Ohm's Law

- So far have assumed that *R* is independent of the magnitude and polarity of the applied *V*

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

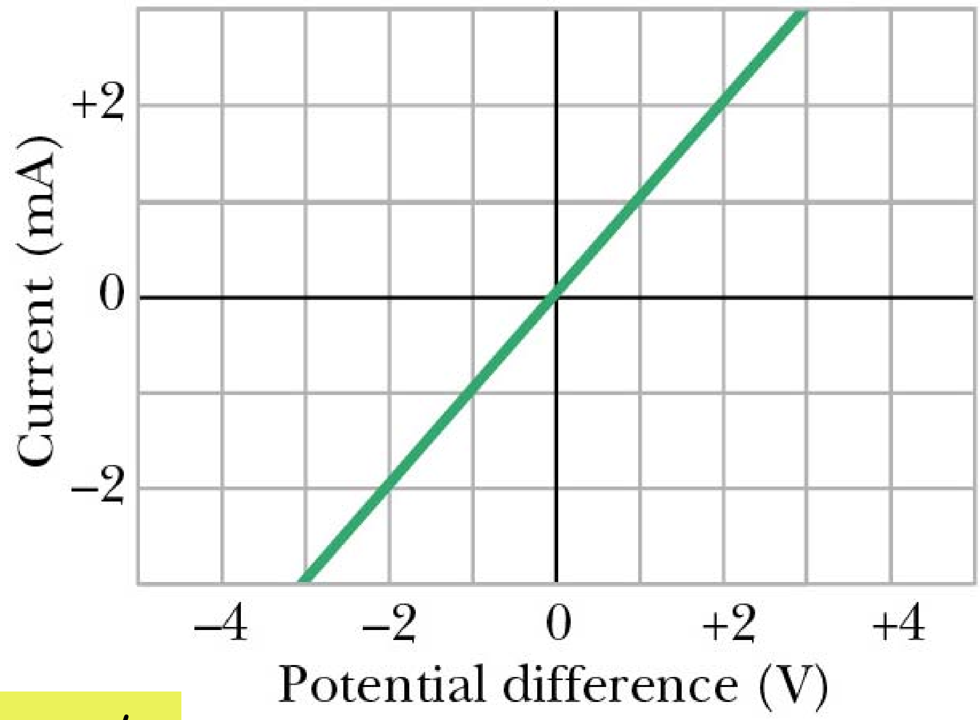
- This is known as Ohm's law

$$V = iR$$

- Ohm's law is not generally valid, but it is a good empirical rule for most systems

Ohm's Law

- **Ohm's law** asserts that current through a device is always directly proportional to the *V* applied to the device
- Plot of *i* vs. *V* is a straight line
  - Slope (i/V) is the same for all values of V

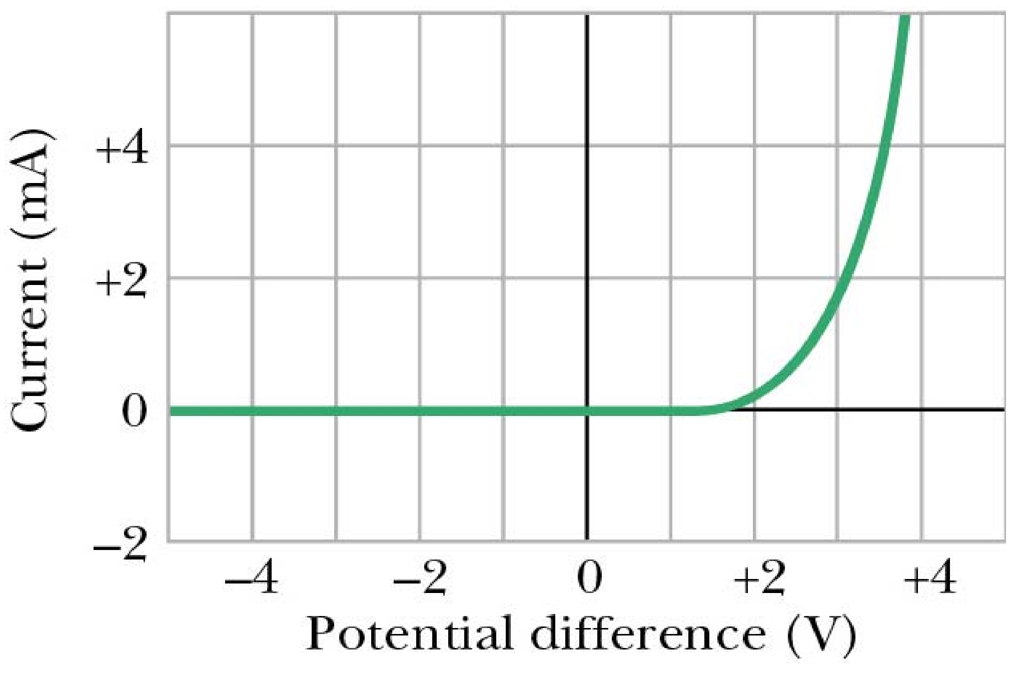


$$R = V/i$$

- A conducting device obeys Ohm's law when *R* is independent of size and direction of *V*

