Lecture 26

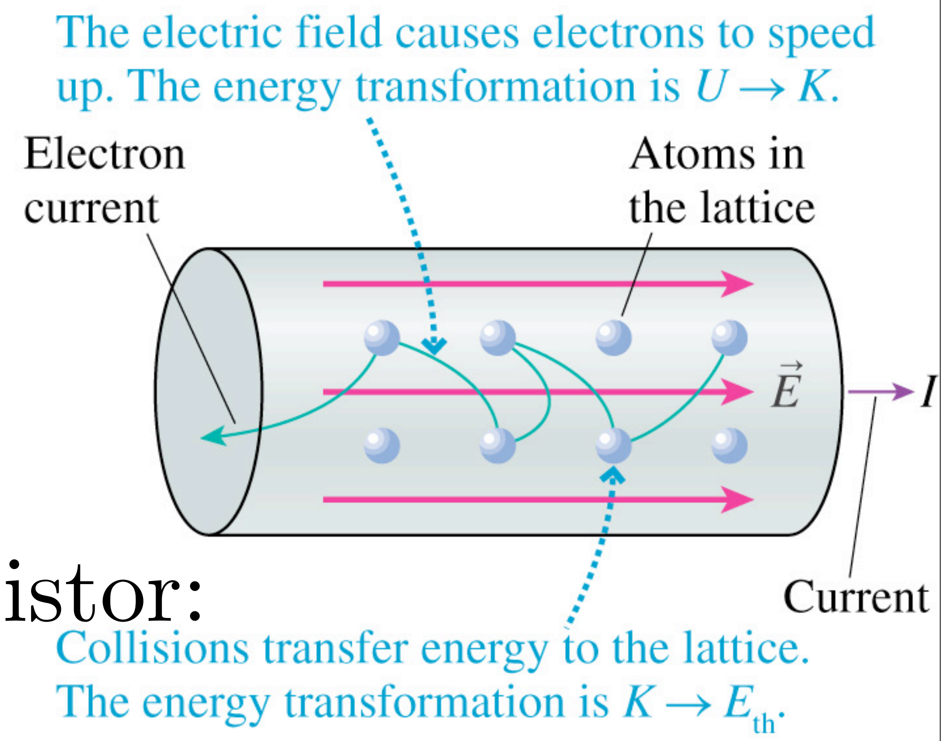
- Energy and Power
- Resistors in Series
- Real batteries
- Resistors in Parallel
- Example of Resistor Circuits
- Grounding

Energy and Power

- In battery: chemical energy → potential...of charges: $\Delta U = q\Delta V_{bat} = q\mathcal{E}$
- power (rate at which energy supplied to charges): $P_{bat} = \frac{dU}{dt} = \frac{dq}{dt}\mathcal{E}$

$P_{bat} = I\mathcal{E}$ (power delivered by an emf)

- In resistor: work done on charges qEd ⟶ kinetic (accelerate) between collisions ⟶ thermal energy of lattice after collisions



After many collisions over length L of resistor:

$\Delta E_{th} = qEL = q\Delta V_R$

rate at which energy is transferred from current to resistor:

$P_R = \frac{dE_{th}}{dt} = \frac{dq}{dt}\Delta V_R = I\Delta V_R$

For basic circuit: $P_R = P_{bat}$ (energy conservation)

Using Ohm's law: $P_R = I\Delta V_R = I^2R = \frac{(\Delta V_R)^2}{R}$ (power dissipated by a resistor)

