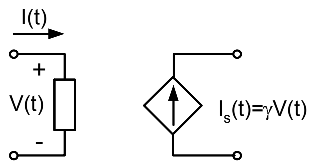


- Current-controlled voltage source (CCVS)

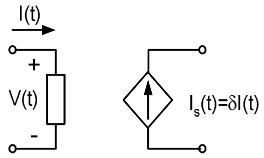


Dependent (Controlled) Source

- Voltage-controlled current source (VCCS)

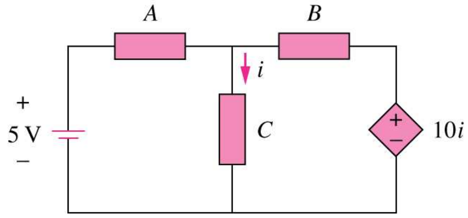


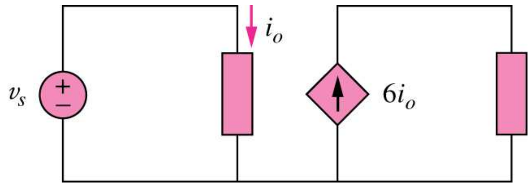
- Current-controlled current source (CCCS)



Example: Dependent Source

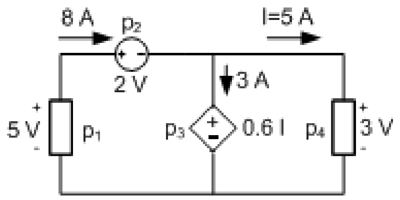
- In the following circuits, identify the type of dependent sources:





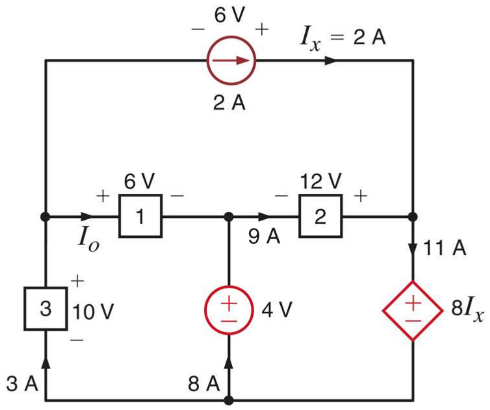
Example: Power Calculation

- Compute the power absorbed or supplied by each component in the following circuit.



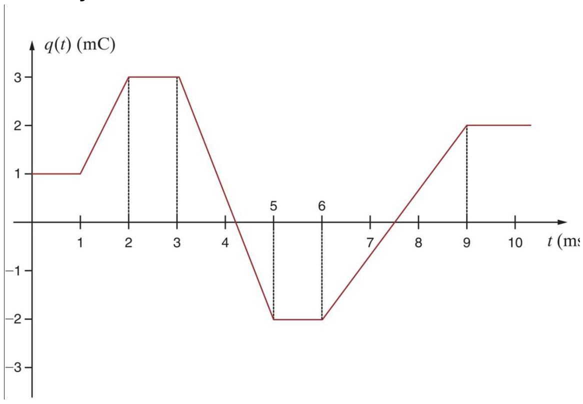
Example

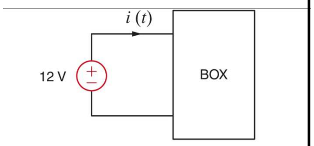
- Use Tellegan's theorem to find the current I_0 in the following circuit:



Example

- The charge that enters the BOX is shown below. Calculate and sketch the current flowing into the BOX and the power absorbed by the BOX between 0 and 10 milliseconds.





Notes

Example

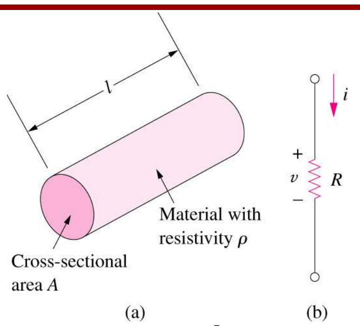
- A third-generation iPod® with a 630 mAh Lithium-ion battery is to be recharged from a high-power USB port supplying 150 mA of current. At the beginning of the recharge, 7.8 C of charge are stored in the battery. The recharging process halts when the stored charge reaches 35.9 C. How long does it take to recharge the battery?

Resistance

- Different material allow charges to move within them with different levels of ease. This physical property or ability to resist current is known as resistance.

- The resistance of any material with a uniform cross-sectional area A and length l is inversely proportional to A and directly proportional to l.

Resistance



$$R \propto \frac{l}{A}$$

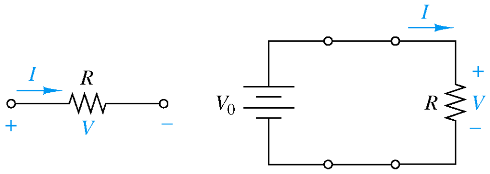
- The constant of the proportionality is the resistivity of the material, i.e., ρ

$$R = \rho \frac{l}{A}$$

Resistance

- In honor of George Simon Ohm (1787-1854), a German physicist, the unit of resistance is named Ohm (Ω).

- A conductor designed to have a specific resistance is called a resistor.



