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Physics 1

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Battery

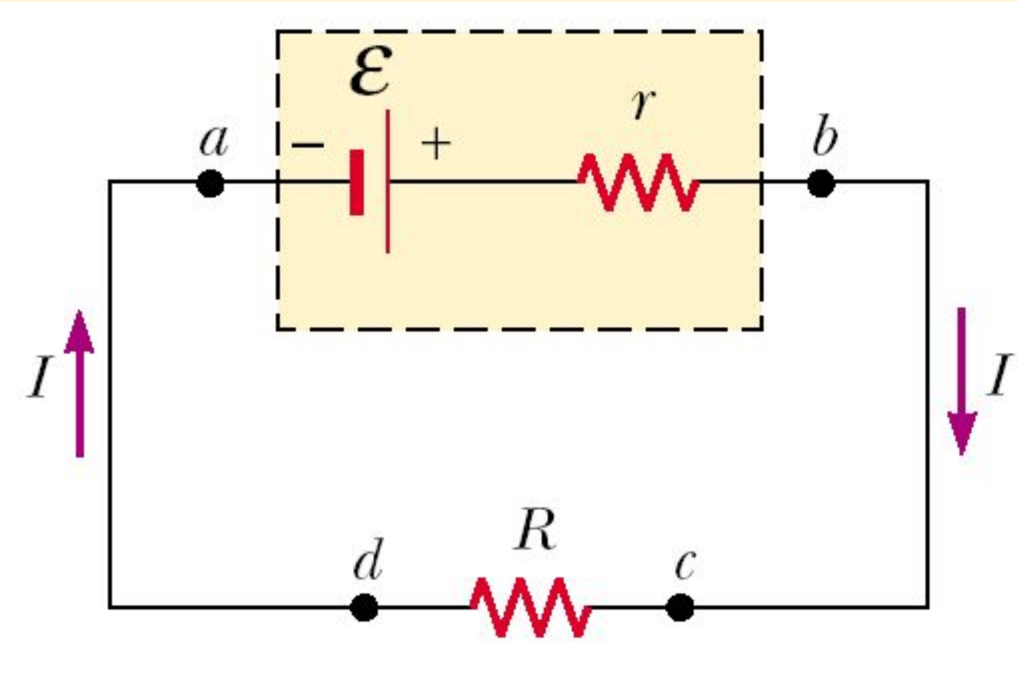
- The emf of a battery is the maximum possible voltage that the battery can provide between its terminals.
- Because a real battery is made of matter, there is resistance to the current within the battery.
- This resistance is called **internal resistance r**.

Direct and Alternating current

There exist two types of current:

Direct current (**dc**) is the continuous flow of charge in only one direction. The whole lecture is devoted only to direct current circuits.

Alternating current (**ac**) is a flow of charge continually changing in both magnitude and in direction.



- ε - emf
- V – potential difference on the battery ($V = V_b - V_a$)
- r – internal resistance of emf
- R – external load

V_b-V_a: $V = \varepsilon - IR$

Circuit current: $I = \varepsilon/(R+r)$

Power output of the battery is ε*I: $\varepsilon * I = I^2R + I^2r$

Energy output of a Battery

$$□ * I = I^2R + I^2r$$

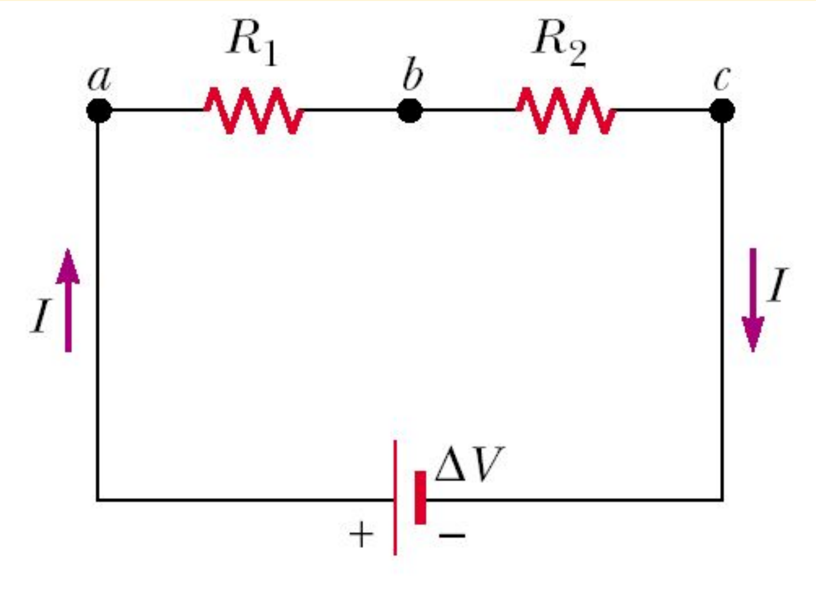
- □*I - Power output of the battery.
- I^2R – energy transferred to the external load
- I^2r – energy loss by the internal resistance

- So the power output of the battery to external resistance is accompanied by the power loss due to internal resistance.

