Circuits and Signals: Biomedical Applications
Week 1

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EECE–2150
Northeastern University

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Week 1 Agenda

- Administrivia
  - Introduction
  - Overview of the Course
  - Review of Syllabus
  - Intro to Mastering Engineering (not for grade)
- Fundamentals
  - Circuits
  - Voltage Sources
  - Current Sources
  - Resistors; Ohm's Law
  - Kirchoff's Current Law
  - Kirchoff's Voltage Law

Me

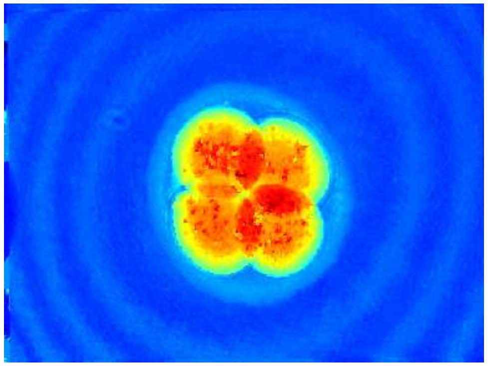
- Education
  - 1969: BS in Engineering Physics, University of Maine
  - 1973: MS in Physics, WPI
  - 1996: Ph.D. in Electrical Engineering, Northeastern
- Employment
  - 1973 — 1987: Raytheon Company (Laser Radar)
  - 1983 — 1987: Northeastern (Part–Time Lecturer)
  - 1987 — 2000: Northeastern (Research Scientist)
  - 2000 — Present: Northeastern ECE Faculty (MIE/BioE)
  - 2014 — 2020: Topical Editor for *Optics Letters*
  - 2014 — 2016: Associate Chair of ECE
- Home: Cambridge, with my Wife, Sheila
- Family: 2 Children, 3 Grandchildren
- Home Ski Area: Killington, Vermont

Personal History

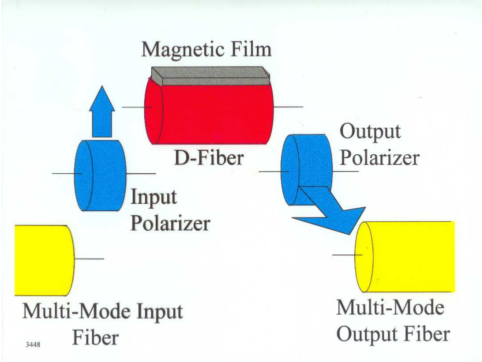
- Raytheon (Jelalian)
  - Aircraft Wake LIDAR
  - Airborne LIDAR
- Northeastern University
  - LIDAR
  - MOKE Sensors
  - Landmine Detection
  - Hyperspectral Imaging (Biomed)
  - Light and Sound
  - Optical Quadrature
  - Multi-Modal Microscopy

Severe Storms

Coal–Dust Lidar



Cell Counting

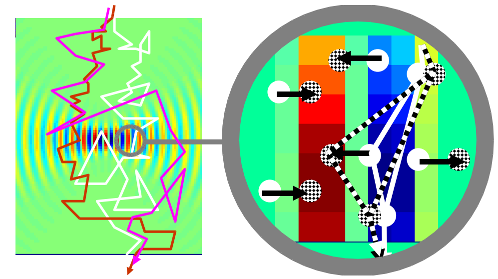


Magnetic Sensor

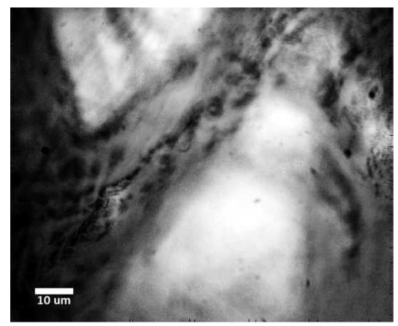
Our Current Research

- Multi–Modal Microscopy
- Light and Sound
- Structured Illumination
- Collagen Orientation
- Stepwise 3–Photon Fluorescence in Melanin
- Lidar (Laser Radar)

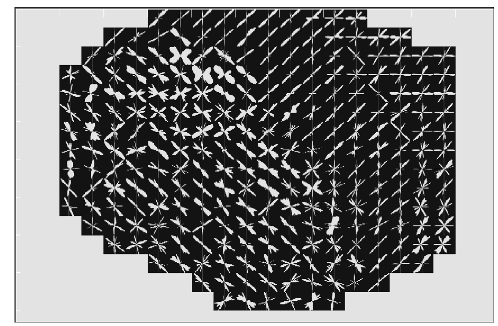
Multi–Modal



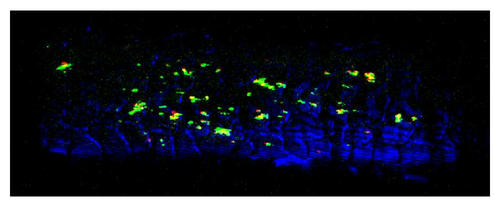
Light and Sound



SIM



Collagen



Melanin

Lidar

Engineers at Play

Teaching Team

- Prof. DiMarzio
- Course Assistants
  - David Hunter
  - Aniket Dhole
  - Kshama Dhaduti
- Other Sections
  - Prof. McGruer
  - Prof. Salama

You

- CE 3, CECS 7,
- ECE 5
- EE 9, EE/Physics 1, EE/Music 1
- Biology 1

Course Goals

- Build and test an ECG instrument
- Learn important parts of ECE
  - Circuits
  - Signals
- Learn ECE Culture, Atmosphere, Expectations, Methodologies
  - Theory
  - Computational Experiments
  - Physical Experiments

Course Components

- Textbook Readings (Not Inclusive)
- Lectures (Synchronously and Recorded)
- Slides (Available on the Website, Not Inclusive)
- Lab Experiments
- In–Class Exercises
- Homework (Mastering Engineering)
- Quizzes
- Final Exam
- Participation
- Office Hours on Zoom

Weekly Schedule

- Before Monday Read The Text Assigned
- Monday Lecture and/or Lab
- Wednesday Lecture and/or Lab
- Homework Due at Midnight on last week's material (One day of grace)
- Thursday Quiz on last week's material
- Thursday Lecture and/or Lab
- Homework submitted by Midnight has no penalty.

A Note About the Slides

These slides are not meant to be complete. They are intended to support the lectures, and not to replace them.

They provide reminders to me and to you.

I encourage you to save the slides to paper or pdf, and take notes on them.

Try This Learning Approach

- There are a lot of equations, conventions, and vocabulary here and it's easy to become confused.
- As engineering students, you can learn most of them when you need them.
- In the lectures and reading, concentrate on the concepts and don't get stuck on the details.
- Our goal is for you to be able to tackle new problems you've never seen, rather than just repeat old procedures,
- But you need to learn some procedures in order to develop your creativity.
- The homework, quizzes and in–class exercises are the place to focus on the details.

Communication

- I am hearing impaired.
- I can understand you better if I can see your face.
- I hear better on my right side.
- I hear better in a quiet environment.
- I hear better if one person speaks at a time.
- I have a portable microphone that can help.
- Do not let this stop you from asking questions.

What is Electrical Engineering

- Moving Electrons
  - Moving Energy
  - Moving Information
- Sub–Disciplines
  - Power
  - Communication
  - Control (Sensors and Actuators and All in Between)
  - Computers (Including Embedded Ones)
  - Circuits and Electronics (RLC, Diodes, Transistors, Chips, more)
  - Electromagnetics, Optics (Photonics)

The Engineer's Knowledge

- Concepts
- Facts
- Procedures

Real equipment glows in the dark!

What you think is most important now will be out of date in less than five years.