Ohm's Law

- The voltage v across a resistor is directly proportional to the current i flowing through the resistor. The proportionality constant is the resistance of the resistor, i.e., $v(t) = Ri(t)$

- One can also write:

$$i(t) = \frac{1}{R}v(t) \Rightarrow i(t) = Gv(t)$$

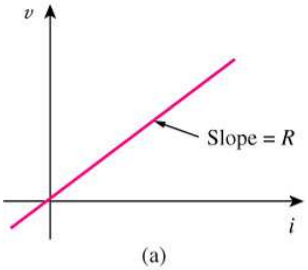
- Instantaneous power dissipated in a resistor

$$p(t) = v(t)i(t) = \frac{v^2(t)}{R} = Ri^2(t)$$

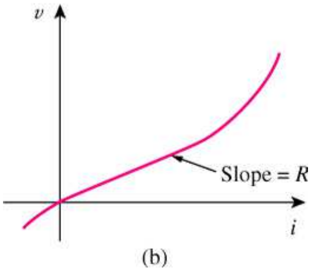
Linear and Nonlinear Resistors

- Linear resistor

Nonlinear resistor



(a)



(b)

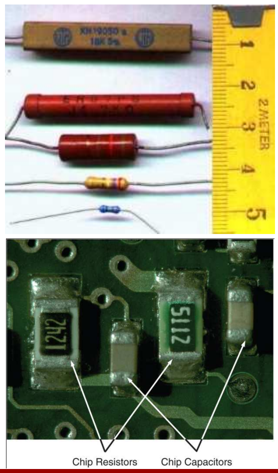
- In this course, we assume that all the elements that are designated as resistors are linear (unless mentioned otherwise)

Resistors (Fixed and Variable)

- Fixed resistors have a resistance that remains constants.
- Two common type of fixed resistors are:
  (a) wirewound
  (b) composition (carbon film type)

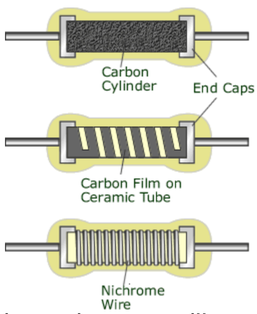
(a)

(b)



Fixed Resistors

- Inside the resistor

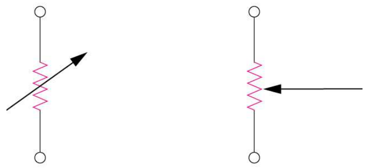


- A common type of resistor that you will work with in your labs:
- It has 4 color-coded bands (3 for value and one for tolerance)
  - How to read the value of the resistor?

Variable Resistors

- Variable resistors have adjustable resistance and are typically called potentiometer (or pot for short).

- Potentiometers have three terminals one of which is a sliding contact or wiper.



(a) (b)

Conductance

- G=1/R is called the conductance of the element and is measured in siemens (S) or mho (℧) .

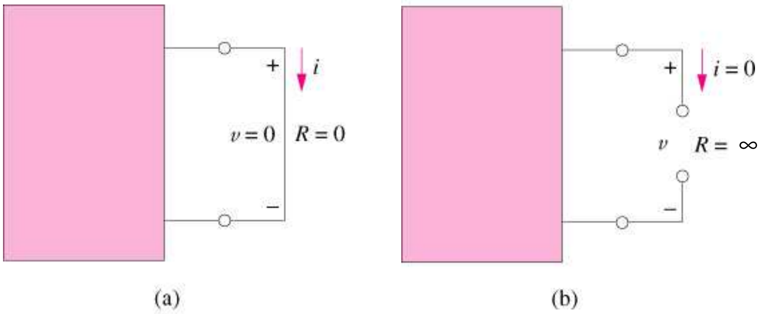
German inventor
Ernst Werner von Siemens
(1816-1892)

- Conductance is the ability of an element to conduct current..

- A device with zero (no) resistance has infinite conductance and a device with infinite resistance has zero conductance.

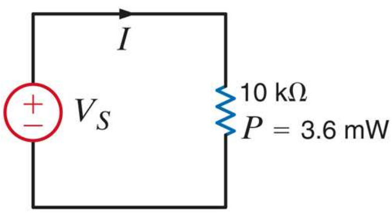
Short and Open Circuits

- A device with zero resistance is called short circuit and a device with zero conductance (i.e., infinite resistance) is called open-circuit.



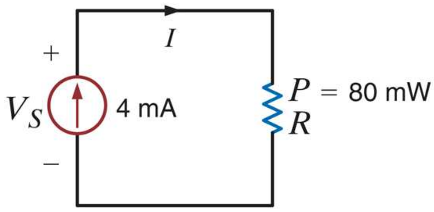
Example

- The power absorbed by the 10-kΩ resistor in the following circuit is 3.6 mW. Determine the voltage and the current in the circuit.



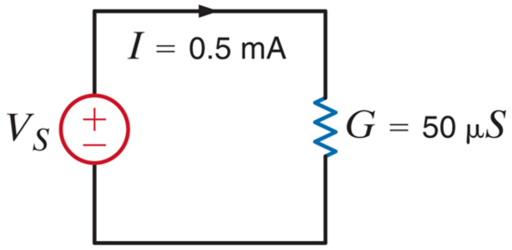
Example

- Given the following network, find R and V_S.