Resistor

- Resistor is a circuit element which is used to control the current level in the various parts of the circuit. It’s main property – it has constant resistivity for a wide range of potential differences.

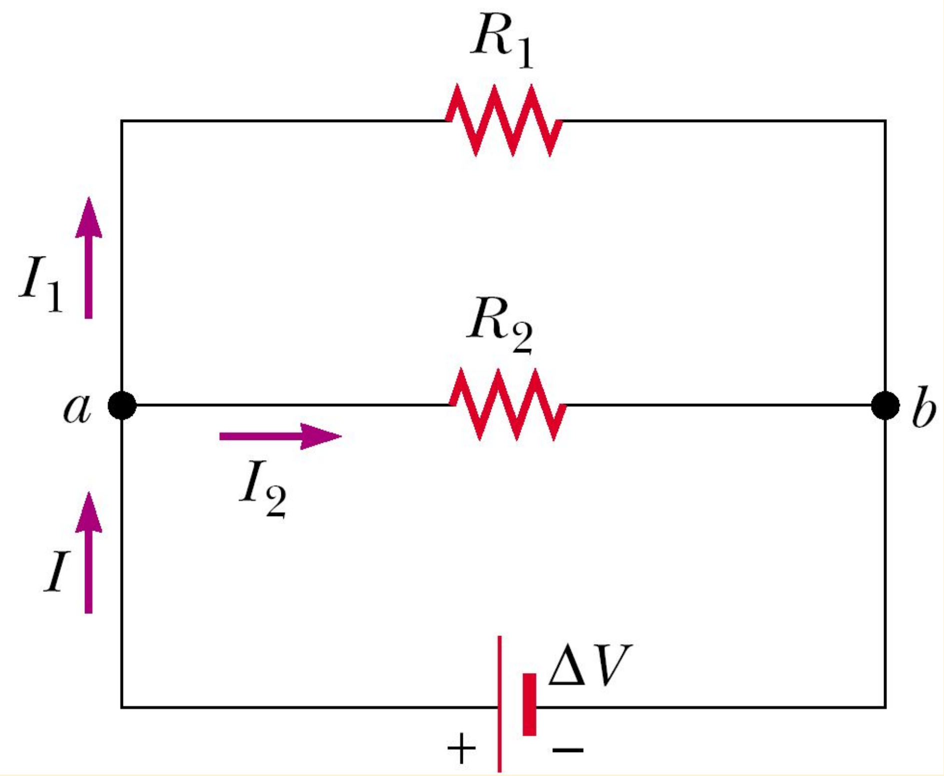
Resistors in Series



- $I_{ac} = I_1 = I_2$
- $V_{ac} = V_1 + V_2$
- $R_{ac} = R_1 + R_2$

- Currents I_1 and I_2 are the same in both resistors because the amount of charge that passes through must also pass through in the same time inter interval.

Resistors in Parallel



- $I = I_1 + I_2$
- $V_{ac} = V_1 = V_2$

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

- When resistors are connected in parallel, the potential differences across the resistors are the same.