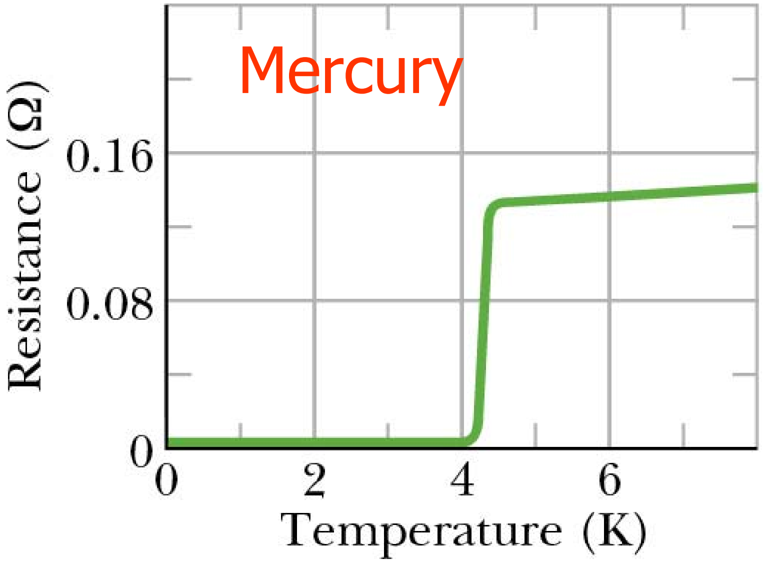
Semiconductors

- What about this graph?
- It's for a semiconductor
  - (Not all materials obey Ohm's law)



Superconductors

- Superconductors: *R* goes to zero at some finite *T*
- Once charges start moving no thermal losses - current forever
- Temperatures are usually very low (4-20 K)



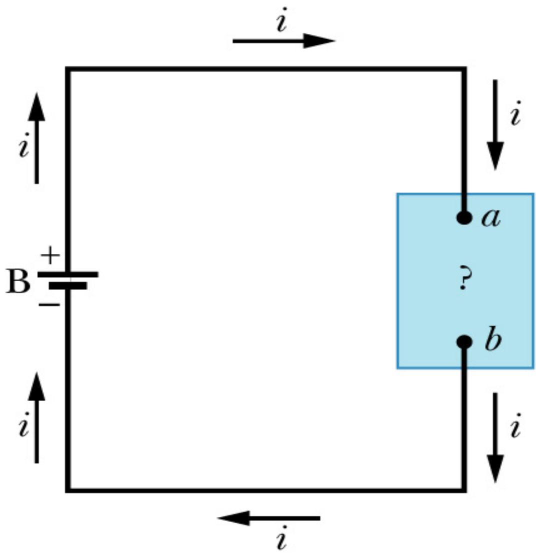
Electric Power

- Calculate the amount of power, *P*, in a circuit

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

$$dU = dq\,V = i\,dt\,V$$

$$P = iV$$



- SI unit is watt, W

$$1W = 1V \cdot A$$

Electric Power

- Transfer potential energy, *U*, to some other form
- For resistors energy is transferred to thermal energy – heat
- Use resistance definition to find