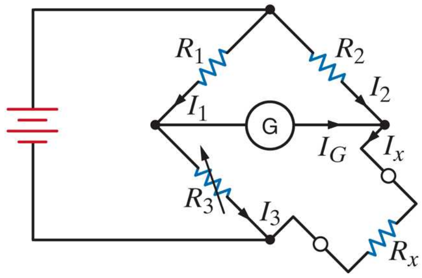
Example

- Given the following circuit, find the value of the voltage source and the power absorbed by the resistance.



Wheatstone Bridge

- A Wheatstone Bridge circuit is an accurate device for measuring resistance. The circuit, shown below, is used to measure the unknown resistor R_x. The center leg of the circuit contains a galvanometer (a very sensitive device used to measure current). When the unknown resistor is connected to the bridge, R_3 is adjusted until the current in the galvanometer is zero, at which point the bridge is balanced.



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Wheatstone Bridge

- In the balanced condition:

$$\frac{R_1}{R_3} = \frac{R_2}{R_x}$$

That is:

$$R_x = \left(\frac{R_2}{R_1}\right) R_3$$

- Invented by Samuel Hunter Christie (1784–1865), a British scientist and mathematician.

- Improved and popularized by Sir Charles Wheatstone FRS (1802–1875), an English scientist and inventor

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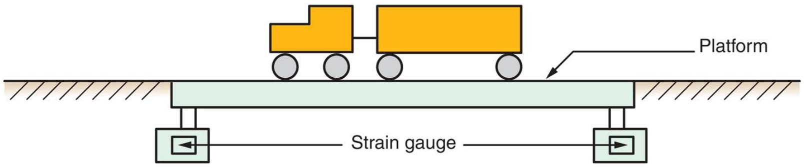
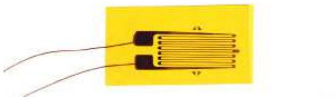
Wheatstone Bridge

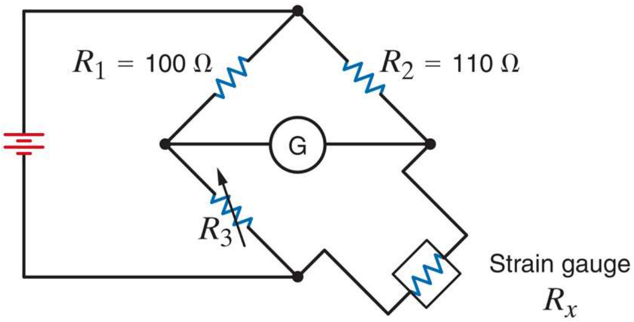
- Engineers use the Wheatstone bridge circuit to measure strain in solid material. For example, in a system used to determine the weight of a truck (shown below). The platform is supported by cylinders on which strain gauges are mounted. The strain gauges, which measure strain when the cylinder deflects under load, are connected to a Wheatstone bridge.





Wheatstone Bridge

- Typically, the strain gauge has a resistance of 120Ω under no-load conditions and changes value under load. The variable resistor in the bridge is a calibrated precision device.

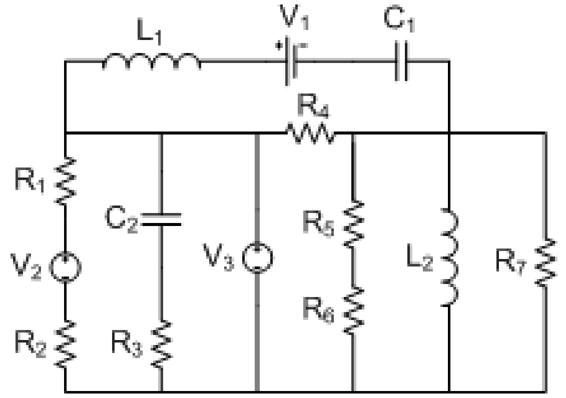


Terminology (Nodes and Branches)

- **Note:** our definition of nodes (and branches) is slightly different from traditional definitions used in the textbooks!
- Please note that almost all components that we deal with in this course are two-terminal components (resistors, sources, …)
- A "**true node**" (or node for short) is the point of connection of three or more circuit elements. (The node includes the interconnection wires.)
- A "**binary node**" (or b-node for short) has only two components connected to it.

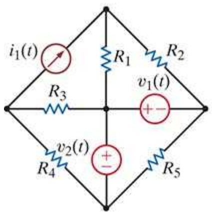
Example

- In the following circuit identify the nodes (and their types).

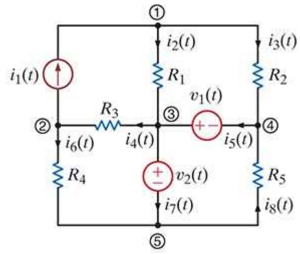


Example

- Are the following two circuits different? Identify the nodes (and their types) in each circuit.



