Lecture 1: Introduction, Overview, and EMag

18-100: Introduction to ECE

Spring 2025

Electrical & Computer ENGINEERING

Carnegie Mellon University

Objectives of this Lecture

- **Gut check: Welcome to 18-100: Intro to ECE**
- Who are we?
- What is electrical and computer engineering (ECE)?
- Why study ECE?
- Course structure
- Electrical and magnetic principles, models, and equations
- Models, models, models

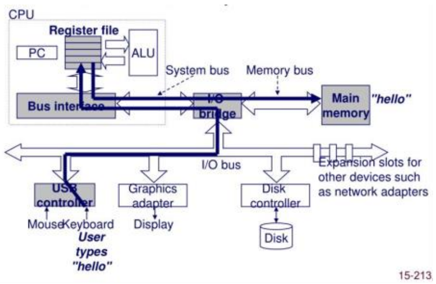
About 18-100

- “ This course introduces basic concepts and principles over the broad spectrum of electrical and computer engineering in an integrated manner. It covers basic concepts in electronic circuits, computer logic circuits, computer architecture, analog and digital signals processing, wired and wireless communication systems, computer network, computer memory, data storage, and data center technologies, machine learning and artificial intelligence, and cryptography and data security. The 9 specially designed labs in the course give students excellent hands-on experience on various examples of practical systems in electrical and computer engineering. The labs also help to consolidate the understanding of the topics covered in lectures. The course is designed to inspire and motivate students through in-depth learning of many present systems and their underlying .” (Official Description)

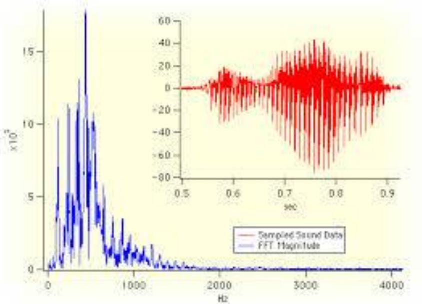
- 12 units
- No Prereqs

18-100 Preparation for Other ECE Core Courses

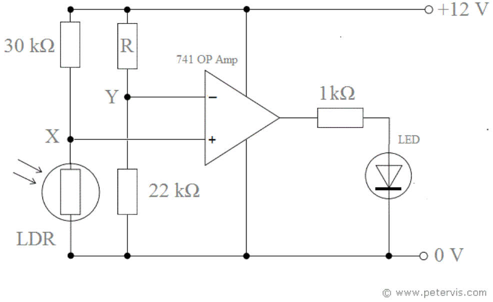
18-213 Computer Systems



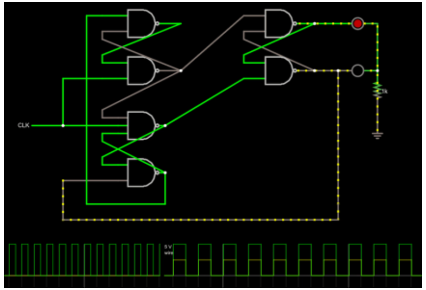
18-290 Signal & Systems



18-220 Electronic Circuits



18-240 Logic Design



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Instructional Team

Prof. Greg Kesden

Prof. Mark Budnik

Amazing Team of TAs (38):

Akshaj Sharma * Angela Wu * Angie Shere * Ankita Kundu * Ashley Yuan * Berin Celik * Caleb Song * Calla Song * Catherine Li * Clair Zhou * Daniel Lin * David Chan * Deniz Balci * Dilan Leon * Eric Ma * Felipe Perotti * Haowen Huang * Henry Kim * Irene Fidone * Jasmine Li * JiWon Jin * John Diaz * Jonathan Waller * Julius Arolovich * Kamya Singh * Kevin Qian * Luna Lee * Miguel Salvacion * Ming Yue * Mohid Rattu * Om Patel * Shirley Li * Shravani Vedagiri * Sylvia Lyu * Tiffany Yang * Victor Li * Wes Lee * Yuvvan Talreja

About Greg Kesden

- Associate Teaching Professor
  - Dedicated full time to teaching and advising stu
  - I’m here for you!
- Recent Teaching
  - 18-213/613: Computer Systems
  - 18-349: Embedded Systems
  - 18-100: Intro to ECE
  - 14-736: Distributed Systems
  - 14-740: Computer Networks
  - 14-760: Adv. Real-World Computer Networks
  - 14-848: Cloud Infrastructure
- Email: gkesden@andrew.cmu.edu
- Cell: 412-818-7813 (Feel free to call 24x7)
- OH, Schedule, Zoom, etc: https://www.Andrew.cmu.edu/~gkesden

About Mark Budnik

- Dedicated full time to teaching

• Time in academia	20 years
• Years at CMU	4 years
• Commonly also teach	18-220, 18-349
• Time in industry	15 years
• Companies include	TI, Hitachi, Intel
• Position(s)	Director of Embedded Systems Engineering
• Email	mbudnik@andrew.cmu.edu

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What is ECE?

- What is *Engineering?*
- What does it mean for something to be *Electrical*
- What are *Computers?*

- What roles are filled by *ECE graduates?*

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Why Does ECE Matter (According to Google AI)

- "Electrical and Computer Engineering (ECE) matters because it forms the foundation for much of modern technology, enabling the design and development of critical systems in areas like communication, healthcare, energy, transportation, and computing, essentially shaping the way we live by creating devices and infrastructure that are essential to daily life; it combines the understanding of electrical circuits with computer programming to solve complex real-world problems and drive innovation across various industries. "

Key Points About the Importance of ECE (According to Google AI)

- **Impact on daily life:**
  - Smartphones, computers, medical devices, power grids, and even advanced vehicles all rely on principles of ECE for their functionality.
- **Interdisciplinary nature:**
  - ECE integrates knowledge from physics, mathematics, and computer science, allowing engineers to tackle multifaceted problems.
- **Innovation potential:**
  - ECE is at the forefront of developing new technologies like robotics, artificial intelligence, renewable energy systems, and advanced communication networks.
- **Career opportunities:**
  - A degree in ECE opens doors to diverse career paths in hardware design, software development, system integration, research and development, and more across various industries.

Not bad, Google AI. Not Bad.

- In summary
  - ECE matters because it is a foundational driver for *everything* around us
    - Everything around us that is “smart” is ECE as is what powers it and the processes that design, build, install, and maintain it.

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Course Components: Lectures

Mondays and Wednesdays 12:30 pm-1:50 pm HOA 160

- Lectures are a critical part of this course.
- Since no textbook, timely comprehension of any given topic is extremely important.
- Lecture slides will be posted prior to each lecture on Canvas.
- Make effort to attend each lecture.