$$P = iV$$

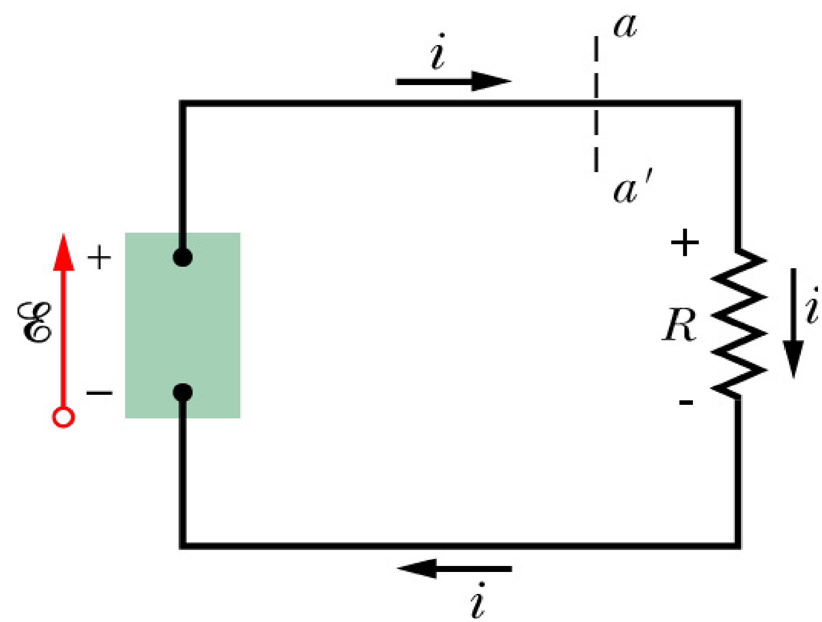
$$R = \frac{V}{i}$$

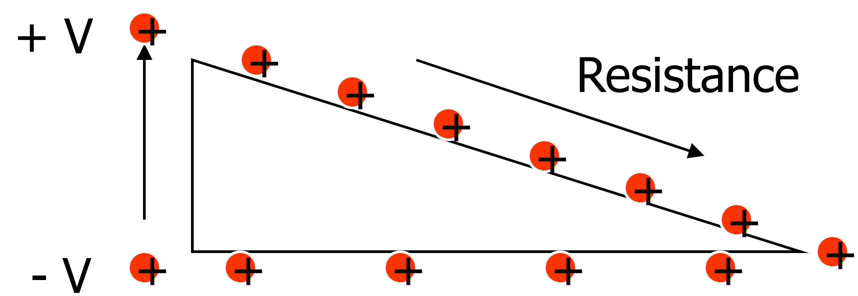
$$P = i^2 R$$

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

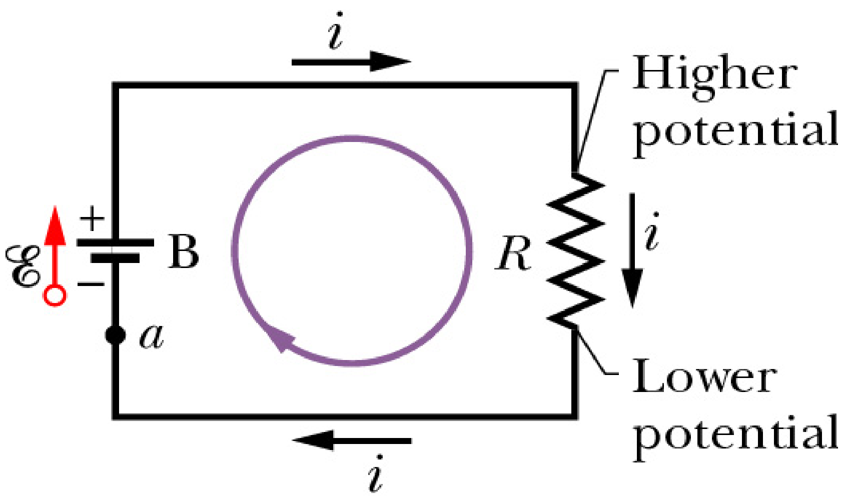
Electromotive Force

- emf device (label terminal at higher *V* as + and lower *V* as –)
- Draw emf, ☜, arrow from – to + terminal
- Label the R with a + and -
- + charge carriers are moved against the *Electric* field in emf device from lower (-) to higher (+) *V*. The emf must do work on the charge. Normally this is supplied by chemical energy.





Electromotive Force

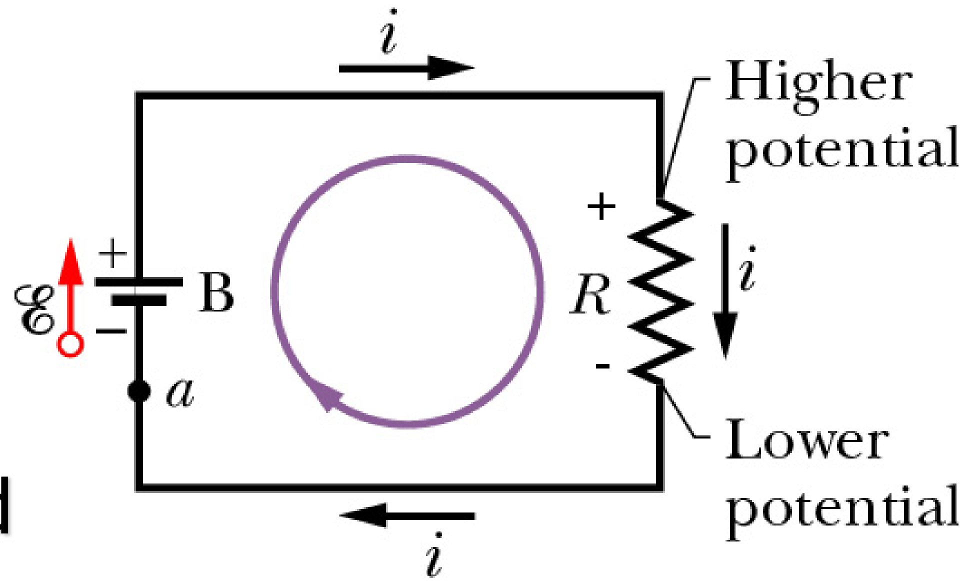


Ohm's Law: $$E = iR$$

(the E supplies the potential difference V)

