# Circuits I

## Lecture 1_2: Introduction and Basics

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**Modified from Dr. Mohamed Fathy Slides**

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# Course Information

- Textbook reference:
  - J. W. Nilsson and S. A. Riedel, Electric
  - C. Alexander and M. Sadiku, Fundamental of Electric Circuits, Mc Graw Hill

# Course Importance

- Many branches of electrical engineering, such as power, electric machines, control, electronics, communications, and instrumentation, are based on electric circuit theory.

- The basic electric circuit theory course is the most important course for an electrical engineering student.

- It is an excellent starting point for a beginning student in electrical engineering education.

# Basic Definitions and Laws

# Introduction

- In electrical engineering, we are often interested in transferring energy from one point to another.

- This requires an interconnection of electrical devices.

- Such interconnection is referred to as an *electric circuit*, and each component of the circuit is known as a circuit *element*.

# Basic Quantities

| Quantity | Symbol | SI units |
|---|---|---|
| Charge | Q | Coulombs (C) |
| Time | t | Seconds (s) |
| Work | W | Joules (J) |
| **Current** | I | Ampare (A) |
| **Voltage** | V | Volt (V) |
| **Power** | P | Watts (w) |

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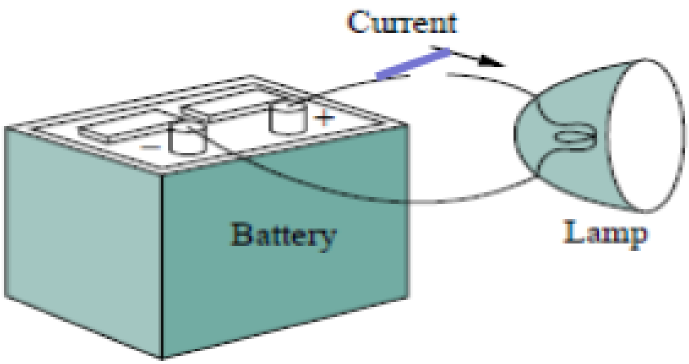
# Introduction

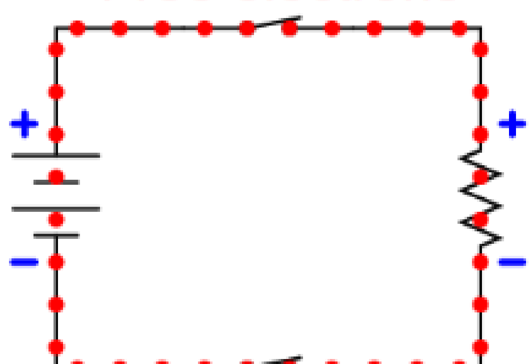


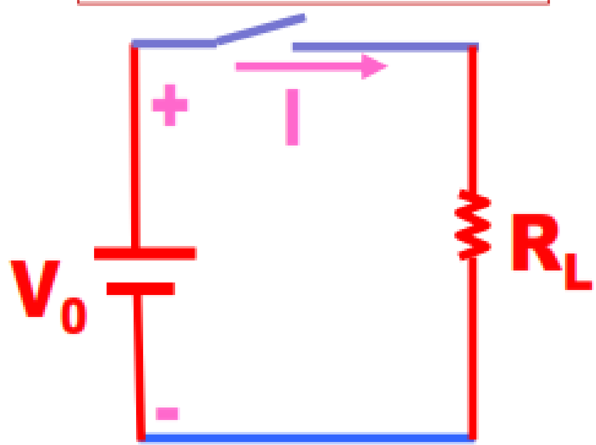

Three basic components: a battery, a lamp, switch and connecting wires.

Flash light circuit.

Voltage, Current, & power.

*Direction of electron motion*

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# Current

- Electric current results from the movement of electric charge.
- Electric Current is the time rate of change of charge measured in amperes A)

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

- I (Ampere) = $\dfrac{\text{Charrge (Q) in Coulmbs}}{\text{time (t) in seconds}}$
- For most electronic circuits the ampere is a rather large unit so the mA unit is more common.

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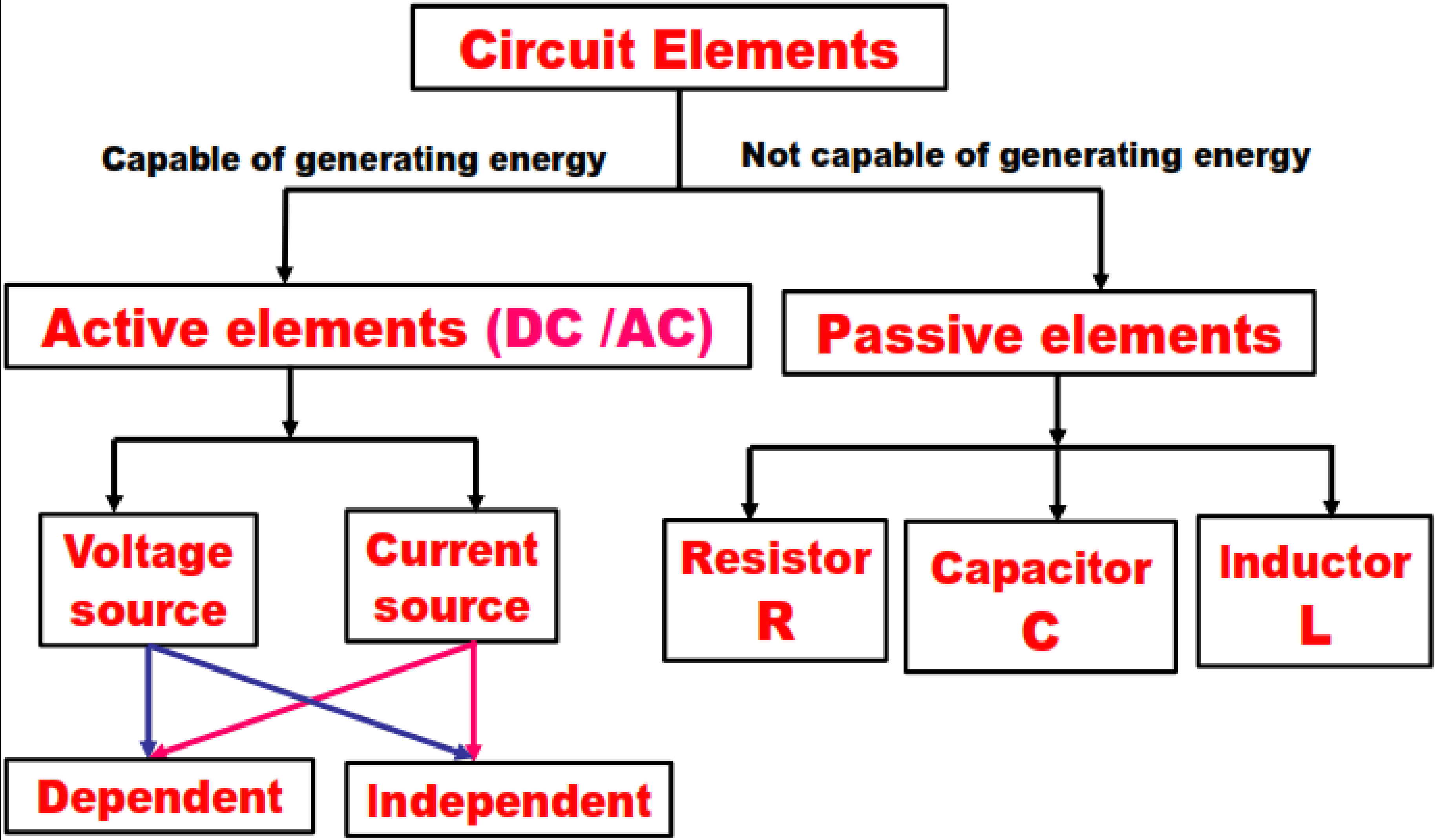
# DC & AC Circuits