(a)

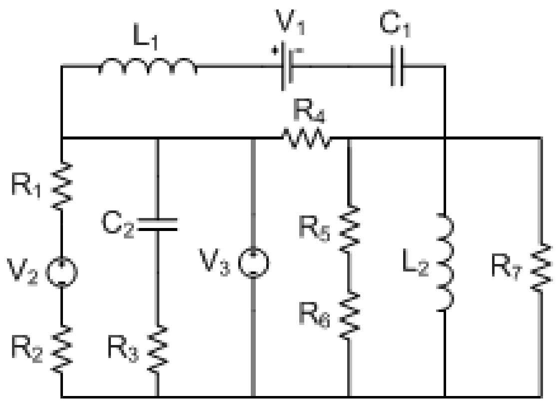


(b)

Branch

- A branch is a collection of elements that are connected between two "**true nodes**" that includes only those two true nodes (and does not include any other true nodes).

- In our example:

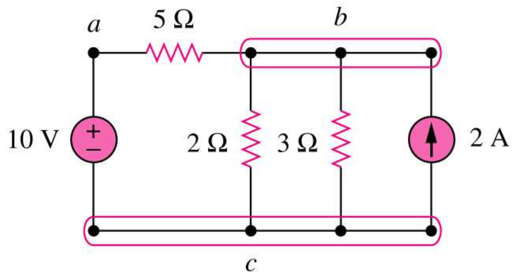


Loop

- A "**loop**" is any closed path in the circuit that does not cross any true node but once.
- A "**window pane loop**" is a loop that does not contain any other loops inside it.
- An **"independent loop"** is a loop that contains at least one branch that is not part of any other independent loop.

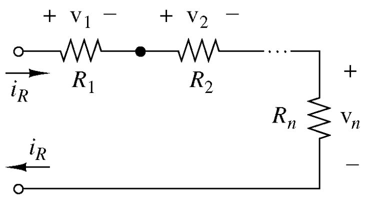
Example

- In the following circuit, find the number of branches, nodes, and window pane loops. Are the window pane loops independent?



Series and Parallel Connections

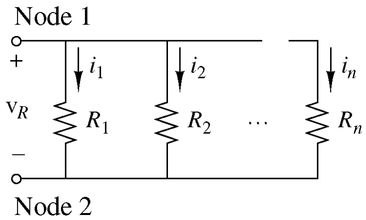
- Two or more elements are connected "**in series**" when they belong to the same branch.(even if they are separated by other elements).
- In general, circuit elements are in series when they are sequentially connected end-to-end and only share binary nodes among them.
- Elements that are in series carry the same current.



Series and Parallel Circuits

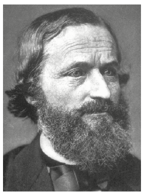
- Two or more circuit elements are "**in parallel**" if they are connected between the same two "true nodes".

- Consequently, parallel elements have the same voltage



Kirchhoff's Current Law (KCL)

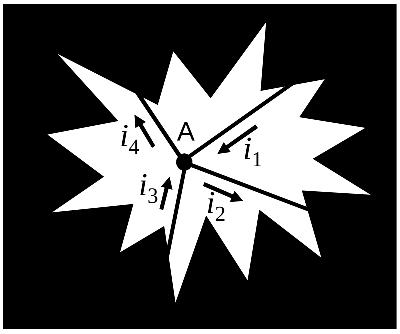
- Gustav Robert Kirchhoff (1824-1887), a German physicist, stated two basic laws concerning the relationship between the currents and voltages in an electrical circuit.



- **KCL:** The algebraic sum of the currents entering a node (or a **closed boundary**) is zero.
- The current entering a node may be regarded as positive while the currents leaving the node may be taken as negative or vice versa.

KCL

- KCL is based on the law of conservation of charge.
- Example: Write the KCL for the node A inside this black box circuit:



Black box circuit

KCL

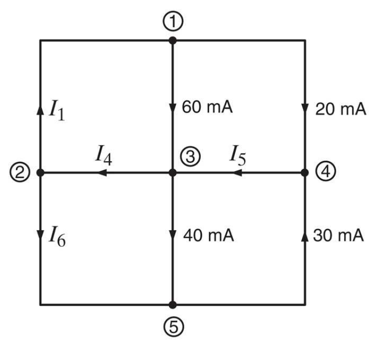
- **Alternative statement of KCL:** For lumped circuits, the algebraic sum of the currents <u>leaving</u> a node (or a closed boundary) is zero.

- Can you think of another statement for KCL?
  The sum of the currents entering a node is equal to the sum of the currents leaving that node.

$$\Sigma i_{in} = \Sigma i_{out}$$

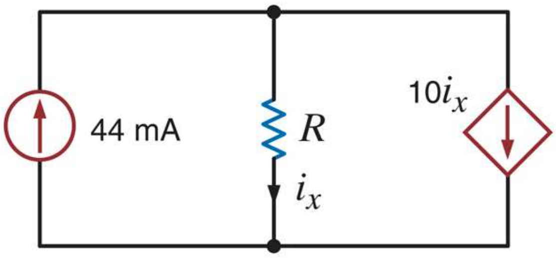
Example

- The following network is represented by its topological diagram. Find the unknown currents in the network.



