Addressing Conceptual Difficulties in Electrical Circuits: What is V? What is I? What is R?

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Outline

Survey of the literature:

- A typical response and an interpretation
- A catalog of common misconceptions

Working hypothesis:

- Conceptual difficulties are linked to inadequate or missing **qualitative** models connecting macroscopic observations with microscopic interactions.

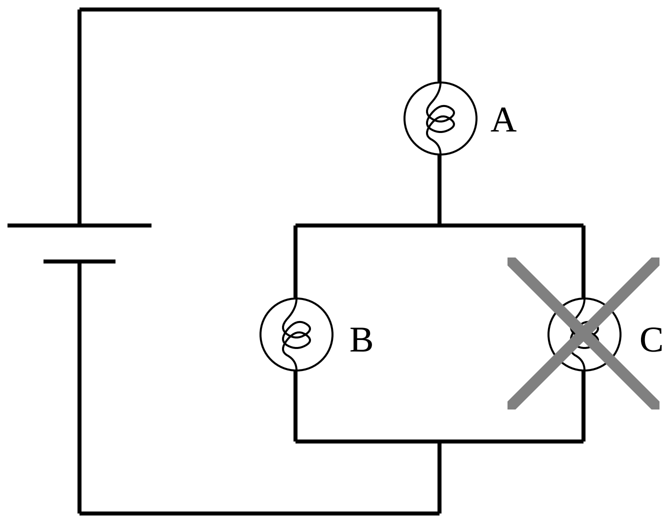
Elements of a **qualitative**, **concept-oriented** approach

- Proper use of words and symbols
- Macro/Micro viewpoints
- Magnifying and exploiting transients
- A modified hydraulic analogy
- Resistance versus conductance
- Connecting wires as electrical points
- 3-D circuit diagrams
- Explicit comparison of current vs. emf sources
- Kirchhoff's rules and self-consistency

Summary

A Typical Response and an Interpretation

Q: What happens to the brightness of bulbs A and B when bulb C is removed from this circuit



A: The current that used to flow through C must now pass through B. Therefore, B gets brighter. No change in A.

Interpretation: "Battery is constant current source" (?)

A Catalog of Common (Apparent) Misconceptions

- Batteries produce constant current.
- Charge/current originates in the battery.
- Charge/current is "used up" by circuit elements.
- Alterations in circuits have only "downstream" effects.
- Resistors (or light bulbs, etc.) are barriers to current flow;
  the more resistors the more resistance.
- Larger resistors use greater amounts of energy.
- Elements connected closer to the positive terminal (and thus "at higher voltage")
  use larger amounts of energy.

Working Hypothesis

Conceptual difficulties are linked to inadequate or missing **qualitative** models connecting macroscopic observations with microscopic interactions.

This results in

- **undifferentiated views** of charge, current, potential, potential difference, energy, and power.
- lack of appreciation for the ways in which equilibrium is dictated by **self-consistency**.
- failure to recognize **global effects** of local changes.
- careless (or uncritically applied) language that reinforces (but also reveals) faulty concepts.

Words and Symbols

- Prepositions (e.g., “across,” “through,” “in,” “of,”...)
- V (“potential,” not “voltage”) versus ΔV (“potential difference” or “p.d.,” not “voltage”) $\Delta V = IR$ $V_B = V_A + \Delta V$
- Implications of the word “resistance.” How about “conductance”?
- Capacitance versus capacity
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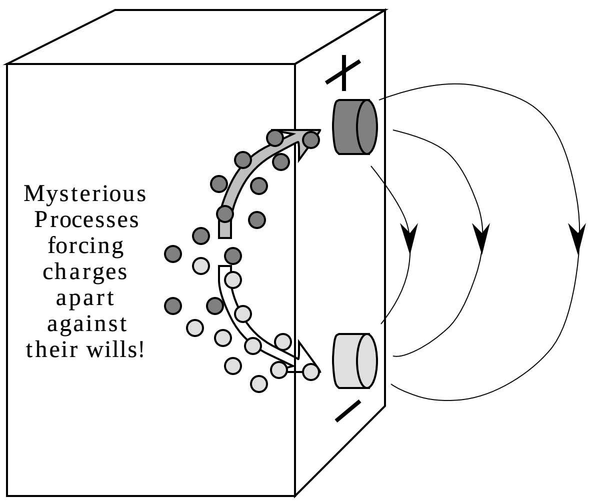
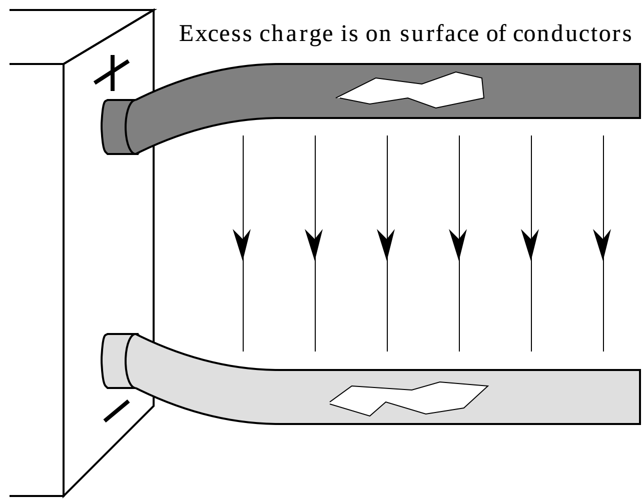
Macro-Micro Viewpoints