## 1- Direct Current Circuits

**Currents (I) and voltages (V) are constant with time.**

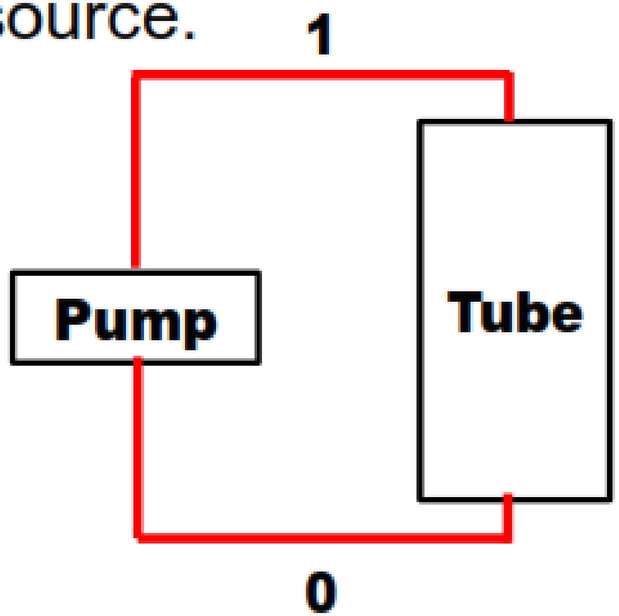
## 2- Alternating Current (AC) Circuits

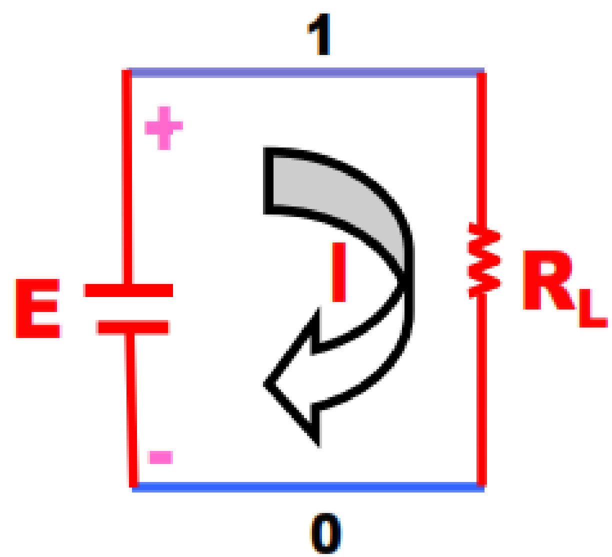
**Current (i) and voltage (v) are time varying**


Circuit Elements
Capable of generating energy
Not capable of generating energy
Active elements (DC /AC)
Passive elements
Voltage source
Current source
Resistor R
Capacitor C
Inductor L
Dependent
Independent

# DC Circuit

- Any combination of ***DC Active*** elements and ***passive*** elements (usually resistors).
- An active elements is either a voltage or a current source.



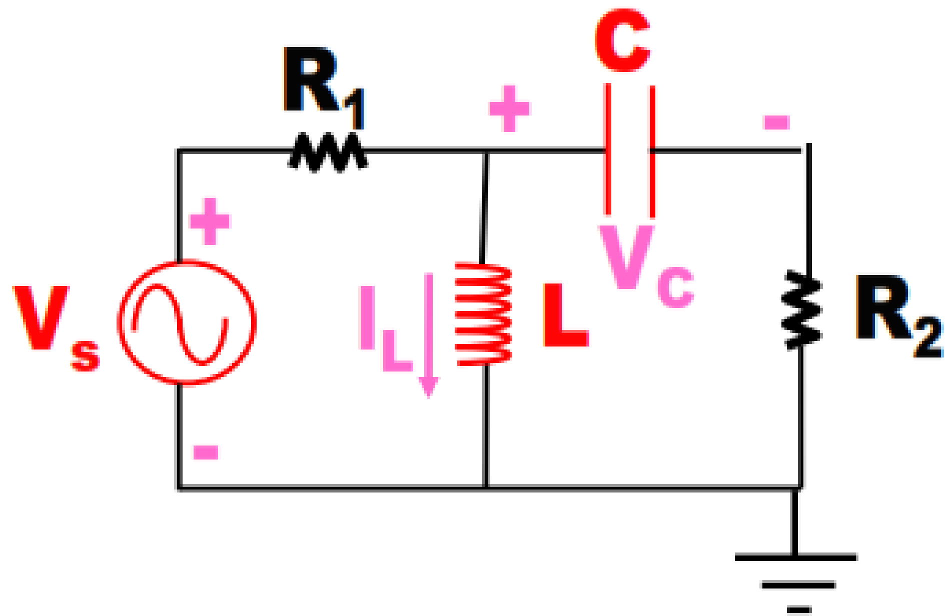

<u>Conservation of energy</u>

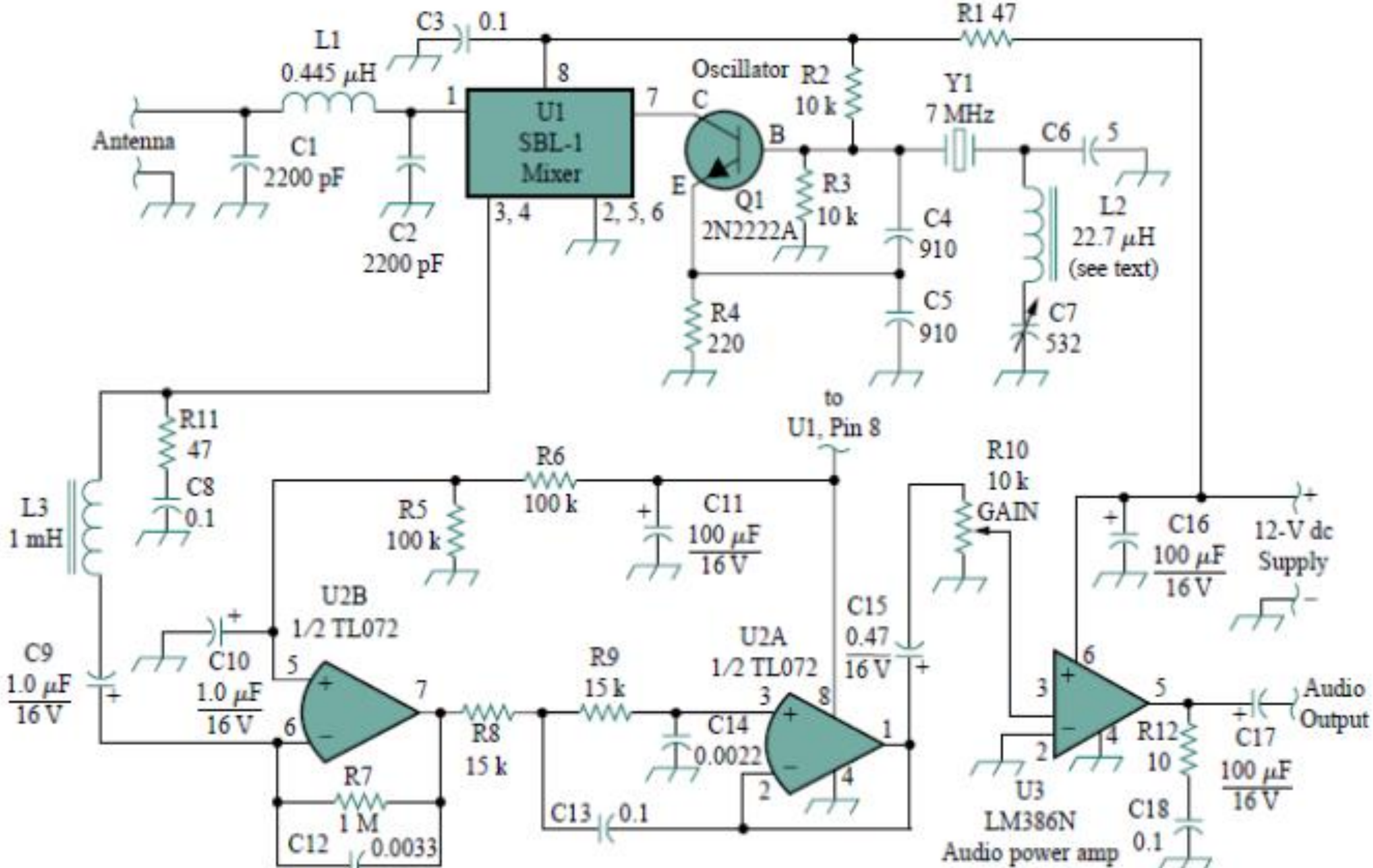
- Sum of power supplied by sources = sum of power18 dissipated by resistors.