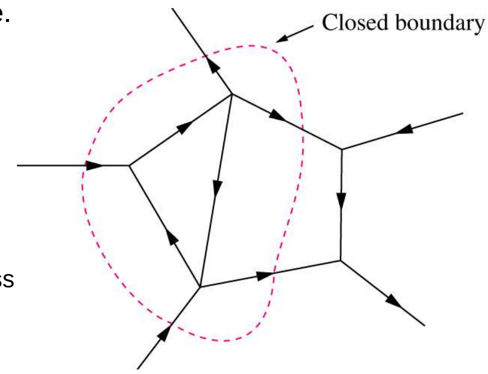
Example

- In the following circuit, find i_x.



Closed Boundary

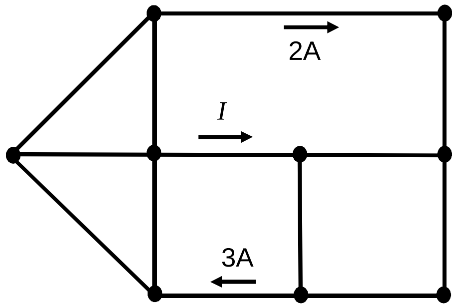
- A closed boundary is a closed curve (or surface), such as a circle in a plane (or a sphere in three dimensional space) that has a well-defined inside and outside.
- This closed boundary is sometimes called supernode or more formally a Gauss surface.



- Johann Carl Friedrich Gauss (1777-1855) German mathematician

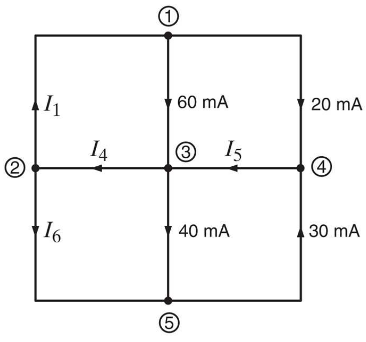
KCL Example

- Draw an appropriate closed boundary to find I in the following graphical circuit representation.



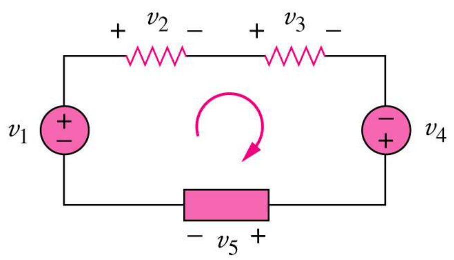
Example

- In the following circuit, use a closed surface to find I_4.



Kirchhoff's Voltage Law (KVL)

- **KVL**: The algebraic sum of the voltage drops around any closed path (or loop) is zero at any instance of time.

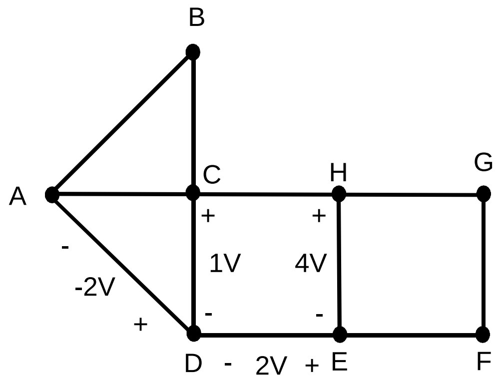


- Write KVL for the above circuit.

Sum of voltage drops=Sum of voltage rises

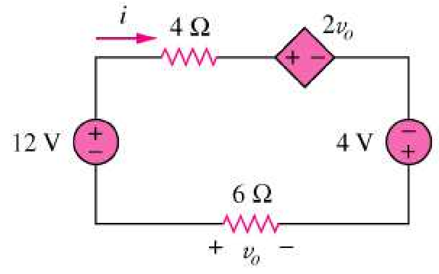
KVL Example

- Find V_{AC} and V_{CH} in the following circuit.



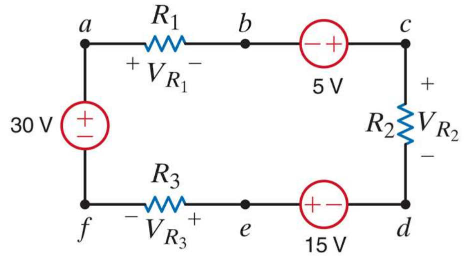
Example

- In the following circuit, find v_o and i.



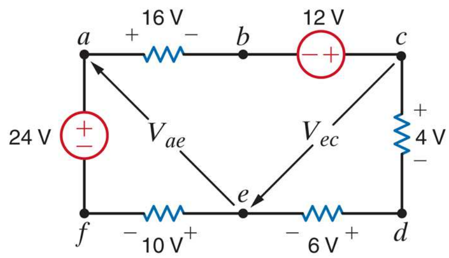
Example

- In the following circuit, assume V_{R1}=26V and V_{R2}=14V. Find V_{R3}.



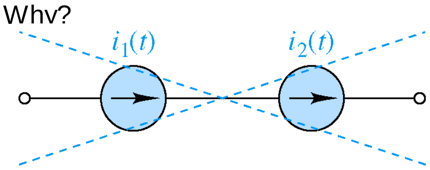
Example

- In the following circuit use KVL to determine V_{ae} and V_{ec}. Note that we use the convention V_{ae} to indicate the voltage of point a with respect to point *e* or $V_{ae}=V_a-V_e$

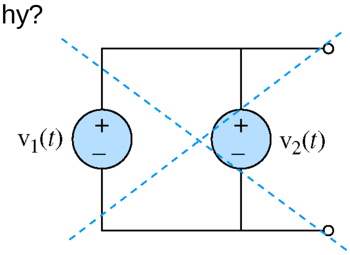


Some Interesting Implications of KCL and KVL

- A series connection of two different current sources is impossible. Why?