- Batteries maintain a potential difference by separating charge.
- Potentials and electric fields in circuits are *the same kinds of things* and exist for *the same reasons* as in electrostatics.





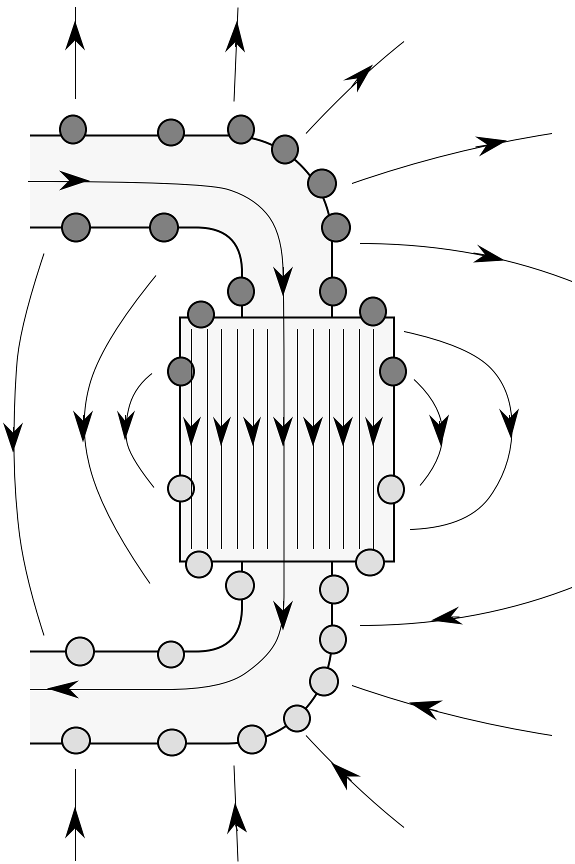
Macro-Micro Viewpoint: Charge Arrangement

The "desired" steady state

- Excess charge on surface produces **E**.
- **E** drives steady (divergenceless) current.