The Syllabus

See Website for Syllabus and Other Material

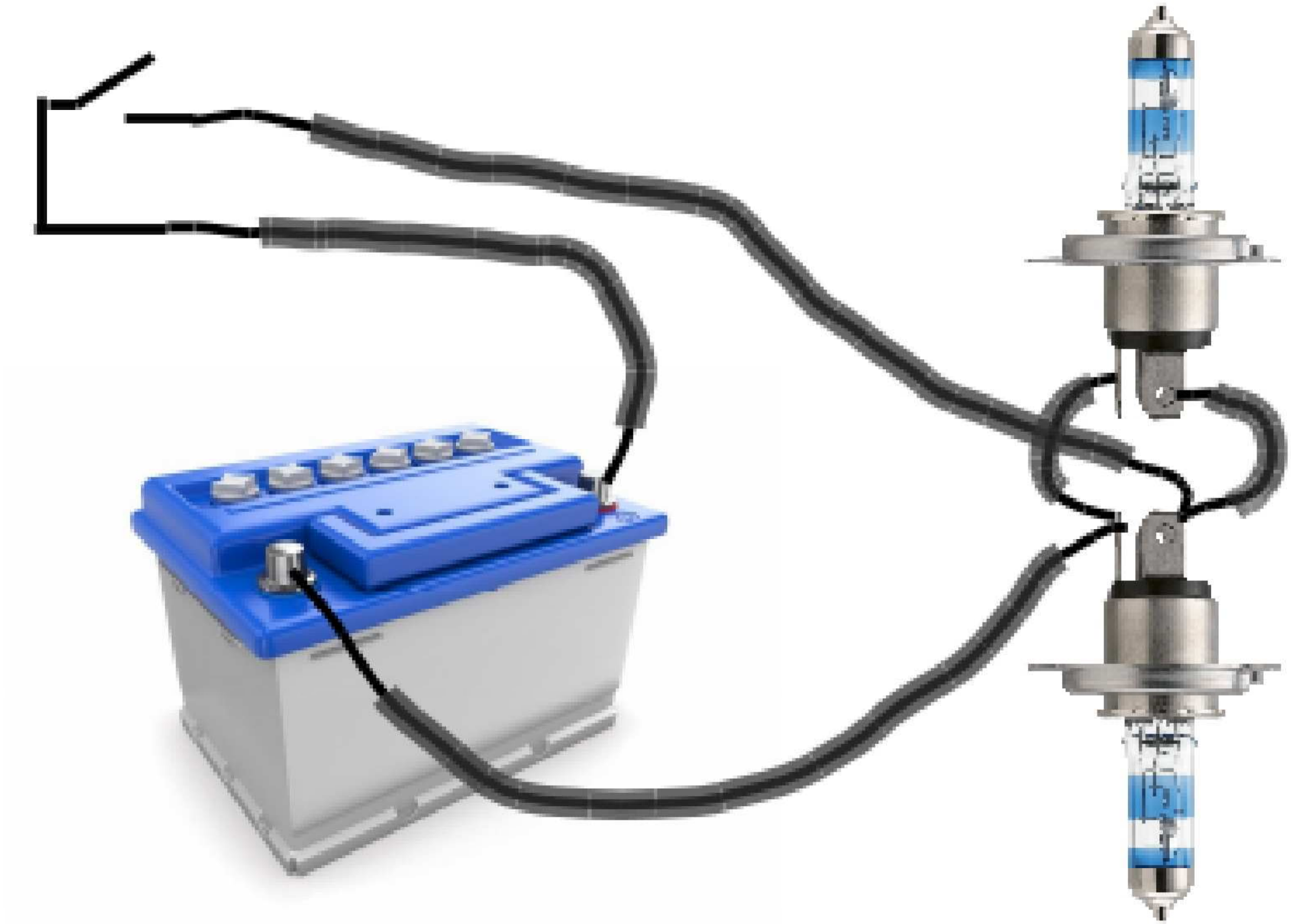
For Tomorrow

- Find the material on the line with Slides1 on the website.
- Read about power supply and multimeter in guide to using lab equipment.
- Prepare for lab 1 on the protoboard. Complete the worksheets.

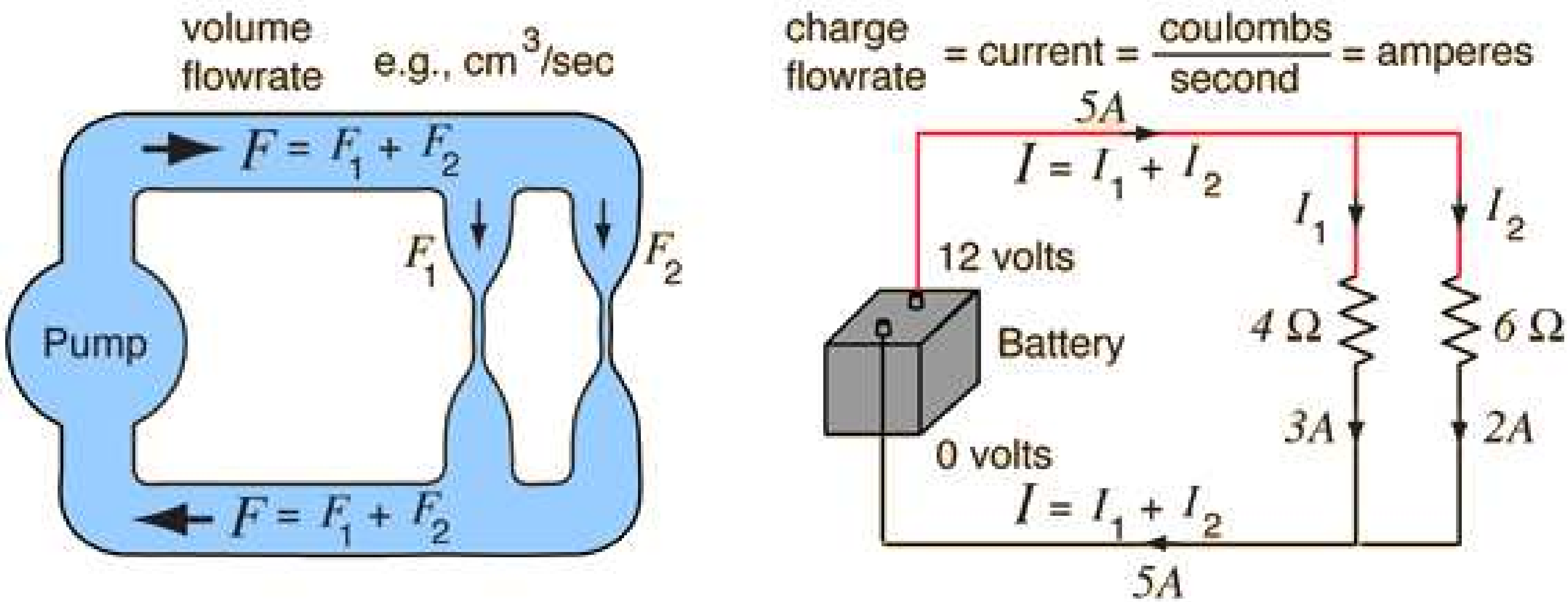
Circuits

- Wires
- Insulators
- Components
  - Power Sources
  - Switches
  - Resistors
  - Capacitors
  - Inductors
  - Op Amps
  - Other (Diodes, Transistors, in Electronics (EECE2412)

Circuit Example



Fluid–Flow Analogy



http://hyperphysics.phy-astr.gsu.edu/hbase/electric/imgele/curlaw3.gif

Nothing happens unless you complete the circuit.

Q: How does the Boston Green Line train work with only one overhead wire?

Current

Current is moving charge

$$q(t) = \int_{t0}^{t} i(t)\,dt + q(t_0)$$

$$i(t) = \frac{dq(t)}{dt}$$

Electrons have negative charge

$$q_e = -1.6 \times 10^{-19}$$

Direction of electron motion is opposite current direction. This is an unfortunate decision made by Benjamin Franklin.