# AC Circuit

- Any combination of ***Active*** and ***passive*** elements (resistors, capacitors and coils).

- The sources are AC voltage or current sources






Electric circuit of radio receiver

Pspice
software

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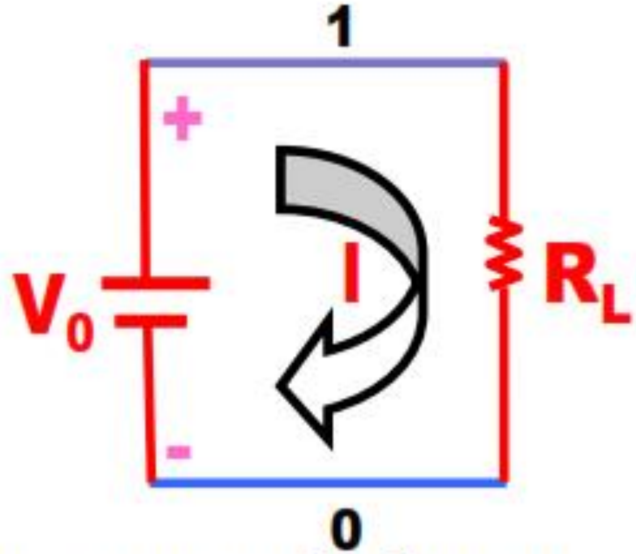
# Voltage




- To move a charge Q from node 0 to node 1, the source should do a work (W).
- Voltage is defined as the work done per unit charge
- It is the measure of "push" available to motivate charge
- Work (W) in Joules= Volt ($V_0$) in Volts * Charge (Q) in Coulombs

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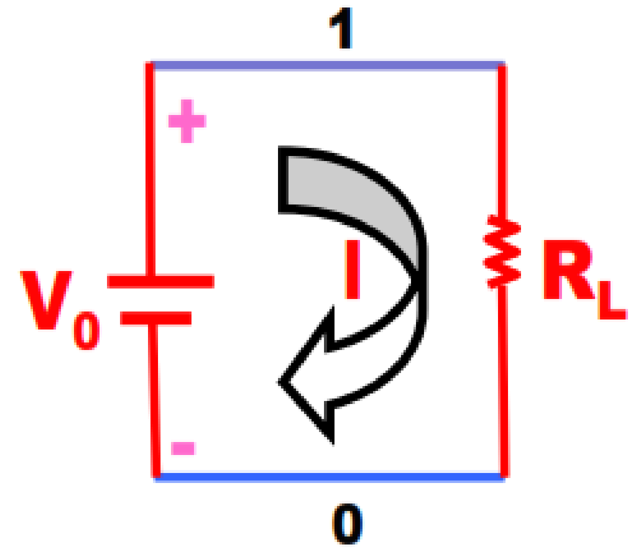
# Voltage




- The SI unit of voltage is Volt (V).

- $$V_0 \text{ (volts)} = \frac{\text{W in Joules}}{\text{Q in Coulmbs}}$$

- Current flows in a resistor if there is a potential difference between its ends.

- Current flows in a resistor from high voltage to low voltage.

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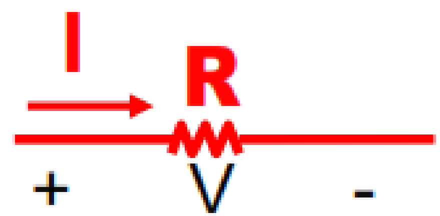
# Resistance and Ohm's low

- The Resistance of an object is a function of its material and shape.

- The voltage (V) across an ohmic resistor and the current (I) through the resistor are related as follows :

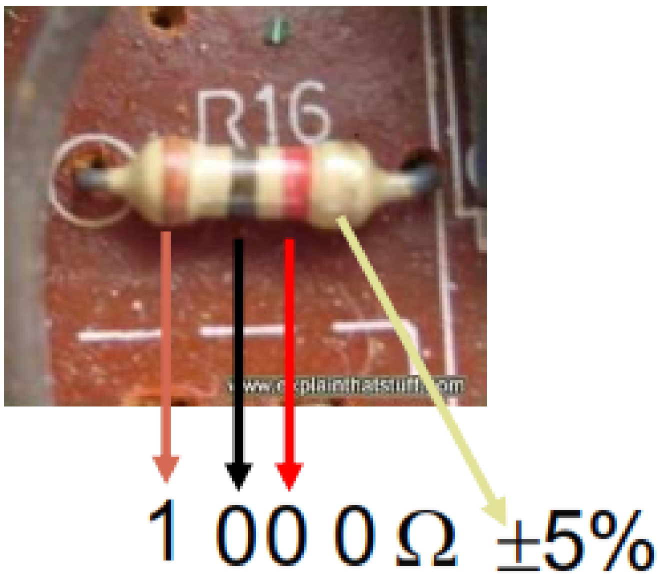
$$V = I * R$$

V → Volts, I → mA, R → kΩ



# Resistance and Ohm's low

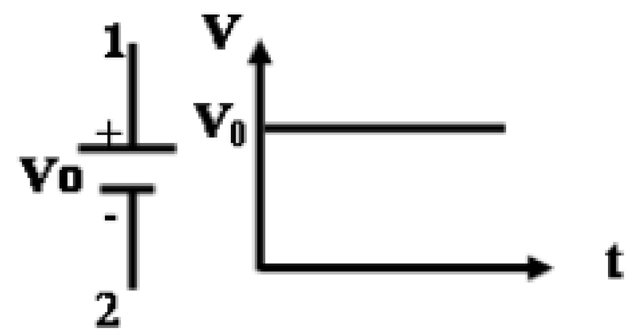
- 3-color code Resistors



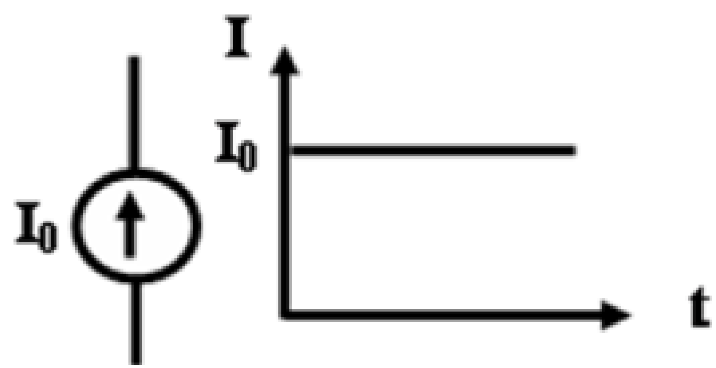

# Active Elements

- Active elements are either voltage or current dependent or independent.
- DC ideal independent sources