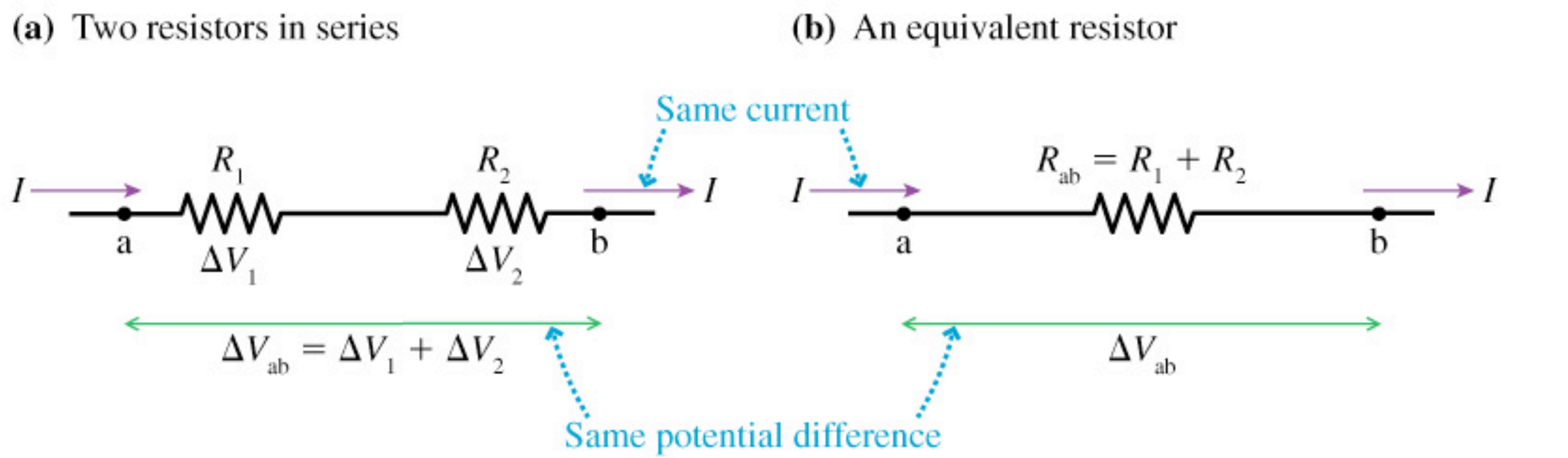
$E_{chem} \to U \to K \to E_{th} \to$ light...

- Common units: P_R kW in Δt hours → $P_R\Delta t$ kilowatt hours

Example on electric power

- A standard 100 W (120 V) lightbulb contains a 9.00 cm-long tungsten filament. The high-temperature resistivity of tungsten is 9.0 x 10^{-7} ohm-meter. What is the diameter of the filament?