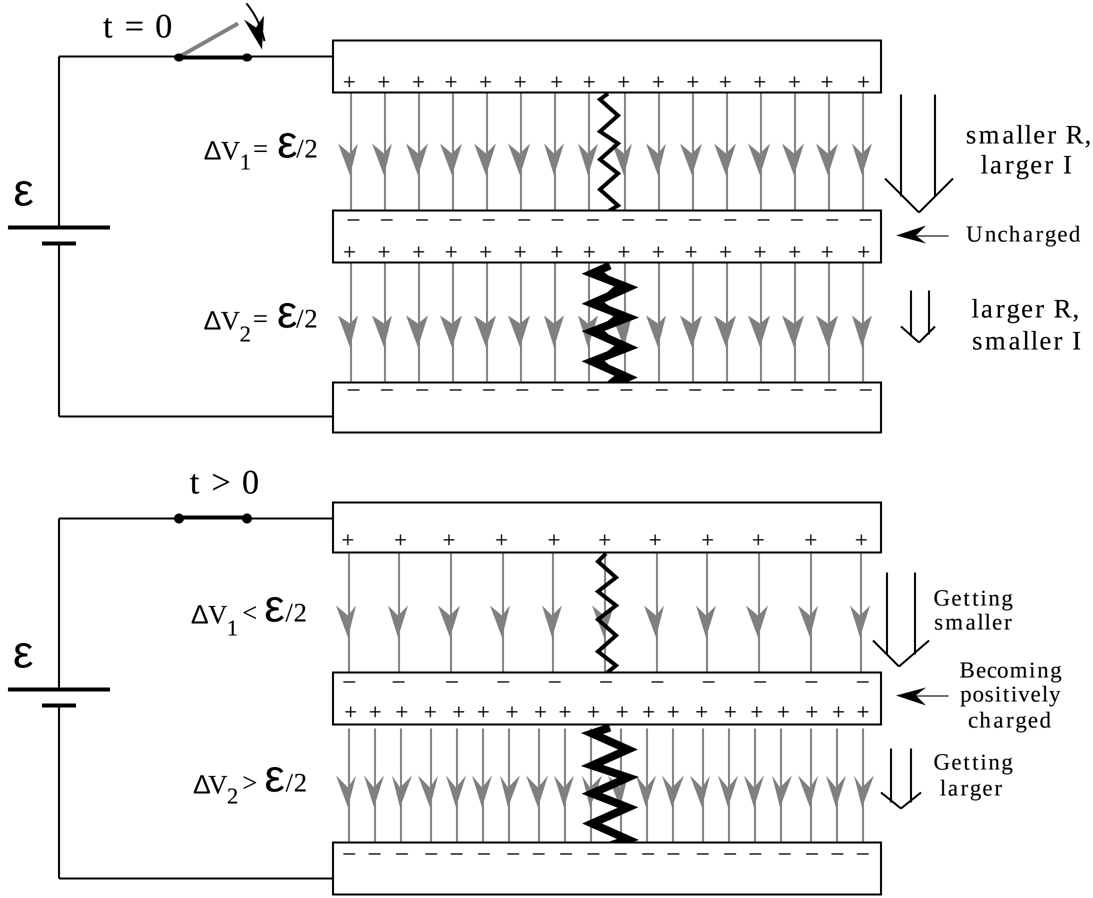
Arriving at the steady state

- The arrangement takes time to establish.
- During the transient phase, current is *not* steady.
- Its divergence *produces* the excess charge.
- The excess charge appears just where it is needed.



This process produces and maintains a **self-consistent solution.**

Magnifying and Exploiting Transient Phenomena



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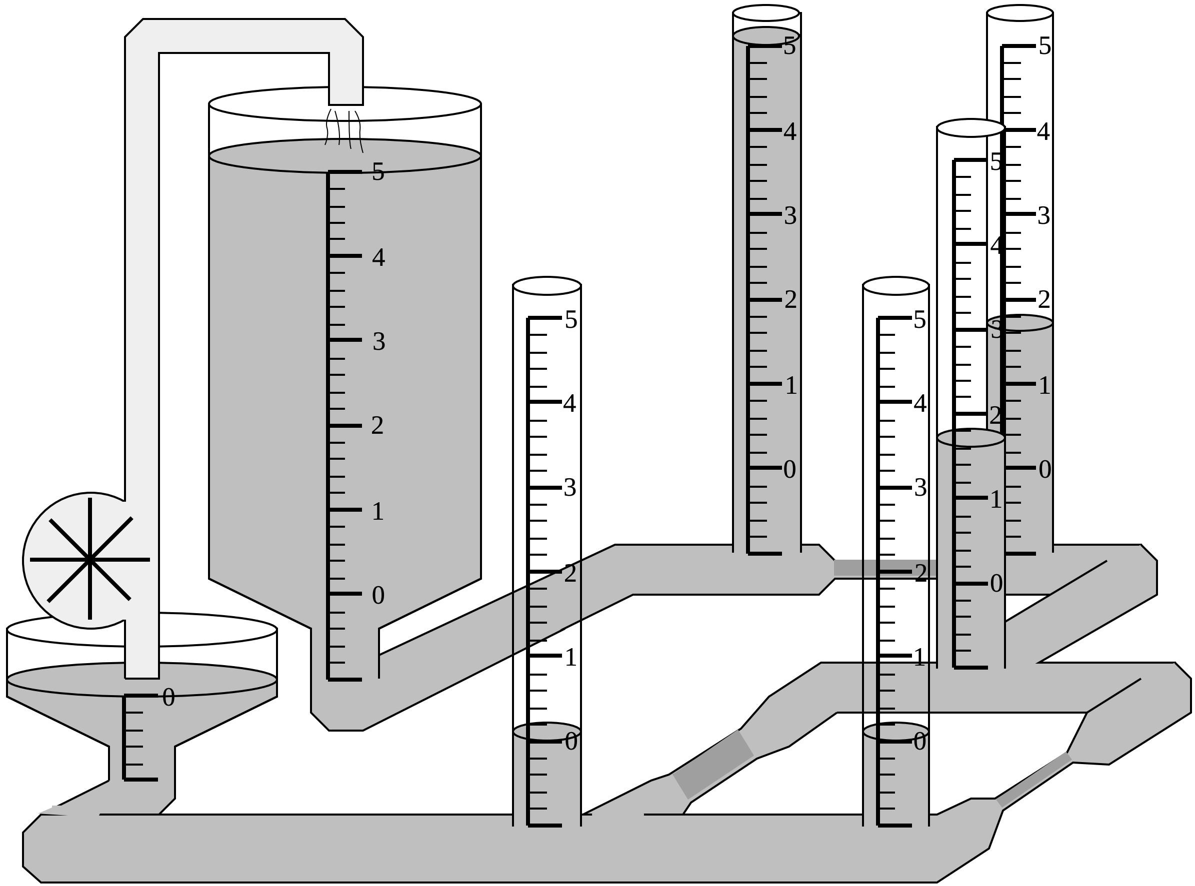
Modified Hydraulic Analogy