**DC voltage source**

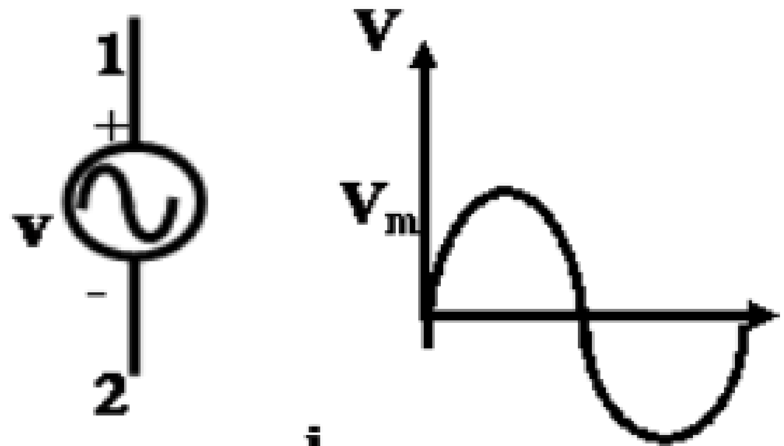



**DC current source**

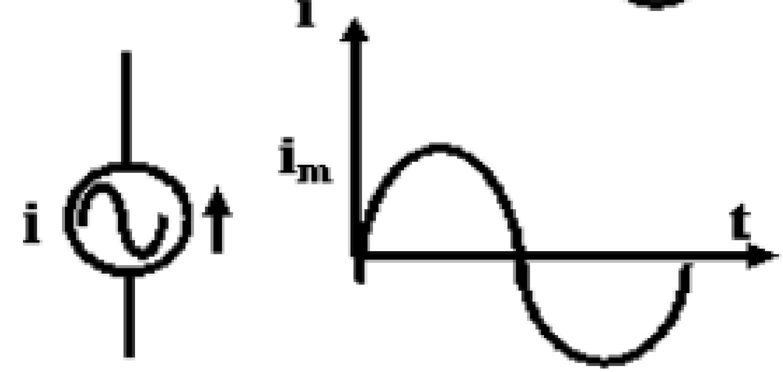


- <u>AC ideal independent sources</u>

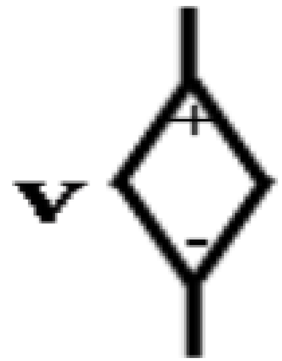
**AC voltage source**




**AC current source**



- <u>Ideal dependent voltage source</u>




- Voltage controlled voltage source (VCVS)

$$v = \mu\, v_x$$

μ is dimensionless

- Current controlled voltage source (CCVS)

$$v = \mu\, i_x$$

μ is in kΩ

• <u>Ideal dependent current source</u>


Current controlled current source (CCCS)

$$\mathbf{i} = \boldsymbol{\mu}\, \mathbf{i}_{\mathbf{x}}$$

$\mu$ is dimensionless

• Voltage controlled current source (VCCS)

$$\mathbf{i} = \boldsymbol{\mu}\, \mathbf{v}_{\mathbf{x}}$$

$\mu$ is in $(k\Omega)^{-1}$

$$\Omega^{-1} \equiv \mathbf{mho} \equiv \mathbf{Siemens}$$

# Basic Circuit laws

## Contents

- Topology of Electric Circuit
- Kirchoff's Laws
  - KVL
  - KCL
  - Series and Parallel Combinations of Resistors
  - Voltage Divider
  - Current Divider

# Topology of Electric Circuit

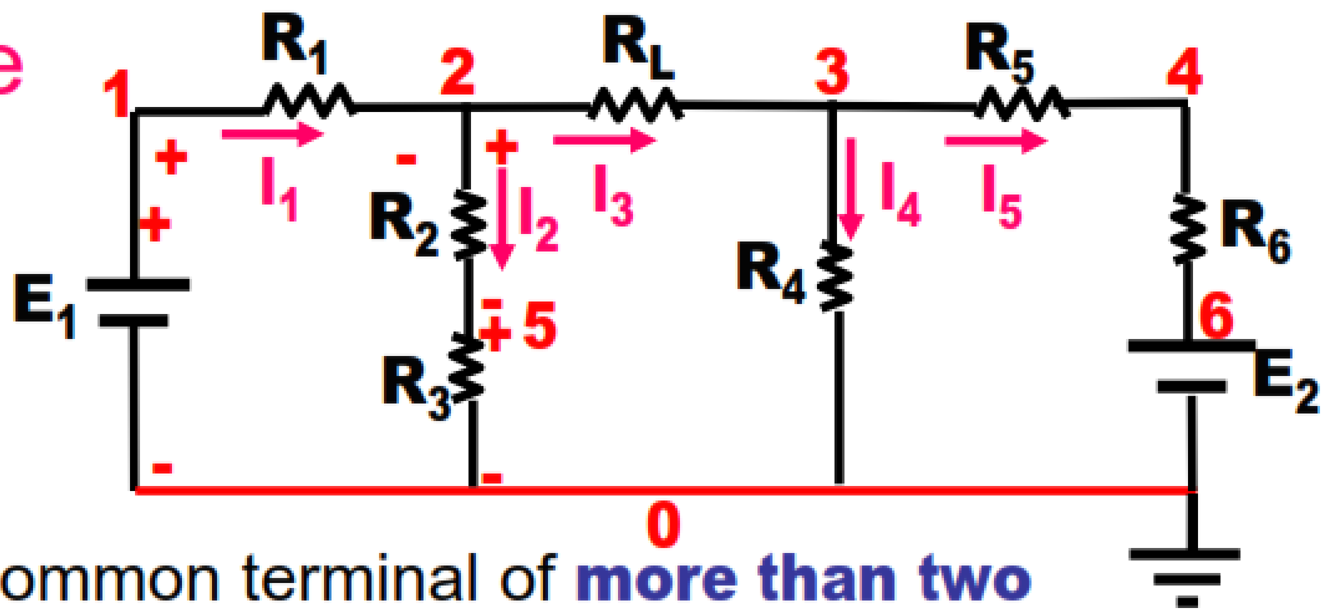
- **Circuit** : A circuit is built of ***Active*** elements and ***passive*** elements

- **Branch** : A part of the circuit whose elements have the same current

- **Node :** A common terminal of two or more branches

- **Loop:** A set of branches making a closed path (starts and ends with the same node)

# Example




- **Node:** A common terminal of **more than two branches**

  **N=3** **(2, 3, 0)** (Non simple nodes)

- **Loop:** A closed path in a circuit

  No. of independent loops **L=3** **12501, 23052, 34603**

- **Branch:** A circuit path having the same current
- **B=5** **012, 250, 23, 30, 3460**
- **In a planer circuit,** **B=N+L-1**

Why 0 is one node?