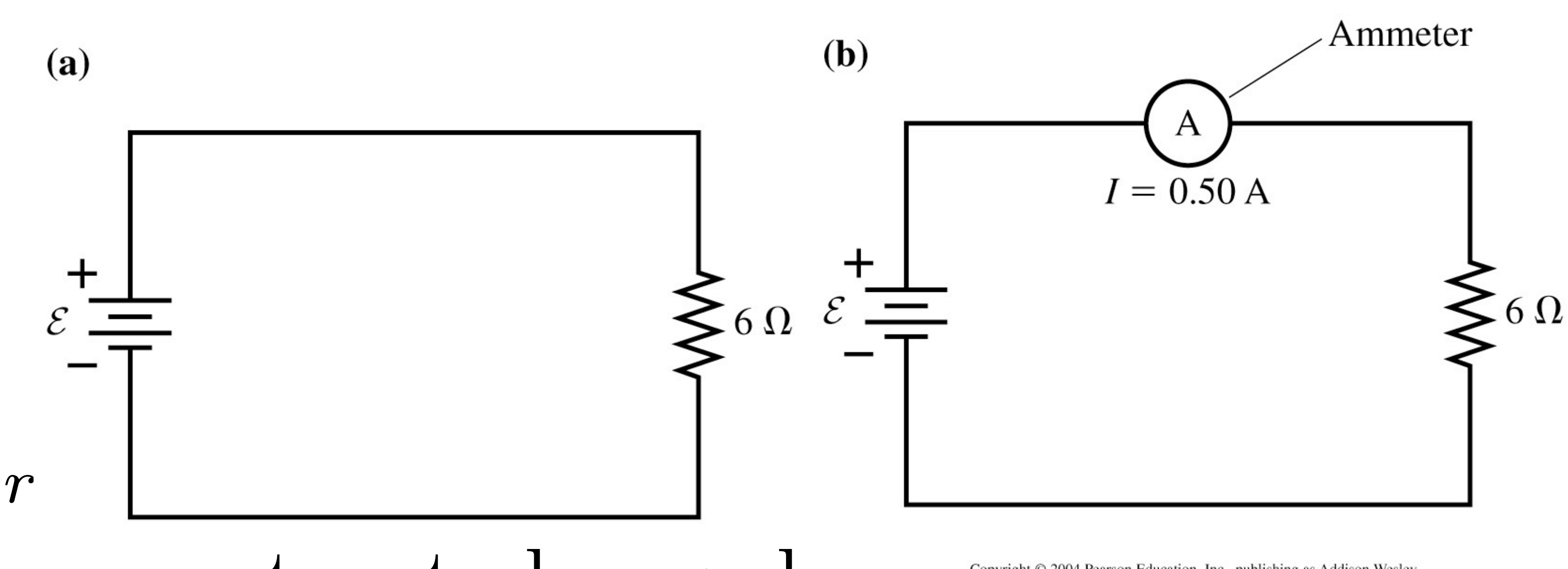
Resistors in Series



- current same in each resistor: $\Delta V_1 = IR_1;\, \Delta V_2 = IR_2 \Rightarrow \Delta V_{ab} = I\,(R_1 + R_2)$
- equivalent resistor: $R_{ab} = \frac{\Delta V_{ab}}{I} = \frac{I(R_1+R_2)}{I} = R_1 + R_2$

$$R_{eq} = R_1 + R_2 + \cdots + R_N \qquad \text{(series resistors)}$$

Ammeters

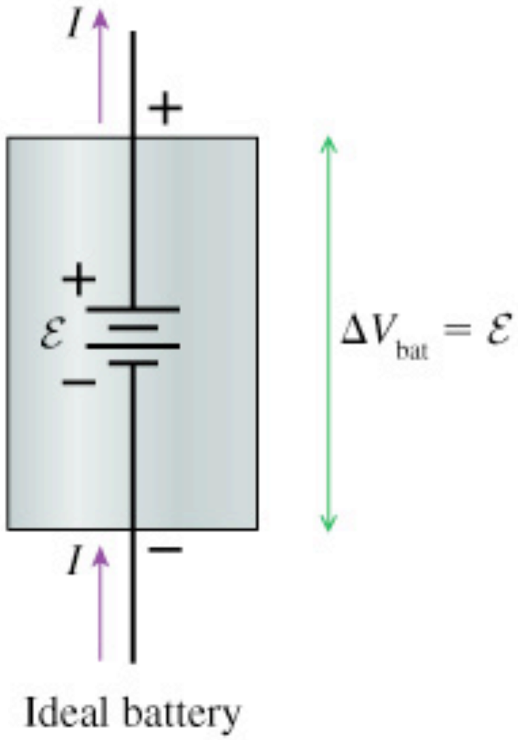


- measures current in circuit element (placed in series):