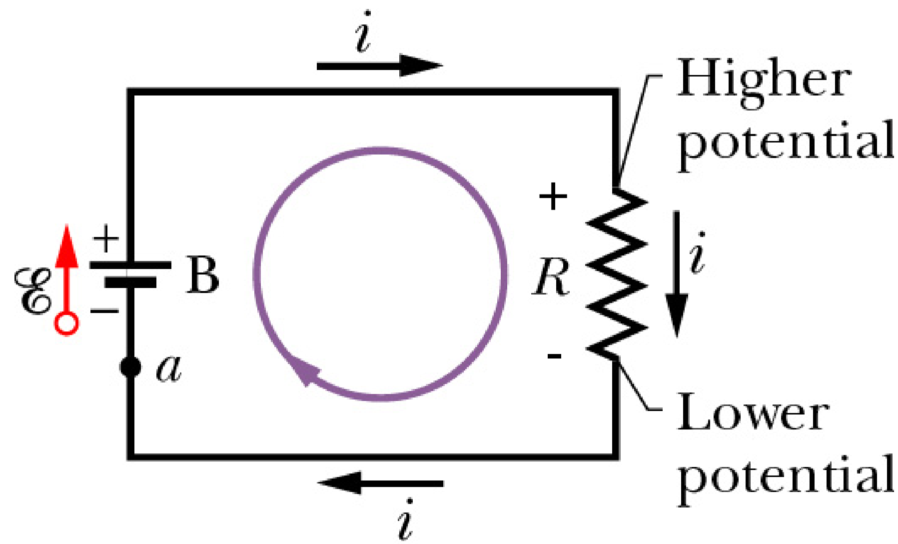
Simplest Circuit

- Calculate the current in single-loop circuit
- Use potential method (as called by the text book).
- Travel around circuit in either direction and algebraically add potential differences



