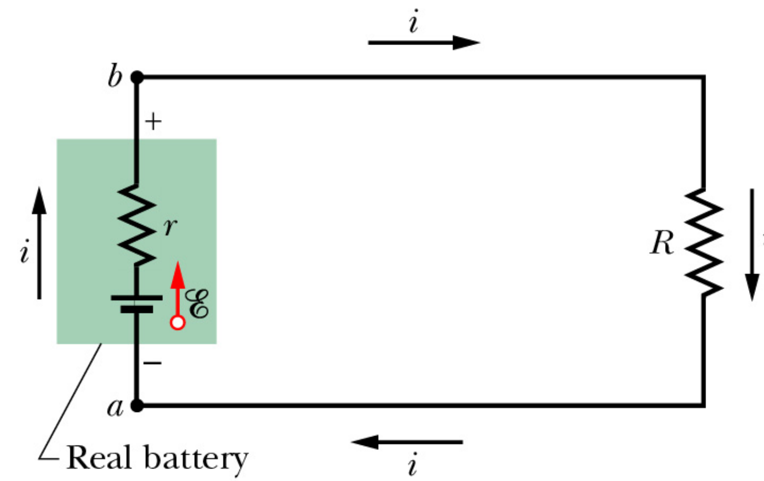
# Exercise

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

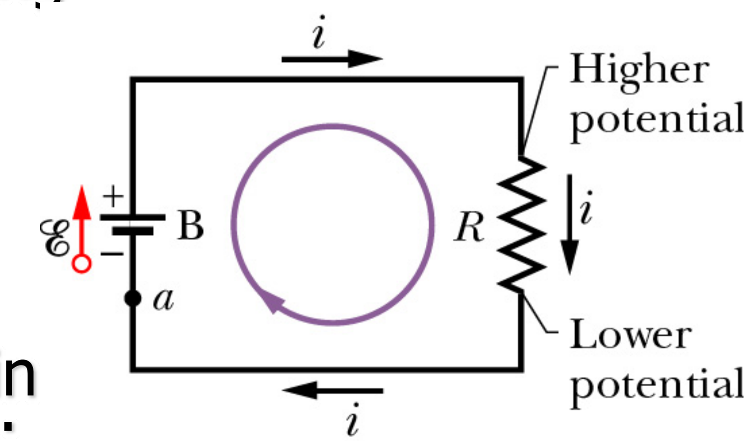



$$V_b - V_a = \mathrm{E}\frac{R}{R+r} = (12V)\frac{10\Omega}{10\Omega + 2\Omega} = 10V$$

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

# Review

- 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 $V = -iR$ (+ to -; higher to lower), in opposite direction $V = +iR$ (- to +; up the hill).

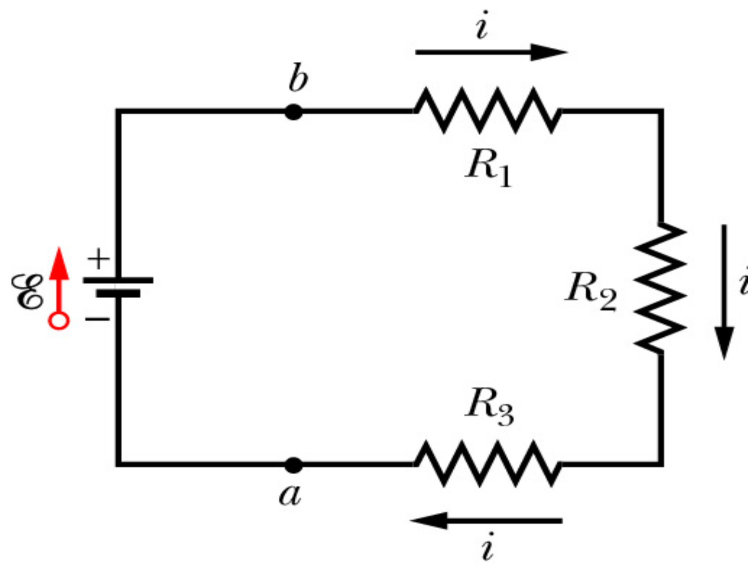
- Emf rule – Move through emf device $V = +\mathcal{E}$ going – to +, in opposite direction $V = -\mathcal{E}$.