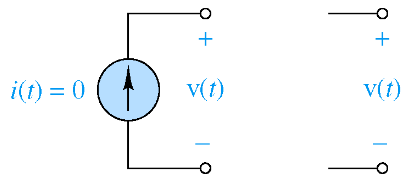


- A parallel connection of two different voltage sources is impossible. Why?

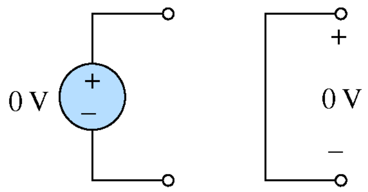


More Interesting Implicationsz

- A current source supplying zero current is equivalent to an open circuit:

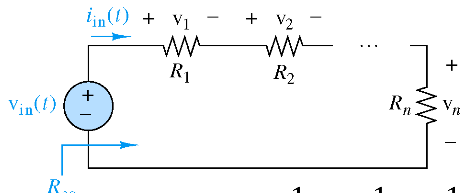


- A voltage source supplying 0V is equivalent to a short circuit:



Series Resistors

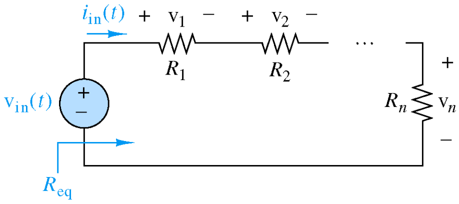
- The equivalent resistance of any number of resistors connected in series is the sum of the resistors (Why?)



$$R_{eq} = R_1 + R_2 + \cdots + R_n \quad \text{or} \quad \frac{1}{G_{eq}} = \frac{1}{G_1} + \frac{1}{G_2} + \cdots + \frac{1}{G_n}$$

Voltage Division

- In a series combination of n resistors, the voltage drop across the resistor R_j for $j=1,2, \ldots, n$ is:

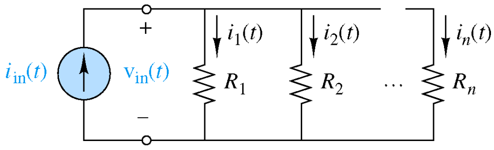


$$v_j(t) = \frac{R_j}{R_1 + R_2 + \cdots + R_n} v_{in}(t)$$

- What is the formula for two series resistors?!

Parallel Resistors

- The equivalent conductance of resistors connected in parallel is the sum of their individual conductances:

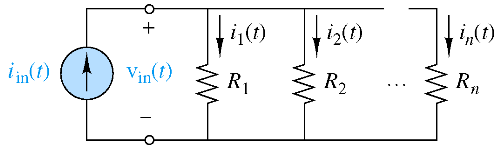


$$G_{eq} = G_1 + G_2 + \cdots + G_n \quad \text{or} \quad \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$

- Why?

Current Division

- In a parallel combination of n resistors, the current through the resistor R_j for $j=1,2, \ldots, n$ is:

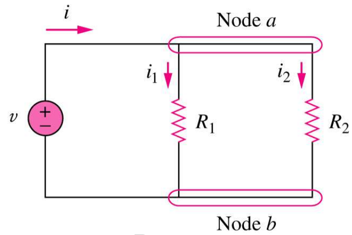


$$i_j(t) = \frac{G_j}{G_1 + G_2 + \cdots + G_n} i_{in}(t)$$

- Why?

Parallel Resistors and Current Division Example

- For the special case of two parallel resistors

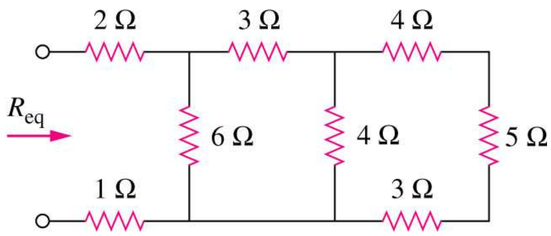


$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}, \quad i_1(t) = \frac{R_2}{R_1 + R_2} i(t), \text{ and } i_2(t) = \frac{R_1}{R_1 + R_2} i(t)$$

- Why?

Example

- In the following circuit find R_{eq}:



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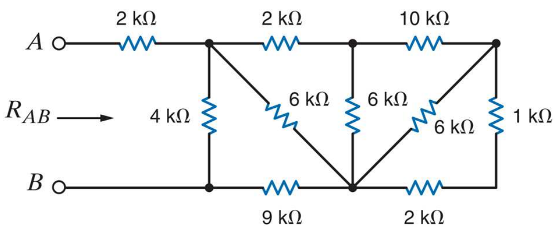
Example

- In the following circuit find the resistance seen between the two terminal s A and B, i.e., R_{AB}
-



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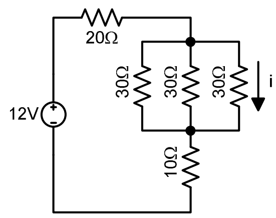
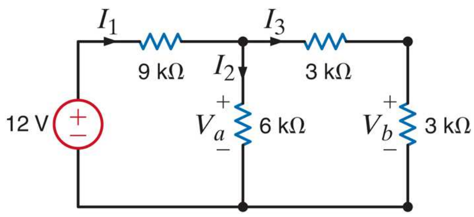
Example

- In the following circuit find the current i.