Simplest Circuit

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



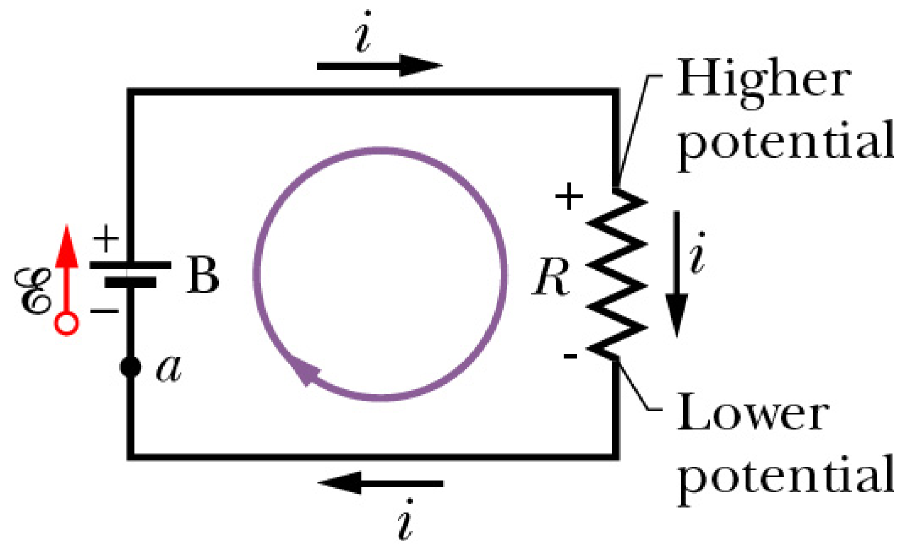
$$V_a + E$$

Simplest Circuit

- 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



$$V_a + E - iR = V_a$$

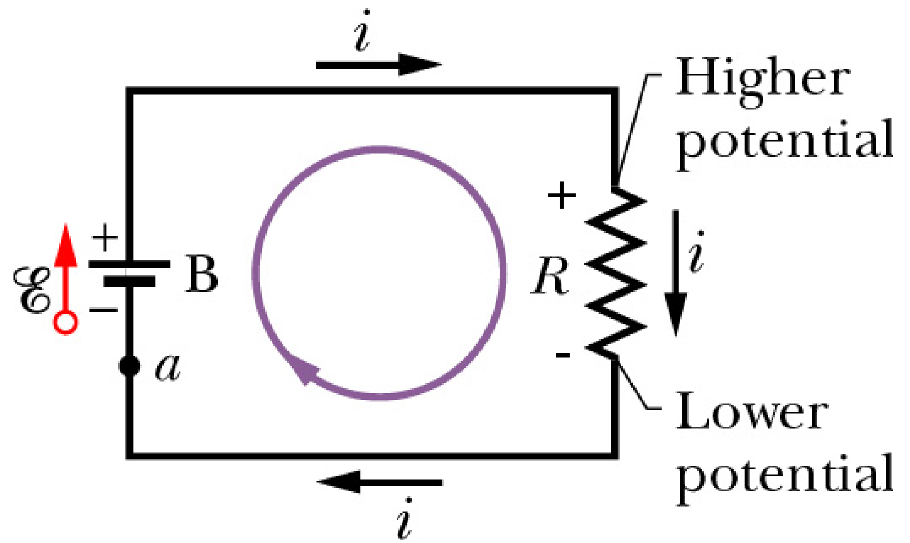
Simplest Circuit

- We get back to Ohm's Law

$$\mathcal{E} = iR$$

- Could move around circuit counterclockwise

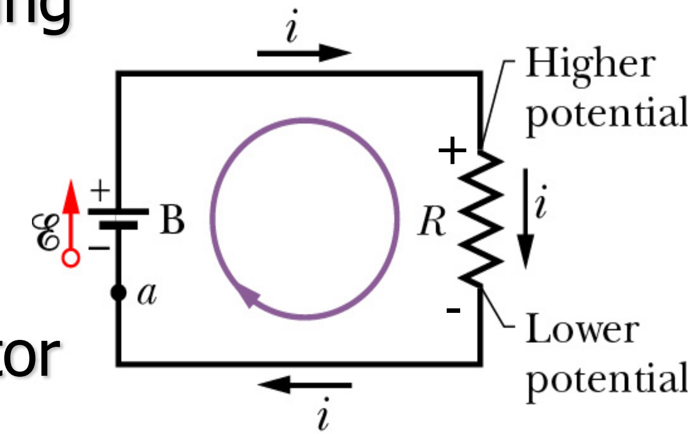
$$V_a - \mathcal{E} + iR = V_a$$



$$\mathcal{E} = iR$$

Kirchoff's rules

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



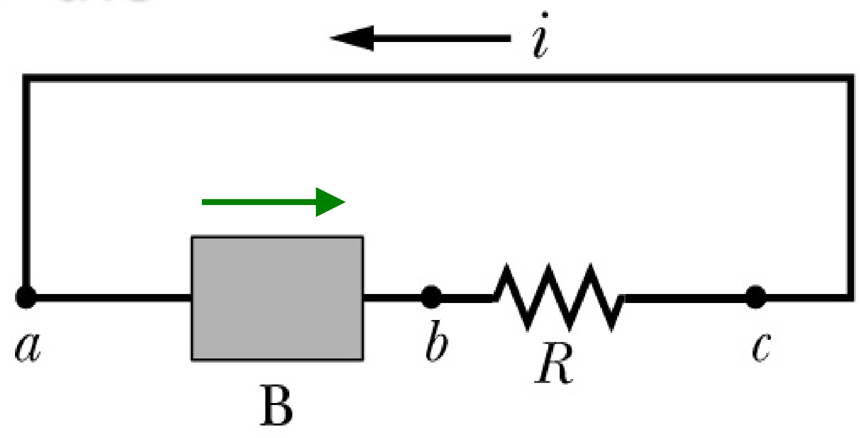
<u>How do we add the changes in V?</u>

- Resistance – Move through resistor in direction of current $V=-iR$ (- because it is down the hill), in opposite direction $V=+iR$ (+ because we move up the hill)
- Emf – Move lower (-) to (+) adds potential and $V=+\mathcal{E}$, in the opposite direction $V=-\mathcal{E}$.

Exercise

- A) What direction should the emf arrow point?

RIGHTWARD



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

All same

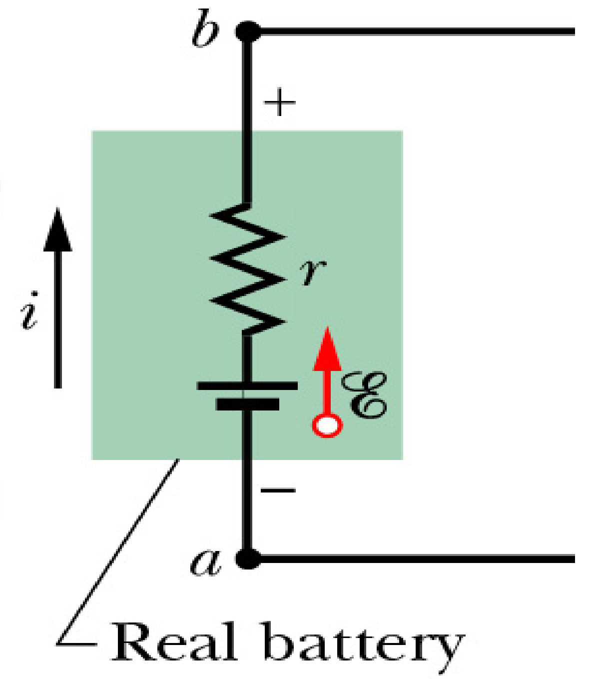
- C) Rank V and U.