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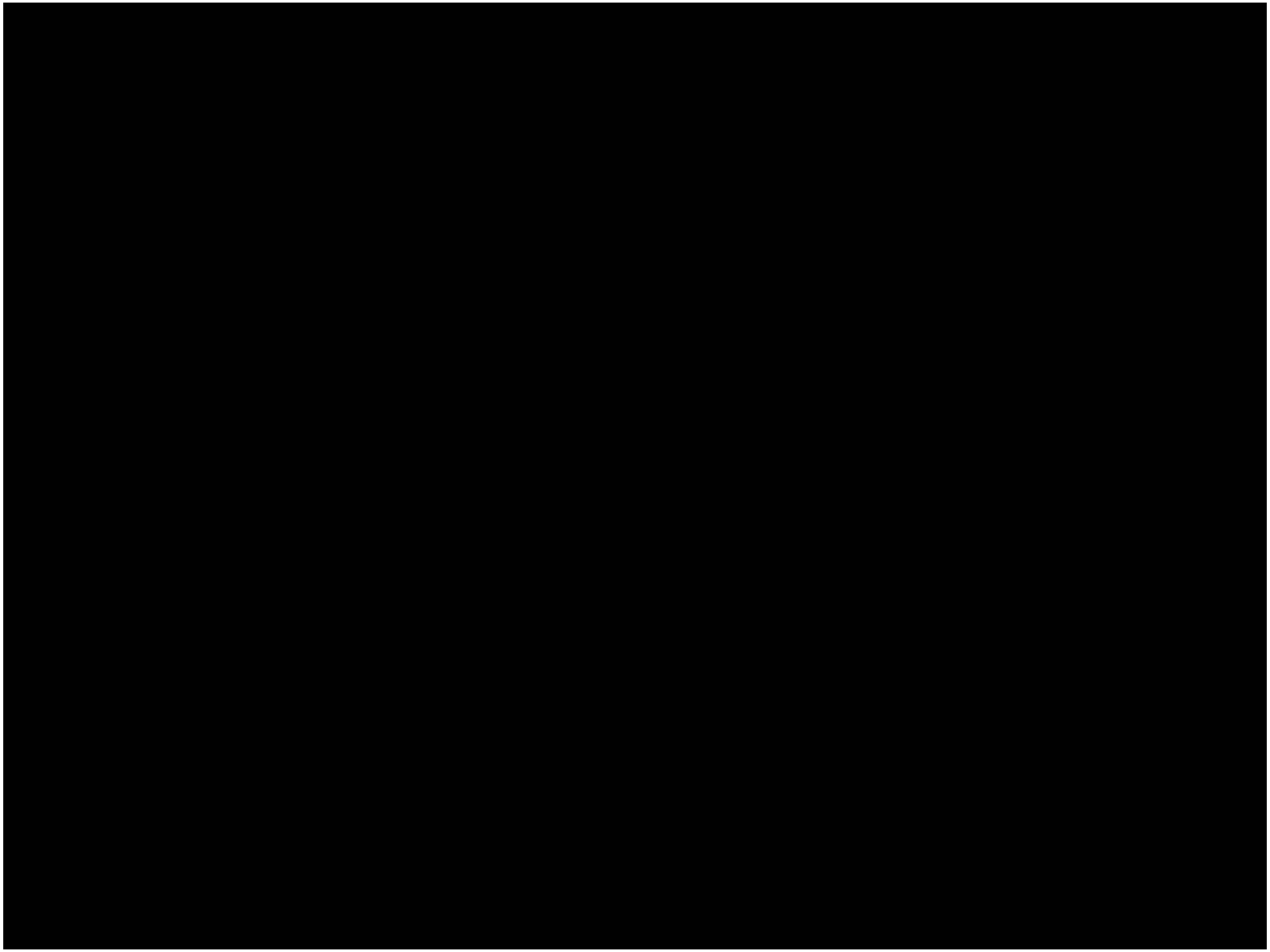
# Group Pressure



# Kirchoff's Laws

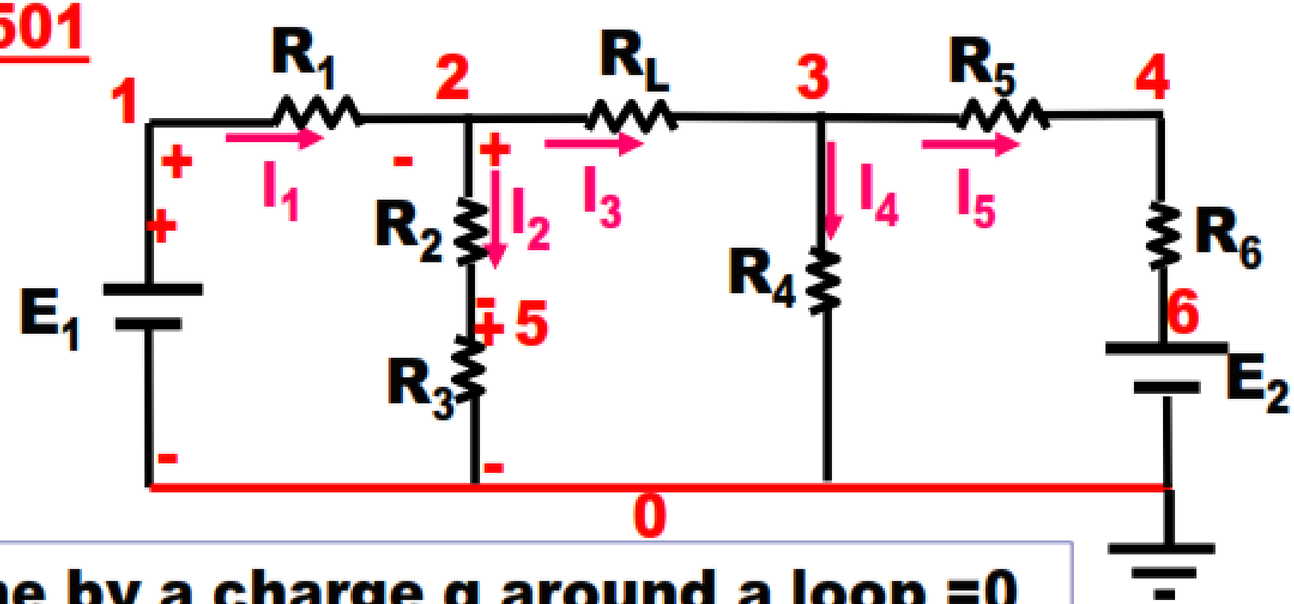
**KVL** **KCL**

- **Kirchhoff's Voltage Law** (KVL): the algebraic sum of the voltages around any loop of *N* elements is zero