# Resistors in Series

- Resistors in series (one path from b to a)
- Have identical currents, *i*, through them
- Use Kirchhoff's loop rule

$$\mathrm{E} - iR_1 - iR_2 - iR_3 = 0$$

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

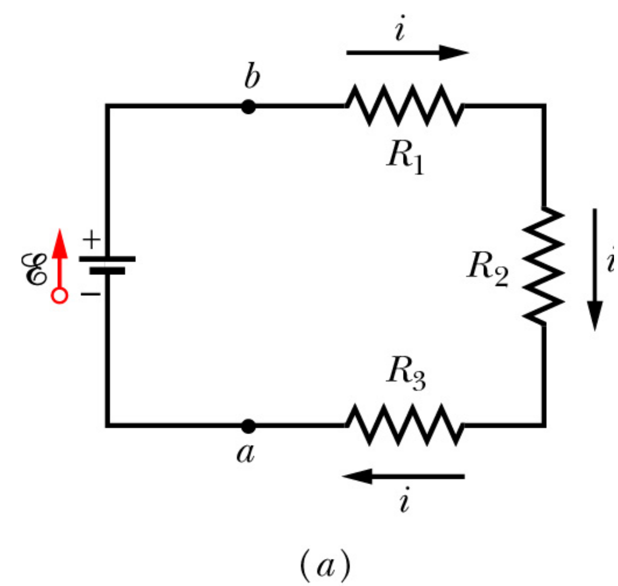


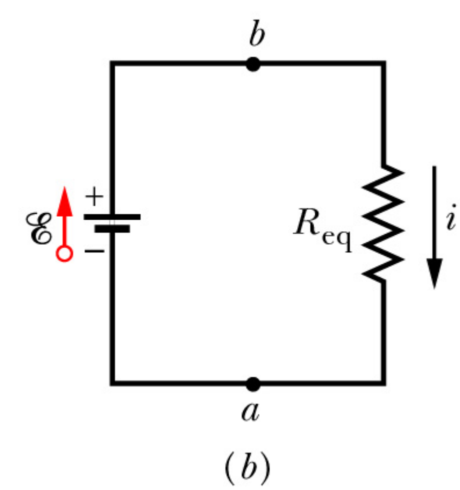
# Resistors in Series

- Resistors in series
- The 3 resistors act the same as an equivalent resistor $R_{eq.}$

$$i = \frac{E}{R_1 + R_2 + R_3} = \frac{E}{R_{eq}}$$

$$R_{eq} = R_1 + R_2 + R_3$$

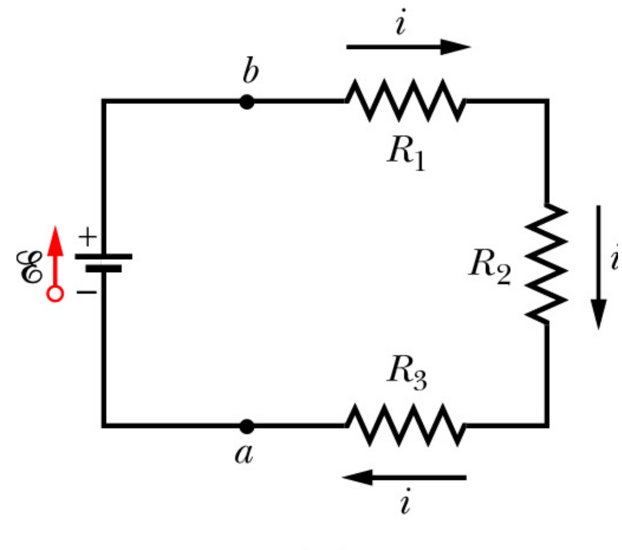


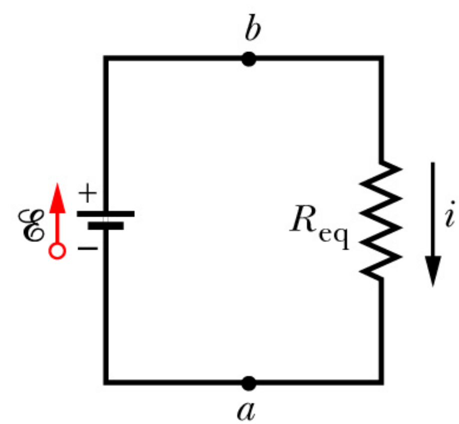
# Resistors in Series

- Resistors in series
- Resistors have identical currents, *i*
- Sum of *V*s across resistors = applied *V*
- $R_{eq}$ is sum of all resistors