b, then a and c tie

Batteries

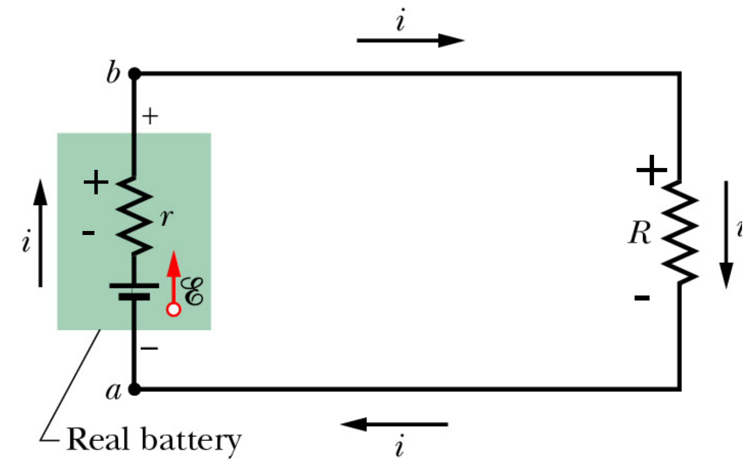
- So far assumed ideal battery – has no internal resistance

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



Circuits with batteries

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



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

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

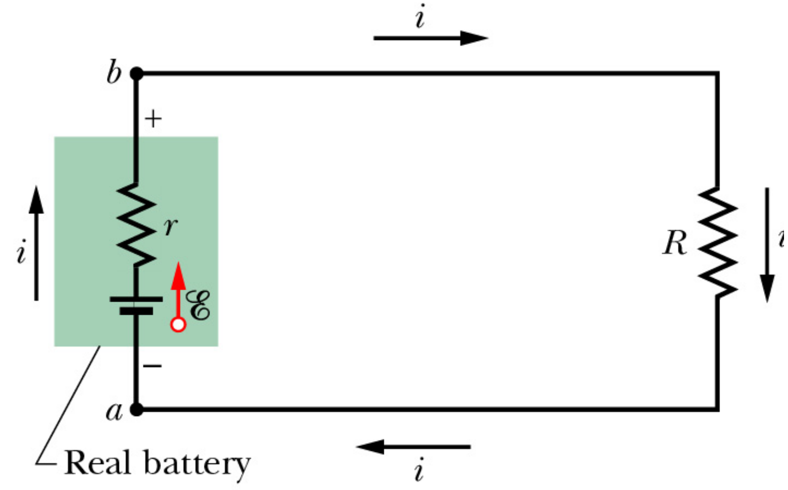
- For ideal battery, r = 0 and we get same as before