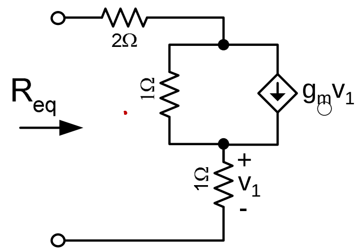
Example

- In the following circuit find I_1, I_2, I_3, V_a, and V_b.



Tricky Example!

- In the following circuit, find the equivalent resistance R_{eq}. Assume g_m=0.5S.



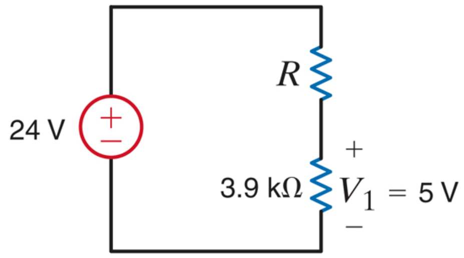
Standard Resistor Values for 5% and 10% Tolerances

TABLE 2.1 Standard resistor values for 5% and 10% tolerances (values available with a 10% tolerance shown in boldface)

1.0	**10**	**100**	**1.0k**	**10k**	**100k**	**1.0M**	**10M**
1.1	11	110	1.1k	11k	110k	1.1M	11M
1.2	**12**	**120**	**1.2k**	**12k**	**120k**	**1.2M**	**12M**
1.3	13	130	1.3k	13k	130k	1.3M	13M
1.5	**15**	**150**	**1.5k**	**15k**	**150k**	**1.5M**	**15M**
1.6	16	160	1.6k	16k	160k	1.6M	16M
1.8	**18**	**180**	**1.8k**	**18k**	**180k**	**1.8M**	**18M**
2.0	20	200	2.0k	20k	200k	2.0M	20M
2.2	**22**	**220**	**2.2k**	**22k**	**220k**	**2.2M**	**22M**
2.4	24	240	2.4k	24k	240k	2.4M	
2.7	**27**	**270**	**2.7k**	**27k**	**270k**	**2.7M**	
3.0	30	300	3.0k	30k	300k	3.0M	
3.3	**33**	**330**	**3.3k**	**33k**	**330k**	**3.3M**	
3.6	36	360	3.6k	36k	360k	3.6M	
3.9	**39**	**390**	**3.9k**	**39k**	**390k**	**3.9M**	
4.3	43	430	4.3k	43k	430k	4.3M	
4.7	**47**	**470**	**4.7k**	**47k**	**470k**	**4.7M**	
5.1	51	510	5.1k	51k	510k	5.1M	
5.6	**56**	**560**	**5.6k**	**56k**	**560k**	**5.6M**	
6.2	62	620	6.2k	62k	620k	6.2M	
6.8	**68**	**680**	**6.8k**	**68k**	**680k**	**6.8M**	
7.5	75	750	7.5k	75k	750k	7.5M	
8.2	**82**	**820**	**8.2k**	**82k**	**820k**	**8.2M**	
9.1	91	910	9.1k	91k	910k	9.1M	

Example

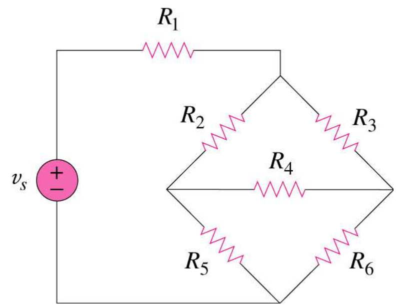
- Given the network shown in Fig. 2.31: (a) find the required value for the resistor R; (b) use Table 2.1 to select a standard 10% tolerance resistor for R; (c) using the resistor selected in (b), determine the voltage across the 3.9-kΩ resistor; (d) calculate the percent error in the voltage V1, if the standard resistor selected in (b) is used; and (e) determine the power rating for this standard component.



Board Notes

Wye-Delta Transformations

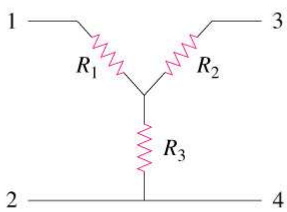
- In some circuits the resistors are neither in series nor in parallel.
- For example consider the following bridge circuit:



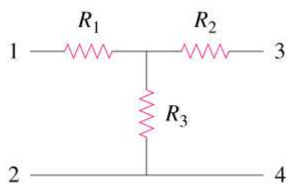
how can we combine the resistors R_1 through R_6?

