https://isaacscience.org/question_decks#ipts25_sat_4b_r1

Electricity ‘under the hood’

Anton Machacek, Associate Director

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Visualizing Potential and Current

- What pictures and models do we use to help?
- For a particular model or picture
  - What does it do well?
  - What does it do badly?
  - Where have we used it to good effect?
- What about not using a model at all?

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Potential and Current – analogies/models

Potential	Current
Height (roller coaster)	Trains each hour
Pressure (hydraulic fluid in pipe)	Flow rate of fluid (volume per unit time)
Temperature (of point in thermal system)	Heat flow rate (energy per unit time)

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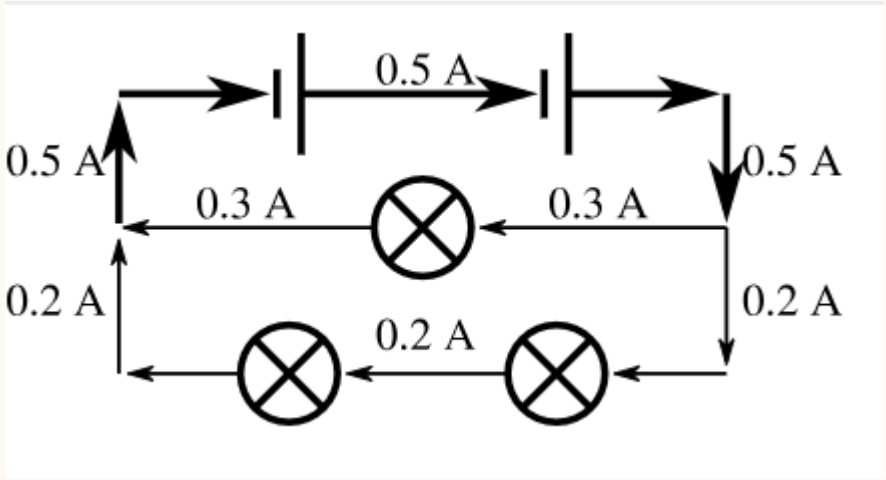
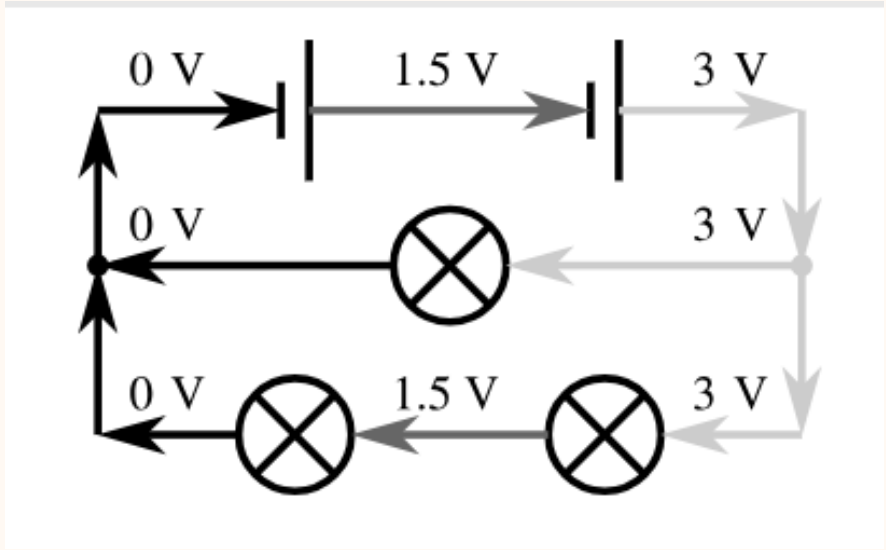
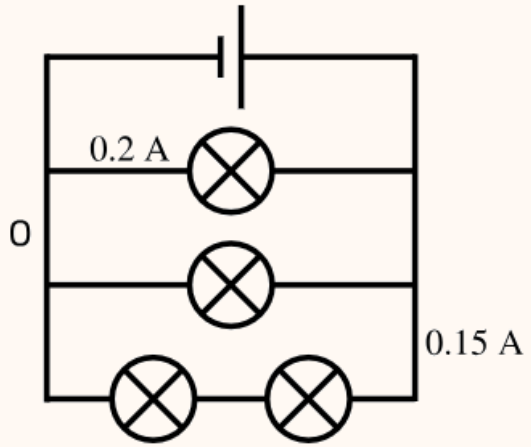
Circuit Rules (easier than the Highway Code?)

