Lecture 14

Chapter 28

Circuits

Chapter 27 Review

- Current, *i*, is defined as amount of charge *q* passing through plane in time *t*

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

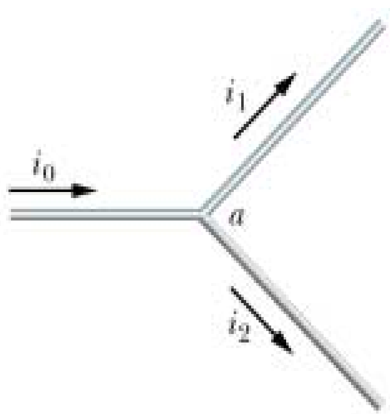
- SI unit ampere, A

$$1A = 1C/s$$

- Charge is conserved

$$i_0 = i_1 + i_2$$

- Current arrow drawn in direction + charge carriers would move



Chapter 27 Review

- Resistance is defined as

$$R = \frac{V}{i}$$

- SI unit is the ohm, Ω

$$1\Omega = 1V / A$$

- Resistance of conducting wire of length *L*, resistivity *ρ*, and cross section *A*

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

- Ohm's Law – *R* is independent of magnitude and polarity of *V*

$$V = iR$$

Circuits (1)

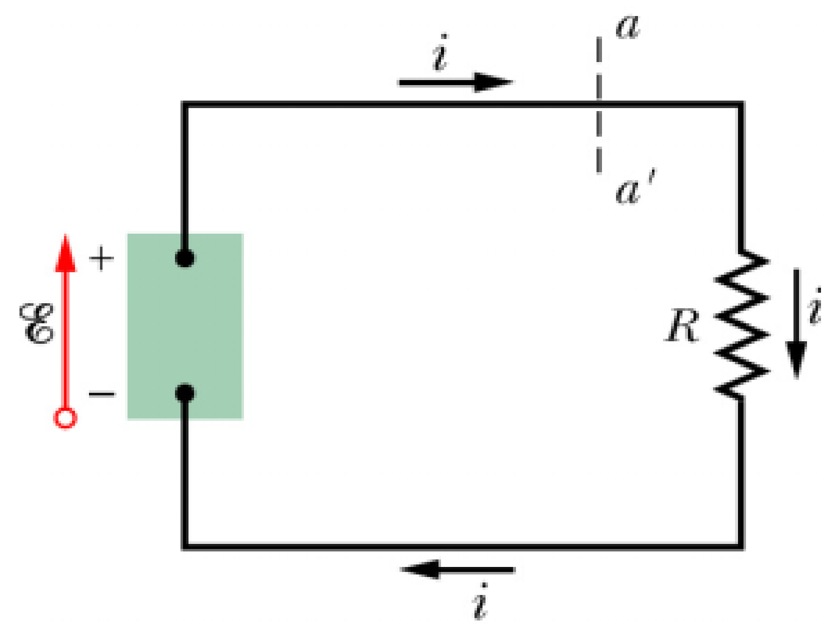
- To produce study flow of charge use an emf device

- Does work on charge carriers to maintain a *V* between its terminals

- Examples:
  - Battery
  - Electric generator
  - Solar cells

Circuits (2)

- emf device label terminal at higher V as + and lower V as –
- Draw emf, $\mathcal{E}$, arrow from – to + terminal
- + charge carriers move against E field in emf device from lower (-) to higher (+) V

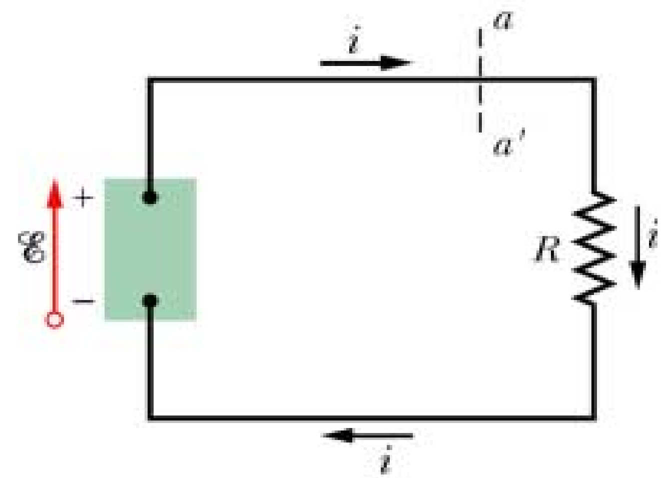


Circuits (3)