$$R_{eq} = R_{load} + R_{ammeter}$$

ideal, $R_{ammeter} = 0 \Rightarrow$ current not changed

Real Batteries

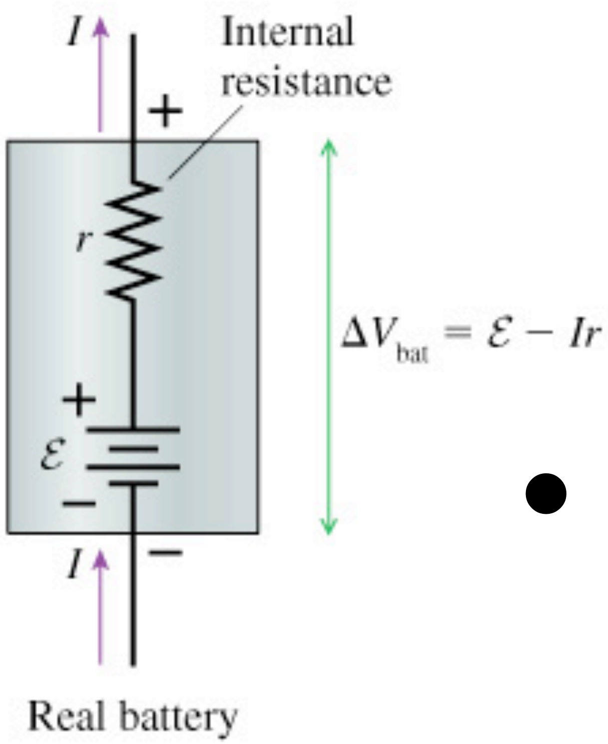


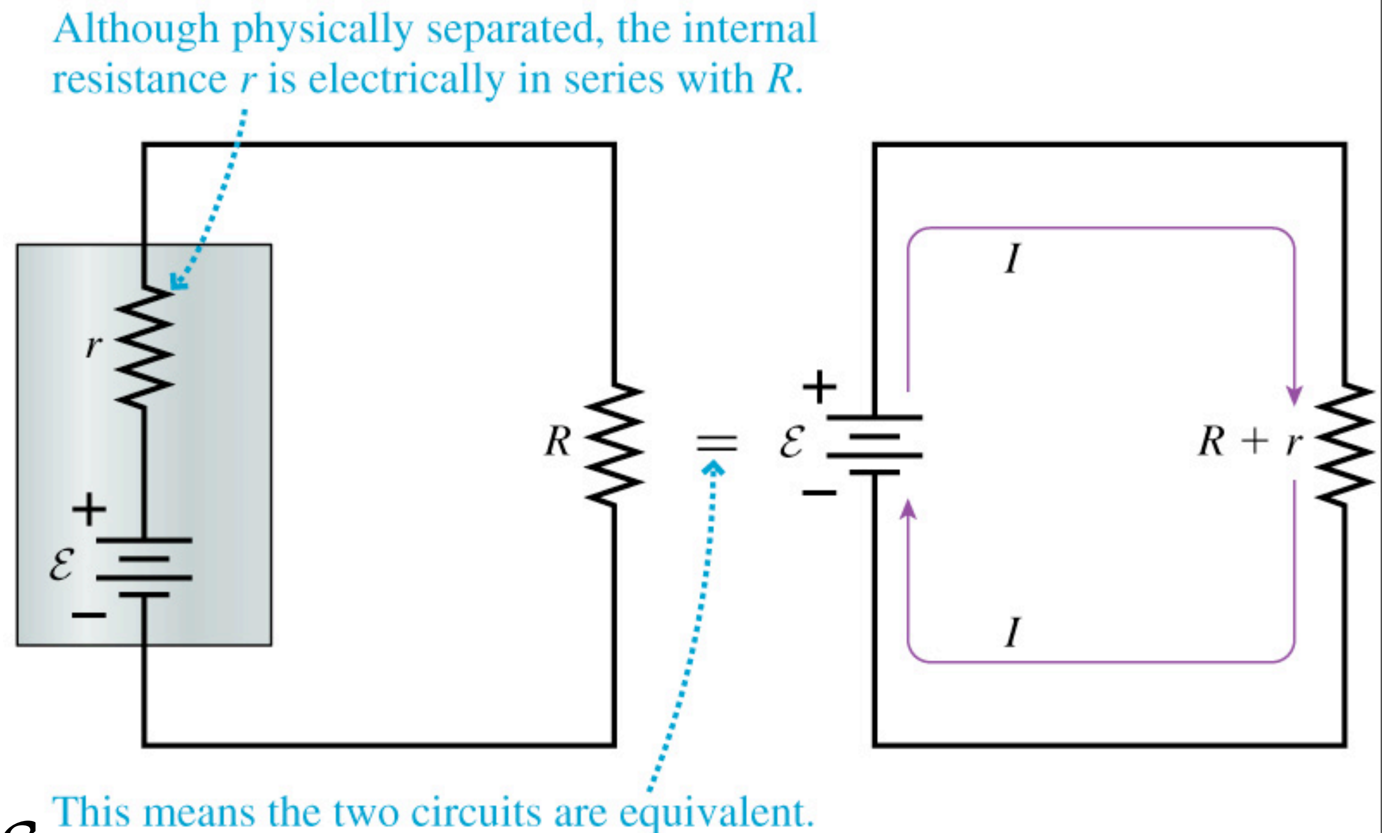
- terminal (user) voltage

$$\Delta V_{bat} = E - I r$$

- for resistor connected:

$$I = \frac{\mathcal{E}}{R_{eq}} = \frac{\mathcal{E}}{R+r}$$
$$\Delta V_R = IR = \frac{R}{R+r}\mathcal{E}$$
$$\Delta V_{bat} = \mathcal{E} - Ir;$$
$$\Delta V_R = \Delta V_{bat} \neq \mathcal{E}$$