Course Components: Recitations

Mondays and Wednesdays 12:30 pm-1:50 pm HOA 160

- Critical reinforcement and enrichment
- Often group-work problem sessions with presentations
- Interesting applications

Course Components: Labs

Lab 1: Circuits Lab – Electrical measurements; LEDs

Lab 2: Adder Lab – Gate-level digital logic; binary adder circuits

Lab 3: MOSFET Lab – Transistor-level logic; flip-flop circuits

Lab 4: 555 Lab – Time and frequency signal generation

Lab 5: Op-Amp Lab – Amplifier circuits using operational amplifier ADC Lab –

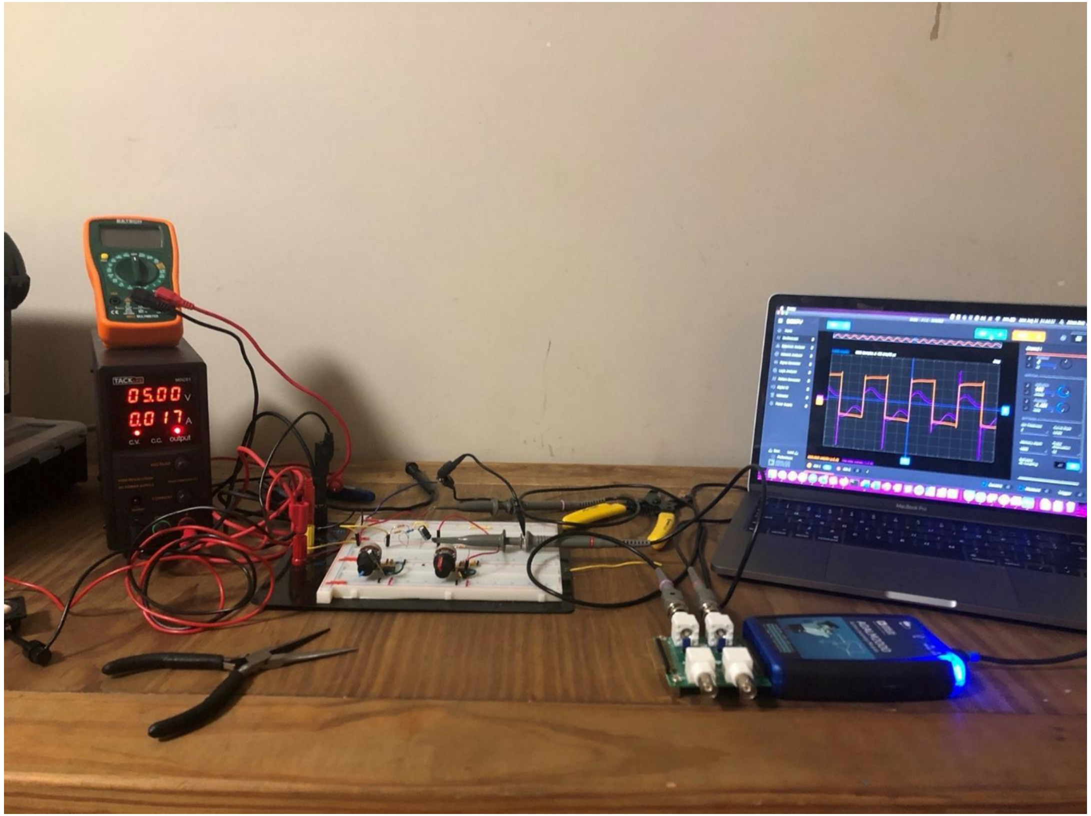
Lab 6: Analog to Digital Conversion

Lab 7: Radio Lab – Amplitude modulation; wireless communication circuits; antennas

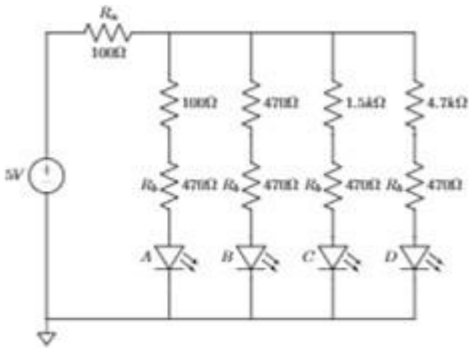
Lab 8: Serial Communication - I^2C serial communication; real-time clocks

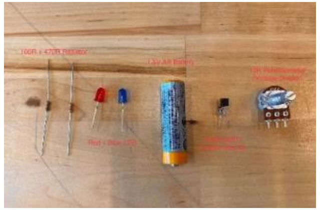
Lab 9: Cryto Lab – Wireless communication with encryption and security attach

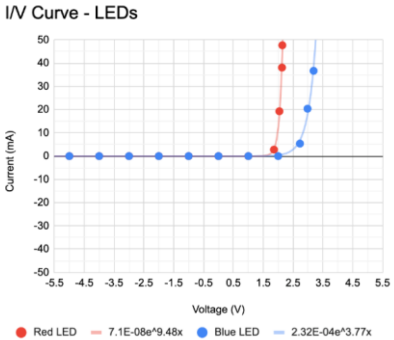
Labs Generally Look Like This:

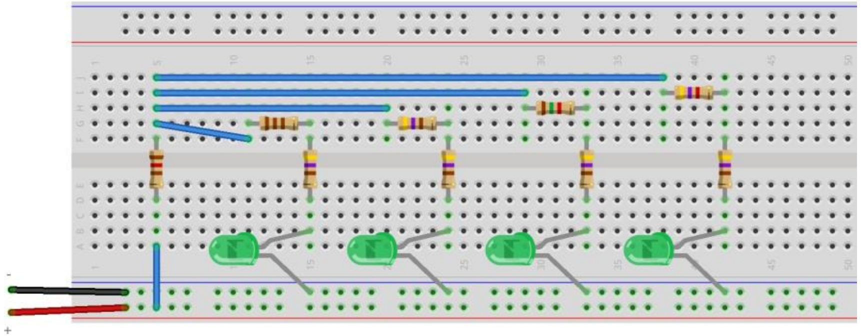


Lab 1 LED Circuit Circuit, LED, Voltage, & Current





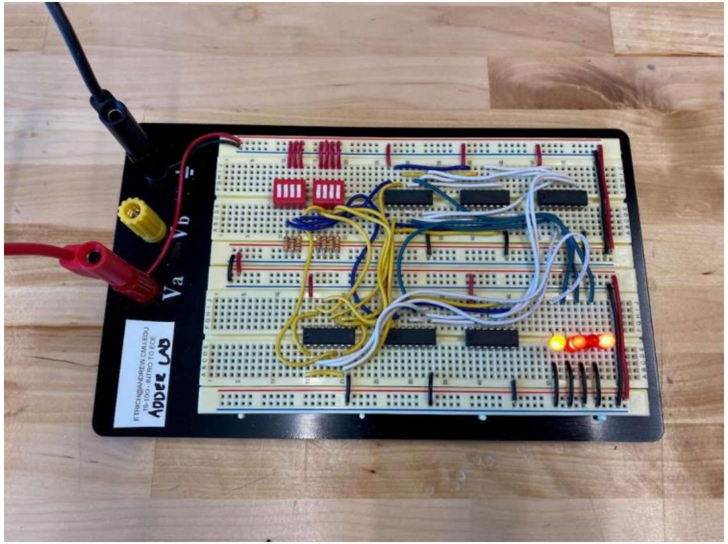


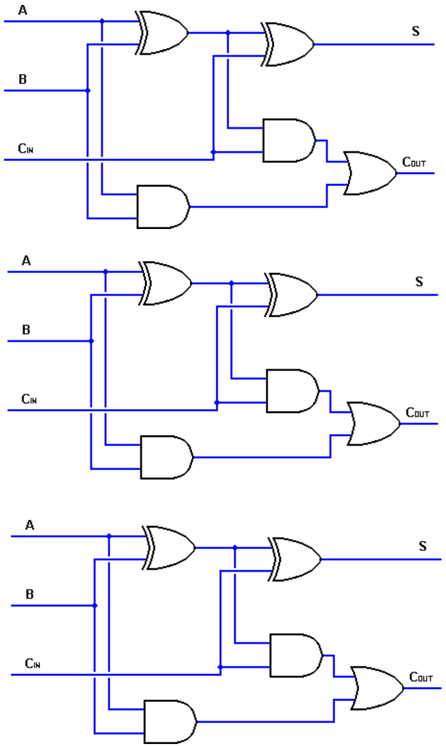


Lab 2 Multi-Bit Adder

Logic Functions

- *Logic gates and logic function.*
- *Logic control and decoder.*
- *Logic gates for adding three digits binary numbers.*
- *Display logic states with LEDs.*



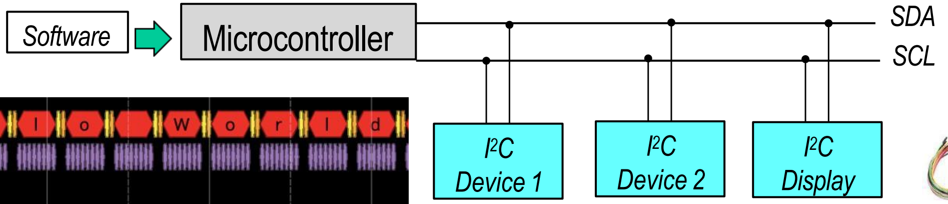


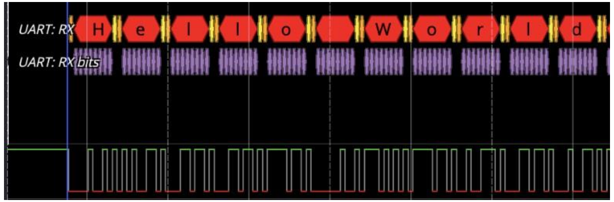
Lab 8 I^2C Bus

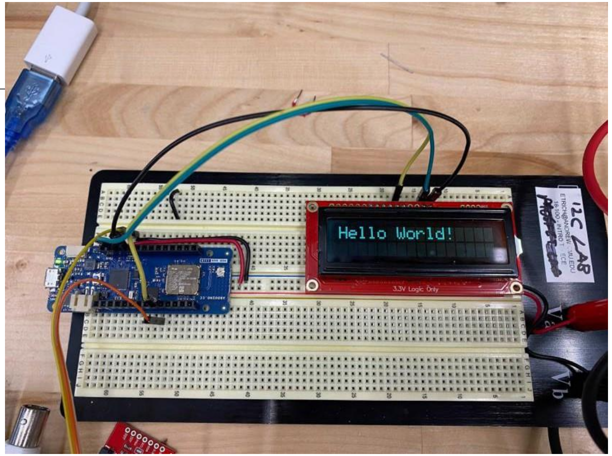
Control Display

- ***Learn how to use a microcontroller.***
- ***Understand communication protocol.***

I^2C Bus

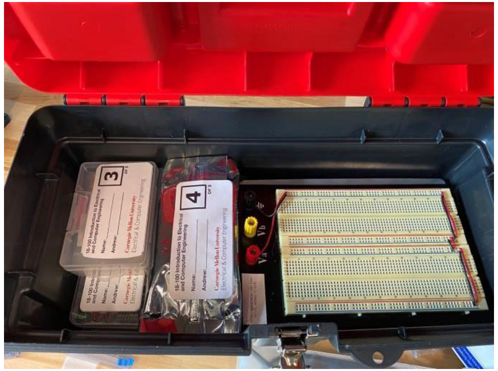







```
  sensor.begin();
  delay(100);
}

void loop()
{
  // Turn sensor on to start temperature measurement.
  sensor.wakeup();

  // read temperature data
  temperature = sensor.readTempC();

  // Print temperature
  Serial.print("Temperature: ");
  Serial.print(temperature);
  Serial.println();

  delay(300);  // Wait 0.3s
}
```

Lab Kit One Tool Box for Each Student



Course Components: Small Groups

- **TA facilitates sessions that:**
  - Review content from the week
  - Prep for upcoming exams
  - Start building the circuits for the week's lab
  - Reinforce and enrich
- **5 students per group, 2 TAs**
- **Occur weekly on Sunday or Monday in HH 1200 wing (Room in SIO)**
- **Mandatory (it's part of your grade)**
  - 2 points are earned per small group
    - 1 point for attendance
    - 1 point for participation

TA Office Hours

- **Sunday - Friday**
  - 7 - 10 pm in HH 1206 and HH 1307 (+HH 1206, if super busy)
- **Show up with questions and ready to collaborate!**
- **Beginning soon (wait for announcement)**

Learning Tips

- **Have fun!**
- **Do not be scared by things that you have not seen before!**
- **Reach out if you have questions!**
  - Small groups
  - Piazza
    - Private posts when the posting contains private information, whether personal or otherwise, e.g. partial solutions.
  - Office hours
    - TA
    - Faculty Instructors
  - 1:1 appointments
    - We have a huge course staff. Just ask!
- **Never be discouraged!**

Policies

- **Please read the syllabus**
  - We didn't read it to you today

- **Please pay attention to the AIV policy**
  - Do your own work
  - Don't ask Chat GPT or other AI tools to do your work
  - Cite all your sources and give credit for all contributors
  - Speak with one of us if you have any concerns
  - Penalties can be very severe (up to "R" in the class).