- Must do work to move charges within emf device

$$W = q\Delta V$$

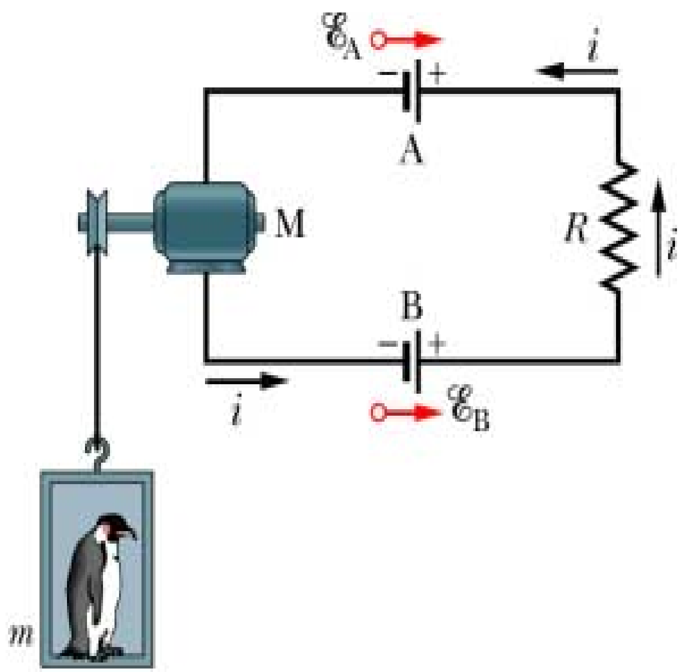
- The emf, $\mathcal{E}$, is the work per unit charge a device does to move + charge from low-*V* terminal to high-*V* terminal
- Energy source to do work may be chemical, mechanical, solar ...

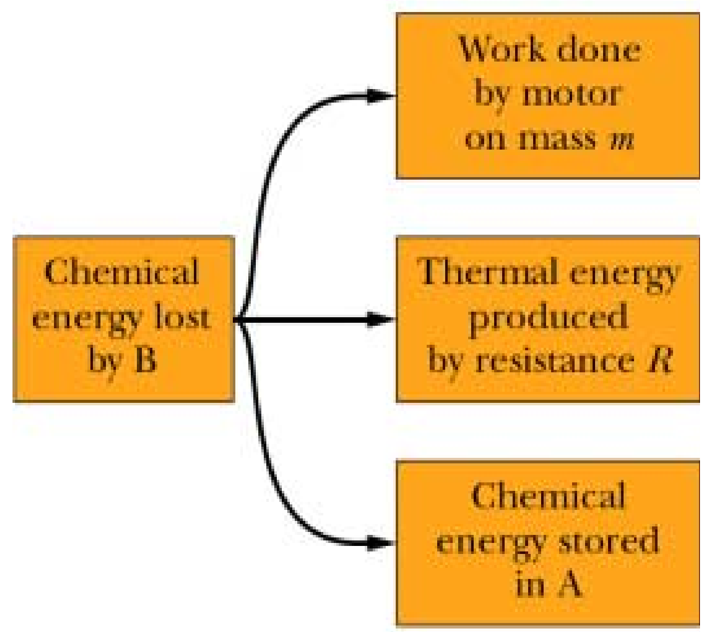


$$\mathcal{E} = \frac{dW}{dq}$$

Circuits (4)

- Emf device transfers energy to charge carriers moving through it
- This energy can be transferred to other devices such as a light bulb or motor

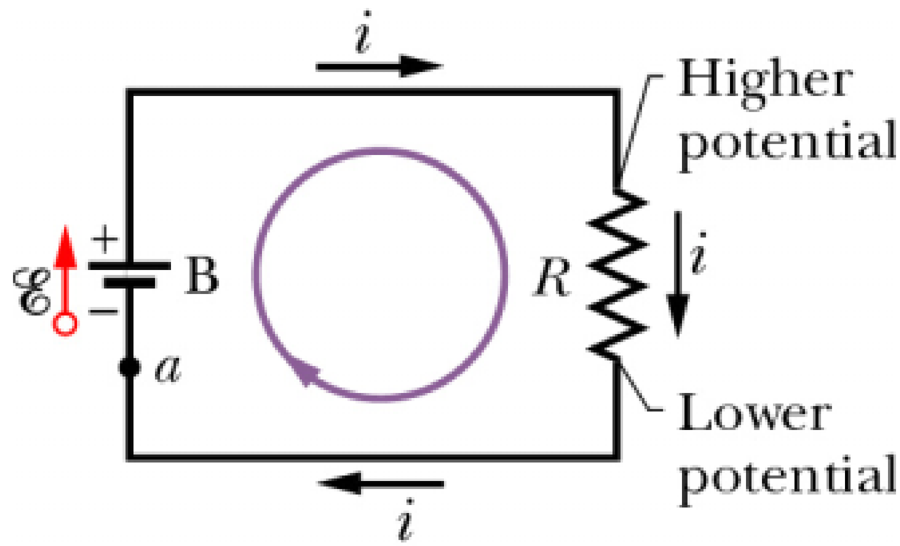




Circuits (5)

- Calculate the current in single-loop circuit
- Use conservation of energy

- Chemical work done by battery must equal thermal energy dissipated in resistor
  - Assume wires negligible