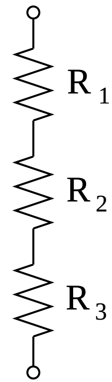


Is Resistance or Conductance the Relevant Concept?

- For elements in series, each element represents an additional *impediment* through which the current *must* flow.

  "Resistance" is the appropriate concept.

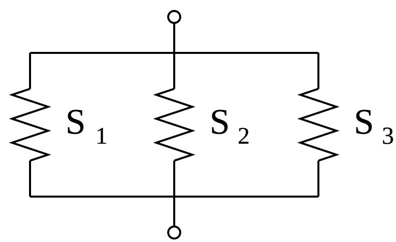
  $R_{tot} = R_1 + R_2 + R_3 + \ldots$



- For elements in parallel, each element represents an additional *path* through which current may *choose* to flow.

  "Conductance" (S = 1/R) is the appropriate concept.

  $S_{tot} = S_1 + S_2 + S_3 + \ldots$



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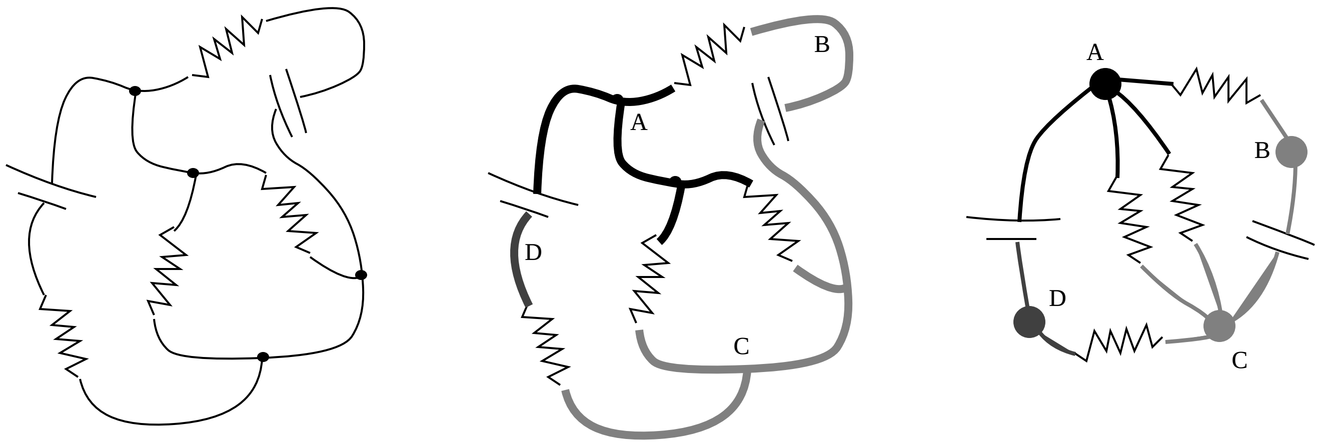
Deciphering Circuit Topology Using Electrical “Points”

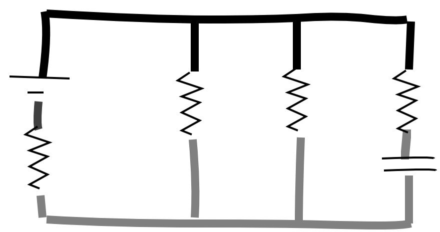


Point A: “Positive battery terminal is connected to three resistors.”

Point B: “One of these resistors is connected to a capacitor.”

Point C: “The capacitor and the other two resistors are connected to a fourth resistor.”

Point D: “The fourth resistor is connected to the negative battery terminal.”