- **There's much more in there, e.g. late penalties, regrade poloicies, etc, etc, etc.**

Logistics: Grading

Your grade will be calculated using the following method:

5%	Quizzes (1 correct = 50%, 2 correct = 90% and 3 correct = 100%.)
5%	Small Group attendance and Participation
15%	Homework
30%	Three Exams (each exam is 10%)
45%	Labs

While lower cutoffs may be used, the following cutoffs are guaranteed:

>=90	A
>=80	B
>=70	C
>=60	D

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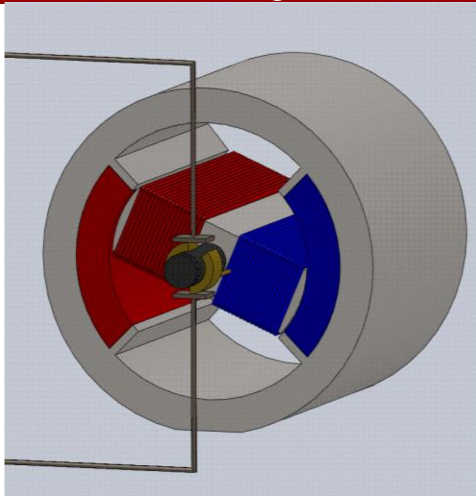
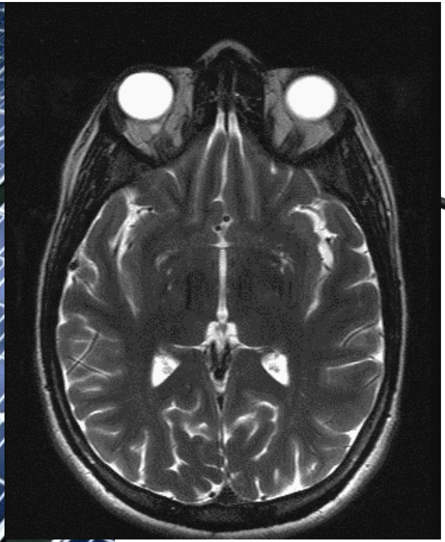
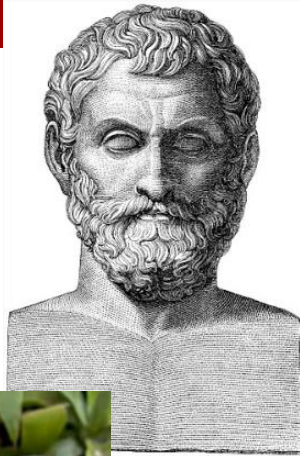
Electromagnetism



- Electricity and magnetism are essentially two aspects of the same thing, electromagnetism:
  A changing electric field creates a magnetic field…
  and a changing magnetic field creates an electric field.



Thales of Miletus (c. 626-548BC)

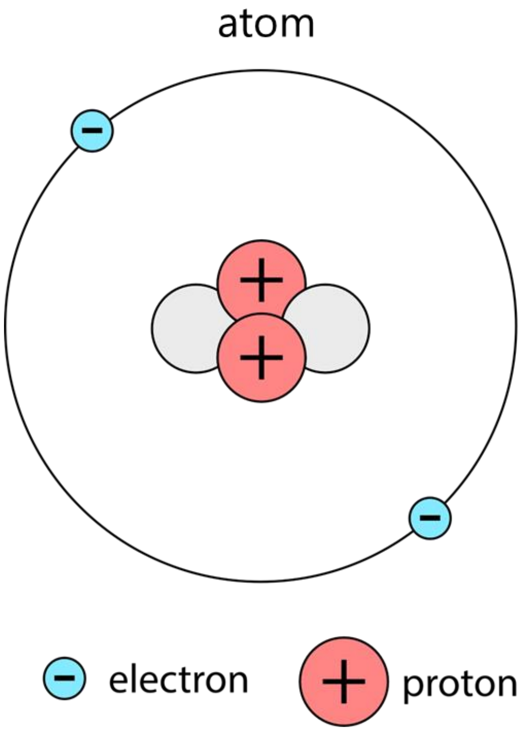


- First philosopher in the Greek tradition
- Used math, science, and reasoning to explain the world

- Accidentally discovered lodestone (naturally occurring magnetic iron ore)
- Identified some materials were attracted to lodestone, while others were not

- Accidentally discovered amber “generated” static electricity when rubbed with silk
- ἤλεκτρον (elektron) is Greek word for amber

Charge Is an Electrical Property of Matter



- **Charge** has either positive or negative **polarity**
- Opposite charges attract
- Like charges repel

- Each electron and proton **has the same magnitude of charge**
- Electrons have negative (–) charge
- Protons have positive (+) charge

- Unit of charge is the **Coulomb (C)**
- **Q** is used in equations to represent charge

$q = Q_{electron} = 1.6\text{x}10^{-19}$ C

Opposite Charges Attract, Like Charges Repel

- When a comb runs through hair, electrons deposited onto it
- The comb is **negatively charged**
- The hair, having lost electrons, is now more positive (that is, **positively charged**)

- These **opposite charges attract**

- **Static electricity:**
  Charges that are not moving

- Static charges apply forces on each other (attract or repel)

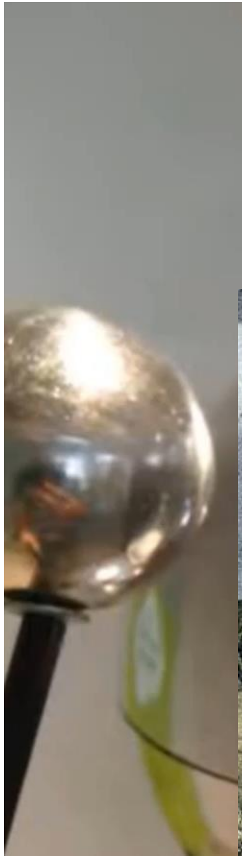
Otto von Guericke (1602 – 1686)

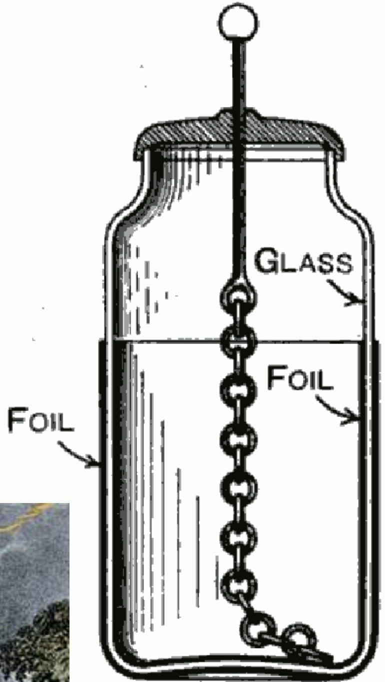
- German politician and inventor
- Wanted to generate **static electricity** more easily

- Invented a hand-cranked machine that rotated a sulfur ball (1663)
- Rubbed a piece of cloth across the ball

Benjamin Franklin (1706 – 1790)

- Observed sparks and arcs between two electrically charged spheres
- Looked like miniature lightning
- Flew a kite in a thunderstorm (1752)
- Used copper wire instead of string
- Heavy brass keys inside of a Leyden jar
- Lightning charged the Leyden jar "battery" (primitive capacitor)





Charles Coulomb (1736 – 1806)

- Civil and structural engineer, studied torsion

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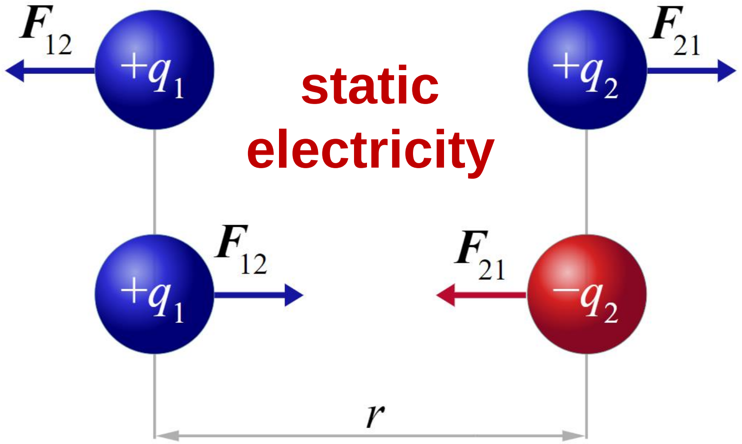
- Civil and structural engineer, studied torsion
- Demonstrated the attraction and repulson of two charged spheres varies inversely with the distance between them (1784)