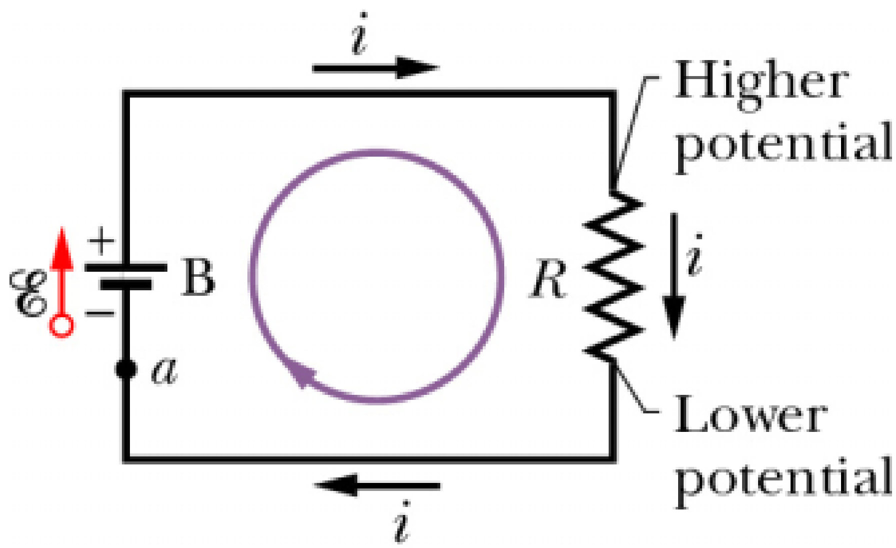
$$W_{battery} = W_{resistor}$$

Circuits (6)

- Start with energy lost in resistor

$$P = \frac{dW}{dt}$$

$$W = Pdt$$



- From chpt. 27 power for a resistor is

$$P = i^2 R$$

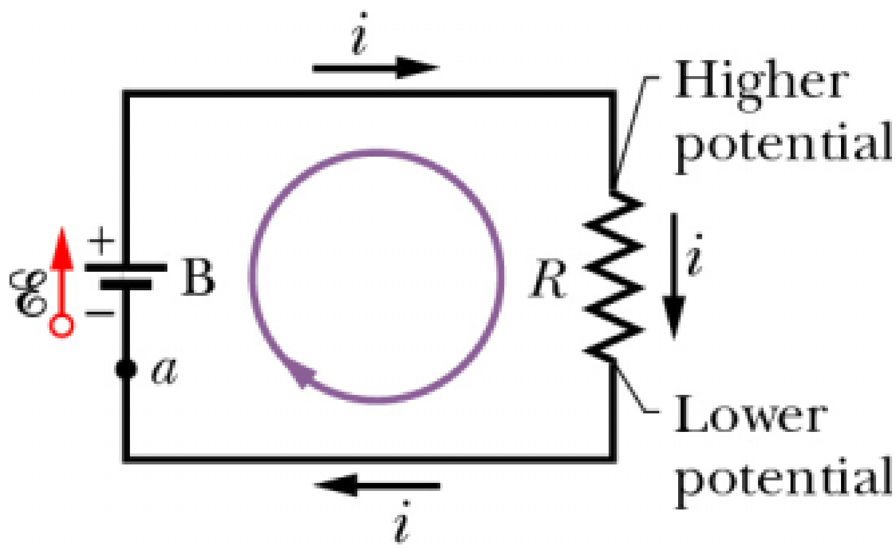
$$W_{resistor} = i^2 R dt$$

Circuits (7)

- Work done by emf is

$$\mathcal{E} = \frac{dW}{dq}$$

$$W = \mathcal{E}\, dq$$



- Remember definition of current

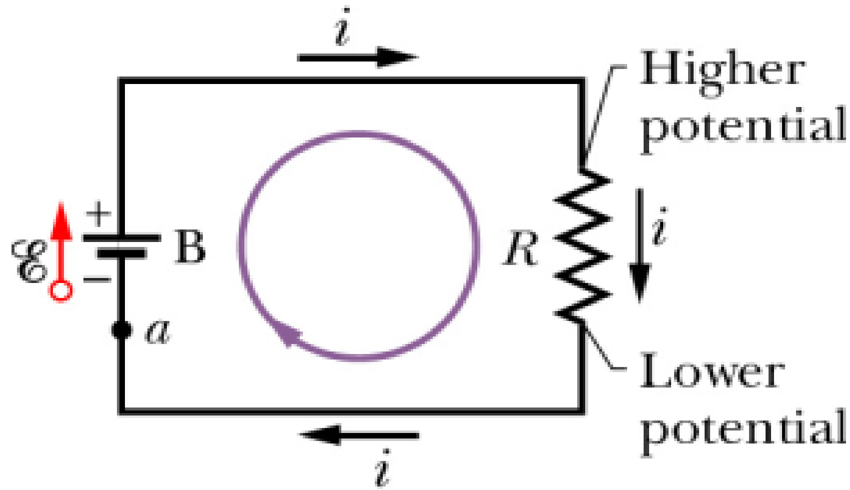
$$i = \frac{dq}{dt}$$

$$W_{battery} = \mathcal{E}\, i dt$$

Circuits (8)