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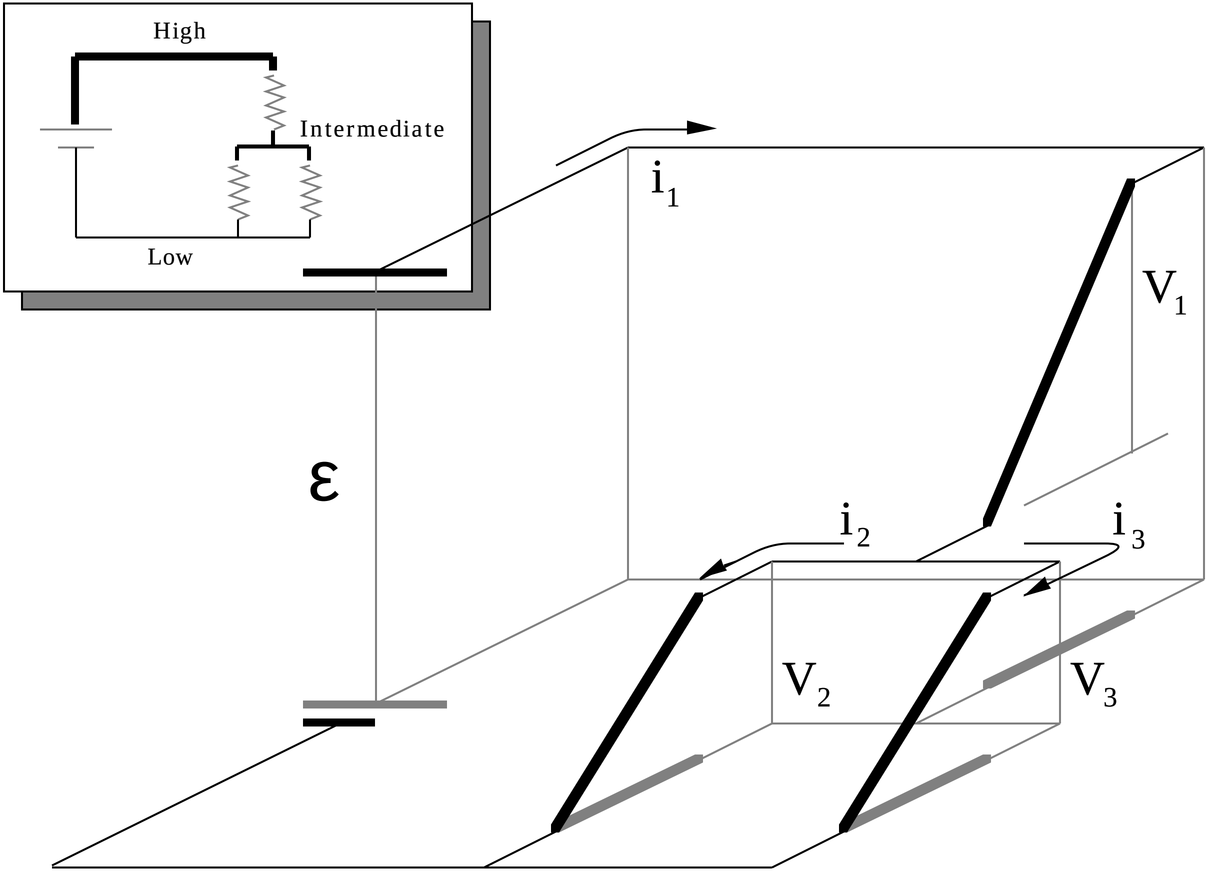
3-D Diagrams for Visualizing Relative Potentials



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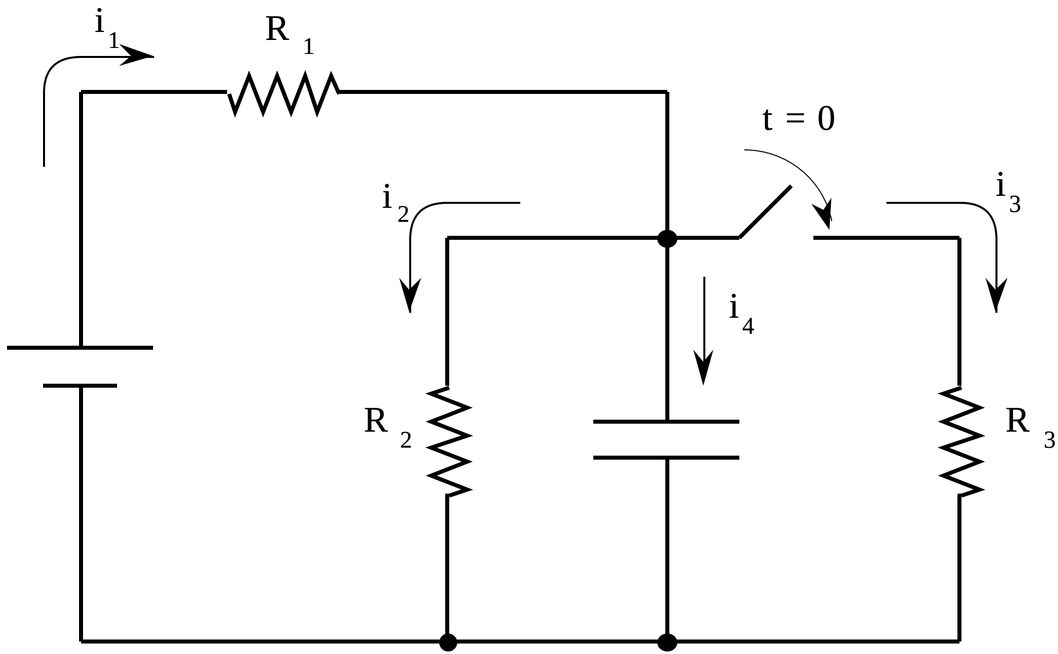
What happens after the switch is closed?