$$\sum_{j=1}^{N} V_j = 0$$

- KVL is a statement of the conservation of energy law

- **Loop 12501**




**Work done by a charge q around a loop =0**

$$qV_{12}+qV_{25}+qV_{50}+qV_{01}=0$$

$$V_{12}+V_{25}+V_{50}+V_{01}=0$$

$$I_1R_1+I_2R_2+I_2R_3-E_1=0$$

# Basic Circuit laws

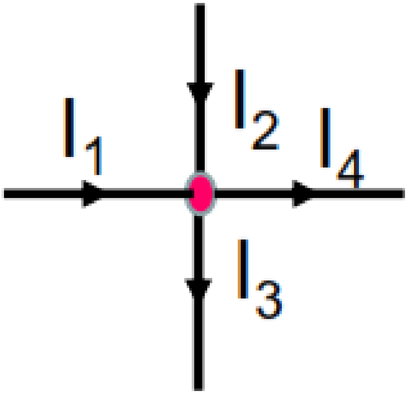
- **Kirchhoff's Current Law (KCL):** The algebraic sum of the currents entering any node is zero.
- **KCL is a statement of conservation of charge.**

$$\sum I_{in} = \sum I_{out}$$

$$\boxed{I_1 + I_2 = I_3 + I_4}$$

$$\text{or } \sum I_{in} = 0 \qquad \boxed{I_1 + I_2 - I_3 - I_4 = 0}$$

$$\text{or } \sum I_{out} = 0 \qquad \boxed{-I_1 - I_2 + I_3 + I_4 = 0}$$



# Series and Parallel Combinations of Resistors

- Circuit elements are in series when a common current passes through each element.

- Circuit elements are in parallel when a common voltage exists across each element.

# Resistors in series

- **Poof (KVL) Loop 12301**

$$V_{12}+V_{23}+V_{30}+V_{01}=0$$

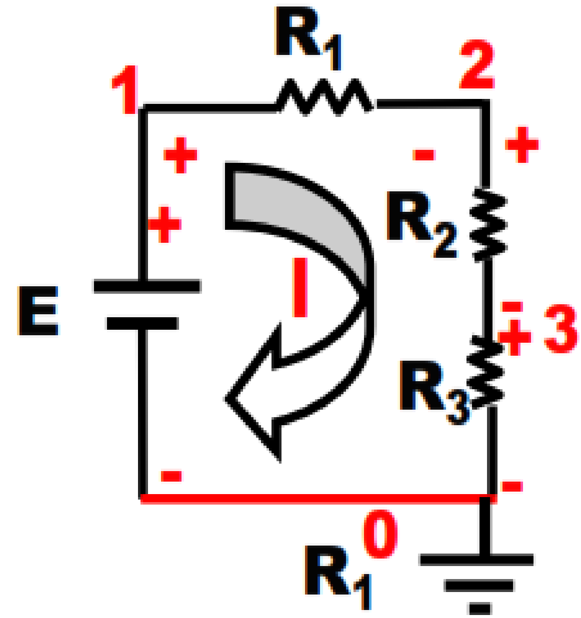
$$IR_1+IR_2+IR_3-E=0$$

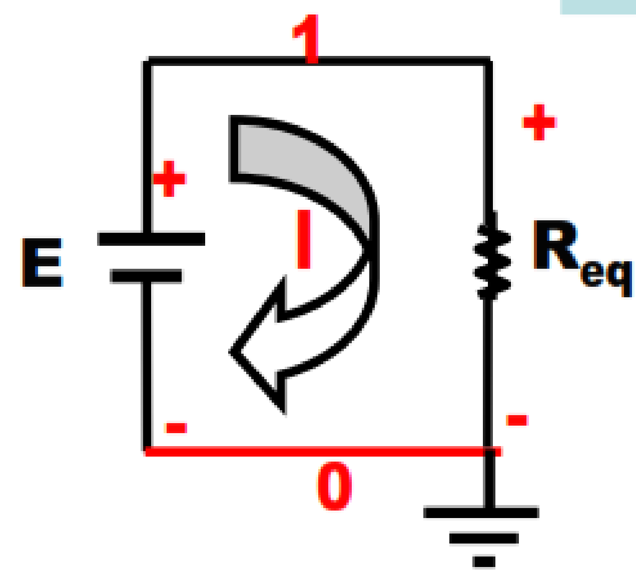
$$I\left(R_1+R_2+R_3\right)-E=0$$

**KVL Loop 101** $\quad V_{10}+V_{01}=0$

$$IR_{eq}-E=0$$

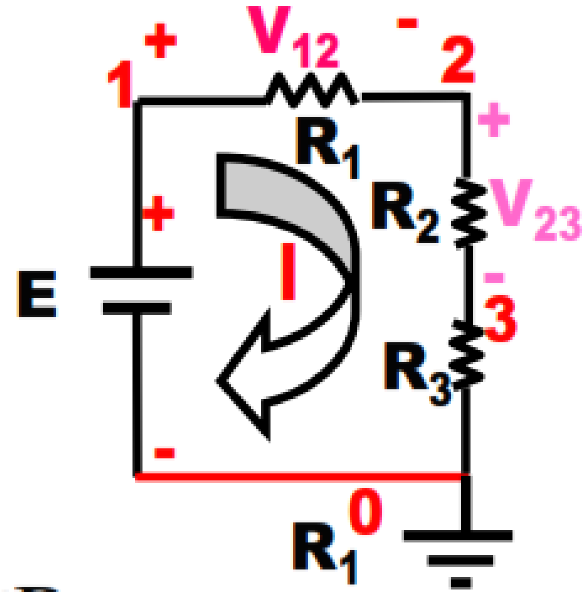
$$R_{eq}=R_1+R_2+R_3=\sum R_i$$



# Resistors in series

- **Voltage Division**




$$I = \frac{E}{R_1 + R_2 + R_3}$$

$$V_{12} = I * R_1 = \frac{E}{R_1 + R_2 + R_3} * R_1$$

$$= E * \frac{R_1}{R_1 + R_2 + R_3}$$

$$V_{23} = E * \frac{R_2}{R_1 + R_2 + R_3}$$

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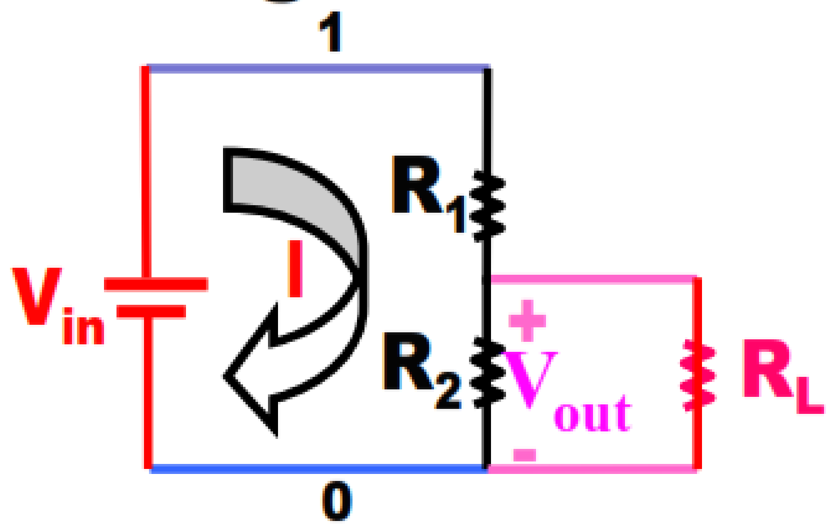
# Voltage Divider




$$V_{out} = V_{AB} = I\,R_2 = \frac{V_{in}}{R_1 + R_2} R_2 = V_{in} \frac{R_2}{R_1 + R_2}$$