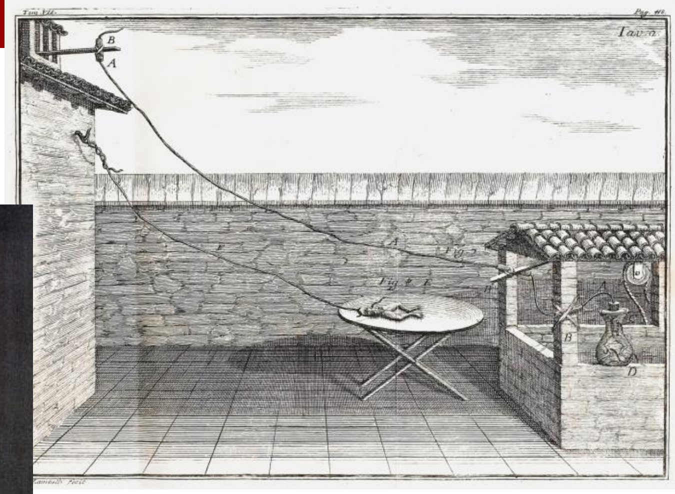
$$\left|\boldsymbol{F}_{12}\right| = \left|\boldsymbol{F}_{21}\right| = \frac{\left|q_1 q_2\right|}{\left(4\pi \in_r \in_0\right) r^2}$$

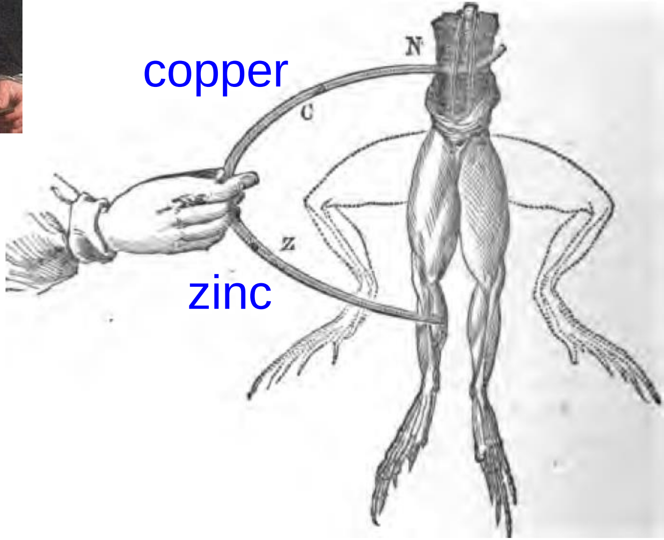
Luigi Galvani (1737 – 1798)

- Began work as a physician
- Voluntarily taught at a local university
- Became a professor of medicine studying the nervous system

- Accidentally discovered lightning made dead frog muscles contract (1780s)

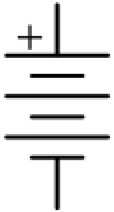
- Accidentally discovered muscles contracted when connected to dissimilar metals such as brass and iron (1791)



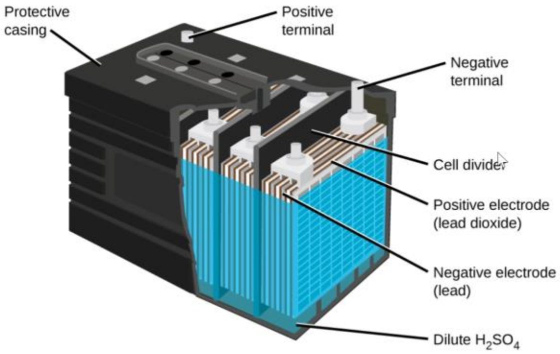


Alessandro Volta (1745 – 1827)

- Professor of Chemistry
- Discovered methane (CH_4)
- Friend of Luigi Galvani
- Believed electrical flow was due to dissimilar metals, not “animal electricity



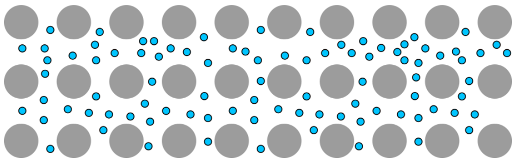
- Created a “pile” of stacked silver and zinc plates separated by an electrolyte (soaked cloth or paper)
- Each stacked pile could generate 1V to 2V (1799)
- Stacks could be connected in series or parallel



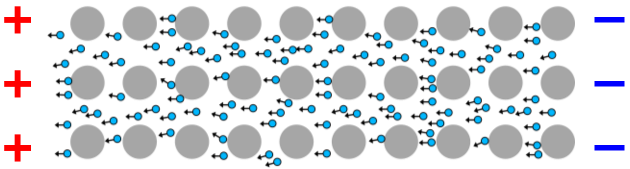
Voltage Difference Required to Turn Static Electricity into Current Electricity (Current Flow)

- Electrons flow toward higher (more positive) potential
- Think of voltage as **electrical pressure**
- Technically, voltage is energy per unit charge: **1 Volt = 1 Joule / 1 Coulomb**

No potential difference, no current



Potential difference produces a current

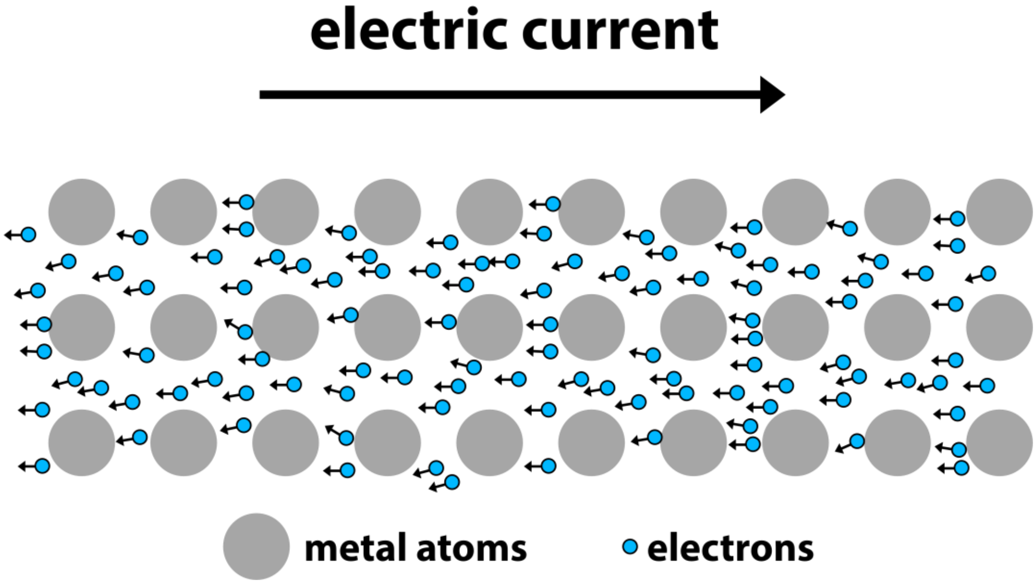


Current = Electrons Flowing

- Unit of current is the Ampere (A)