Electrons as Quanta of Charge

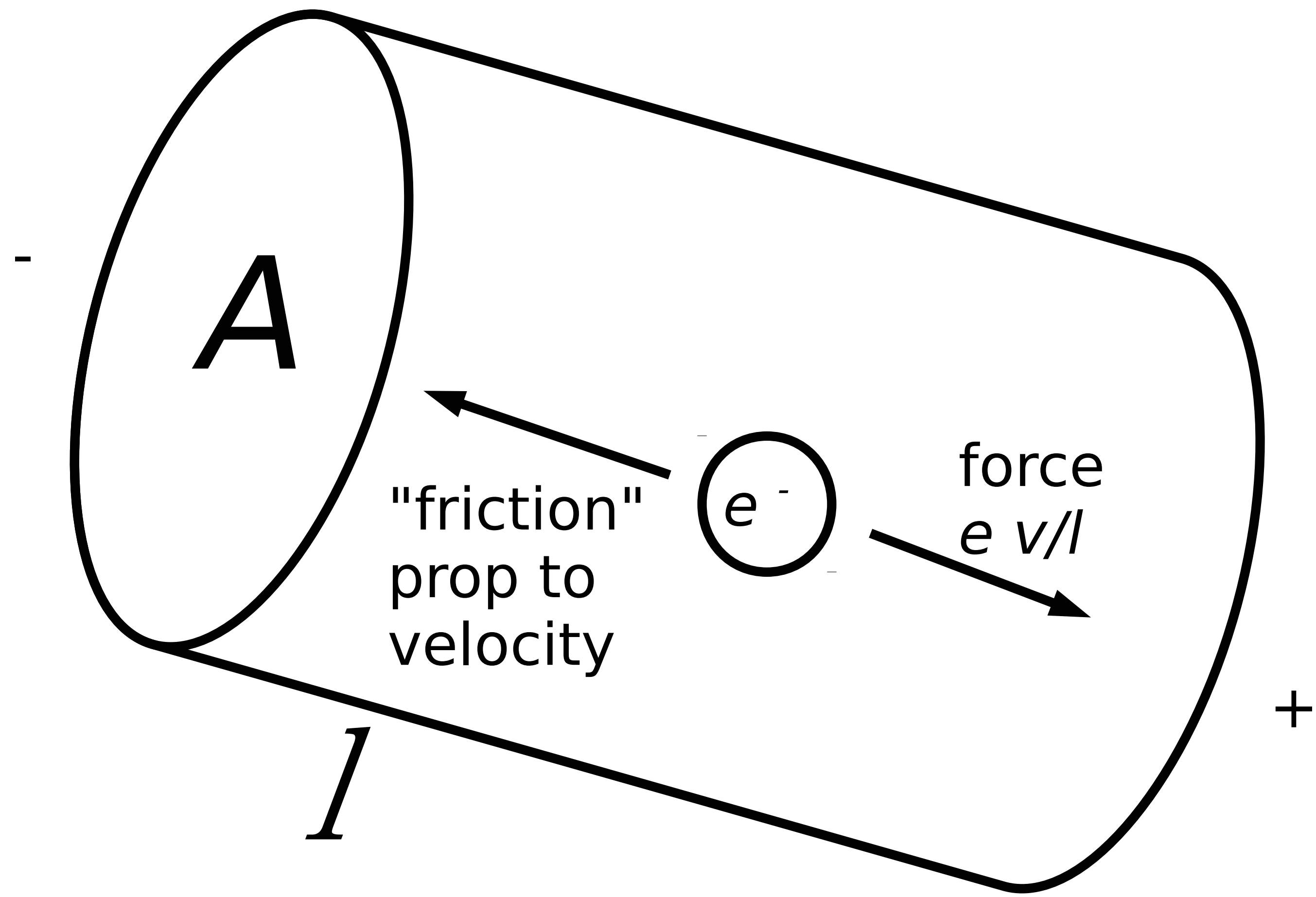
- $N = \frac{it}{e}$: Why do we care about the number of electrons?
- Noise!
  - Number: $N = \frac{it}{e}$
  - Poisson Distribution: $\sigma_N = \sqrt{N}$
  - $\sigma_i = \frac{e\sigma_N}{t}$

$$\sigma_i = \frac{e}{t}\sqrt{\frac{it}{e}} = \sqrt{i\frac{e}{t}}$$

Q: How many electrons per second equals 1 Ampere?

Voltage Measures Energy

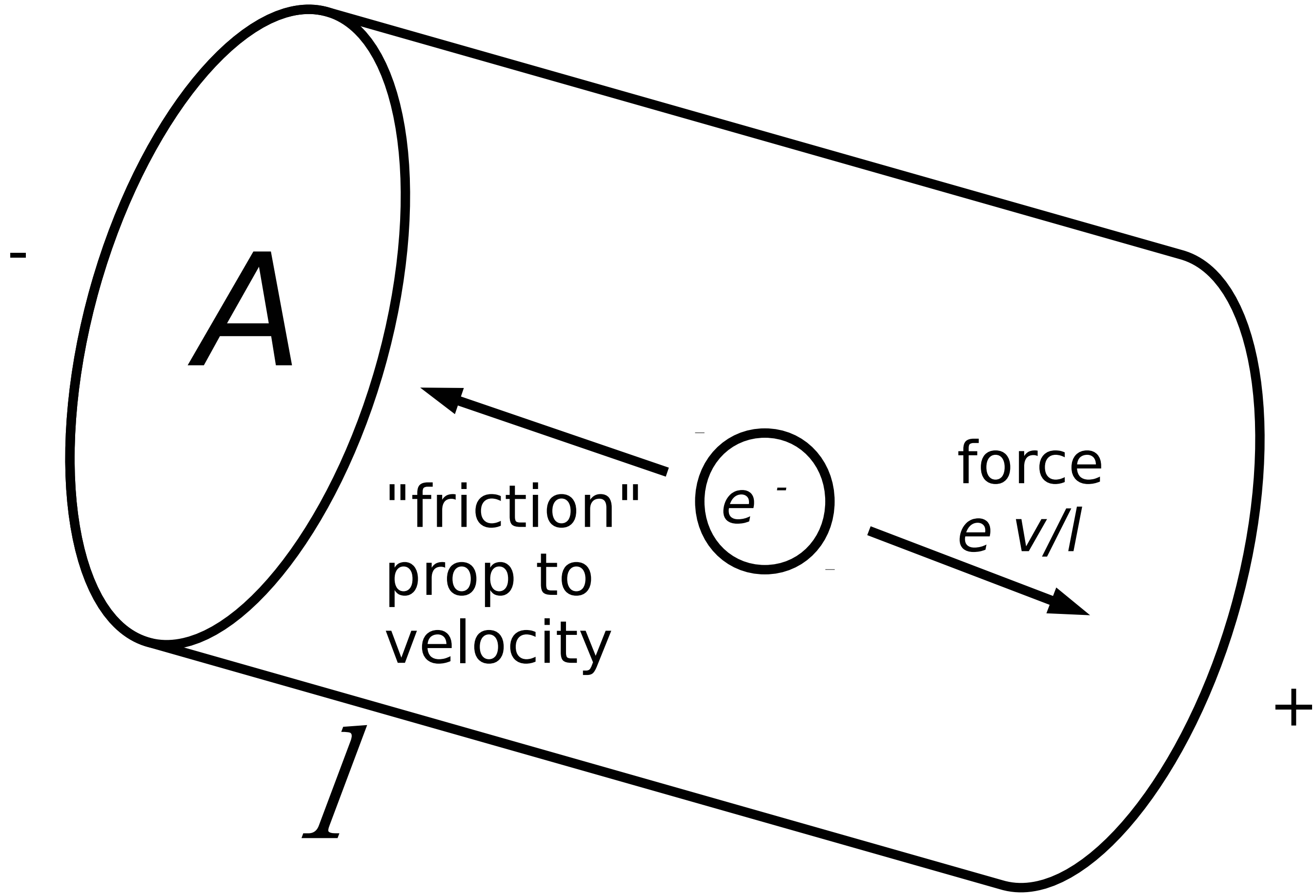
$$\text{Energy Change} = \Delta v \times q = \left(v_+ - v_-\right) \times (-e)$$



Electron (-e) has more energy at negative end

Electron Motion and Resistance

$f = \frac{v}{l}e$, Collisions cause "friction," $\frac{i}{A} = \frac{v}{l}\mu_n n e$