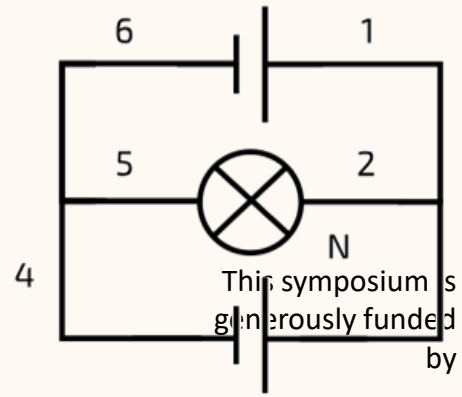




- What makes this circuit hard?



- And this one?



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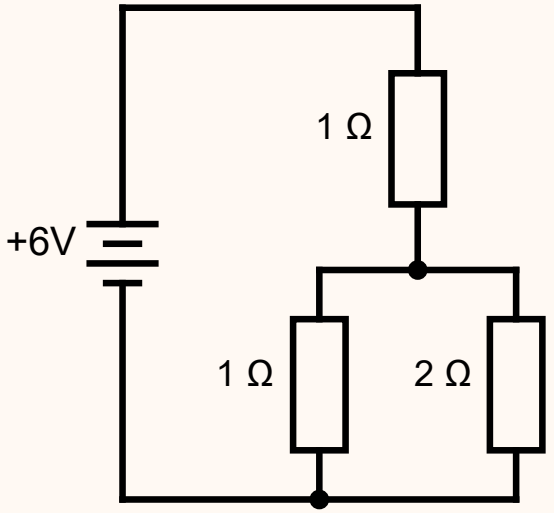
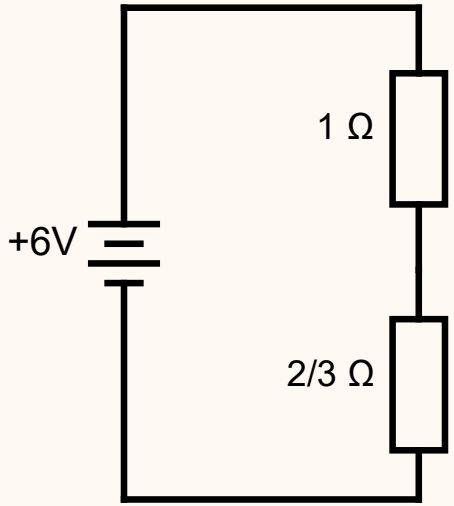
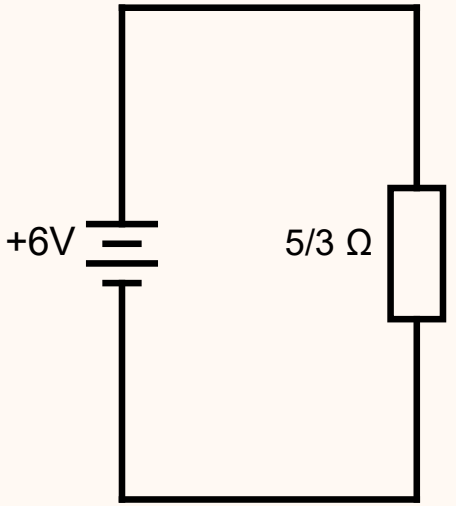
Solving circuits 1

- Combine then separate resistances







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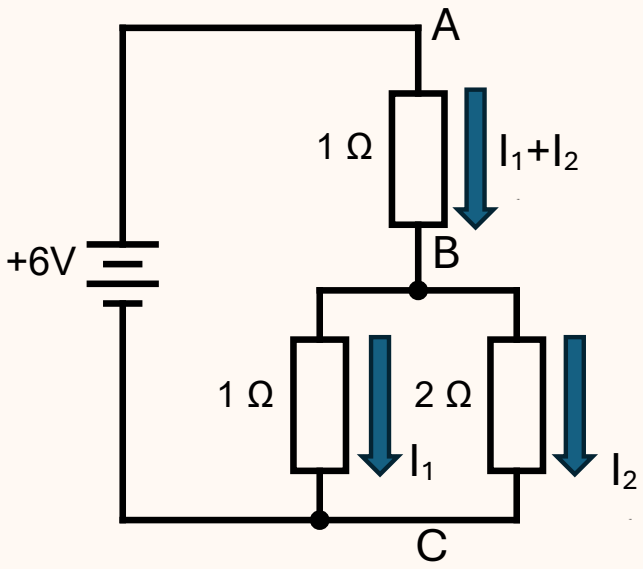
Solving circuits 2

- Raw algebra



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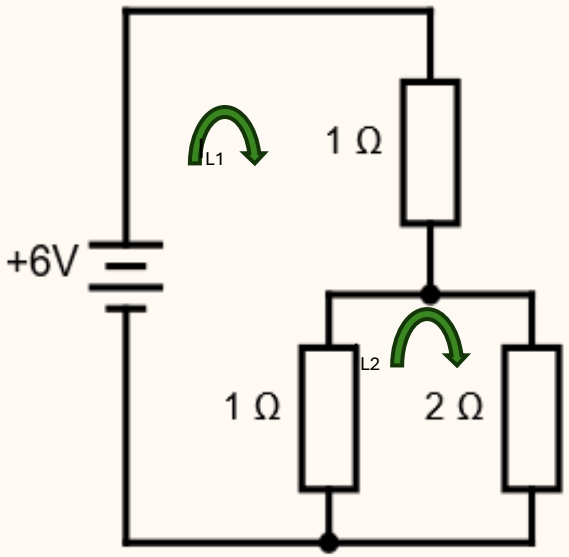
Solving circuits 3