$$1\,Ampere = \frac{1\,Coulomb}{second}$$

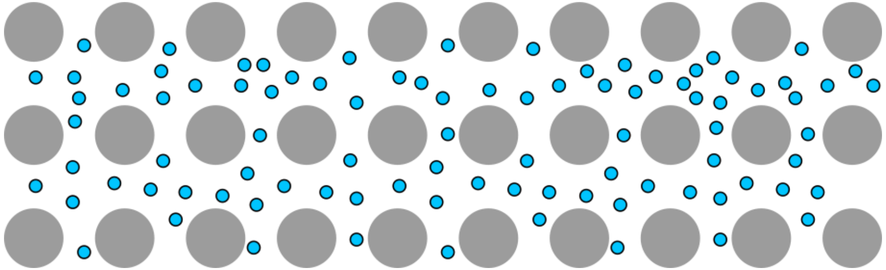
- **Conventional current** follows the flow of **positive** charges (the **opposite** direction of negatively charged electron flow)



Conductors vs. Insulators

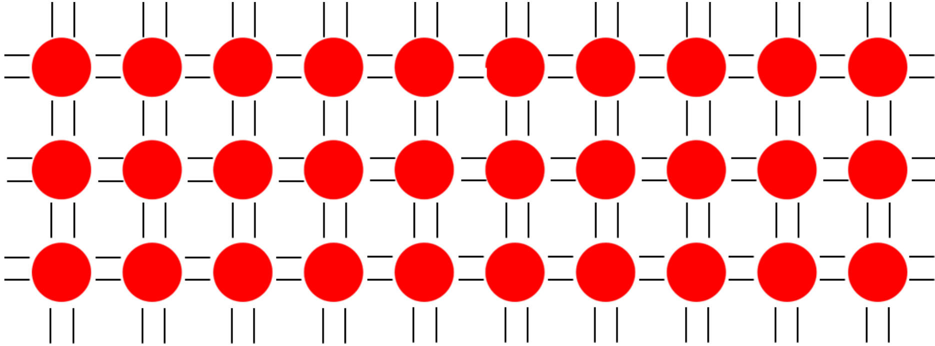
- Material **conductivity** is a material electrical property
- More free electrons, more current can flow

Conductors have many free electrons



Gold, copper, aluminum, salt water…

Insulators have few free electrons



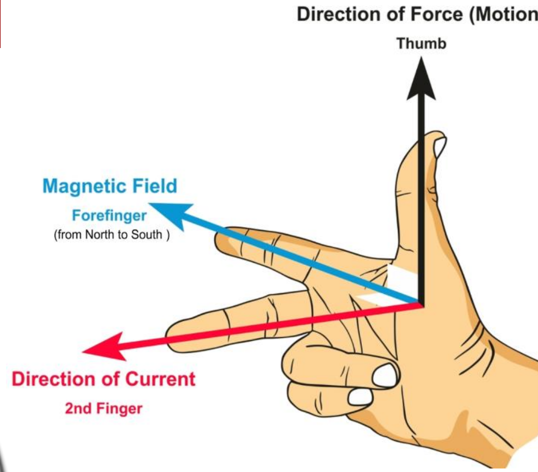
Rubber, glass, plastic, rust…

Hans Christian Ørsted (1777 – 1851)

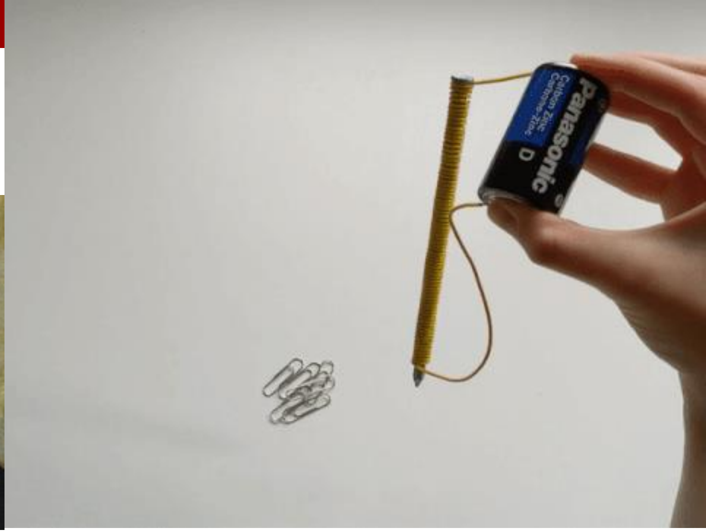
- Magnetism was known since Thales (600BC)
- Relationship with electricity not known

- Professor of Chemistry and Physics
- Used Volta's pile battery to experiment with current (charges in motion)

- Switched current passing through a wire near a compass caused needle to swing to a position ***at right angles*** to axis of the wire (1820)

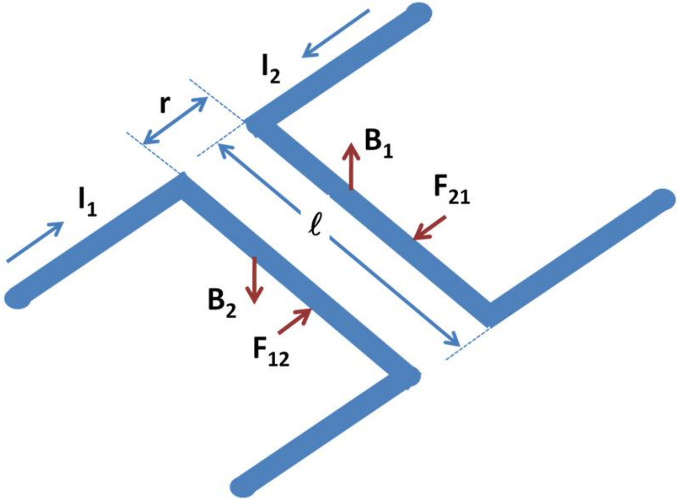


Andre-Marie Ampere (1775 – 1836)



- Physicist and mathematician
- One of the founders of the science of classical electromagnetism

- Just weeks after Oersted's experiment (1820):
  - Observed that coil of wire acts **as a magnet** when current passes through its turns
  - React to attract or repel each other