Voltage Across Something (Difference), Current Through Something

Voltage

High Voltage, High Energy

Energy Difference $\Delta w = q\Delta v = -e\Delta v$ where

$e = 1.6 \times 10^{-19}$ Coulombs

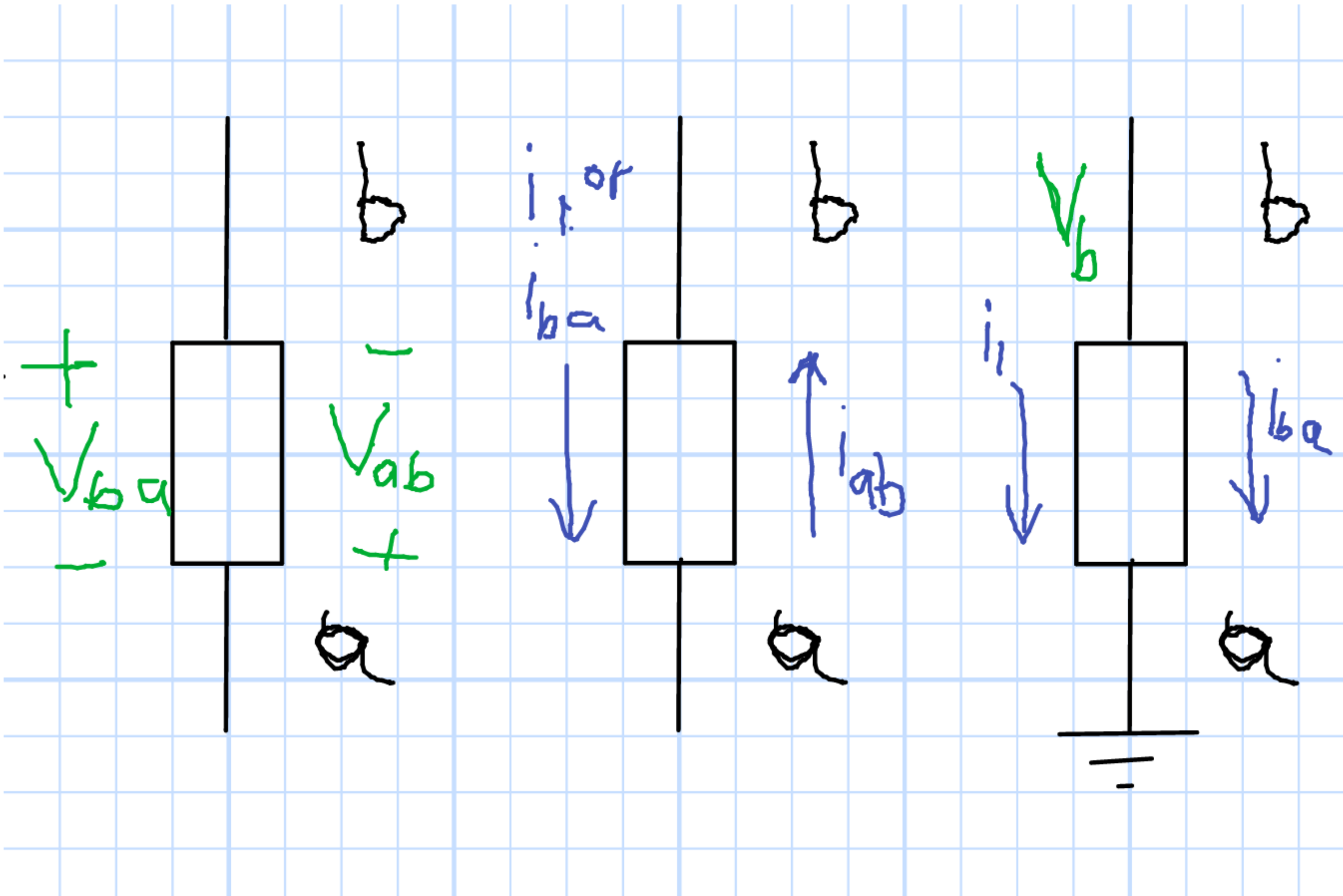
Charge times Voltage = Energy

Alternative Energy Unit: Electron Volt

$1\text{eV} = 1.6 \times 10^{-19}$Joules

Low Voltage, Low Energy

Current and Voltage Notation
Passive Sign Convention



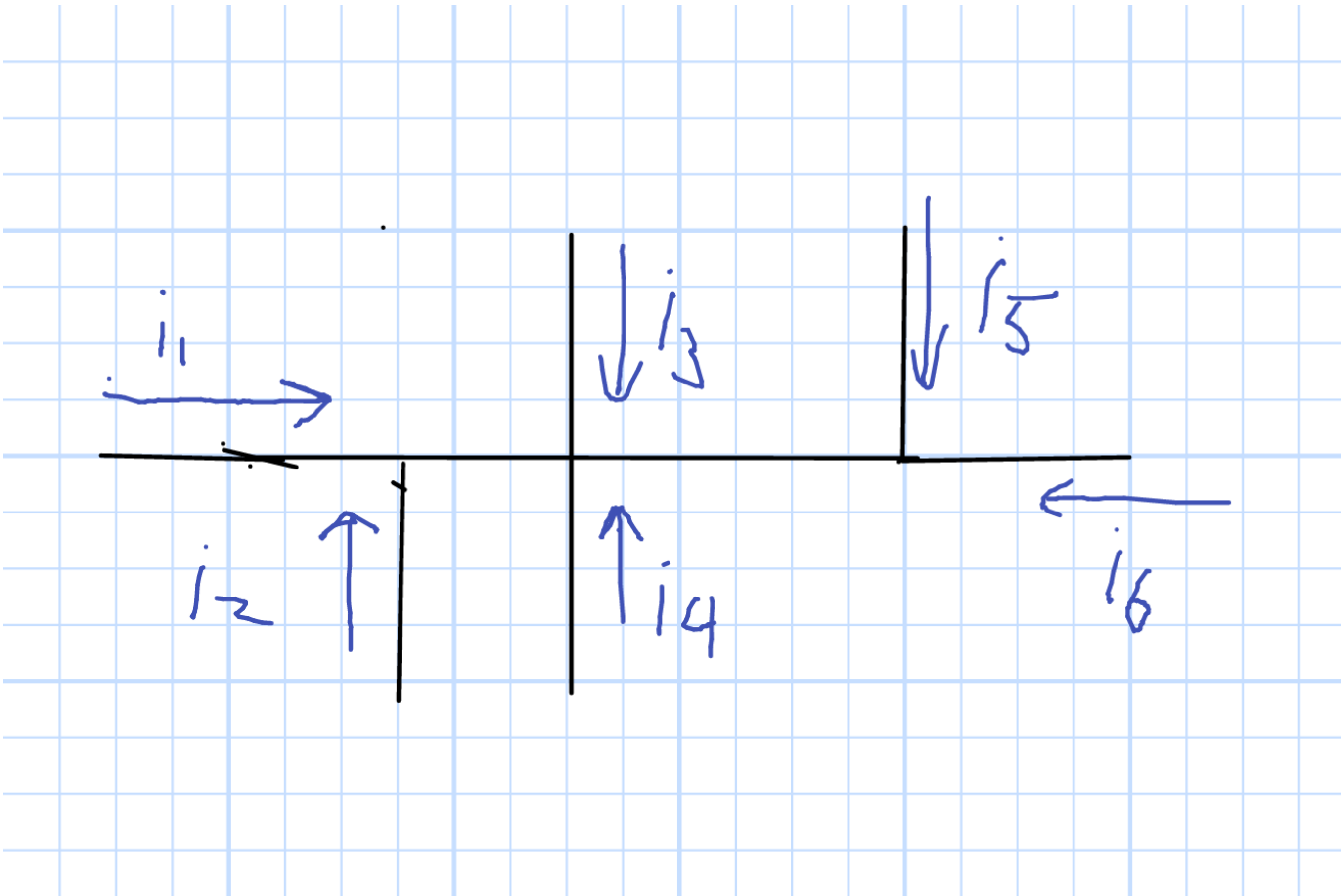
$iv > 0$ Means Power Absorbed; *eg.* $i_{ba}v_{ba}$ or i_1v_b

Kirchoff's Current Law (KCL)

One of Two Laws for Circuits

Conservation of Electrons

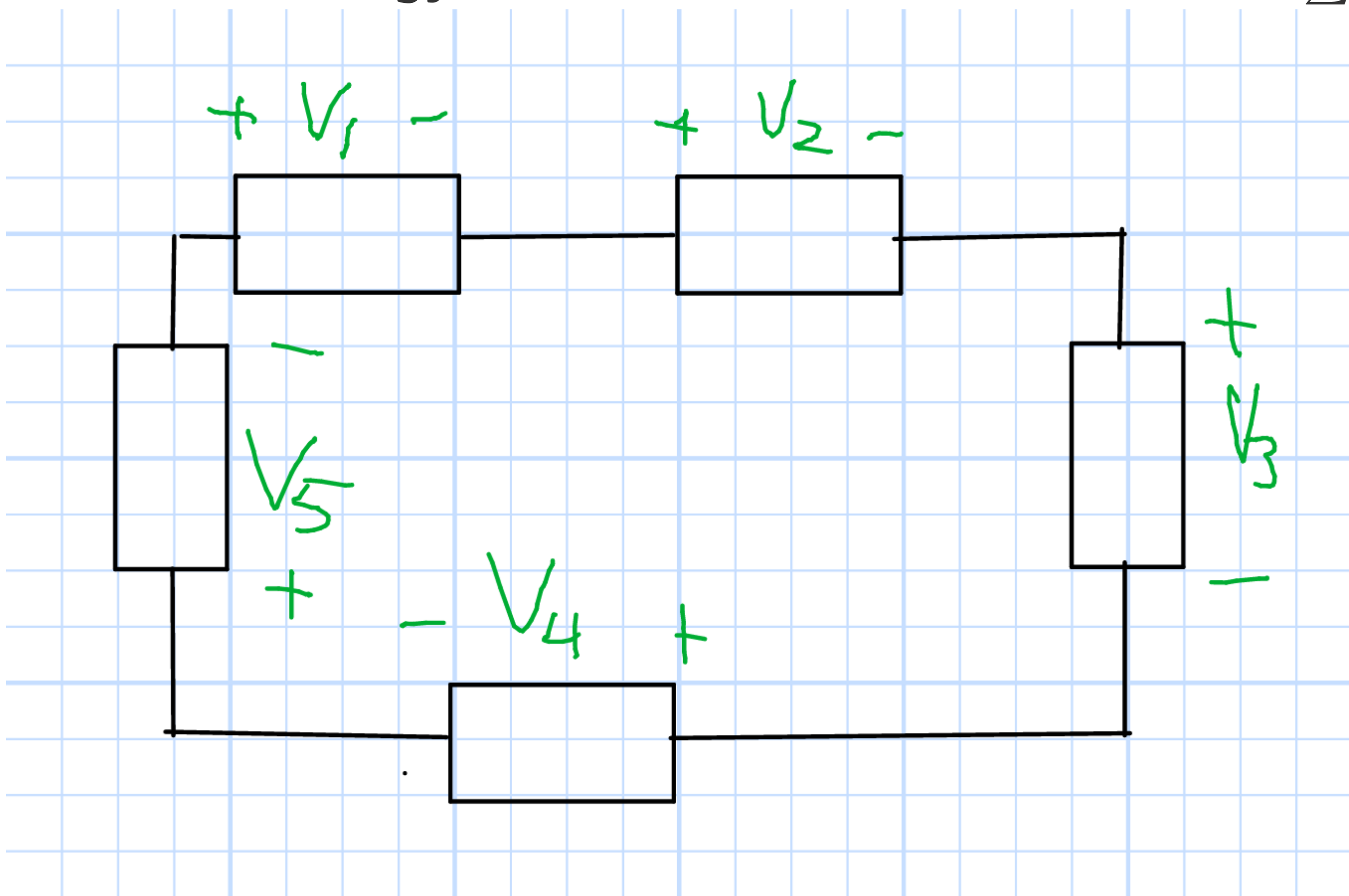
$\sum i_n = 0$



Kirchoff's Voltage Law (KVL)