- By conservation of energy

$$W_{battery} = W_{resistor}$$



$$W_{resistor} = i^2 R dt$$

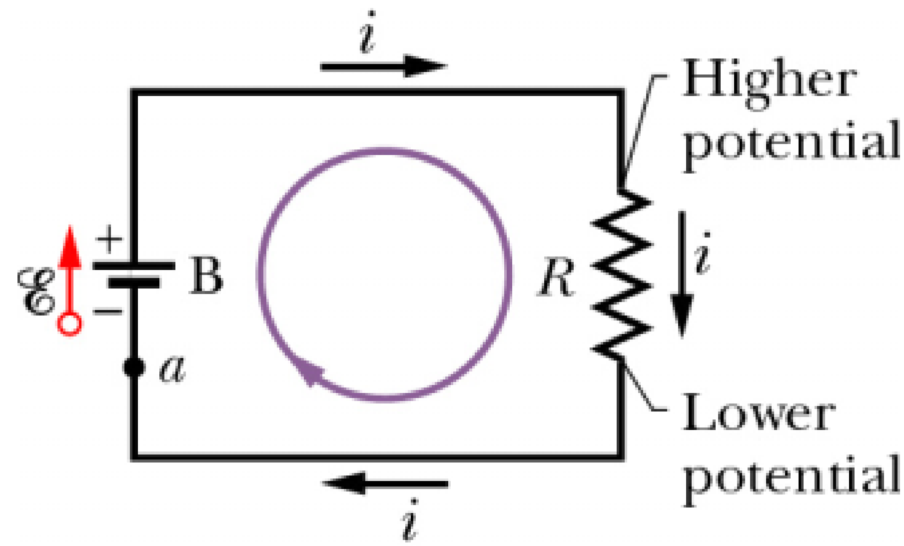
$$W_{battery} = \mathcal{E}\, i dt$$

- Solving gives

$$\mathcal{E} = iR$$

Circuits (9)

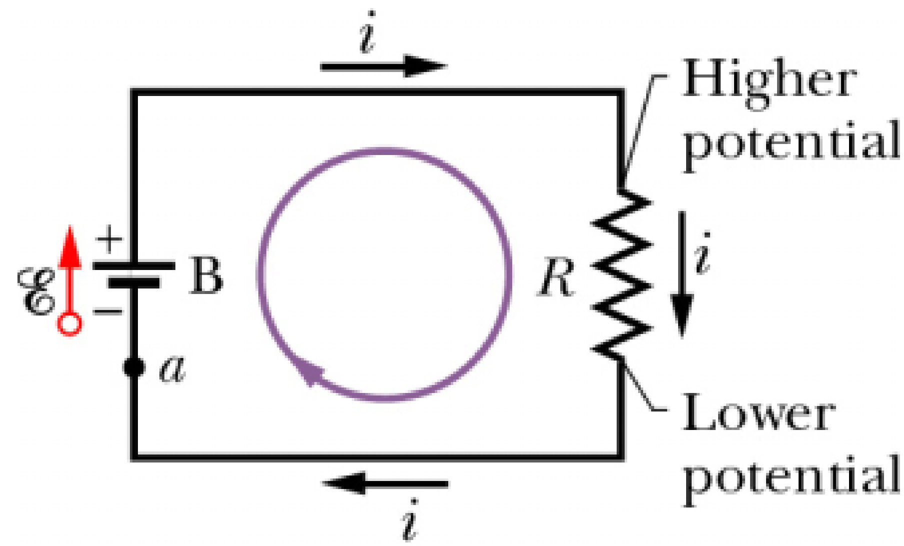
- Calculate the current in single-loop circuit
- Now use potential method



- Travel around circuit in either direction and algebraically add potential differences

Circuits (10)

- Start at point a with potential V_a
- Move clockwise around circuit
- Pass through battery moving to higher V, change in V is $+\mathcal{E}$
- Neglect resistance of connecting wires

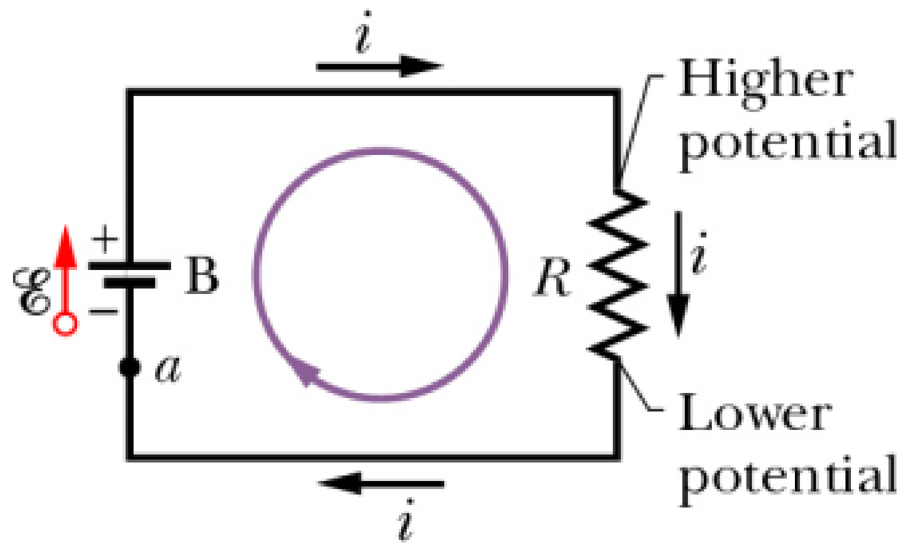


$$V_a + \mathcal{E}$$

Circuits (11)