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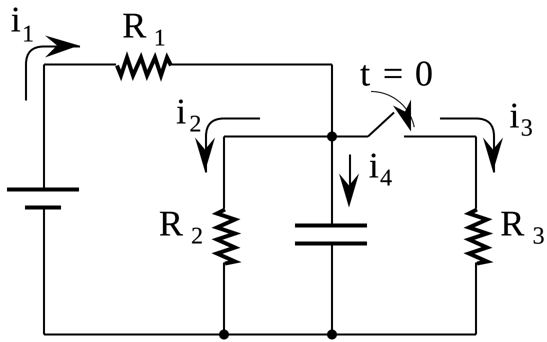

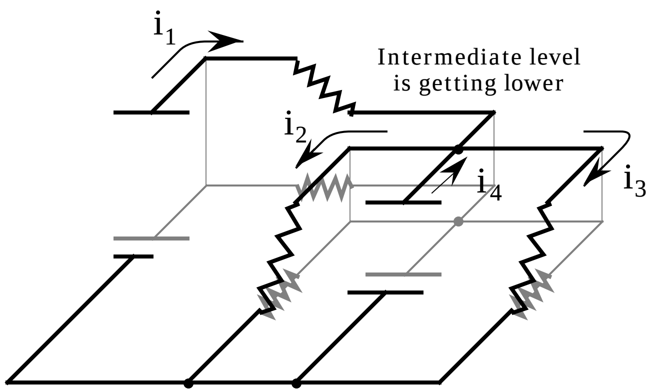

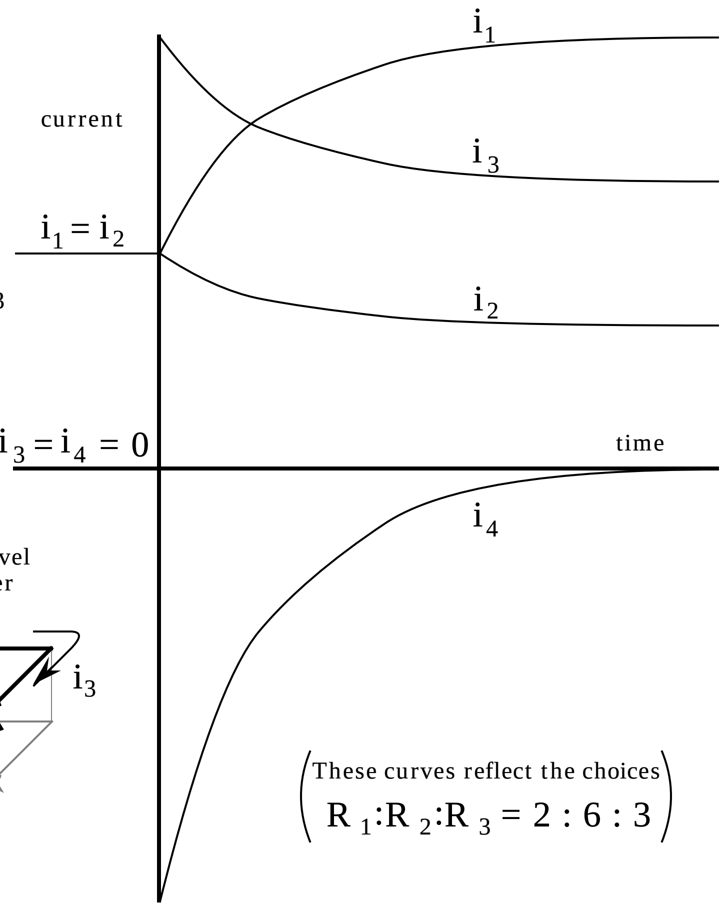

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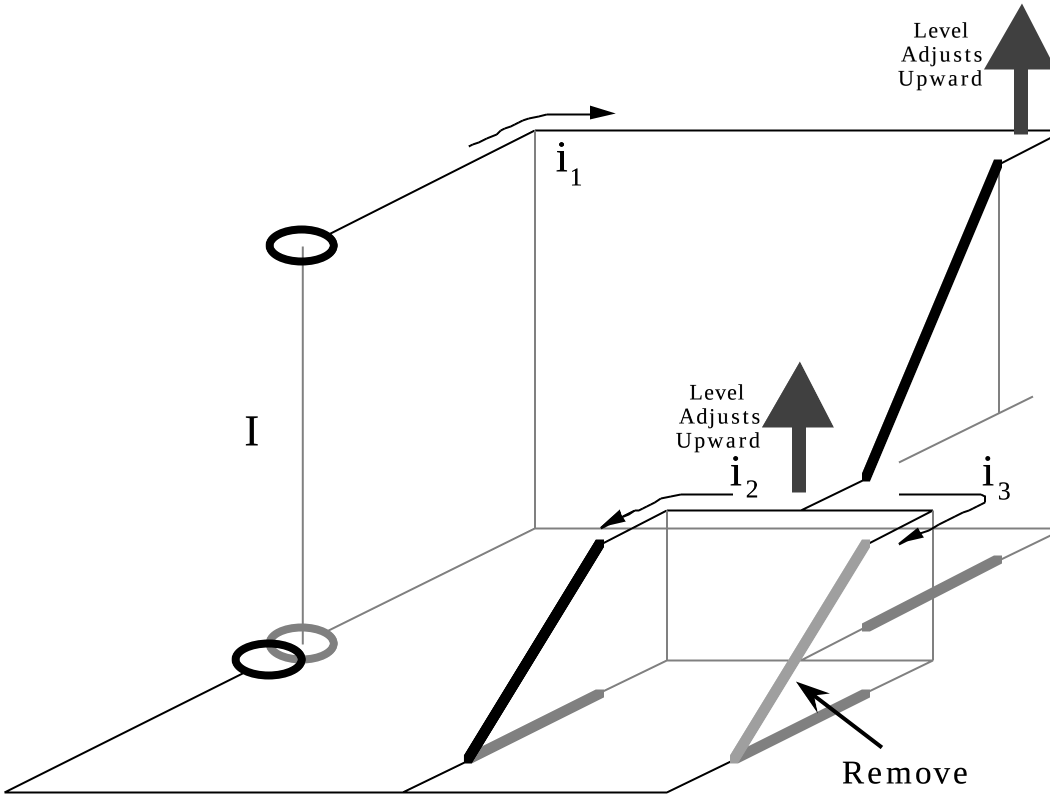