$$R_{eq} = \sum_{j=1}^{n} R_j$$



(a)



(b)

# Exercise

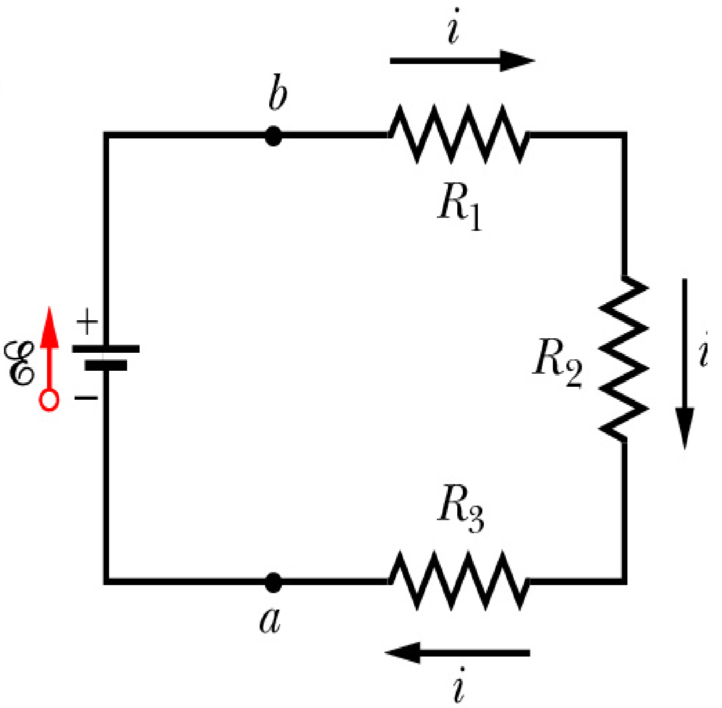
- If R1>R2>R3, rank greatest first
- A) current through resistors

  i is same for all, tie

$$V = iR$$

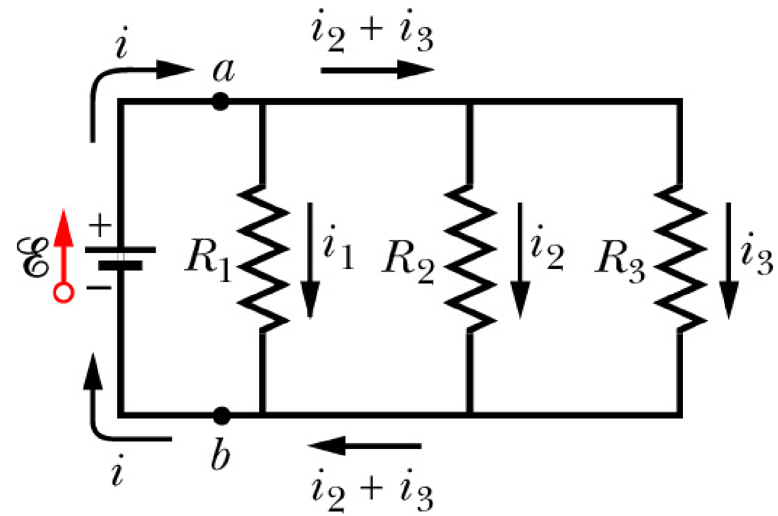
- B) V across them

  R1, R2, R3



# Resistors in Parallel

- Resistors in parallel
- Have same V across them
- Arbitrarily choose direction for currents in each branch
- Write down current relation for each resistor