- Top of resistor at same V as battery
- Pass through resistor V decreases and

$$V = iR$$



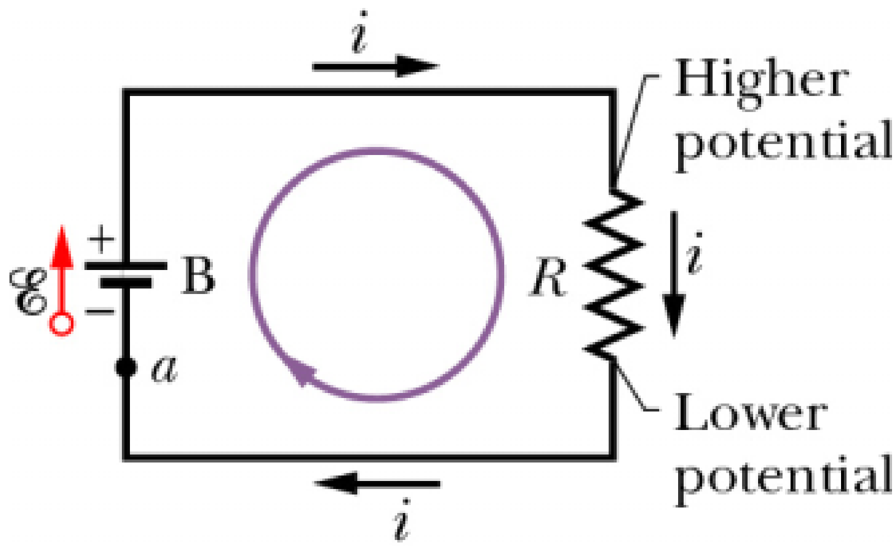
- Return to point a on bottom wire back to potential V_a so

$$V_a + \mathcal{E} - iR = V_a$$

Circuits (12)

- Get same answer as before

$$\mathcal{E} = iR$$



- Could move around circuit counterclockwise

$$V_a - \mathcal{E} + iR = V_a$$

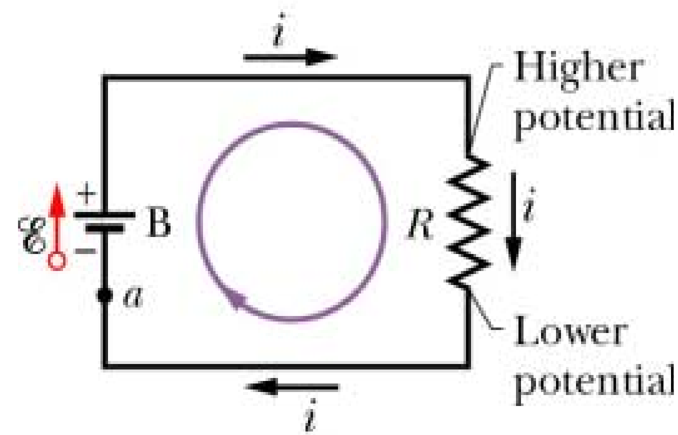
$$\mathcal{E} = iR$$

Circuits (13)

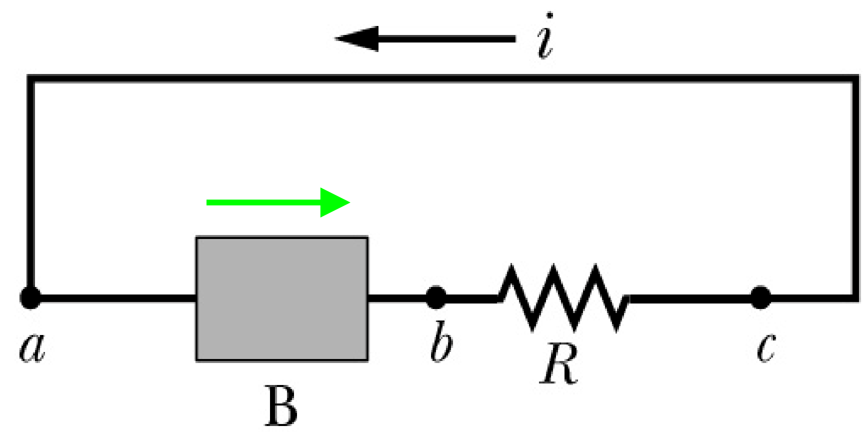
- Kirchhoff's loop rule – in traversing a circuit loop the sum of the changes in *V* is zero, $\Delta V = 0$

- Resistance rule – Move through resistor in direction of current $V = -iR$, in opposite direction $V = +iR$

- Emf rule – Move through emf device in direction of emf arrow $V = +E$, in opposite direction $V = -E$



Circuits (14)



- Checkpoint #1 –
- A) What direction should the emf arrow point?

  RIGHTWARD

- B) Rank magnitude of current at points a, b, and c.