Any number of resistors

- **In series:**

  $I = I_1 = I_2 = I_3 = \ldots$

  $V = V_1 + V_2 + V_3 + \ldots$

  $R_{ac} = R_1 + R_2 + R_3 + \ldots$

- **In parallel:**

  $I = I_1 + I_2 + I_3 + \ldots$

  $V = V_1 = V_2 = V_3 = \ldots$

$$\frac{1}{R_{\mathrm{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

Kirchhoff's Rules for Direct Current Circuits

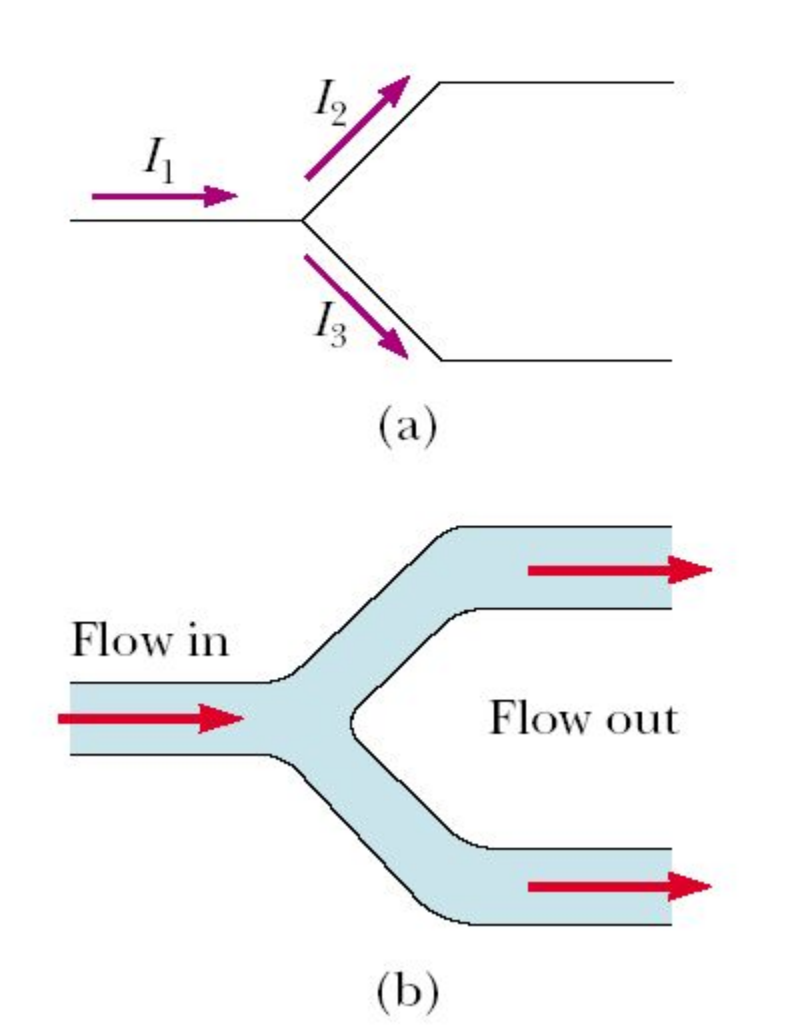
1. **Junction rule.** The sum of the currents entering any junction in a circuit must equal the sum of the currents leaving that junction.

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

2. **Loop rule.** The sum of the potential differences across all elements around any closed circuit loop must be zero.

$$\sum_{\substack{\text{closed}\\\text{loop}}} \Delta V = 0$$

Junction Rule

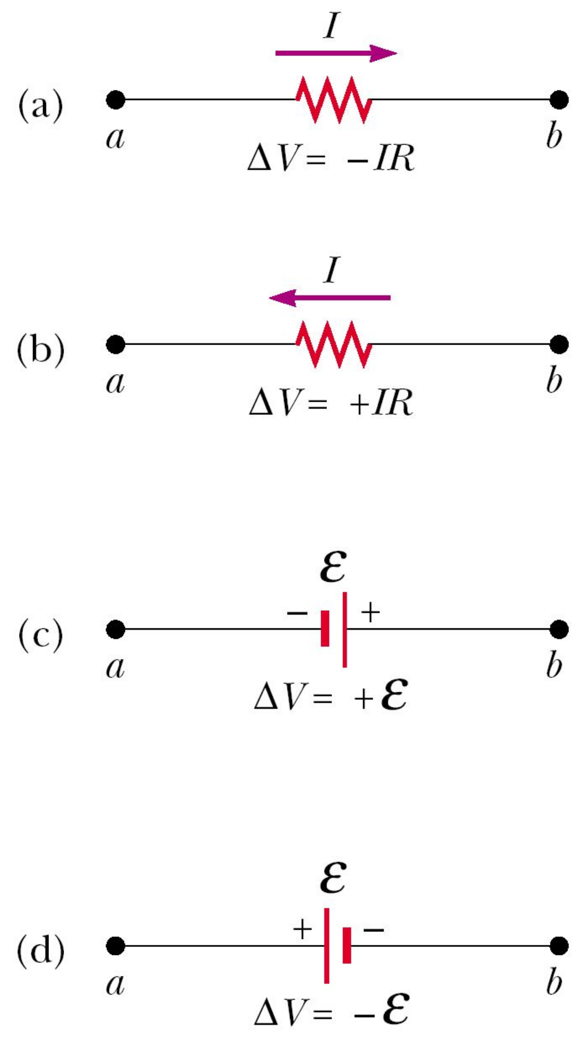


- $I_1 = I_2 + I_3$
- The Kirchhoff's junction rule is an analogue for fluid current.
- The junction rule is a consequence of the Charge conservation law.

