Physical Science
Electricity, Magnetism, & the Nature of Matter

By David Harriman

Notes for Classes 1- 68

Physical Science: Course Outline

Electricity and Magnetism

Early History

- Discovery of amber and lodestone
- Invention of the magnetic compass
- Differences between electricity and magnetism
- Gilbert discovers the earth's magnetism

Static Electricity

- Gray discovers electrical conduction
- DuFay discovers two kinds of electric charges
- Von Kleist invents the Leyden jar
- Research of Benjamin Franklin
  - Fluid theory of electricity
  - Principle of charge conservation
  - Lightning is an electrical discharge
- Coulomb's law of electrical force

Light

- Infrared and ultraviolet
- Young's wave theory
- Polarization

Electric Current

- Galvani discovers electric current in frogs
- Volta generates electric current without the frogs
- Invention of the electric battery
- Voltage, resistance, and Ohm's law

Electromagnetism

- Oersted's discovery
  - Currents exert forces on magnets, and vice versa!
- Ampere's law
  - Currents cause circular magnetic forces around them

How to figure our the direction of the forces

A current through a coil of wire acts like a magnet!

Applications: electric motors, TVs, etc.

Faraday's Law

A moving magnet causes a current in a loop of wire!

Direction of the induced current

Applications: electric generators, telephones, etc.

Magnets can rotate polarized light

Maxwell completes the mathematical theory

Discovery of the missing term

Proof that light is an electromagnetic wave!

Other kinds of electromagnetic waves

Applications: radio, microwave ovens, satellite TV

More on atmospheric electricity and thunderstorms

Atomic Theory of Matter

Background of early Chemistry

Discoveries about metals and dyes

Alchemy

Chemistry becomes a science

Evidence from Chemistry

Proust's law of constant proportions

Dalton's law of multiple proportions

Dalton's atomic theory

Gay-Lussac's law of combining gas volumes

Avogadro's hypothesis

Discovery of allotropes and isomers

Faraday's laws of electrolysis

Evidence from Physics

Dulong-Petit law of heat capacities

Rumford and Joule convert kinetic energy into heat

Waterston derives the basic law of gases

Final pieces of the Proof

Chemistry

The idea of "valence"

Cannizzaro's atomic weights

Mendeleev's periodic table of elements

Physics

The idea of "mean free path"

Diffusion, heat conduction, and viscosity

Maxwell's strange prediction

Loschmidt calculates the size of atoms

Structure of Atoms

The electron

Thompson's experiments on "cathode rays"

Millikan measures the charge of the electron

Radioactivity

The nucleus

Rutherford's experiments

Chadwick's discovery of the neutron

Technology based on atomic and nuclear physics

Notes for Class 1

Introduction

Course covers: scientific discoveries of the 18th and 19th centuries

1. Electricity and Magnetism
2. Nature of matter

Early History of E & M

Thales (600 BC)

Amber: when rubbed, it attracts straw, animal fur ("electron")

Lodestone: attracts iron, repels/attracts other lodestone (found in "magnesia")

Chinese (c. 300 AD)

Spin game: lodestone needle always aligns North-South

Europeans (c. 1200)

Use magnetic compasses for navigation

When did modern science begin? c.1600.

Notes for Class 2

William Gilbert: On the Magnet (1600): First scientific investigation of E&M.

Highlights

1. The earth is a magnet.

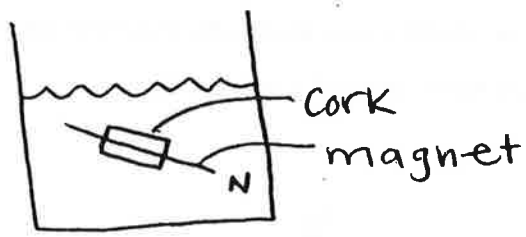


Figure 2.1 - Magnetic compass points North

Magnetic compass points towards the earth ("magnetic inclination")

2. Invented the electroscope

Figure 2.2 - Gilbert's electroscope

Detects electrical force

Shows dependence of force and distance

3. Many materials carry electricity

"electrics": move the electroscope, e.g. gems, amber, glass, sulfur

"non-electrics": don't move the electroscope, e.g. metals

4. Tested and refuted false ideas about electricity

   Heat is irrelevant.

   Movement of air is irrelevant.