Wye and Delta Networks

- A useful technique that can be used to simply many such circuits is transformation from wye (Y) to delta (Δ) network.
- A wye (Y) or tee (T) network is a three-terminal network with the following general form:



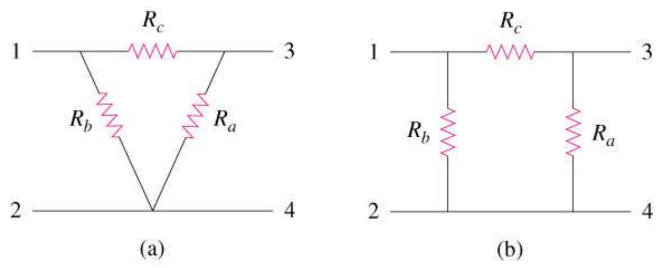
(a)



(b)

Wye and Delta Networks

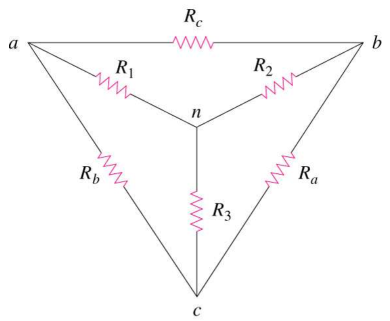
- The delta (Δ) or pi (Π) network has the following general form:



Delta-Wye Conversion

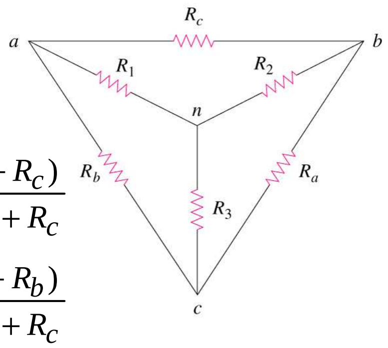
- In some cases it is more convenient to work with a Y network in place of a Δ network.

- Let's superimpose a wye network on the existing delta network and try to find the equivalent resistances in the wye network



Delta-Wye Conversion

- We calculate the equivalent resistance between terminals a and c while terminal b is open in both cases:



$$R_{ac}(Y) = R_1 + R_3$$

$$R_{ac}(\Delta) = R_b \| (R_a + R_c)$$

$$R_{ac}(Y) = R_{ac}(\Delta) \Rightarrow R_1 + R_3 = \frac{R_b(R_a + R_c)}{R_a + R_b + R_c}$$

Similarly:

$$R_1 + R_2 = \frac{R_c(R_a + R_b)}{R_a + R_b + R_c}$$

$$R_2 + R_3 = \frac{R_a(R_b + R_c)}{R_a + R_b + R_c}$$

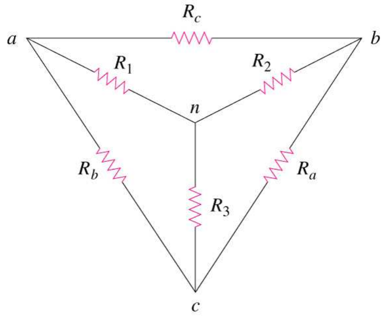
Delta-Wye Conversion

- Solving for R_1, R_2, and R_3 we have:

$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c}$$

$$R_2 = \frac{R_c R_a}{R_a + R_b + R_c}$$

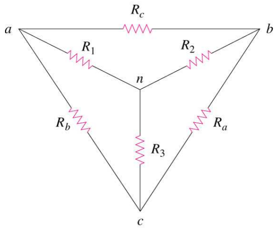
$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c}$$



- Each resistor in the Y network is the product if the resistors in the two adjacent Δ branches, divided by the sum of the three Δ resistors.

Wye-Delta Conversion

- From the previous page equations, we have:



$$R_1R_2 + R_2R_3 + R_3R_1 = \frac{R_aR_bR_c(R_a + R_b + R_c)}{(R_a + R_b + R_c)^2} = \frac{R_aR_bR_c}{R_a + R_b + R_c}$$

- Dividing this equation by each of the previous slide equations:

$$R_a = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_1},\ R_b = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_2},\ \text{and } R_c = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_3}$$

- Each resistor in the Δ network is the sum of all the possible products of Y resistors taken two at a time, divided by the opposite Y resistor

Wye-Delta Transformations

- Y and Δ networks are said to be balanced when:

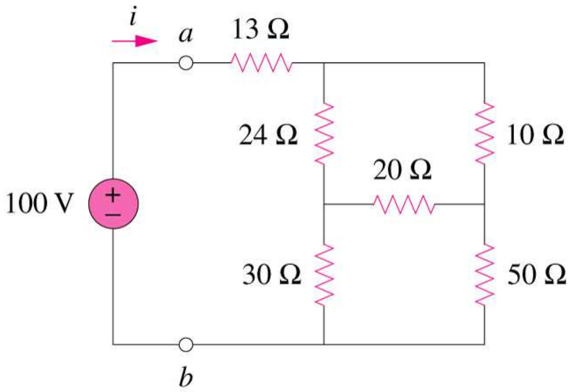
$$R_1 = R_2 = R_3 = R_Y \text{ and } R_a = R_b = R_c = R_\Delta$$

- For balanced Y and Δ networks the conversion formulas become:

$$R_Y = \frac{R_\Delta}{3} \text{ and } R_\Delta = 3R_Y$$

Example

- For the following bridge network find R_{ab} and i.



Example

- Find I_S?