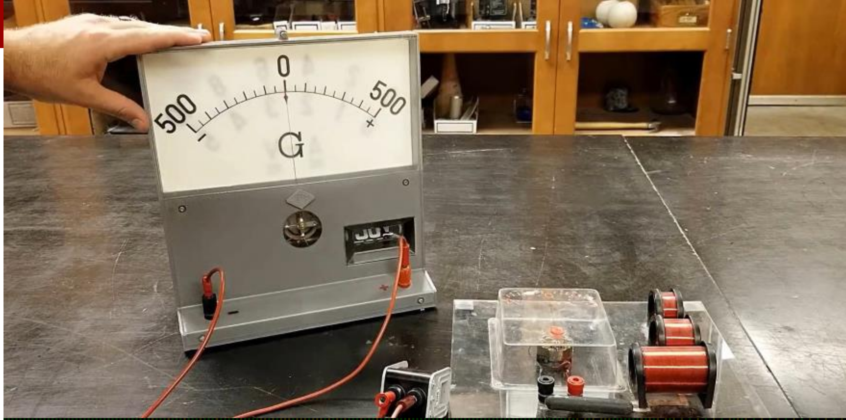


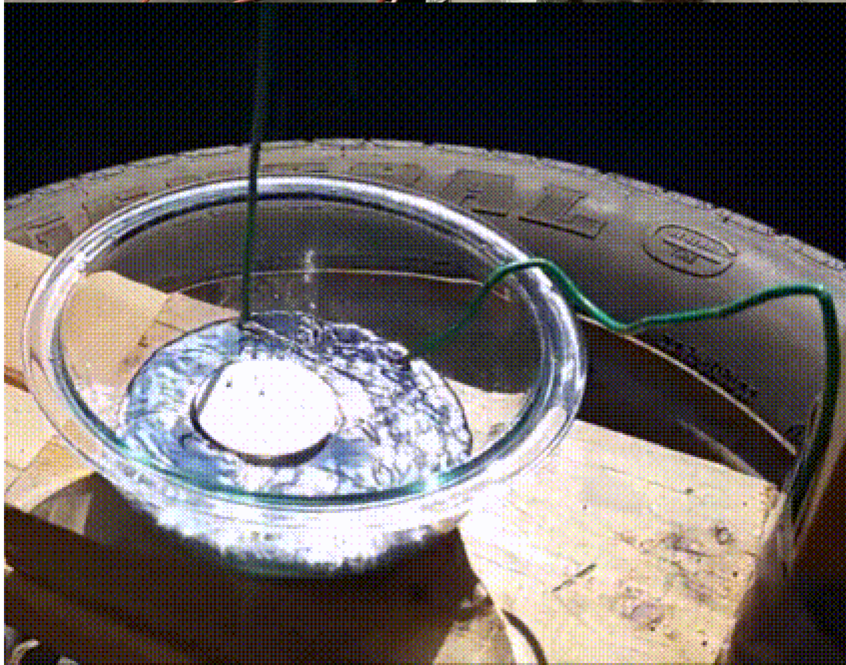
Michael Faraday (1791 – 1867)

- Professor of Chemistry, Physicist
- Excellent experimentalist that conveyed his ideas in clear and simple language

- Demonstrated mutual inductance:
  A changing magnetic field produces an electric field AND a changing electric field produces a magnetic field (1821)

- Developed first electric motors





Joseph Henry (1797– 1878)

- Professor of mathematics and “natural philosophy”
- Refined electromagnets
- Discovered mutual inductance before Faraday, but did not publish his results until 1831
- Inductance units [Henries]
- Capacitance units [Farads]

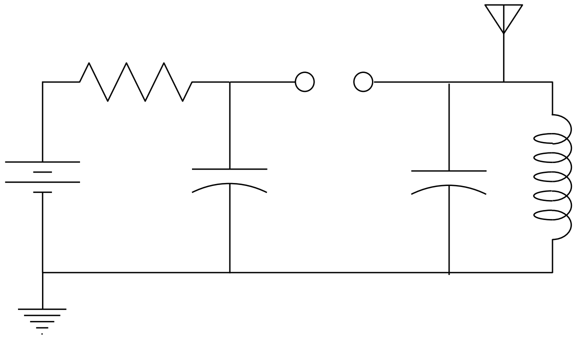
James Clerk Maxwell (1831 – 1879)

- Physicist and mathematician

- Compiled and unified the previous work into an elegant set of 20 equations (1862)
- Electricity and magnetism relationship

- "Founder of electrical engineering"
- Work was refined into the **four** laws **now known** as Maxwell's equations

Heinrich Hertz (1857 – 1894)



- Professor of Physics

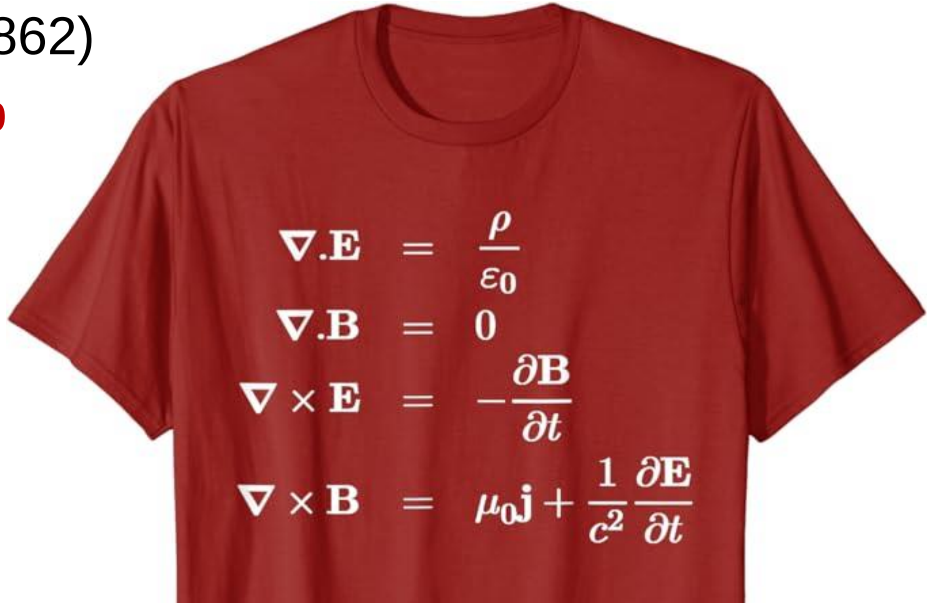
- In 1887, experimented with radio waves to validate Maxwell's 1862 equations
- Developed the spark gap transmitter and dipole antenna

James Clerk Maxwell (1831 – 1879)