5. Differentiated electricity from magnetism

   Earth is not electrical

   Electrics attract many materials, magnets attract only iron

   Magnets have "poles," electrics do not

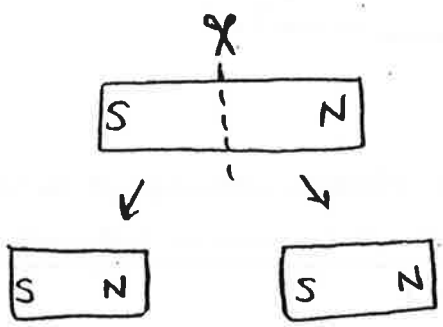


Figure 2.3 - Magnets have poles

   a. Electrics need to be rubbed, magnets do not

Notes for Class 3

Early Electricity

Gilbert's differences between E&M cont'd

Electrical power can be blocked (e.g. paper), magnetism cannot.

Heat can destroy magnets, but has no effect on electricity.

Further 17th century discoveries

Italians

Electrified bodies attract objects, and after touching, repel them.

Electrical forces are mutual; each body exerts a force on the other.

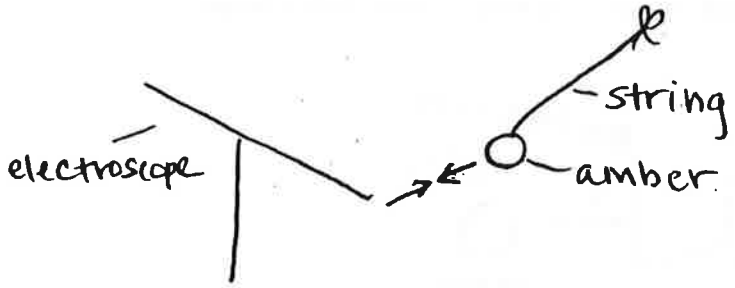


Figure 3.1 Electrical forces are mutual.

Robert Boyle

Electrical force doesn't depend on air.

Otto Von Guericke

Invented the frictional electric generator

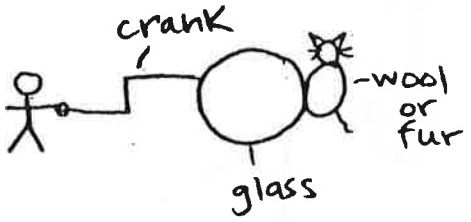


Figure 3.2 - Von Guericke's frictional electric generator

Notes for Class 4

Static Electricity: Conductors and Insulators

Stephen Gray (1645-1736)

Conducts first experiments with transfer of electricity

a) glass + cork: charge

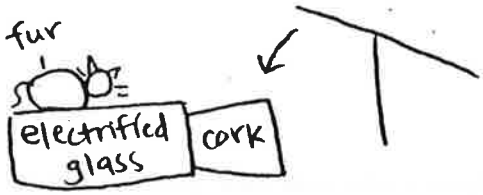


Figure 4.1

b) glass + cork + 6 in. iron wire + ivory ball: charge

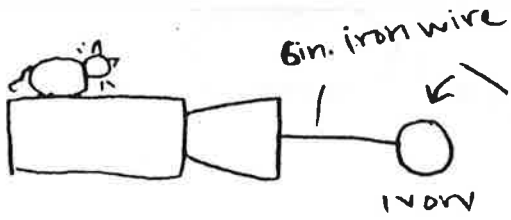


Figure 4.2

c) glass + cork + 3 ft. damp packthread + ivory ball: charge

d) glass + cork + 30 ft. damp packthread + ivory ball: charge

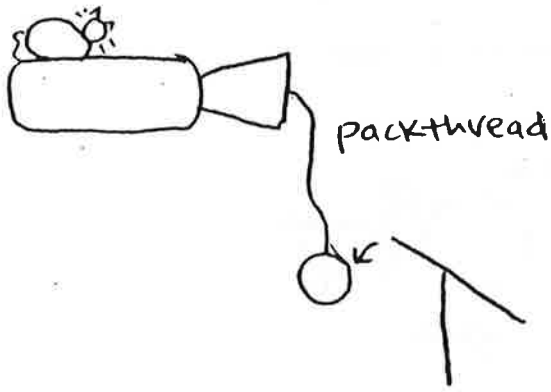


Figure 4.3

e) …+100 ft packthread hung by nails: no charge!

Were the nails too thick?