One of Two Laws for Circuits

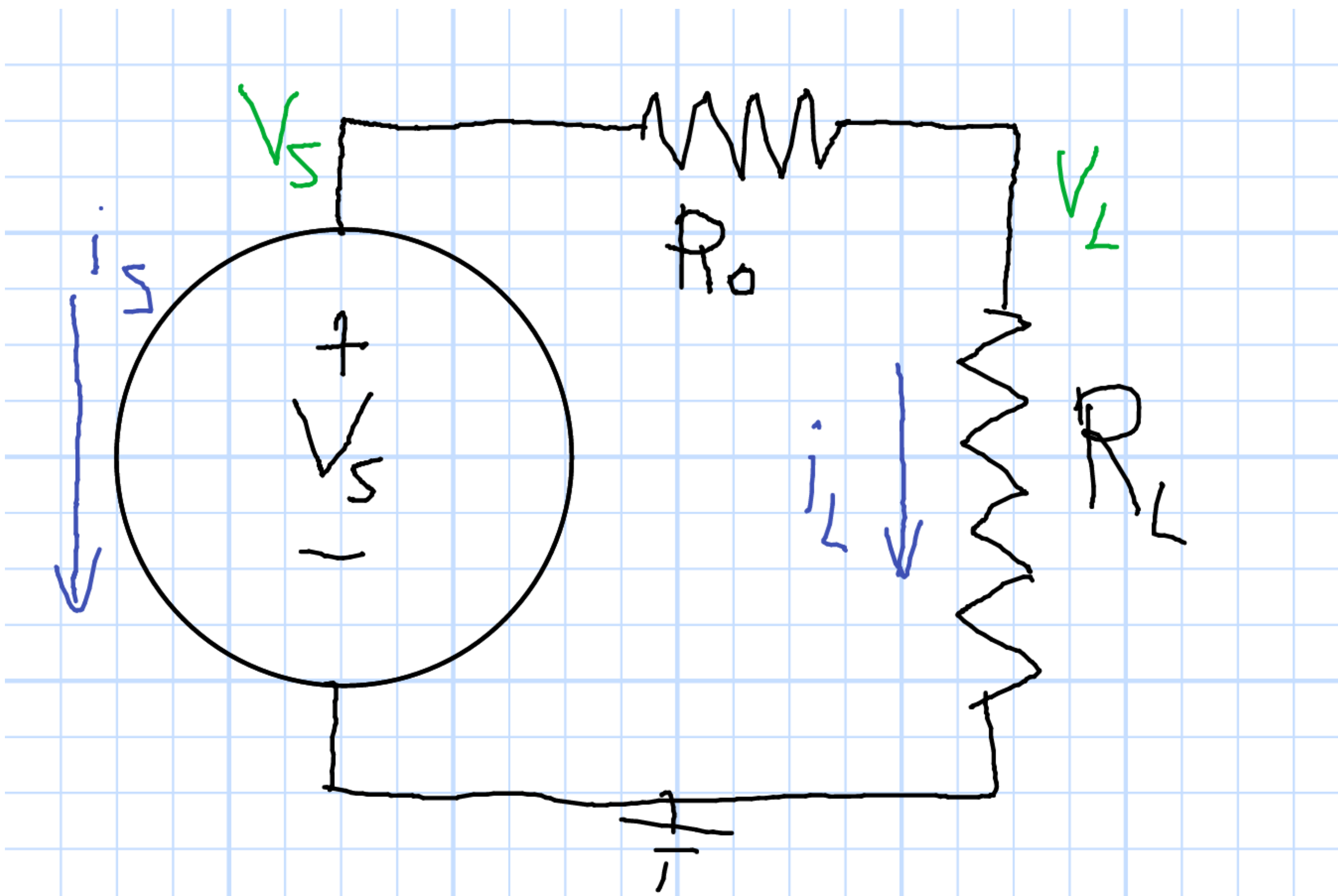
Conservation of Energy $\sum v_n = 0$



A Circuit with Passive Sign Convention

Power Absorbed $P = iv$

$P < 0$ $P > 0$



A Cup of Coffee

- Energy: Pt (1000 Watts $\times$?Sec = Joules)
- Heat a Cup of Water $T_0 = 20$C to $T_1 = 60$C (250mℓ)

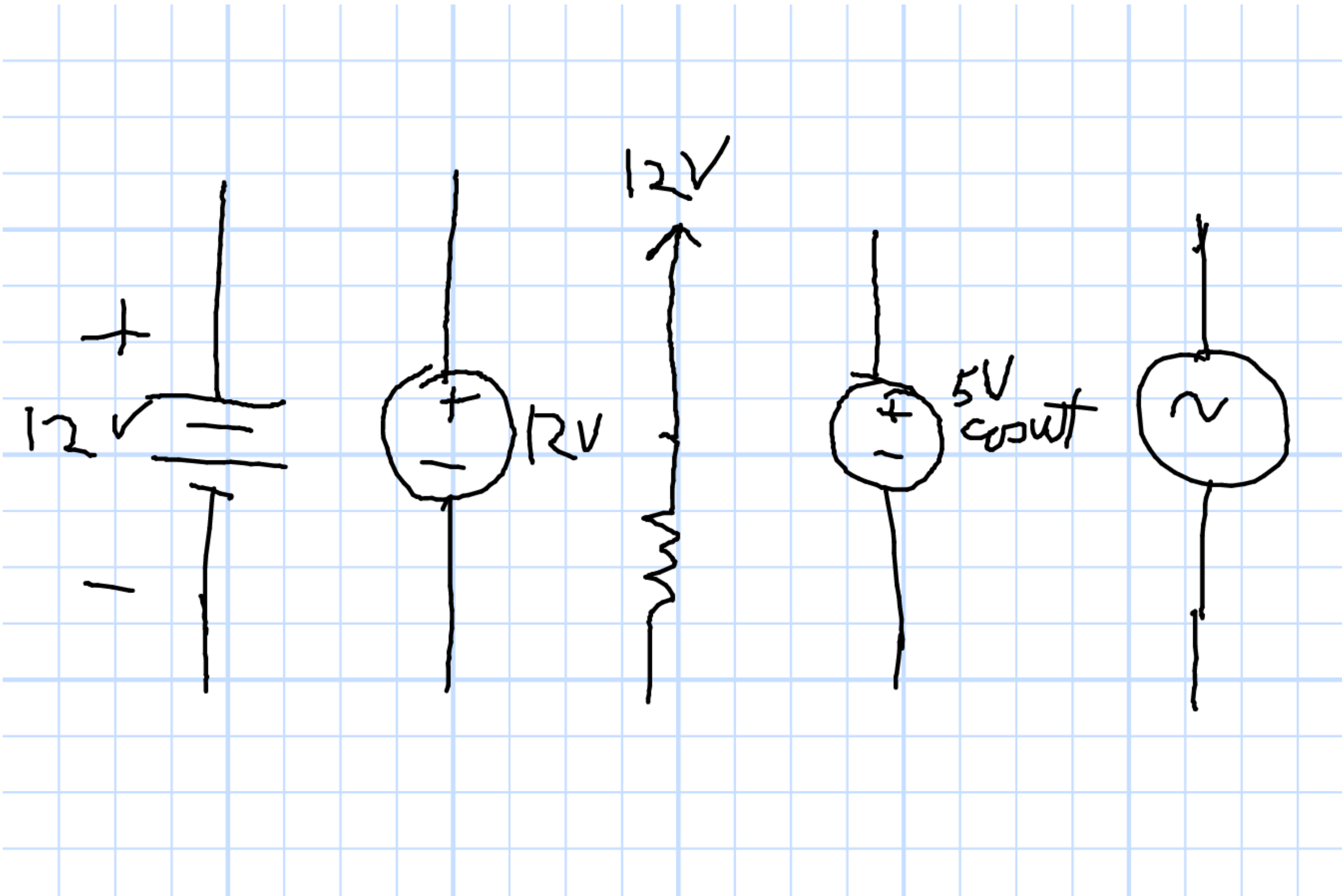
A Cup of Coffee

- Energy: Pt (1000 Watts $\times$?Sec = Joules)
- Heat a Cup of Water $T_0 = 20$C to $T_1 = 60$C (250mℓ)
- Energy Required 4.18J/K/mℓ
- 1kW Heater