  All same

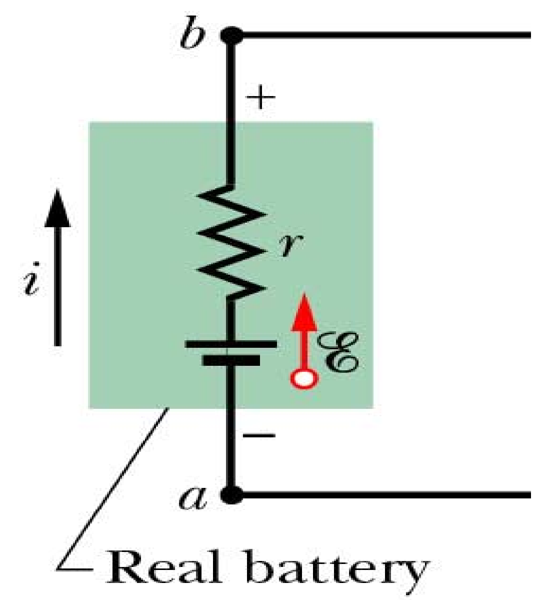
- C) Rank V and U.

  B, then A and C tie

Circuits (15)

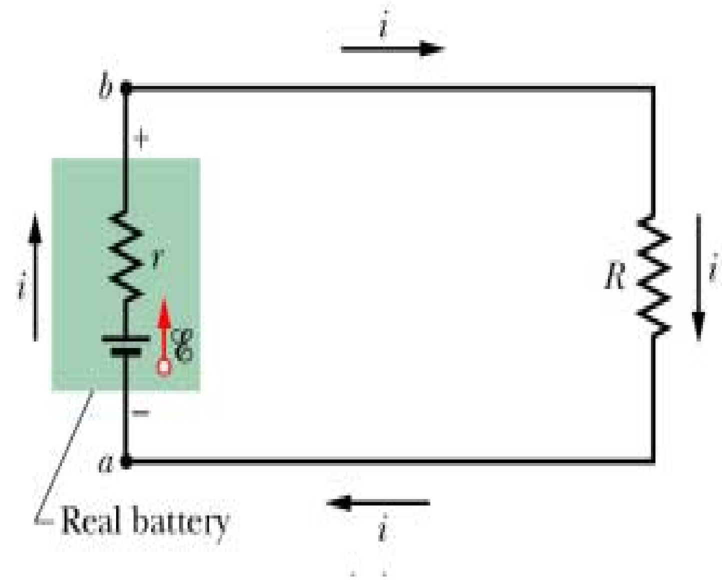
- So far assumed ideal battery – has no internal resistance

- Real battery has internal resistance to movement of charge
- Not in circuit $V = \mathcal{E}$ of battery
- If current present $V = \mathcal{E} - iR$, where R is the internal resistance of the battery



Circuits (16)

- Put real battery in circuit
- Using Kirchhoff's loop rule and starting at point a gives



$$\mathcal{E} - ir - iR = 0$$

$$\mathcal{E} = i(r + R)$$

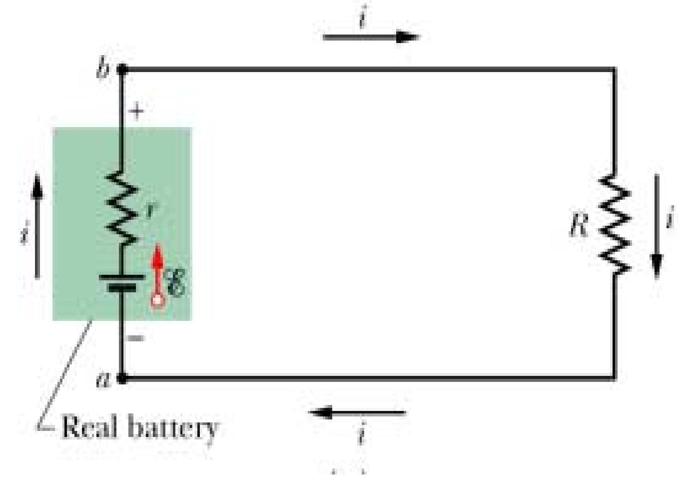
- For ideal battery, r = 0 and we get same as before