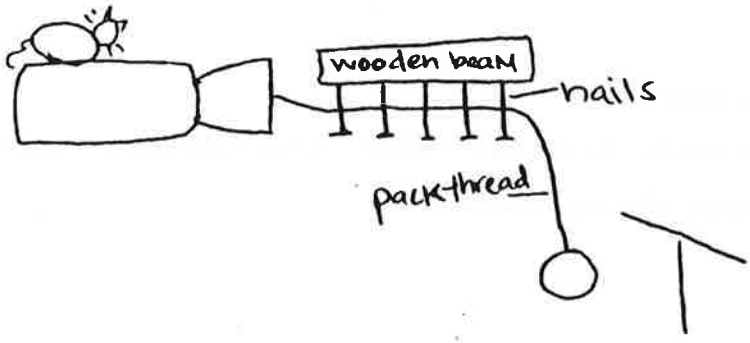


Figure 4.4

f) …+ 100 ft. packthread hung by silk cord: charge

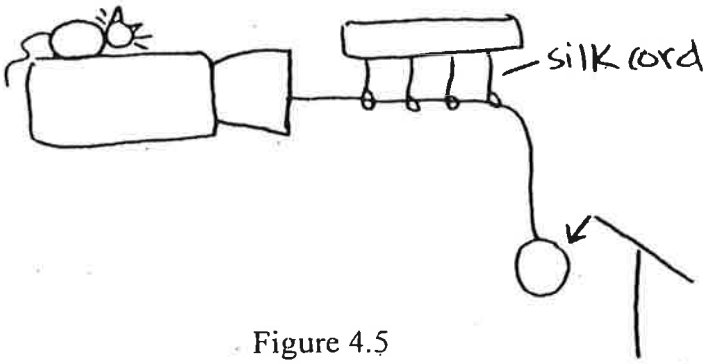


Figure 4.5

g) …+ 100 ft. packthread hung by thin brass wire: no charge

Metal, not thickness, prevented the charge

h) replace ivory ball with metal: charge

i) replace metal with human: charge!

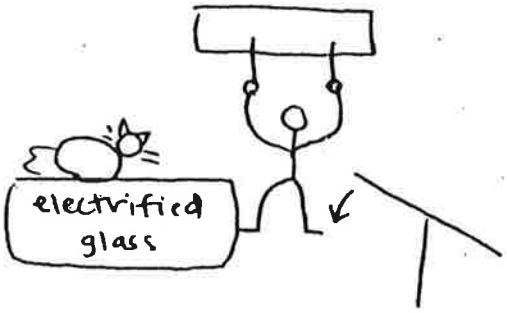


Figure 4.6

Concludes: there are two kinds of materials:

Conductors

e.g. iron, brass, damp packthread, people, any metal

Insulators

e.g. silk, glass, cork

Note: Gilbert's non-electrics are conductors. Gilbert couldn't charge up metals because the electricity ran into him, also a conductor.

Notes for Class 5

Static Electricity: Gray and DuFay

Gray's discoveries

1. electrical conduction
2. conductors and insulators
3. "electrification by influence": transfer electricity without contact

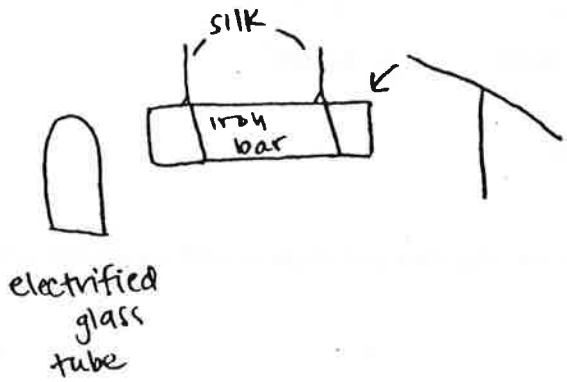


Figure 5.1 – Electrification by influence

4. blunt vs. sharp metal objects, lightning comparison

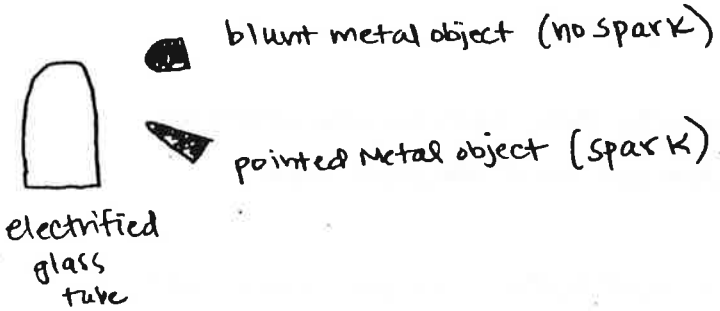


Figure 5.2 – Electricity transfer

Charles DuFay (1698-1739)

1st principle: An electrified body attracts any non-electrified body, then repels it after touching and transferring electricity to it.