$$Pt = 4.18\text{J/K/m}\ell \times 250\text{m}\ell \times (60C - 20C)$$

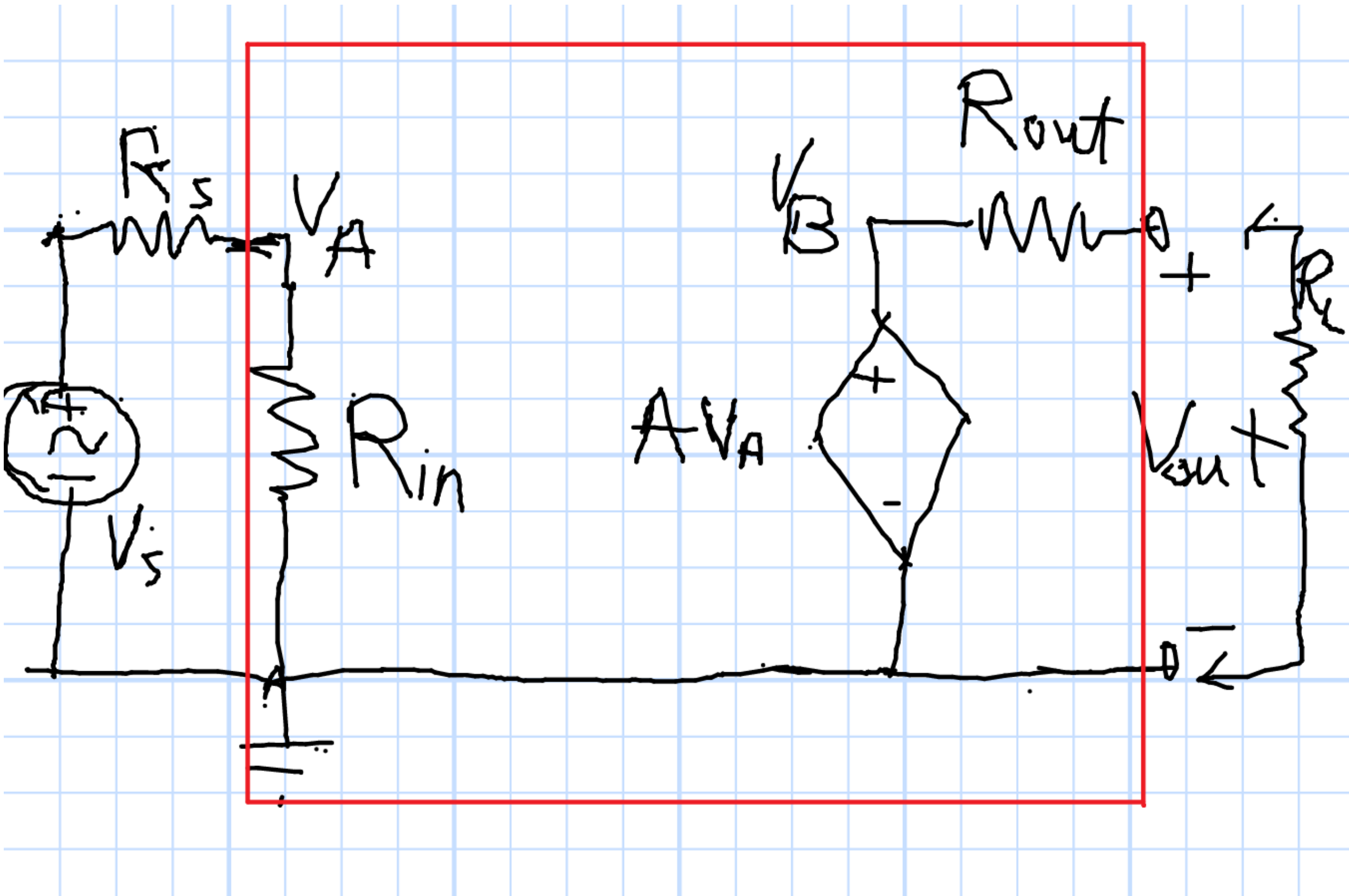
$$t = 42\text{s}$$

Voltage Sources



What does the Center one mean?

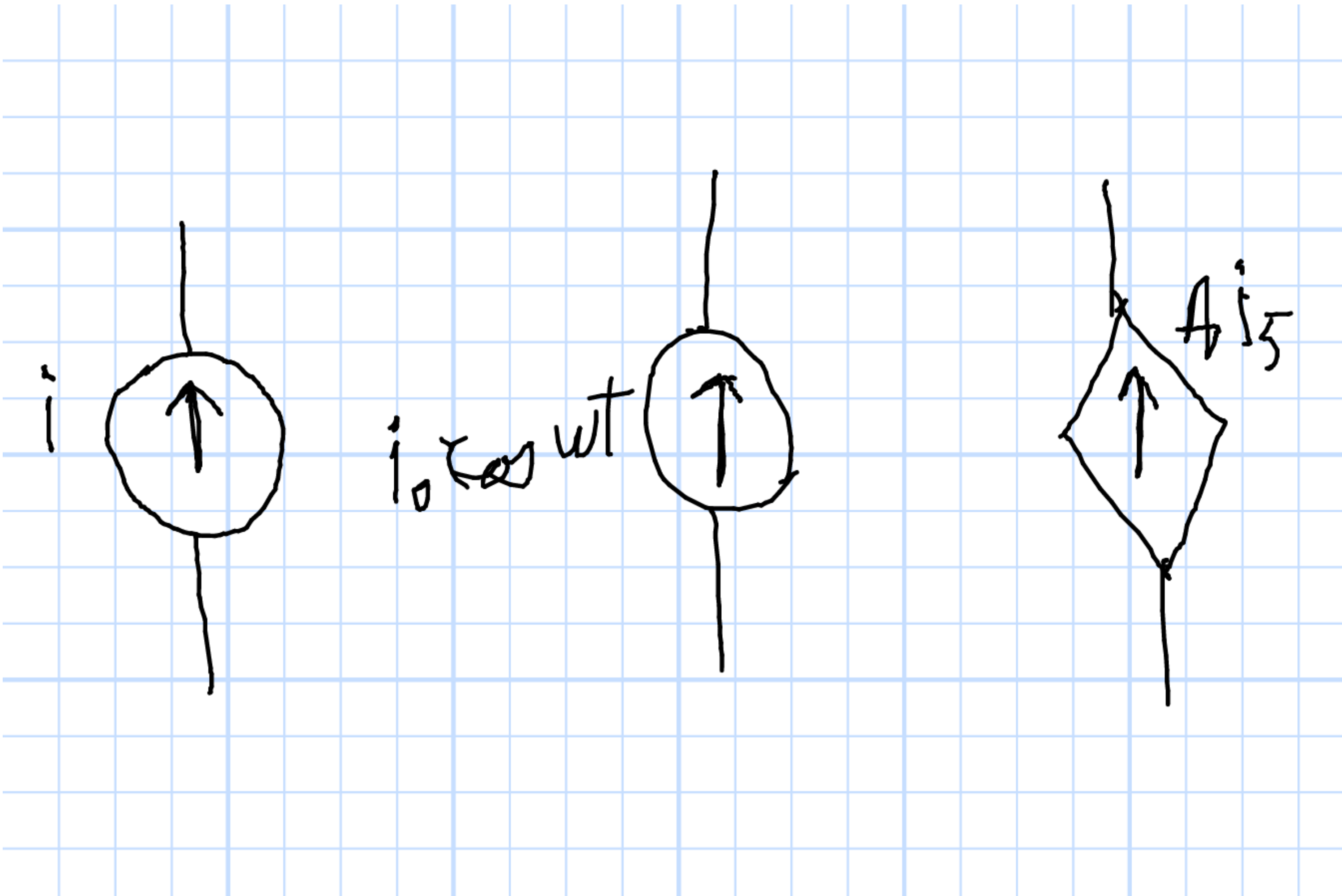
Example Dependent Voltage Source



Note Diamond Shape for Dependent Source.

Note Ground and Voltages with Single Subscripts.

Current Sources



Constants for dependent sources can have units, *e.g.* Av_3.