$$\mathrm{E} = iR$$

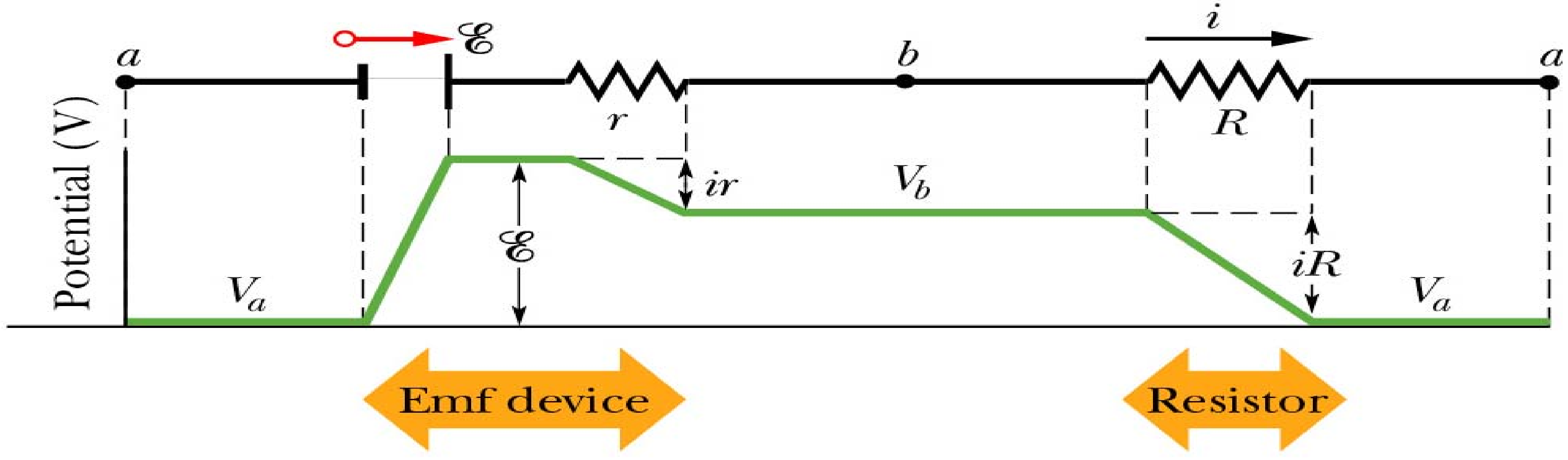
Potential gains and drops

- Can represent changes in potential graphically

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



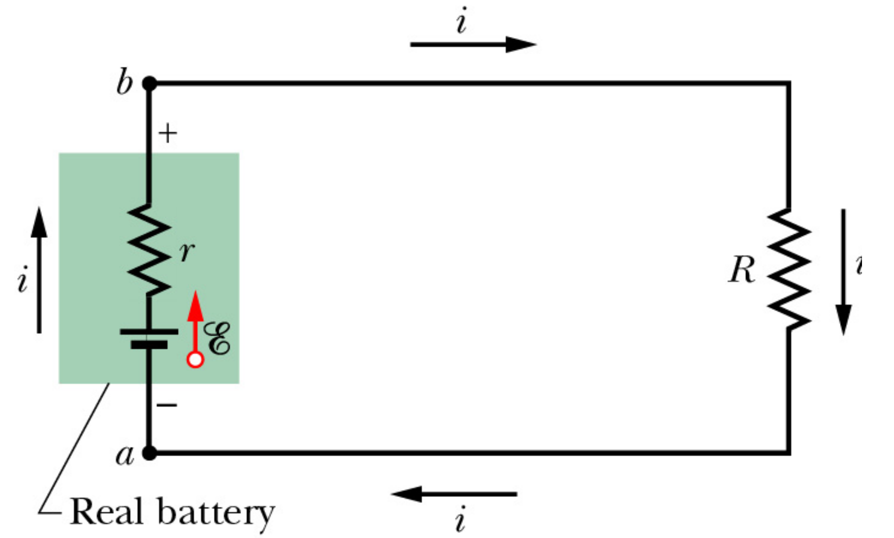
(a)



(b)