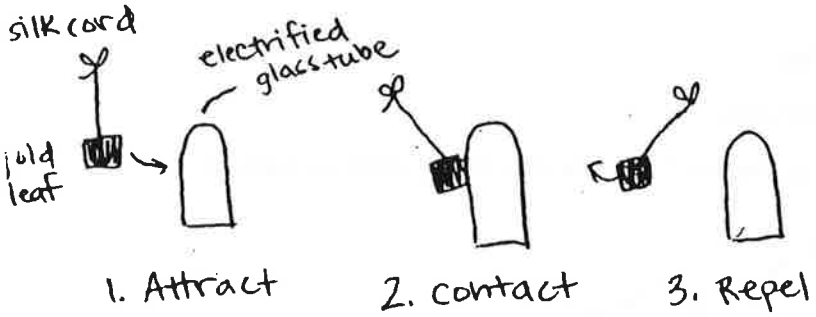


Figure 5.3 – DuFay's 1st Principle

DuFay's hypothesis: any two electrically-charged objects will repel one another.

Crucial Experiment (1734)

Step 1: Electrify gold leaf with electrified glass. They repel each other, his gold also repels all other electrified glass.

Step 2: Electrified amber attracts the gold leaf!

Two kinds of electricity

1. Glass-type electricity: glass, precious stones, animal fur
2. Amber-type electricity: amber, silk, paper, copal

Bodies with the same kind repel, bodies with opposite kinds attract.

Notes for Class 6

Static Electricity: DuFay to Franklin

Review

E.G. von Kleist:

Can electricity be contained in a jar?

Invents the Leyden Jar (1745)

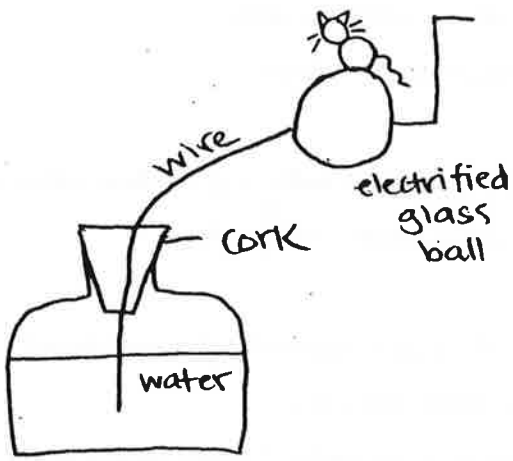


Figure 6.1 – Electricity flows into the Leyden Jar

Observes:

1. Electricity will remain in the jar for days after the transfer
2. If he holds the jar with one hand and touches the wire with the other, his arm goes numb.
3. He can hold larger amounts of electricity in the jar if he:
    a. Coats the inside with metal
    b. Coats the outside with metal
    c. Uses mercury (better conductor) instead of water

Why did he get shocked?

Notes for Class 7

Benjamin Franklin

First to develop a theory to explain the facts observed.

Franklin's Theory:

1. An "electrical fluid" exists within bodies.
2. Non-electrified bodies have a normal, or equilibrium, amount of fluid.
3. Bodies with excess electrical fluid are "positively charged"
4. Bodies with a deficiency of electrical fluid are "negatively charged"
5. Electrical fluid repels other electrical fluid
6. Ordinary matter repels other ordinary matter
7. Electrical fluid and ordinary matter attract.

An electrified body attracts any non-electrified body (e.g. rubbed amber attracts the electroscope). How does Franklin's theory explain this?

1. Deficiency of electrical fluid in a negatively charged object attracts the electrical fluid in a non-electrified object.
2. Excess of electrical fluid in a positively charged object attracts the ordinary matter in a non-electrified object.

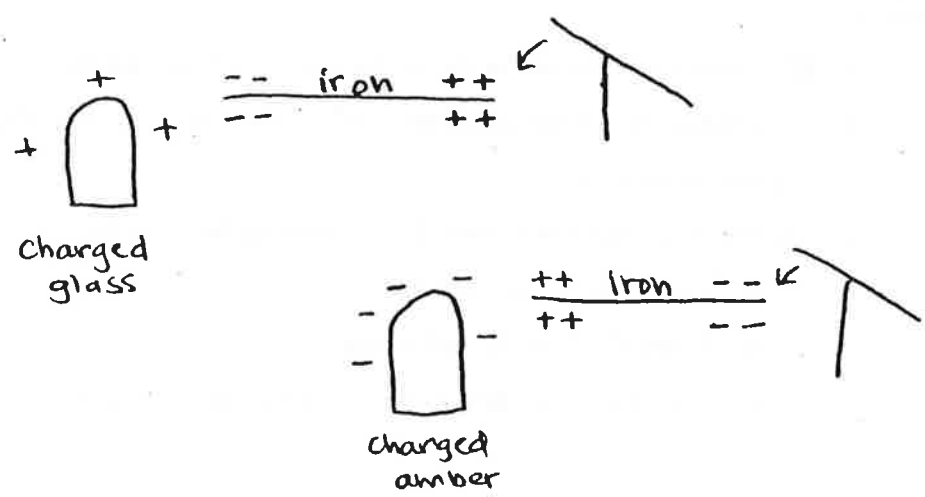


Figure 7.1 Franklin's theory explains electrification by influence

Notes for Class 8

Electricity: Benjamin Franklin

Principle of Electric Charge Conservation:

The total amount of electric charge is always the same; electric charge is merely transferred between bodies.