Resistors

Conductors: $R \approx 0,\ V \approx 0$

Resistors in General: $v = iR$

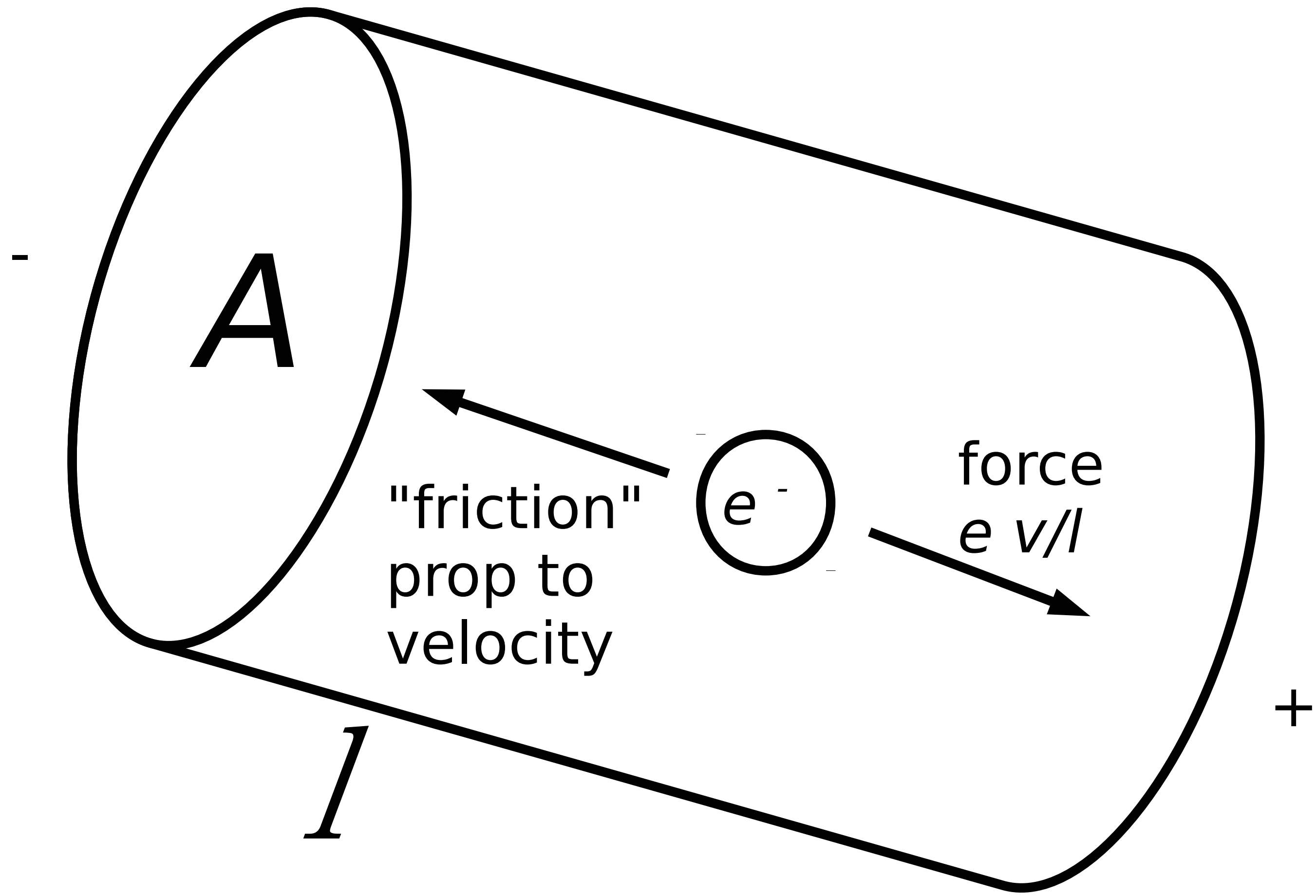
Insulators: $R \rightarrow \infty,\ i \approx 0$

Conductors

- Typically Copper
- Low Resistivity
- Sufficient Diameter
- Usual Approximation: $R = 0$.
- Validity?

Resistance: Ohm's Law

$v = iR$ Ohm's Law



$R = \frac{\rho \ell}{A}$

Copper Wire

$$A = \pi r^2 = \pi \times (1\text{mm}/2)^2$$

$$\ell = 1\text{m}$$

$$\rho = 1.72 \times 10^{-8}\Omega m$$

$$R = \frac{\rho\ell}{A} = 0.02\Omega$$

Is that a lot?

Glass Resistor

$$A = (1\text{cm})^2$$

$$\ell = 1\text{mm}$$

$$\rho = 10^{12}\Omega m$$

$$R = \frac{\rho\ell}{A} = 10^{13}\Omega$$

A much larger resistance despite being thicker and shorter than the copper wire

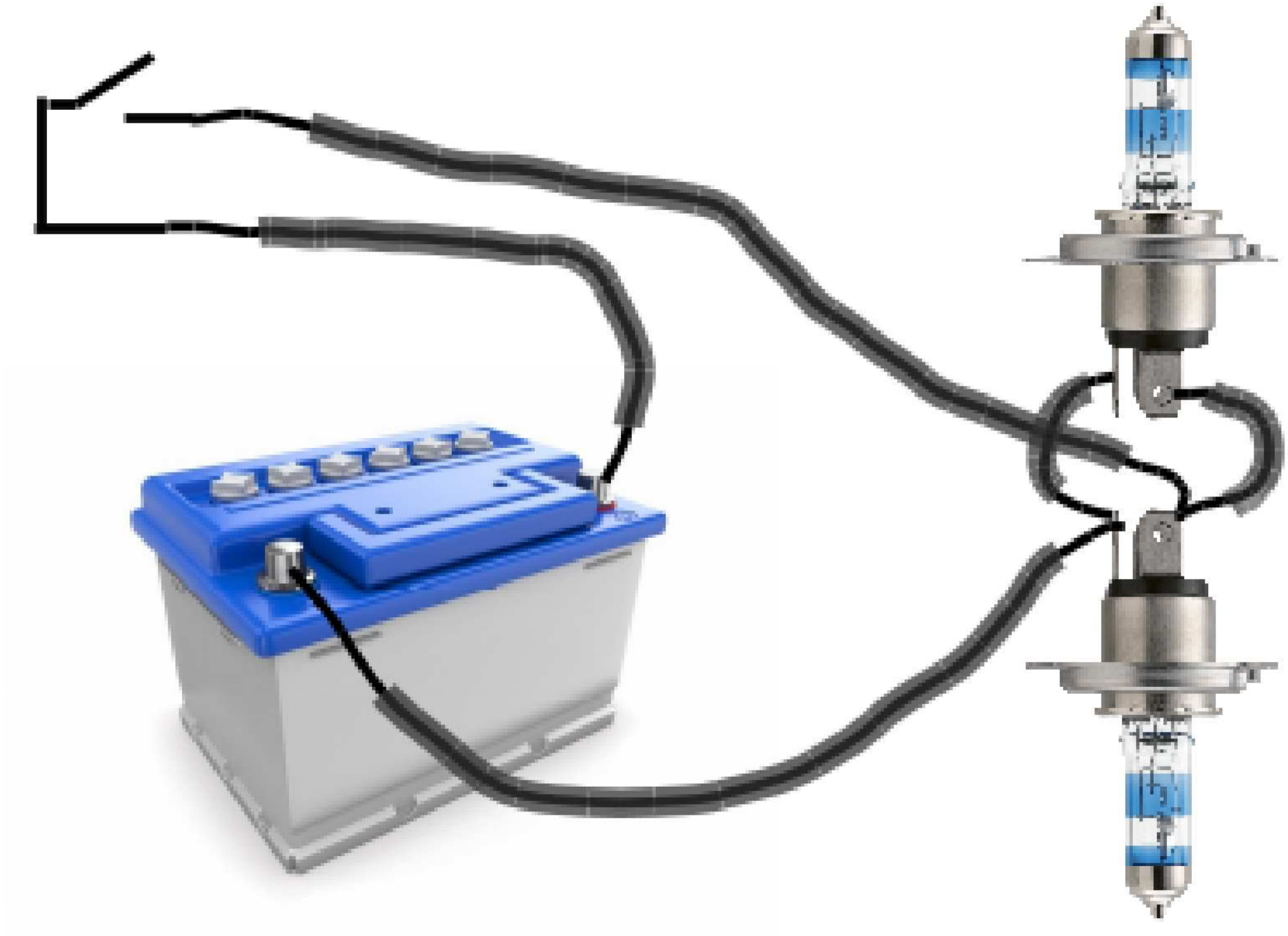
Air is a “pretty good” insulator.

Q: What happens if the voltage is “Really high?”