Removing a bulb: Constant current source



Before: $i_1 = I$, $i_2 = i_3 = I/2$

After: $i_1 = i_2 = I$ (#1 stays the same, #2 gets brighter)

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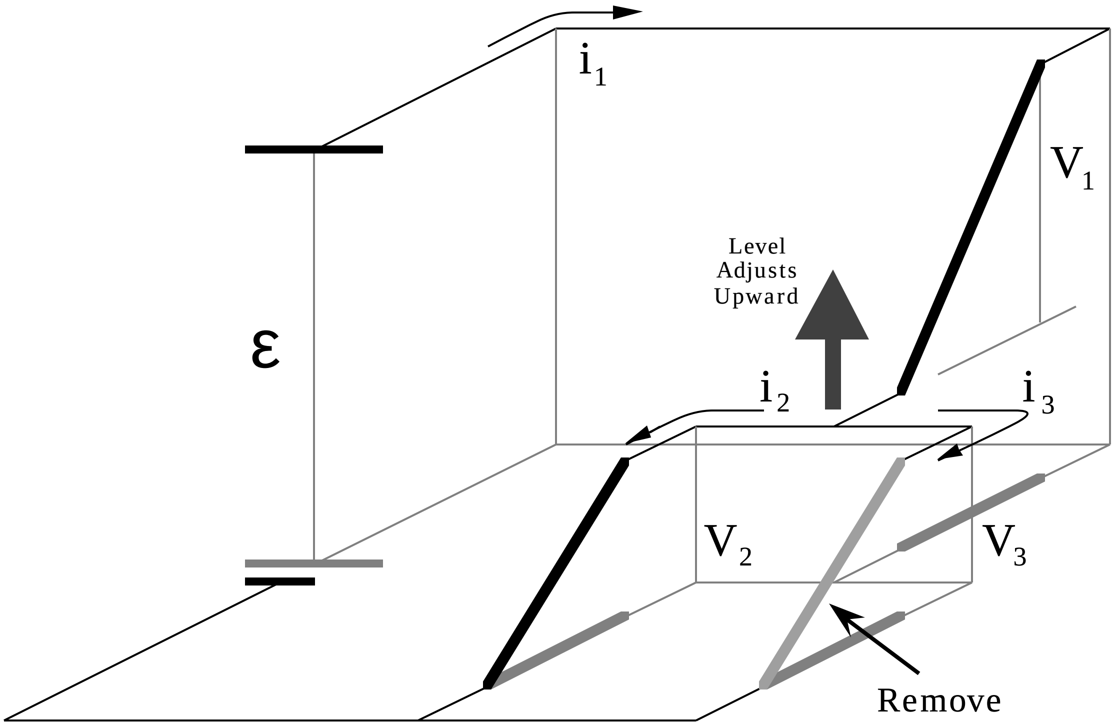
Removing a bulb: Constant emf source