- Physicist and mathematician

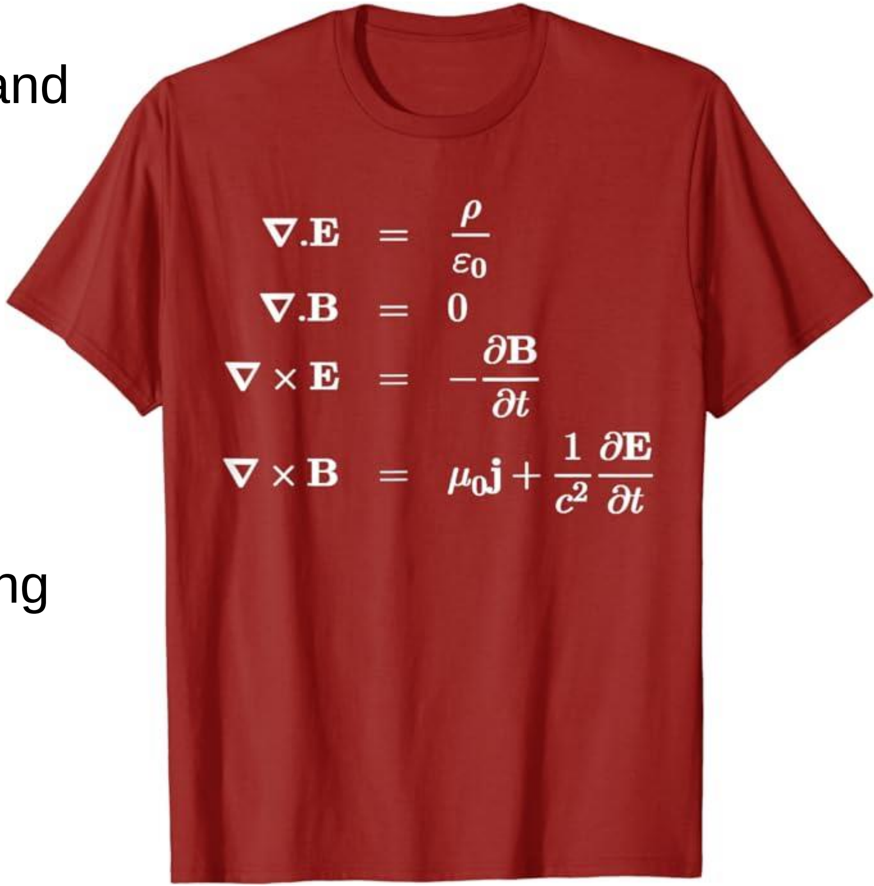
- Compiled and unified the previous work into an elegant set of 20 equations (1862)
- Electricity and magnetism relationship

- “Founder of electrical engineering”
- Work was refined into the **four** laws **now known** as Maxwell’s equations



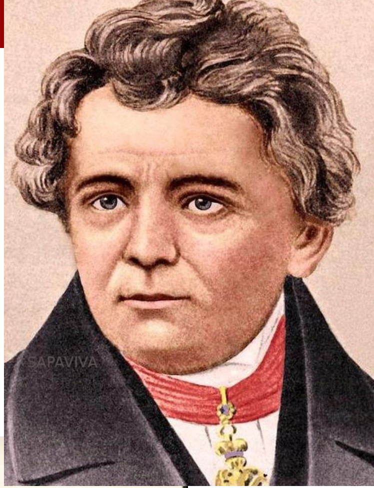
Maxwell's Equations

- Mathematically describe how electricity and magnetism are interrelated
- Serve as an excellent recruiting tool for computer science
- We use **models** to design and analyze electrical systems without always resorting to differential equations



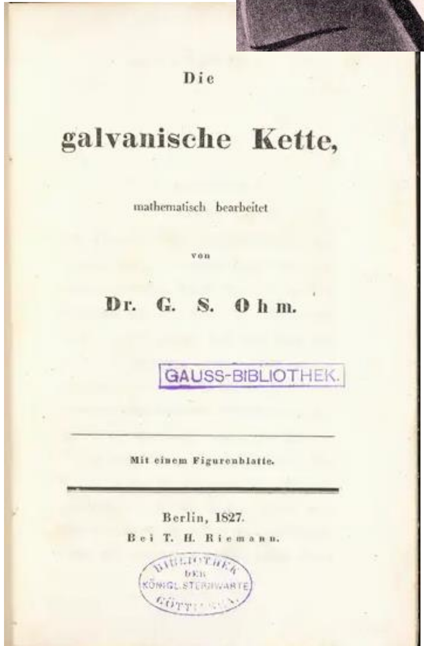
Models

- Allow us to use or see a complex system with less work or effort
- Requires the sacrifice of some level of detail or accuracy



Georg Simon Ohm's Law (Model)

- High school math teacher
  (Jesuit High School, Cologne, Germany)
- Electrical experiments
- *The Galvanic Circuit Investigated Mathematically*, 1827



- $\Delta V = IR$
- So poorly received, he was forced to **resign**

https://www.eeweb.com/did-you-know-ohms-law-almost-destroyed-georg-ohms-life/

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Did You Know? Ohm's Law Almost Destroyed Georg Ohm's Life

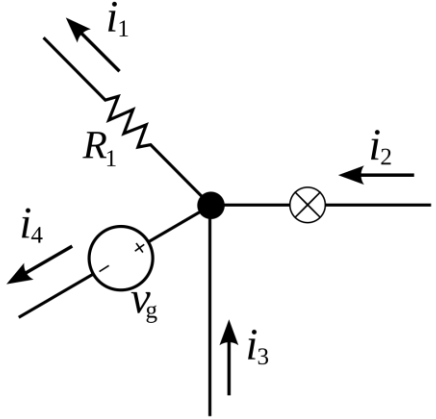
By Kathy Joseph | Wednesday, January 4, 2023

? SHARES

There are few things in EE that are more basic than Ohm's Law ($V = IR$), which was published by Georg Simon Ohm in 1827. In fact, it seems so clear and obvious that one would think it must have been accepted by the scientific and engineering community as soon as it was conceived. However, that wasn't the case. Instead, critics attacked it, which cost Ohm his job and almost destroyed his life.

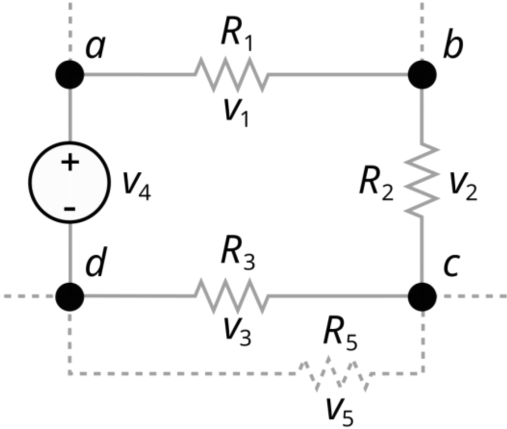
Gustav Kirchhoff

- College student in 1845
- Formulated two laws (models) that generalized the work of Ohm



KCL: *The algebraic sum of currents in a network of conductors meeting at a point is zero*

KVL: The directed sum of the potential differences (voltages) around any closed loop is zero.



Wrap-Up

We've been here:

- Gut check: Welcome to 18-100: Intro to ECE
- Who are we?
- What is electrical and computer engineering (ECE)?
- Why study ECE?
- Course structure
- Electrical and magnetic principles, models, and equations
  - Models, models, models

Next class:

- **Introduction to electrical circuits, resistors, and LEDs.**