Loop Rule Basis

- Kirchhoff's second rule follows from the law of conservation of energy. Let us imagine moving a charge around a closed loop of a circuit. When the charge returns to the starting point, the charge –circuit system must have the same total energy as it had before the charge was moved. The sum of the increases in energy as the charge passes through some circuit elements must equal the sum of the decreases in energy as it passes through other elements.
- The potential energy decreases whenever the charge moves through a potential drop $-IR$ across a resistor or whenever it moves in the reverse direction through a source of emf. The potential energy increases whenever the charge passes through a battery from the negative terminal to the positive terminal.

Loop rule



In Figures a-d each element is traversed from left to right.

- If a resistor is traversed in the direction of the current, the potential difference across the resistor –*IR.* (Fig. a)
- If a resistor is traversed in the direction *opposite* the current, the potential differ-difference the resistor is +*IR.* (Fig. b)
- If a source of emf (assumed to have zero internal resistance) is traversed in the direction of the emf (from - to +), the potential difference is + ℰ. The emf of the battery increases the electric potential as we move through it in this direction. (Fig. c)
- If a source of emf (assumed to have zero internal resistance) is traversed in the direction opposite the emf (from + to -), the potential difference - ℰ. In this case the emf of the batter battery reduces the electric potential as we move through it. (Fig. c)

Kirchhoff’s rules validity

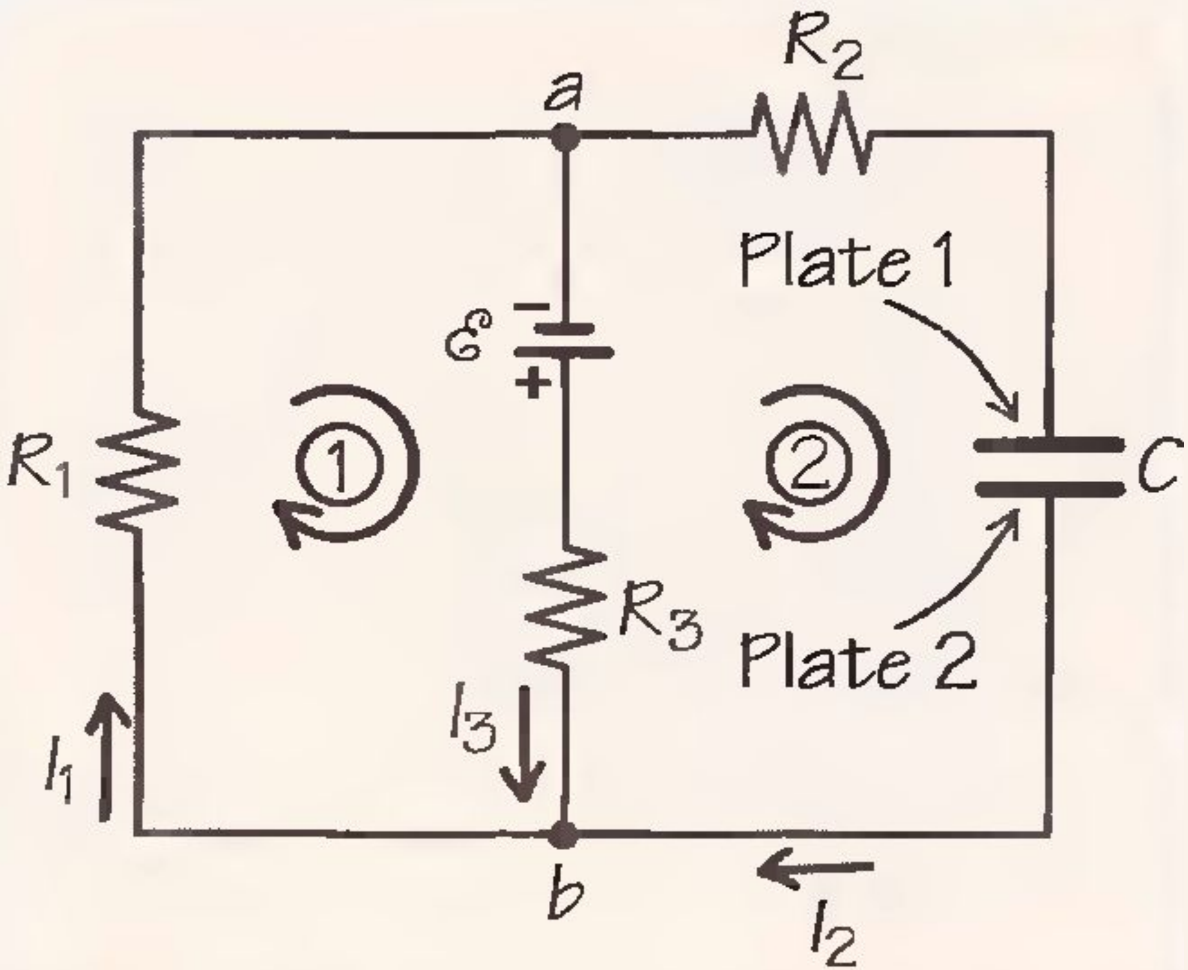
- Kirchhoff’s rules are valid only for steady-state conditions - that is, the currents in various branches are constant.
- Any capacitor acts as an open branch in a circuit; that is, the current in the branch containing the capacitor is zero under steady-state conditions.