Example

- 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

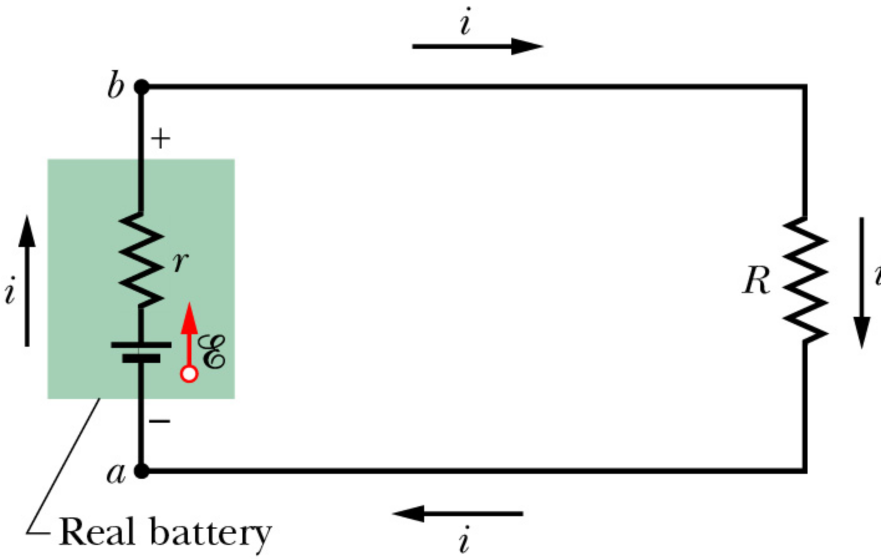


Example

- Moving from b to a clockwise gives

$$V_b - iR = V_a$$

$$V_b - V_a = iR$$



- From loop rule know

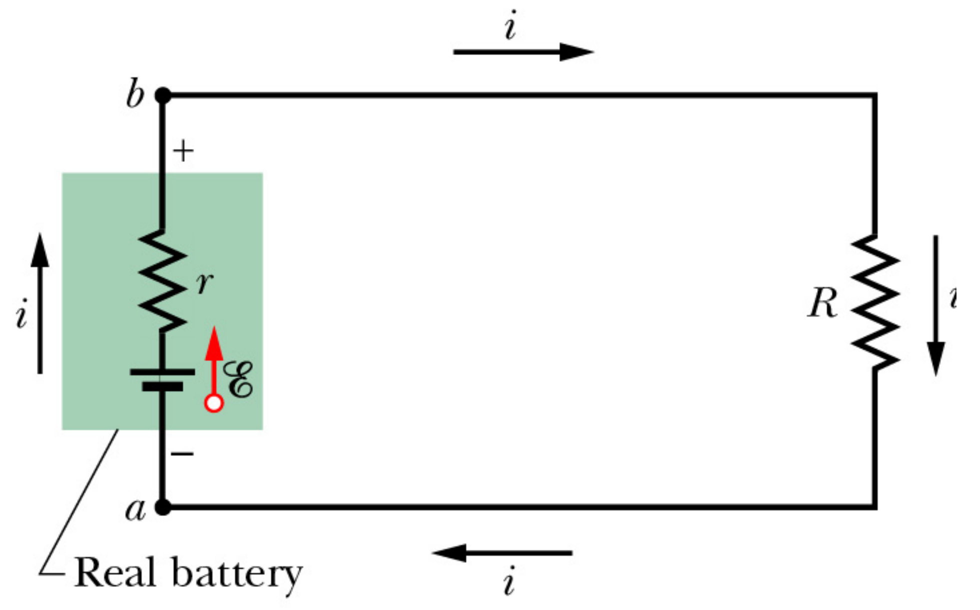
$$\mathrm{E} - ir - iR = 0$$

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

Example

$$V_b - V_a = iR$$

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



- Substituting for *i* gives

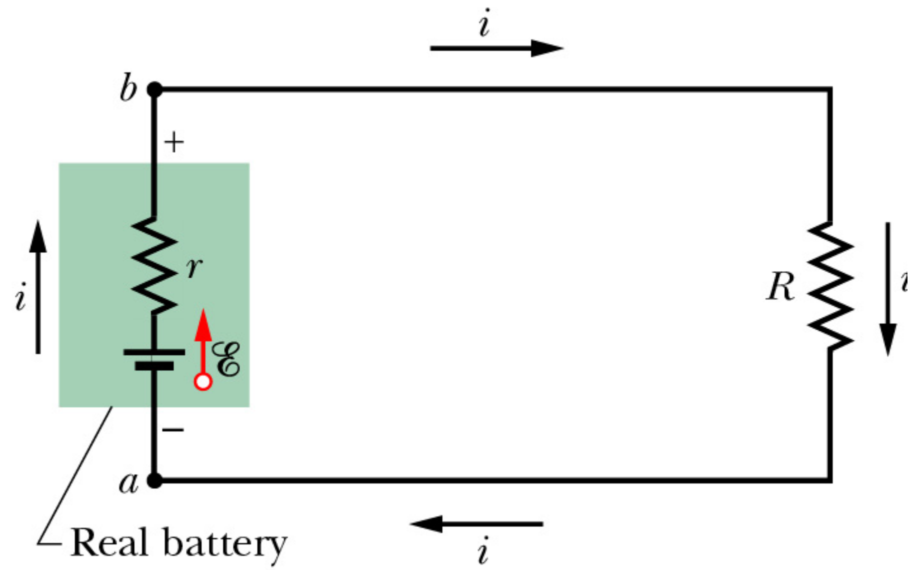
$$V_b - V_a = \mathcal{E}\frac{R}{R+r}$$

Example

- Now move from b to a counterclockwise

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

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



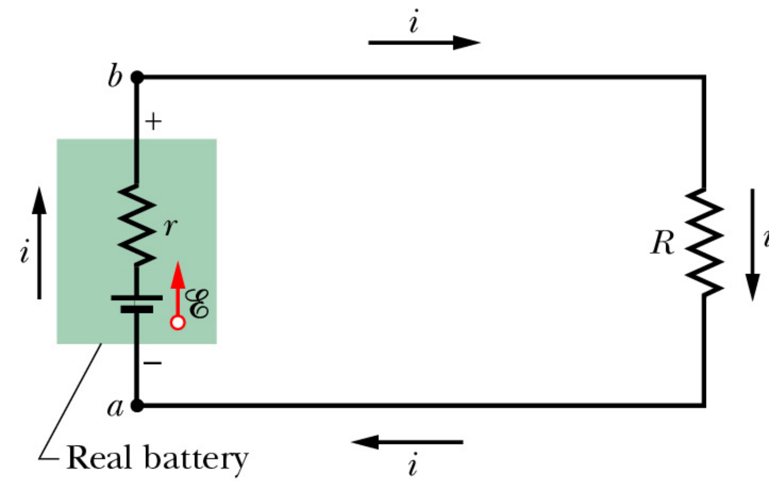
- Substituting *i* from loop rule

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

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

Exercise

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



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

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