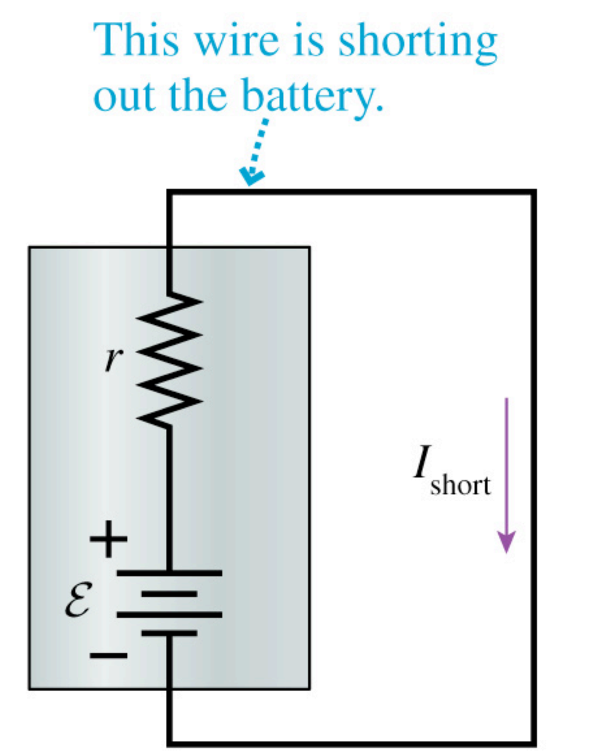




Short Circuit

- replace high by zero resistance → $I_{short} = \frac{E}{r}$ (∞ for ideal, $r = 0$)

- maximum possible current battery can produce



Parallel Resistors

- potential differences same:

$$\Delta V_1 = \Delta V_2 == V_{cd}$$

- Kirchhoff's junction law: $I = I_1 + I_2$
- Ohm's law:

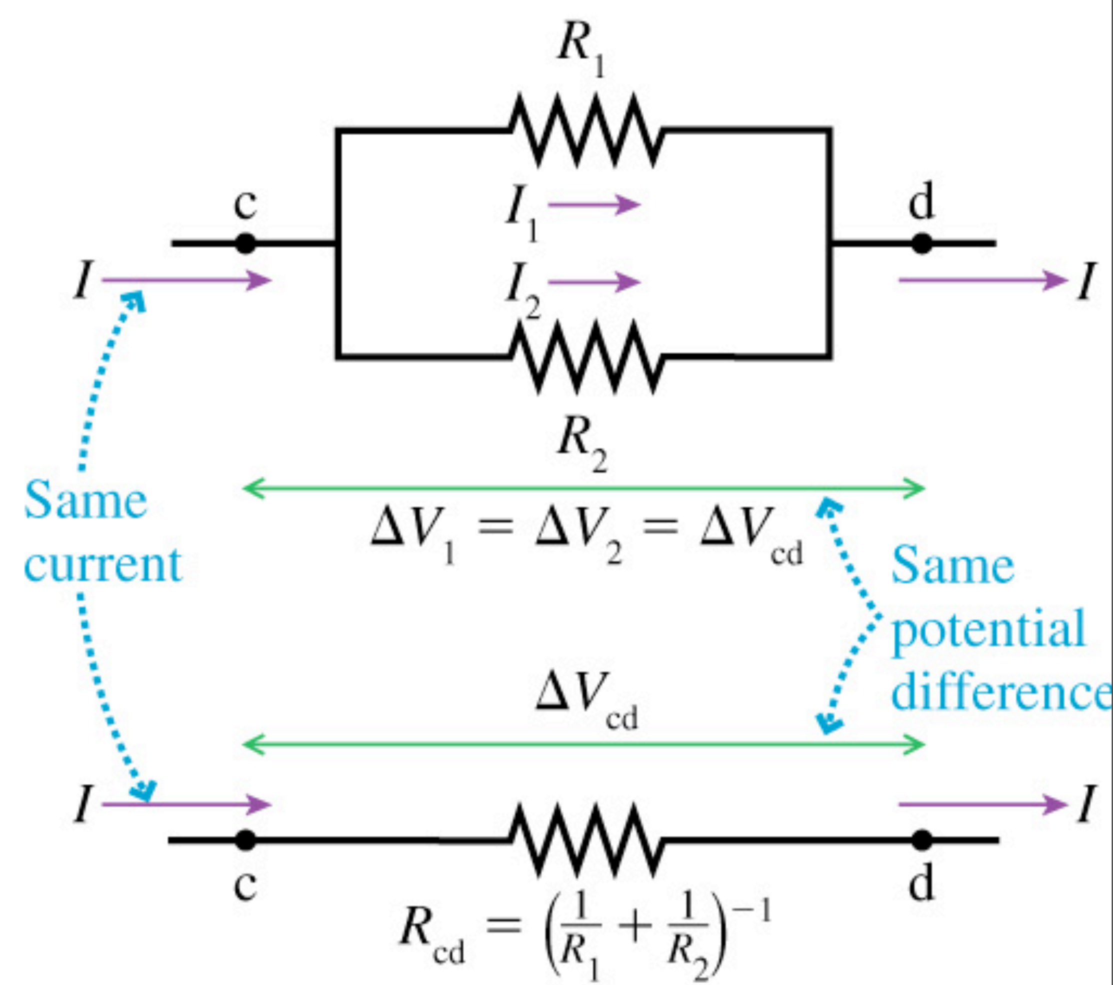
$$I = \frac{\Delta V_1}{R_1} + \frac{\Delta V_2}{R_2} = \Delta V_{cd}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