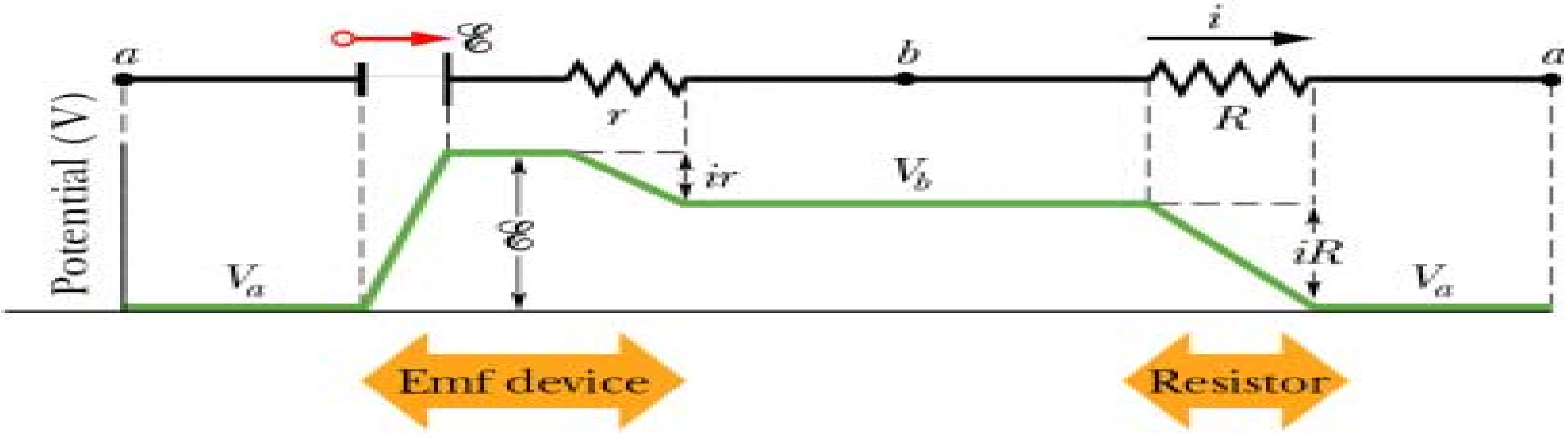
$$\mathcal{E} = iR$$

Circuits (17)

- Can represent changes in potential graphically

$$\mathcal{E} - ir - iR = 0$$

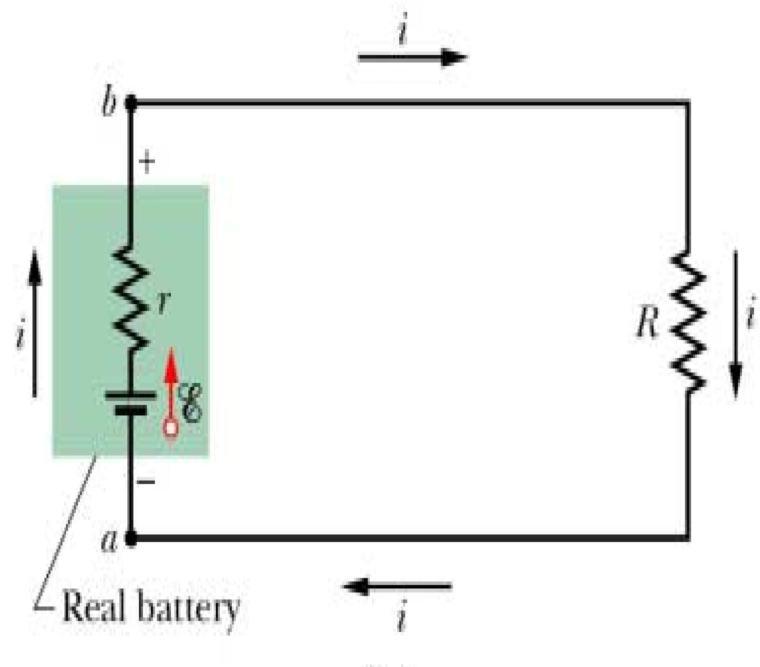




(b)

Circuits (18)

- What is the potential difference, *V*, between points a and b?
- To find *V* between any 2 points in circuit
  - Start at one point and traverse circuit to other following any path
  - Add changes in V algebraically

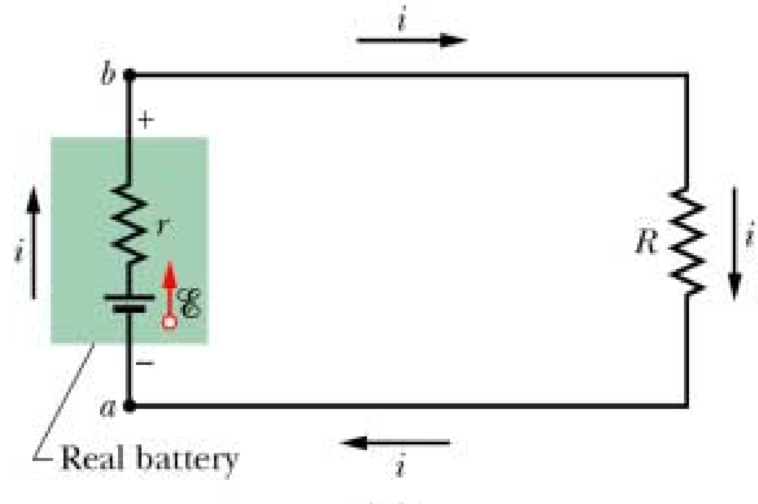


Circuits (19)