PROBLEM-SOLVING HINTS

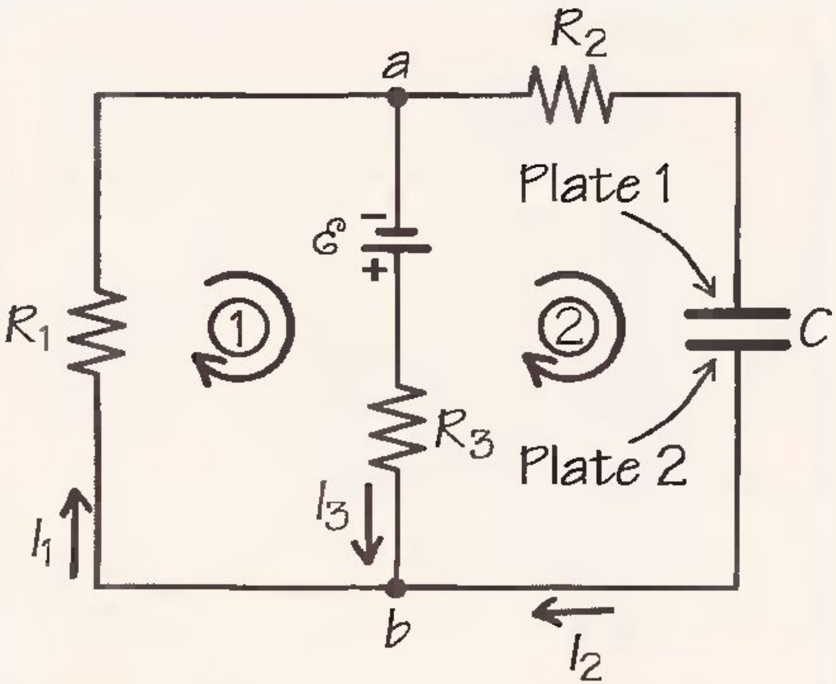
Kirchhoff's Rules

- Draw a circuit diagram, and label all the known and unknown quantities. You must assign a *direction* to the current in each branch of the circuit. Although the assignment of current directions is arbitrary, you must adhere rigorously to the assigned directions when applying Kirchhoff's rules.
- Apply the junction rule to any junctions in the circuit that provide new relationships among the various currents.
- Apply the loop rule to as many loops in the circuit as are needed to solve for the unknowns. To apply this rule, you must correctly identify the potential difference as you imagine crossing each element while traversing the closed loop (either clockwise or counterclockwise). Watch out for errors in sign!
- Solve the equations simultaneously for the unknown quantities. Do not be alarmed if a current turns out to be negative; *its magnitude will be correct and the direction is opposite to that which you assigned.*

Example: a multiloop circuit



All currents are steady state means that there is no changes in currents. In steady-state condition the capacitor acts as an open switch despite the fact that it has voltage.



So first we choose directions in the two circuits as it shown in the picture.

I_2=0, as the capacitor is not charging. =>

=> For junction b: $I_3 = I_1$.

For loop 1: $□ - I_3R_3 - I_1R_1$ =>

$R_3 = □/I_1 - R_1$

For loop 2: $□ - I_3R_3 - V_C = 0$ =>

$V_C = □ - I_3R_3 = □ - I_3R_3 = I_1R_1$

Units in Si

- Capacitance C F=C/V
- Current I A=C/s
- Resistance R Ohm=V/A
- Electro motive force (emf) □ V