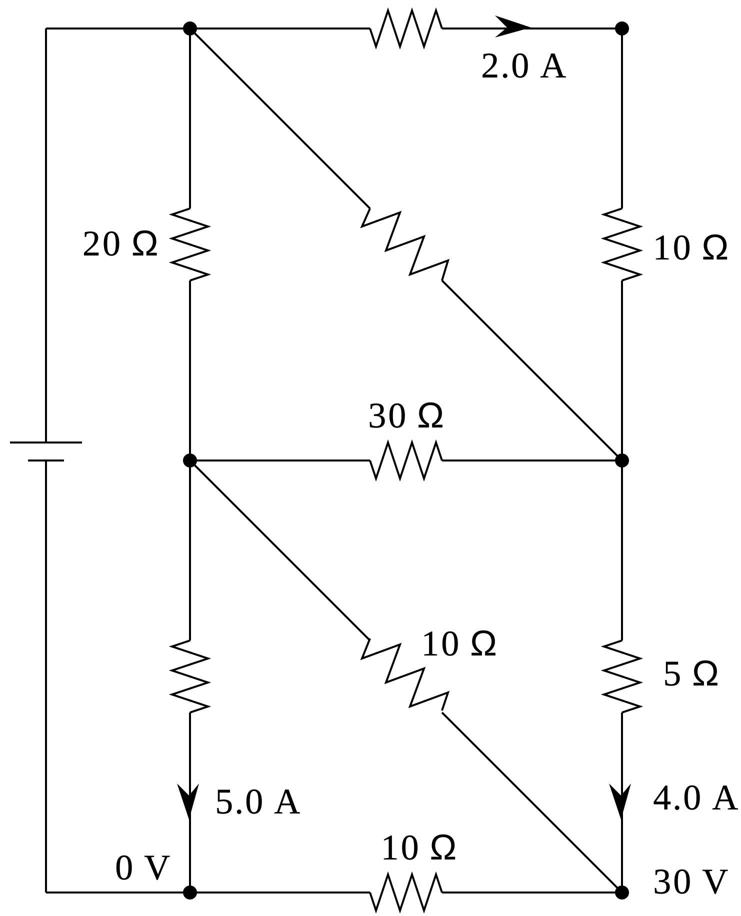


Before: $i_2 = i_3 = i_1/2$ $V_1 > \mathcal{E}/2 > V_2 = V_3$

After: $i_1 = i_2$ $V_1 = V_2 = \mathcal{E}/2$ (#1 gets dimmer, #2 gets brighter)

Self-Consistency and Kirchhoff's Laws

- Six currents and four potentials to be determined.
- Five loops and five junctions yield ten Kirchhoff equations.
- Problem is designed so that a step-by-step method will work.



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Summary

An old refrain:

An ability to solve traditional quantitative problems does *not* imply “understanding.”

Instructional approaches to electric circuits should include **qualitative, concept-oriented** material designed to enhance students’ ability to

- **differentiate** between charge, current, potential, potential difference, energy, and power.
- appreciate the ways in which equilibrium is dictated by **self-consistency**.
- recognize **global effects** of local changes.

Elements of such an approach

- Proper use of words and symbols
- Macro/Micro viewpoints
- Magnifying and exploiting transients
- A modified hydraulic analogy
- Resistance versus conductance
- Connecting wires as electrical points
- 3-D circuit diagrams
- Explicit comparison of current vs. emf sources
- Kirchhoff’s rules and self-consistency

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