- Replace by equivalent resistance:

$$R_{cd} = \frac{\Delta V_{cd}}{I} = \left[\frac{1}{R_1} + \frac{1}{R_2}\right]^{-1}$$

$$R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}\right)^{-1} \quad \text{(parallel resistors)}$$

(a) Two resistors in parallel



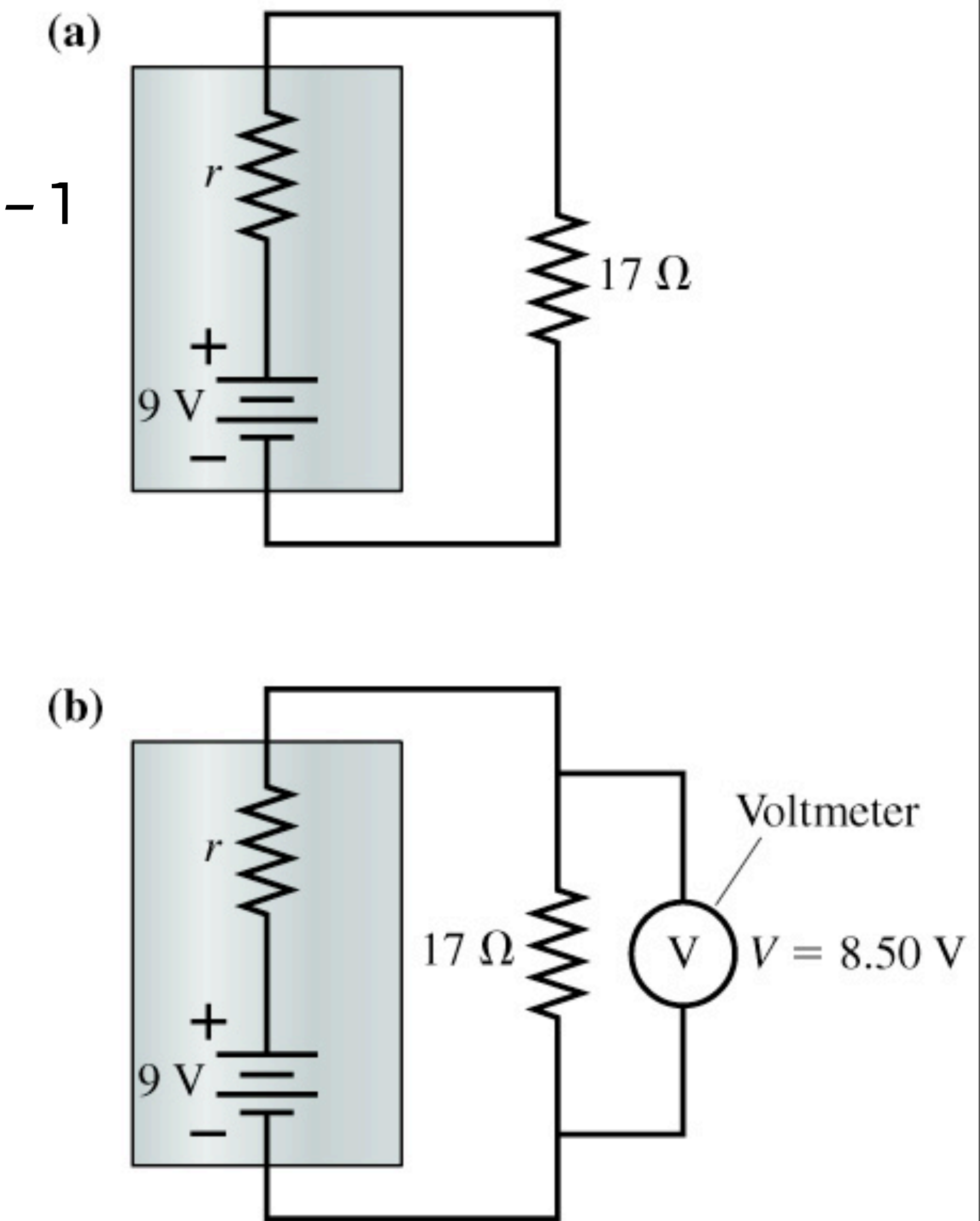
(b) An equivalent resistor

- Identical resistors($R_1 = R_2$): $R_{series\ eq} = 2R$; $R_{parallel\ eq} = \frac{R}{2}$