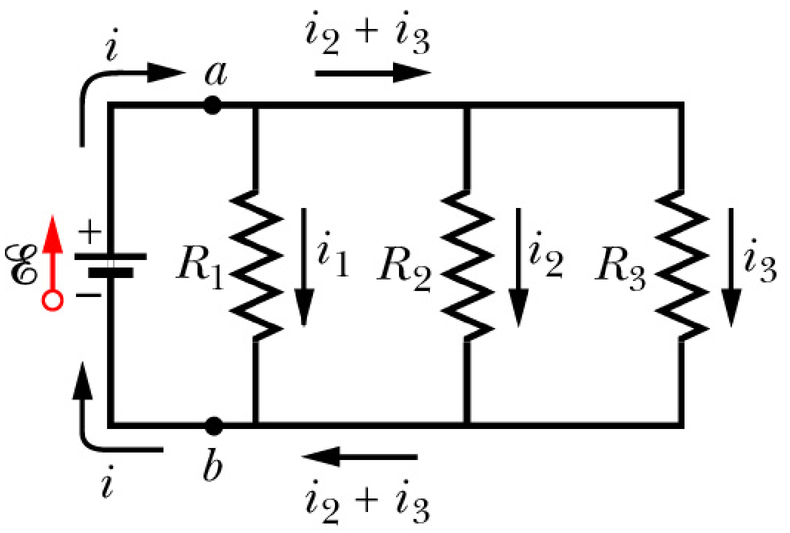

$$i_1 = \frac{V}{R_1}$$

$$i_2 = \frac{V}{R_2}$$

$$i_3 = \frac{V}{R_3}$$

# Resistors in Parallel

- Resistors in parallel (more than one path from a to b)
- Apply Kirchhoff's junction rule at point a
- Substitute current values

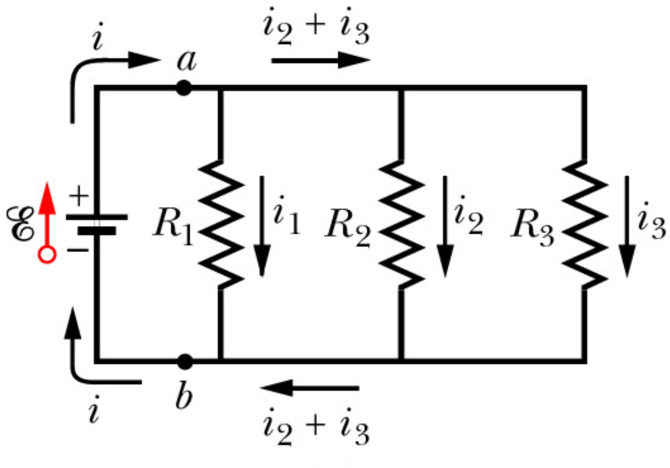



$$i = i_1 + i_2 + i_3$$

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

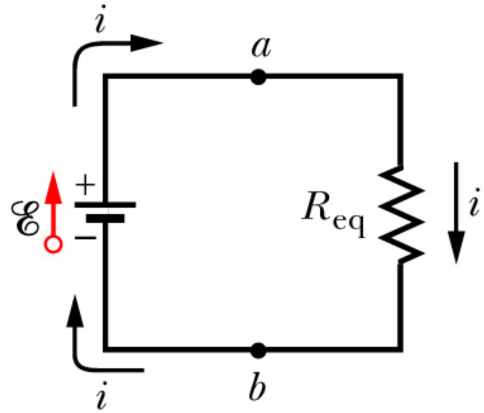
# Resistors in Parallel

- Resistors in parallel
- Replace 3 resistors with equivalent resistor, $R_{eq}$



$(a)$

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



$(b)$

# Exercise

- Battery with potential V supplies current i to 2 identical resistors

- What is $V$ across and $i$ through either of the resistors if they are connected in

- A) Series – What is constant?

$i$ is same, $V_1 = V/2$

- B) Parallel – What is constant?