- Moving from b to a clockwise gives

$$V_b - iR = V_a$$

$$V_b - V_a = iR$$



- From loop rule know

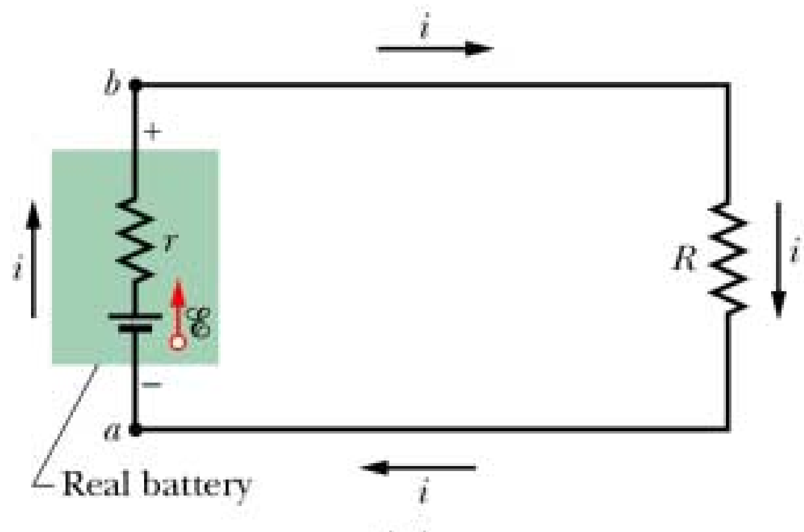
$$\mathcal{E} - ir - iR = 0$$

$$i = \frac{\mathcal{E}}{r + R}$$

Circuits (20)

$$V_b - V_a = iR$$

$$i = \frac{\mathcal{E}}{r + R}$$



- Substituting for *i* gives

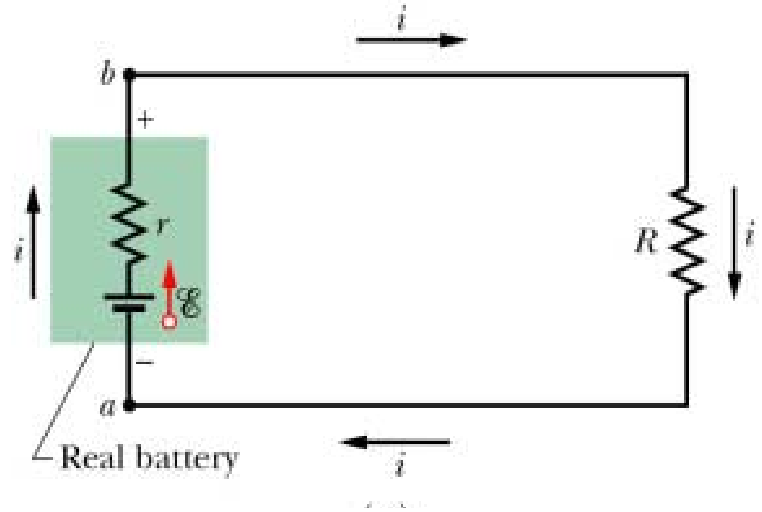
$$V_b - V_a = \mathcal{E}\frac{R}{R + r}$$

Circuits (21)

- Now move from b to a counterclockwise

$$V_b + ir - \mathcal{E} = V_a$$

$$V_b - V_a = \mathcal{E} - ir$$



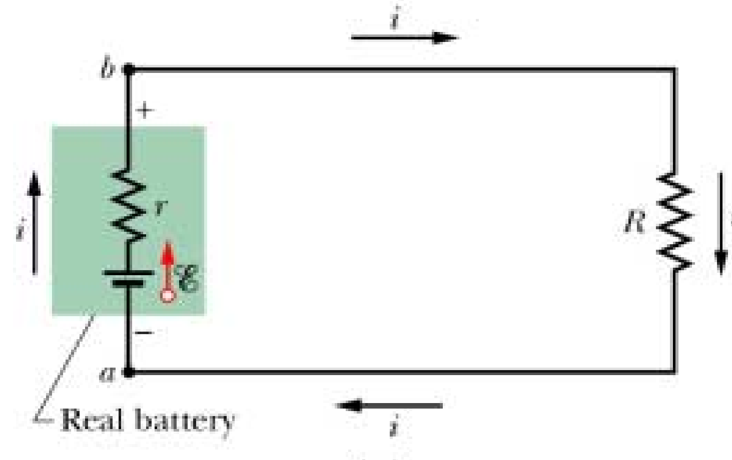
- Substituting *i* from loop rule

$$i = \frac{\mathcal{E}}{r + R}$$

$$V_b - V_a = \mathcal{E}\frac{R}{R + r}$$

Circuits (22)

- Suppose $\mathcal{E}$ = 12V, R=10 Ω and r=2Ω
- Potential across battery's terminals is



$$V_b - V_a = \mathcal{E}\frac{R}{R+r} = (12V)\frac{10\Omega}{10\Omega+2\Omega} = 10V$$

- *V* across terminals only equal to $\mathcal{E}$ if no internal resistance (*r* =0) or no current (*i* =0)

Circuits (23)

- A real battery transfers energy to
  - Charge carriers through a chemical reaction
  - Thermal energy due to internal resistance (called resistive dissipation)
- Net energy transfer or power from an emf device to charge carries is
  - Where V is across terminals

$$P = iV$$

Circuits (24)

- For real battery just found $$V_b - V_a = \mathcal{E} - ir$$
- Substituting gives:

$$P = iV = i(\mathcal{E} - ir) = i\mathcal{E} - i^2 r$$

Internal dissipation rate, P_r

$$P_r = i^2 r$$

Power of emf device, P_{emf}

$$P_{emf} = i\mathcal{E}$$