- In general, $R_{eq} < R_1$ or R_2...in parallel

Voltmeters

- measure potential difference across circuit element (place in parallel; don't need to break connections, unlike for ammeter)
- total resistance: $R_{eq} = \left(\frac{1}{R} + \frac{1}{R_{voltmeter}}\right)^{-1}$
- in order not to change voltage:

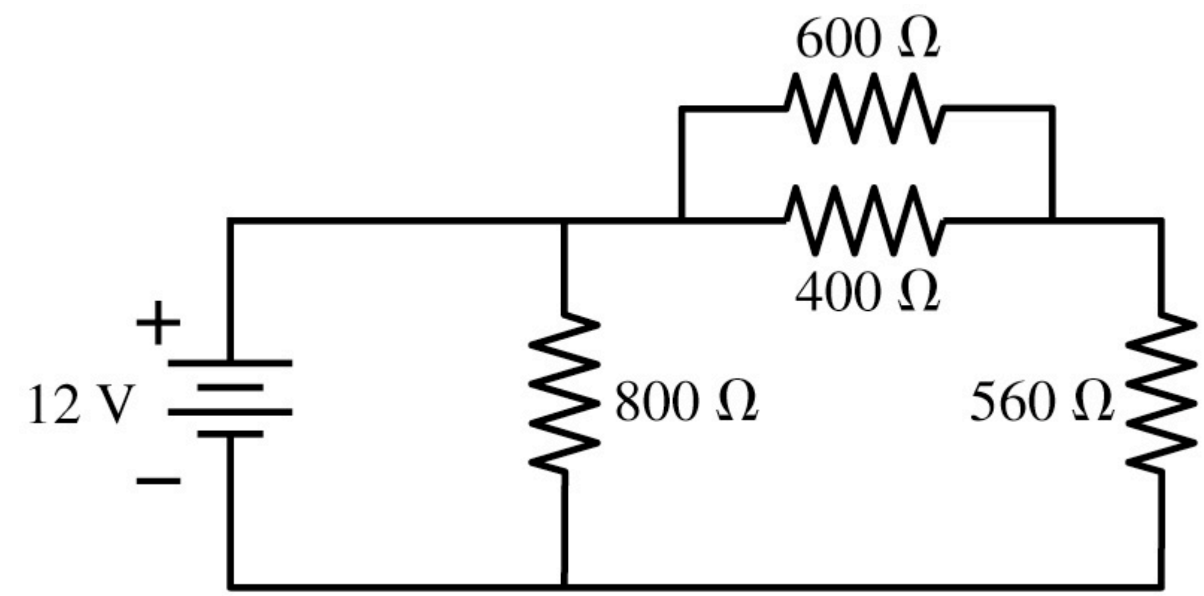
$$R_{voltmeter} \gg R \text{ (ideally, } \infty)$$