$V$ is same, $i_1 = i/2$

$$V = iR$$

# Resistors and Capacitors

- Resistors
- Series

$$R_{eq} = \sum_{j=1}^{n} R_j$$

- Parallel

$$\frac{1}{R_{eq}} = \sum_{j=1}^{n} \frac{1}{R_j}$$

- Capacitors
- Series

$$\frac{1}{C_{eq}} = \sum_{j=1}^{n} \frac{1}{C_j}$$

- Parallel

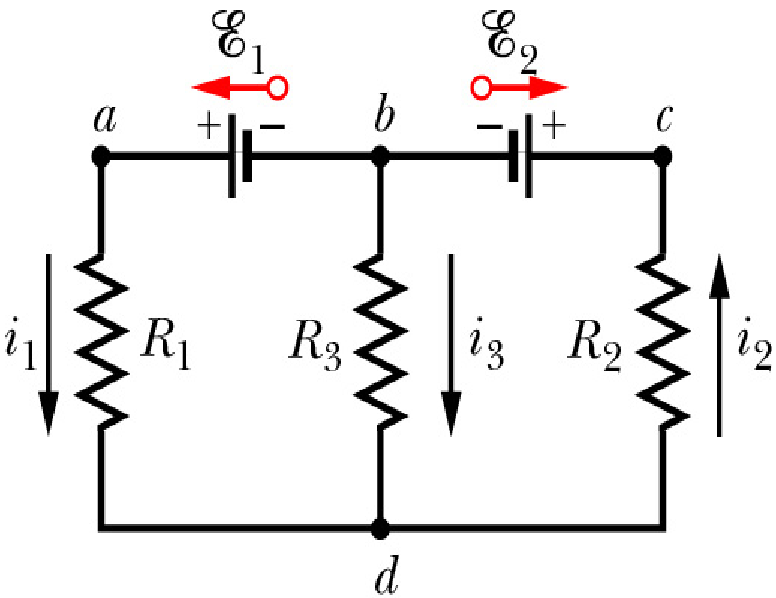
$$C_{eq} = \sum_{j=1}^{n} C_j$$

# How to Analyze Complex Circuits

- Kirchhoff’s junction rule (or current law) –
  - From conservation of charge
  - Sum of currents entering a junction is equal to sum of currents leaving that junction
- Kirchhoff’s loop rule (or voltage law) –
  - From conservation of energy
  - Sum of changes in potential going around a complete circuit loop equals zero

# Kirchhoff's Rule #1

- Arbitrarily label currents, using different subscript for each branch
- Using conservation of charge at each junction