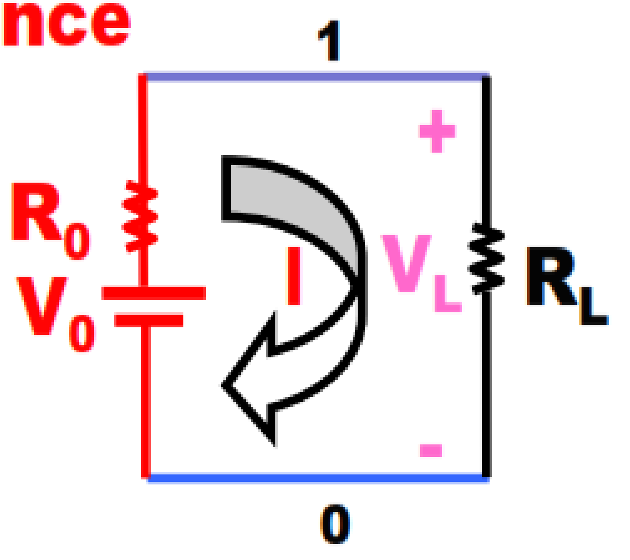
$$= V_{in} \frac{R_2}{R_1 + R_2}$$

**What is the effect on** $V_{out}$ when $R_L$ is connected?

# Actual sources

- Actual voltage source

**$R_0$ :Source internal resistance**




$$I = \frac{V_0}{R_0 + R_L}$$

$$V_L = I\,R_L = V_0\,\frac{R_L}{R_0 + R_L}$$

$$V_L \approx V_0 \quad \text{if} \quad R_0 << R_L$$

# Resistors in parallel

- **KCL Node 1**

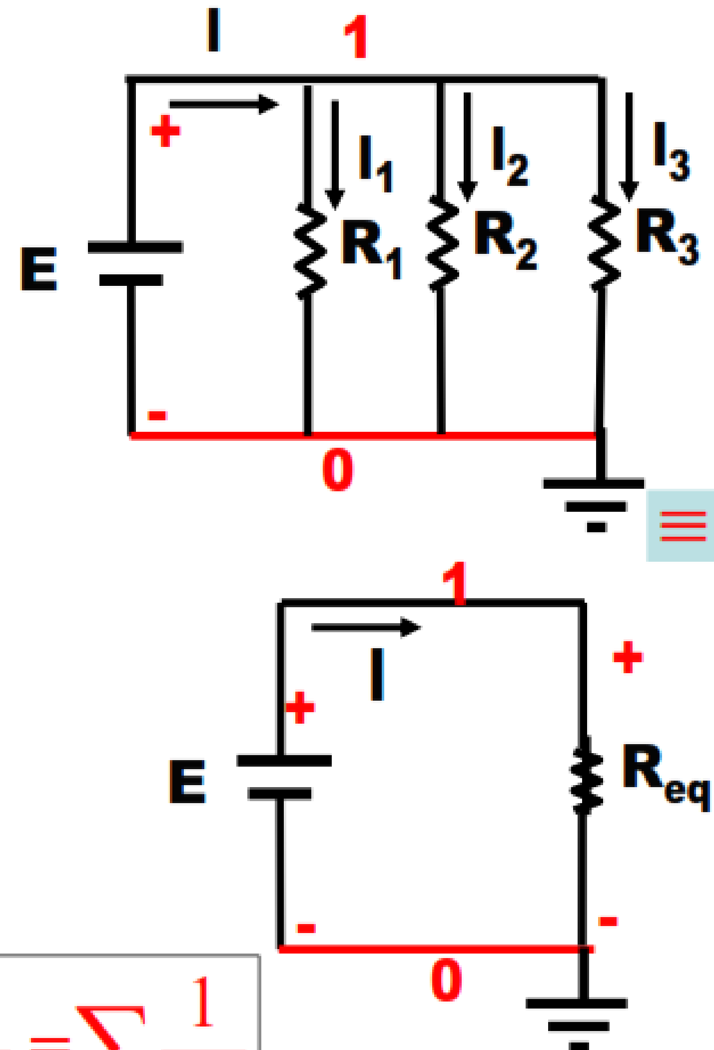
$$I = I_1 + I_2 + I_3$$

$$= \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3}$$

$$= E\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$I = \frac{E}{R_{eq}}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \sum \frac{1}{R_i}$$

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- The equivalent resistance of a combination of resistors connected in parallel is given by :

$$\frac{1}{R_{eq}} = \Sigma \frac{1}{R_i} \qquad \text{or} \qquad G_{eq} = \sum G_i$$

G is the conductance in $\Omega^{-1}$(mho) or seimens

- The equivalent resistance of two resistors connected in parallel is : $R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$
- The equivalent resistance of N equal parallel resistors each = R connected in parallel is : $R_{eq} = \frac{R}{N}$

# Resistors in parallel

- **Current division**

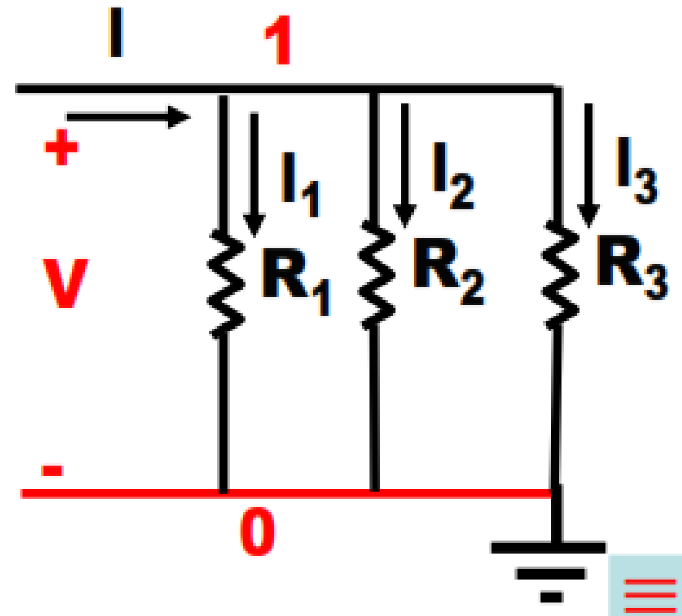
$$\frac{1}{Req} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