Power in Resistors

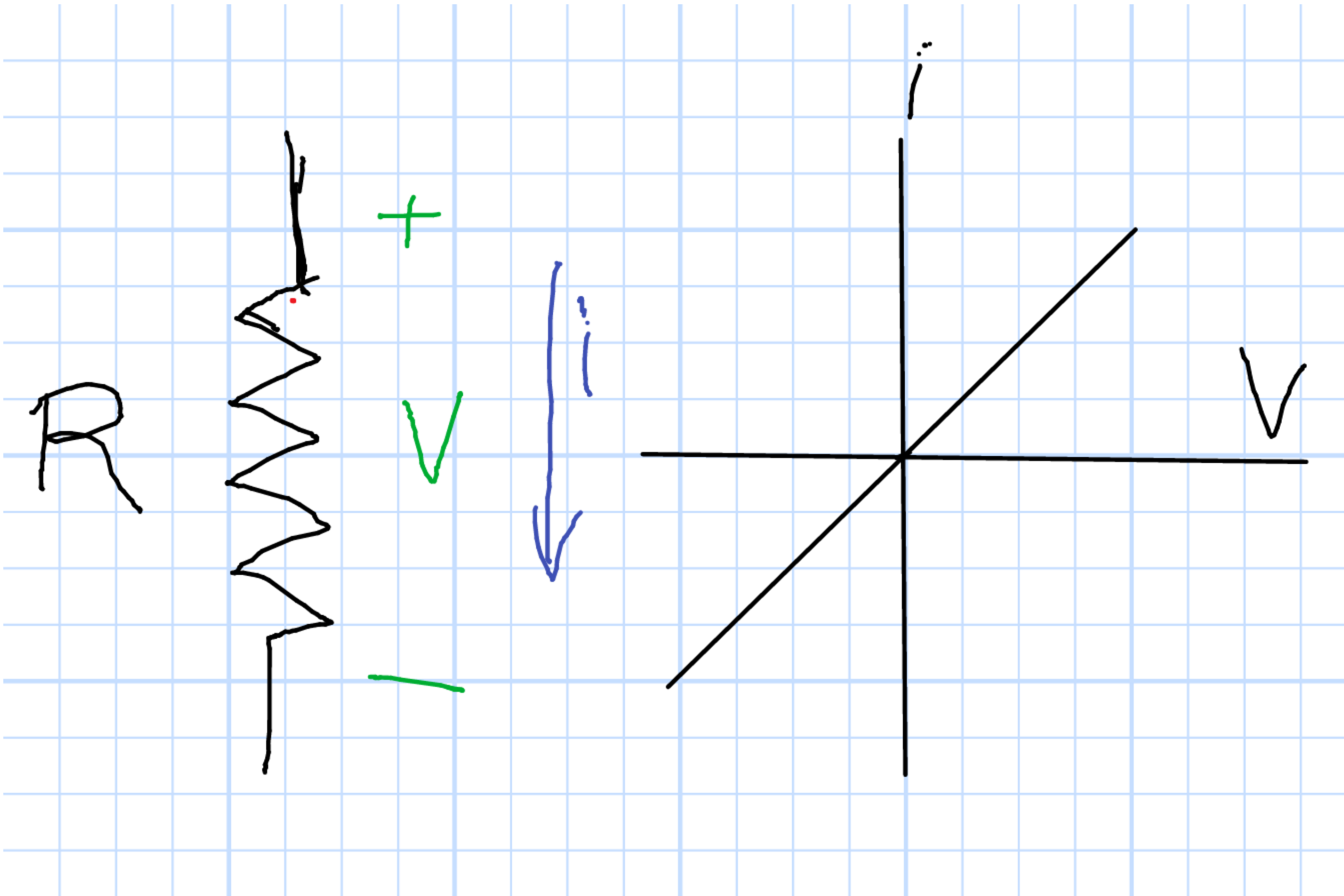
- Energy $= qv$
- Power = Energy / Time
- $P = \frac{dq}{dt} v$
- $i = \frac{dq}{dt}$
- $P = i \times v = i \times iR = i^2 R = \frac{v^2}{R}$

Wires (= Conductors?) and Insulators



The Resistor

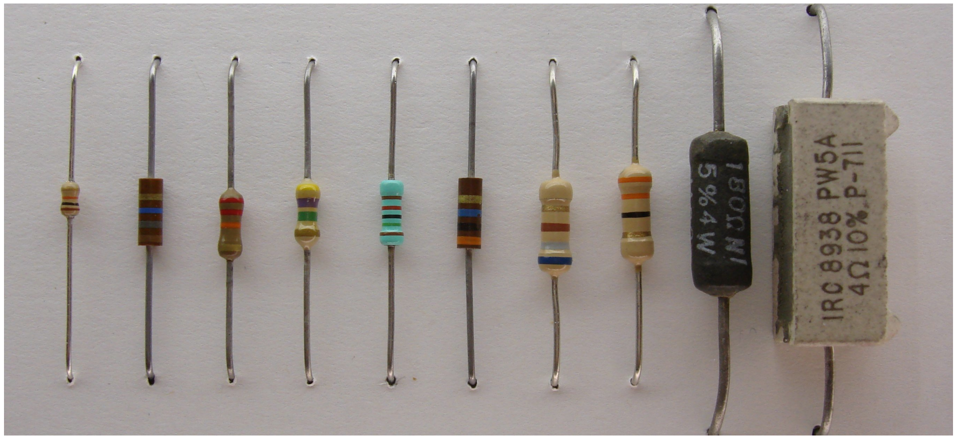
New Concept: Terminal Charcteristics



Resistors

Power Ratings Low to High from Left to Right

Typical in Our Lab



Dynamic Braking

http://ecee.colorado.edu/ mathys/ecen1400/labs/resistors.html

trainweb.org

Parameters

- Resistance
- Tolerance
- Power Rating (Maximum)

Power Ratings

$p = v^2/R$

A typical resistor we might use in the lab has a power rating of 1/4 Watt. Is this ok?

- 1 Volt on a 1kOhm Resistor?
-
- 12 Volts on a 100 Ohm Resistor?
-

Power Ratings

$p = v^2/R$

A typical resistor we might use in the lab has a power rating of 1/4 Watt. Is this ok?

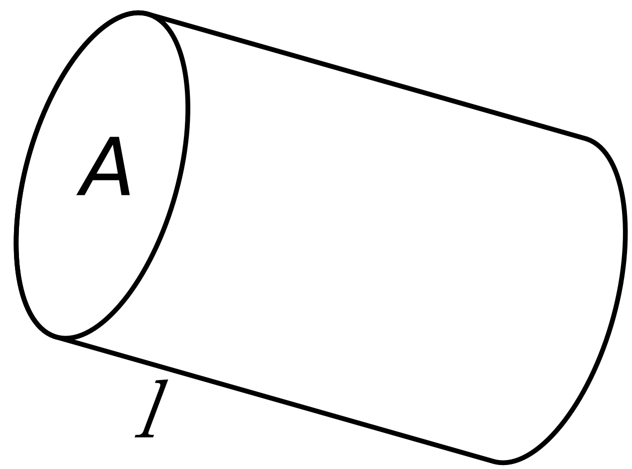
- 1 Volt on a 1kOhm Resistor?
- ($p =$ 1mW: Ok)
- 12 Volts on a 100 Ohm Resistor?
- $p =$ 1.44W: No!

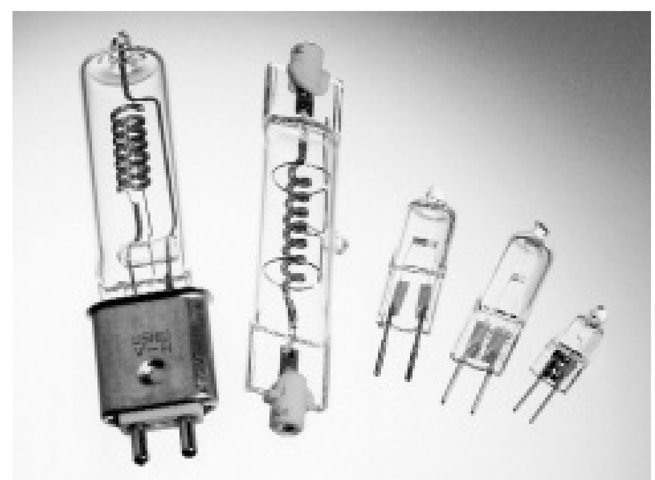
Quartz–Halogen Lamp

- Tungsten Light
  - 3000 K
  - Glass Bulb
  - Failure: Evaporation and Condensation
- Quartz–Halogen
  - 3500 K
  - Halogen Catalyst Prevents Condensation
  - Large Diameter Tungsten Filament ($R\downarrow$ so $V\downarrow$)
  - Lower Voltage for Low Power
  - Quartz Bulb

$$R = \frac{\rho\ell}{A}$$

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

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