$$i_{in} = i_{out}$$

- At point d

$$i_1 + i_3 = i_2$$

- At point b

$$i_1 + i_3 = i_2$$

- At point a

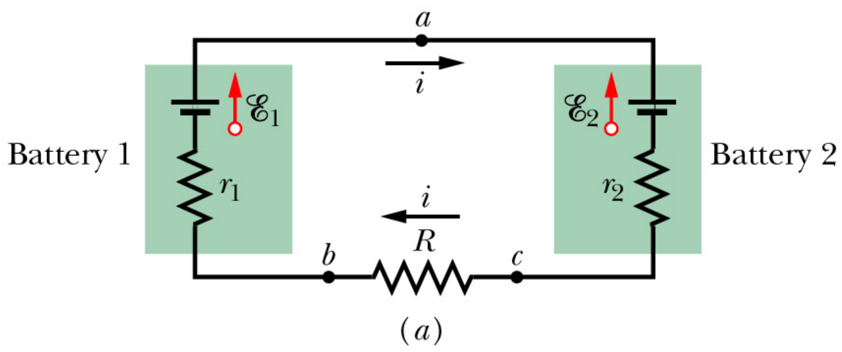
$$i_1 = i_1$$

- At point c

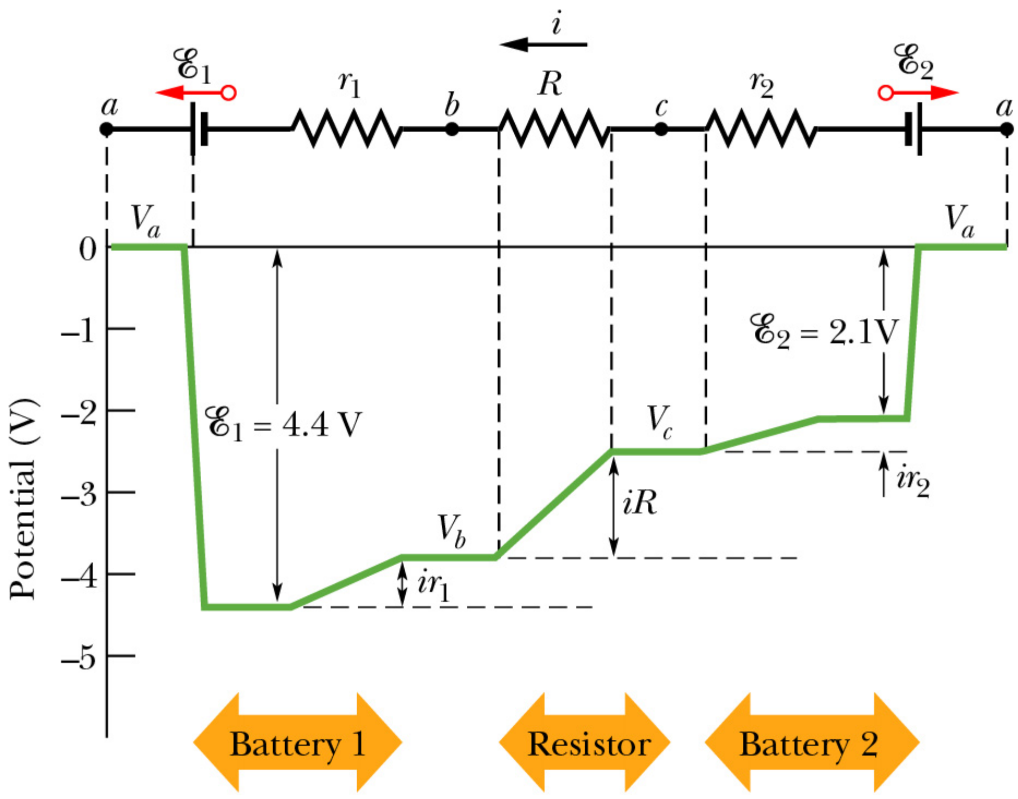
$$i_2 = i_2$$

# Exercise

- What is *i* of the circuit?