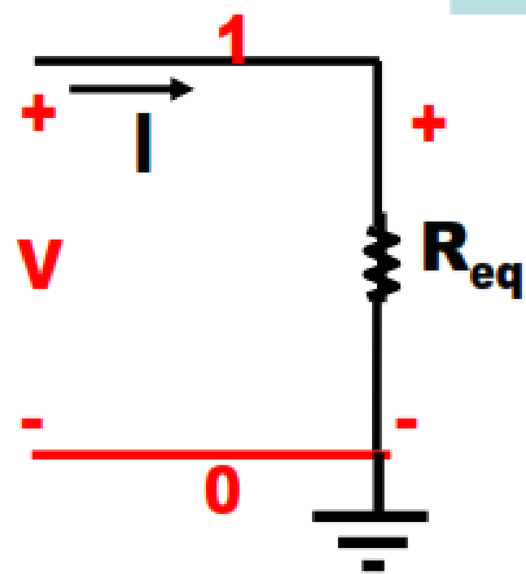
$$V = I^* R_{eq}$$

$$I_1 = \frac{V}{R_1}$$

$$I_2 = \frac{V}{R_2}$$

$$I_j = \frac{V}{R_j}$$

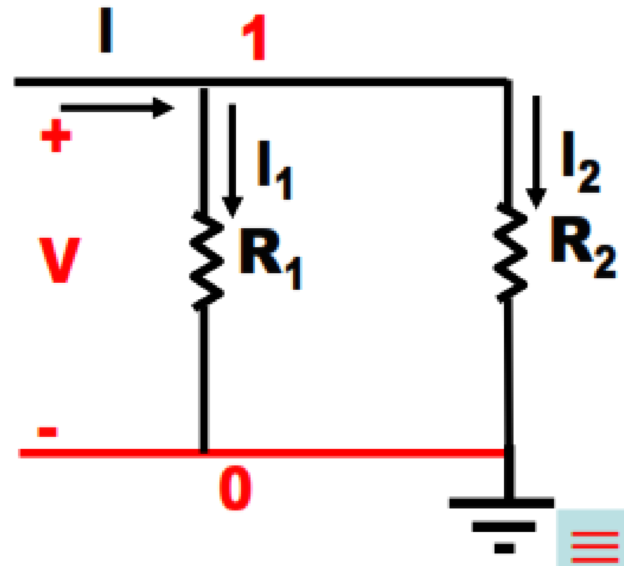


# Resistors in parallel

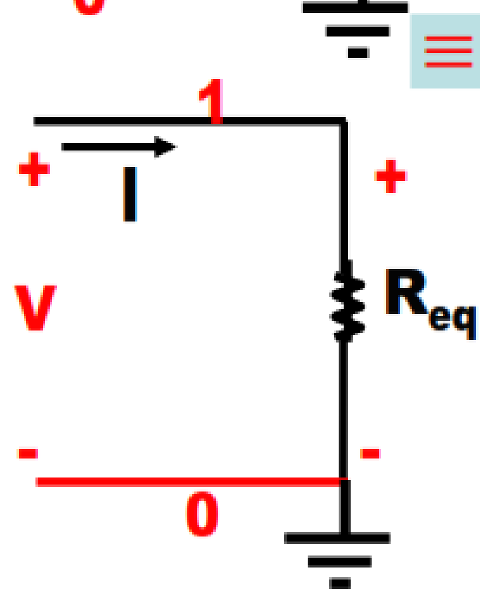
- **Current division**

$$Req = \frac{R_1 R_2}{R_1 + R_2}$$




$$V = I^* R_{eq} = I^* \frac{R_1 R_2}{R_1 + R_2}$$

$$= I_1 {}^* R_1 \quad = I_2 {}^* R_2$$




$$I_1 = I^* \frac{R_2}{R_1 + R_2} \qquad I_2 = I^* \frac{R_1}{R_1 + R_2}$$

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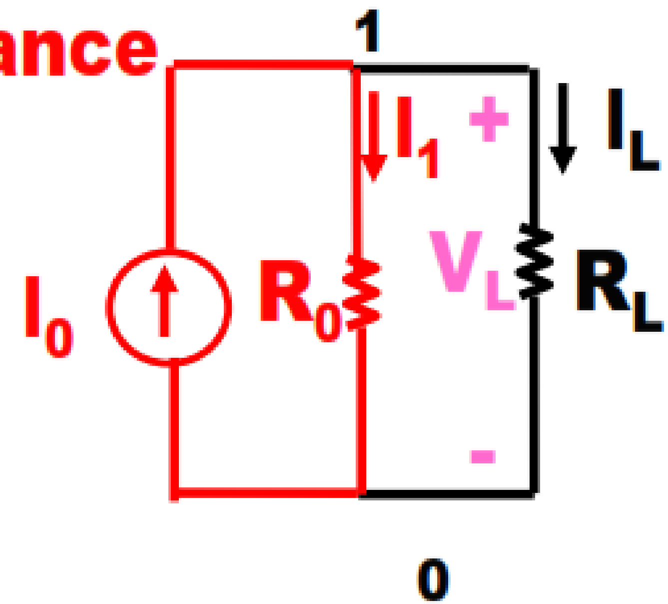
# Actual sources

- Actual Current source

**$R_0$ :Source internal resistance**




$$I_L = I_0 \frac{R_0}{R_L + R_0} \approx I_0 \qquad \text{if } R_0 >> R_L$$

# IQ Question

**V.**

| | | | |
|---|---|---|---|
| 4 | 5 | 7 | 3 |
| 8 | 3 | 3 | 9 |
| 7 | 6 | 9 | 5 |
| 6 | 9 | 8 | ? |

What number should replace the question mark?

# IQ Question

V.

| | | | |
|---|---|---|---|
| 4 | 5 | 7 | 3 |
| 8 | 3 | 3 | 9 |
| 7 | 6 | 9 | 5 |
| 6 | 9 | 8 | ? |

What number should replace the question mark?

Answer: 8

**Explanation:**

The sum of the numbers in each line across increases by 4.

# Power & Energy

- Power is the time rate of delivering or absorbing energy, measured in watts (W).

$$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = V*I$$

**P=V*I**

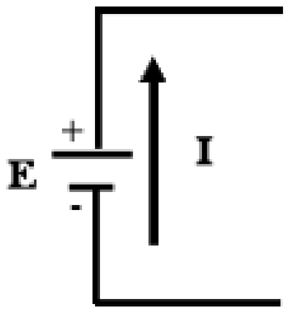
- For a resistor, power is always dissipated.
- For a linear resistor, $\mathbf{V = I * R}$

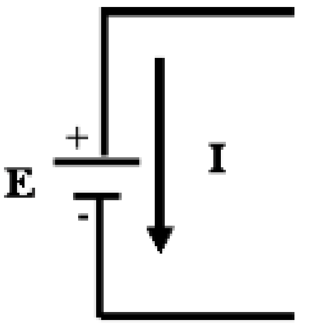
$$P = V*I = I^2 R = \frac{V^2}{R}$$

# Power & Energy

- **For a source, power is either delivered or absorbed.**

## Voltage Source



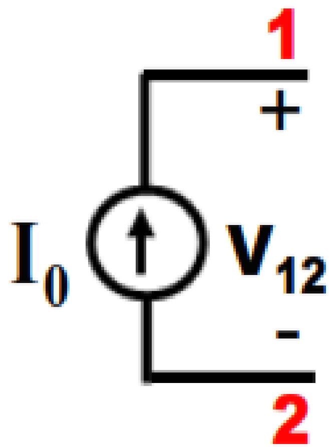

**P (delivered)=E*I**

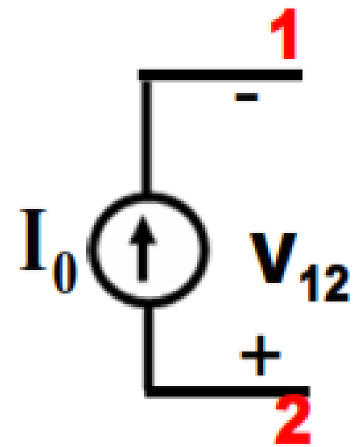
**P (delivered)=E*(- I)**
**(absorbed)**

- **Power balance :** **Σ Power delivered by sources**
  **=Σ Power dissipated by resistors**

# Power & Energy

- **Current source.**




| P (delivered)= $I_0 * V_{12}$ | P (delivered)= $I_0 * V_{12}$ |
|---|---|
| P is +ve (delivered) | P is –ve (absorbed) |

- **Power balance :** $\Sigma$ Power delivered by sources
  =$\Sigma$ Power dissipated by resistors