- Loop currents



From O, clockwise

$$6 - 1 \times I_{L1} - 1 \times (I_{L1} - I_{L2}) = 0$$
$$-1 \times (I_{L2} - I_{L1}) - 2 \times I_{L2} = 0$$

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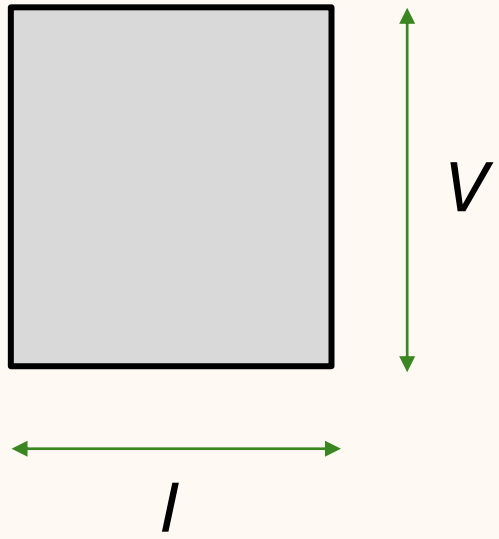
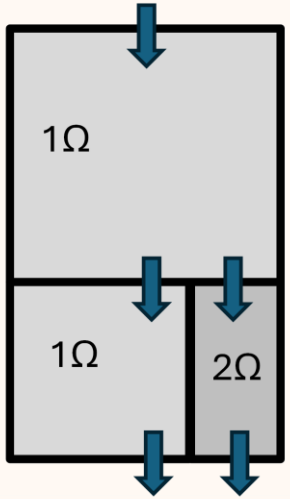
Solving circuits 4

- AVOW diagram: components are rectangles
  - Area is…
  - Gradient of diagonal is…
  - Circuit laws mean…





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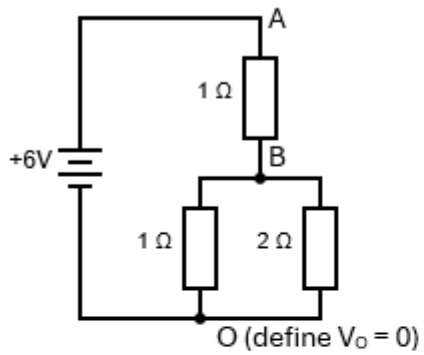
Solve circuits 5

- Matrix



$I_A = I_{AB}$ $\quad I_A = G_{AB}(V_A - V_B) = 1 \times (V_A - V_B)$

$I_B = I_{BA} + I_{BO}$ $\quad 0 = G_{BA}(V_B - V_A) + G_{BO}(V_B - V_O)$

$0 = 1 \times (V_B - V_A) + (3/2) \times V_B$

$$\begin{pmatrix} I_A \\ 0 \end{pmatrix} = \begin{pmatrix} 1 & -1 \\ -1 & 5/2 \end{pmatrix} \begin{pmatrix} V_A \\ V_B \end{pmatrix} \text{ so } \begin{pmatrix} V_A \\ V_B \end{pmatrix} = \frac{1}{3/2} \begin{pmatrix} 5/2 & 1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} I_A \\ 0 \end{pmatrix}$$

In general: (this matrix for 4 points O, A, B, C)

$$\begin{pmatrix} I_A \\ I_B \\ I_C \end{pmatrix} = \begin{pmatrix} G_{AB} + G_{AC} + G_{AO} & -G_{AB} & -G_{AC} \\ -G_{AB} & G_{BA} + G_{BC} + G_{BO} & -G_{BC} \\ -G_{AC} & -G_{BC} & G_{CA} + G_{CB} + G_{CO} \end{pmatrix} \begin{pmatrix} V_A \\ V_B \\ V_C \end{pmatrix}$$

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Ohm’s law unpacked

- Assume:
  - Free electrons in a metal accelerate as a result of the potential difference provided by the battery.
  - They stop as a result of a collision, and re-accelerate in a repeating cycle.
  - The average time between collisions is called the **relaxation time**.

  - https://isaacscience.org/questions/ohms_law_unpacked

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Electron speed – exclusion principle

- The electron is a fermion. So what?

- We can use ideas of standing waves to work out the speed of the colliding electrons:
  - https://isaacscience.org/questions/fermi_velocity

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