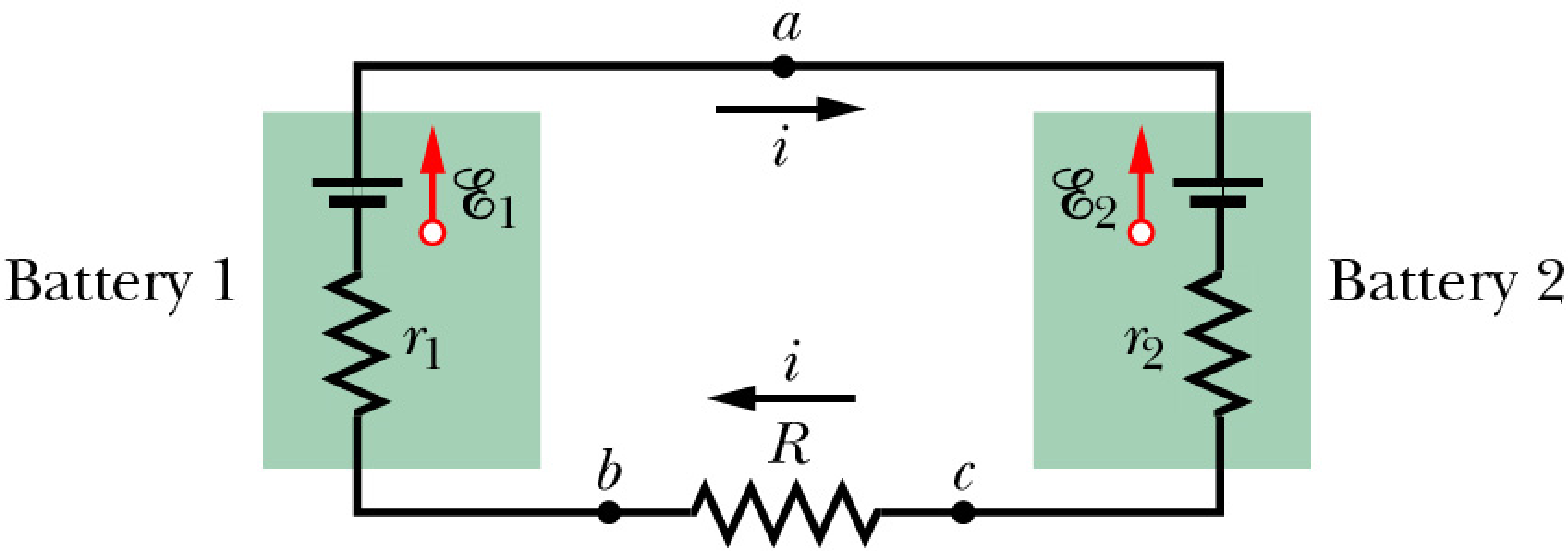


(a)



(b)

- Use Kirchhoff's loop rule




- Clockwise from point a gives

$$-\mathrm{E}_2 - ir_2 - iR - ir_1 + \mathrm{E}_1 = 0$$

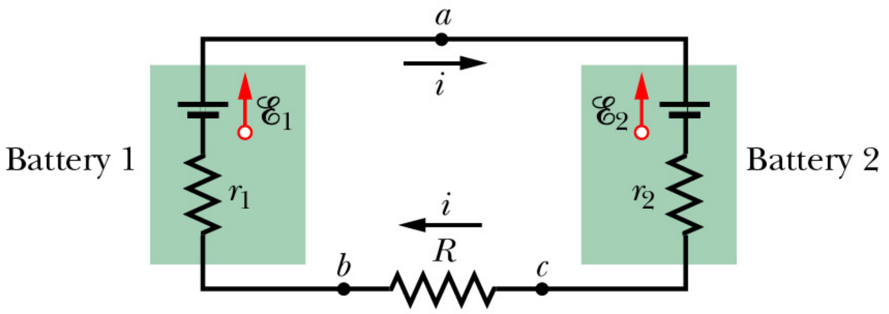
- Counterclockwise from point a gives

$$-\mathrm{E}_1 + ir_1 + iR + ir_2 + \mathrm{E}_2 = 0$$

# Exercise

- Solve for *i* $-\mathrm{E}_1 + ir_1 + iR + ir_2 + \mathrm{E}_2 = 0$

$$i = \frac{\mathrm{E}_1 - \mathrm{E}_2}{R + r_1 + r_2}$$




$\mathrm{E}_1 = 4.4V$ $\mathrm{E}_2 = 2.1V$

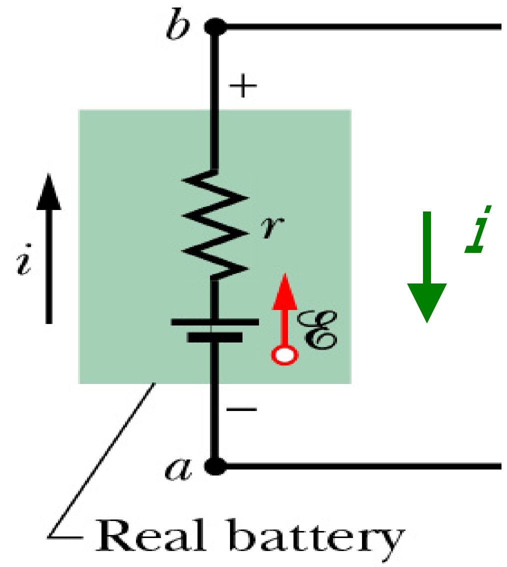
$r_1 = 2.3\Omega$ $r_2 = 1.8\Omega$

$R = 5.5\Omega$

$$i = 0.2396A \approx 240mA$$

# Exercise

- A real battery has ☜ =12V and *r* = 2Ω. Is the V across the terminals greater than, less than or equal to 12V if the current in the battery is




- A) from – to + terminal

LESS THAN

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

- B) from + to -

GREATER THAN

$$V_a + \mathrm{E} + ir = V_b$$

- C) *i* = 0

EQUAL TO 12V