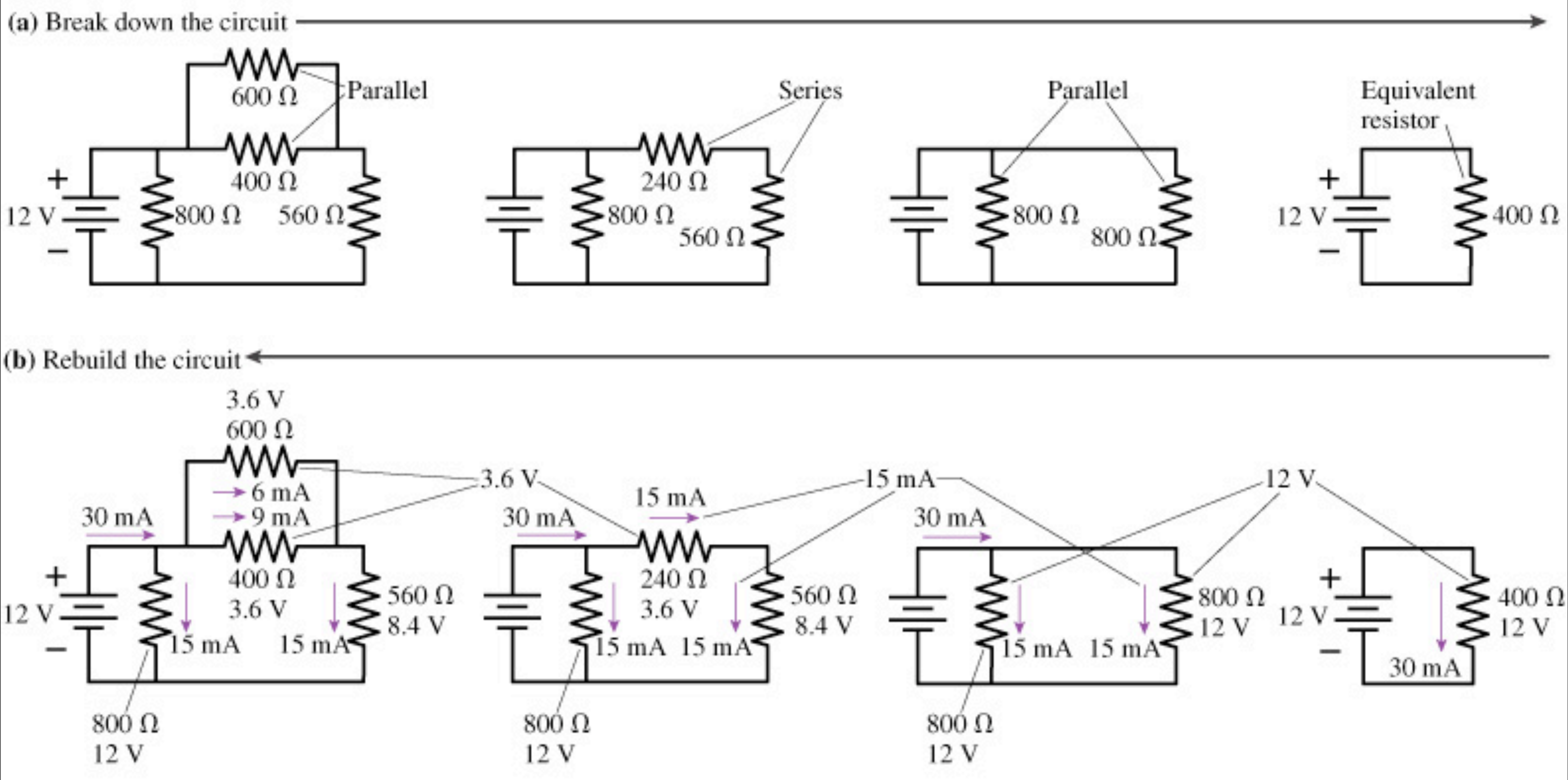
Strategy for Resistor Circuits

- assume ideal wires, batteries
- use Kirchhoff's laws and rules for series and parallel resistors
- reduce to equivalent resistor (basic circuit)
- rebuild using current same for series and potential difference same for parallel

Example of Resistor Circuit



- Find I and ΔV for each resistor



Grounding

- so far, potential difference, ΔV (physically meaningful), enters Ohm's law (no need to establish zero point)
- need common reference point for connecting 2 circuits
- grounding: connect 1 point in circuit to earth ($V_{earth} = 0$) by ideal wire: no return wire (no current); wire is equipotential $\longrightarrow$ point in circuit has earth's potential $\longrightarrow$ specific value of potential at each point
- does not change how circuit functions... unless malfunction/breaking of circuit (enclose circuit in grounded case insulated from circuit): case comes in contact with circuit ($\longrightarrow$ touching would have caused electrocution) $\longrightarrow$ current thru' wire (fuse blows...)