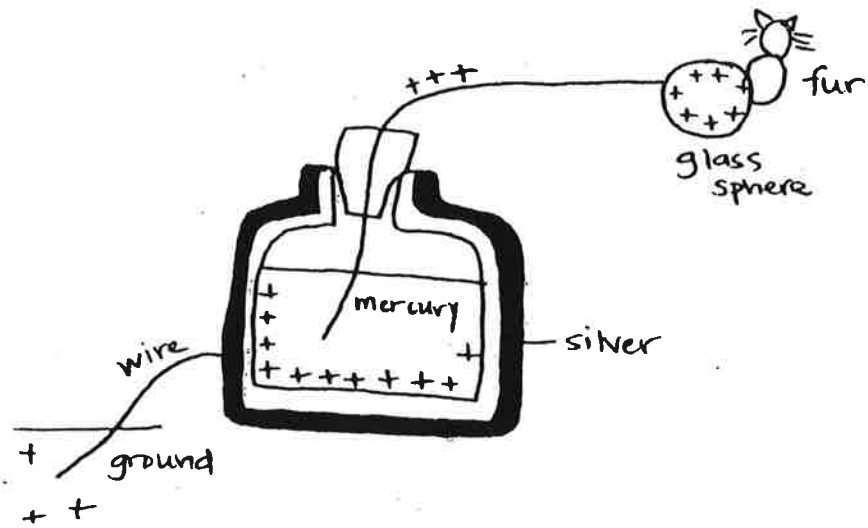


Figure 8.1 – what happens in a Leyden Jar

1. Cat and glass have normal amount of electrical fluid.
2. Electrical fluid from cat fur is transferred to glass: glass has excess, cat has deficiency
3. Excess electrical fluid in glass is attracted to ordinary matter in wire, repels electrical fluid in wire, which moves across into the mercury.
4. Process is repeated to transfer more and more positive charge to the mercury

Why is it important to coat the jar with a conductor?

Why did von Kleist get electrified?

Franklin's kite experiment:

Return to Gray's comparison of electric sparks and lightning.

Are thunderclouds charged? Is lightning an electrical spark?

Notes for Class 9

Electricity: Franklin to Coulomb

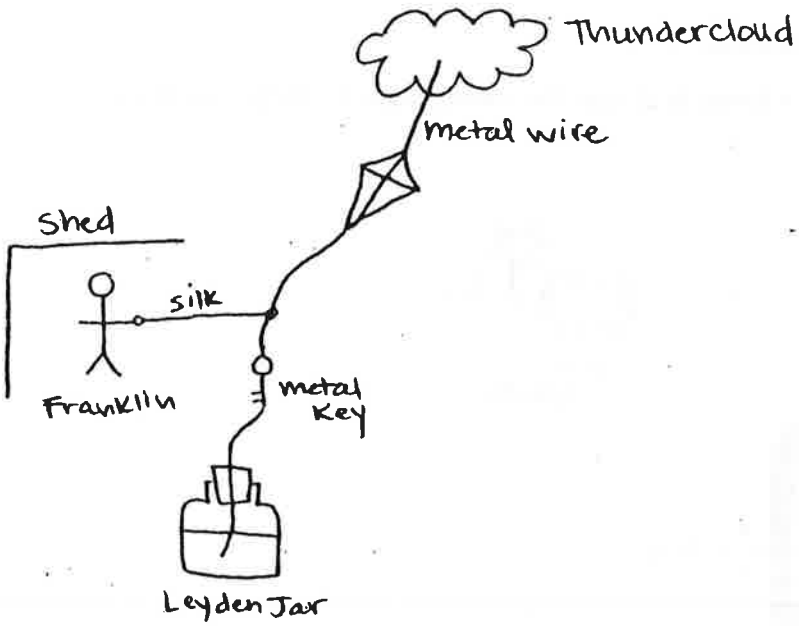


Figure 9.1 - Franklin's Kite Experiment

Proof that lightning is an electrical discharge:

Sparks fly off the wire

Leyden jar is charged

Fraying bits of kite string repel each other

Electrical forces are strong!

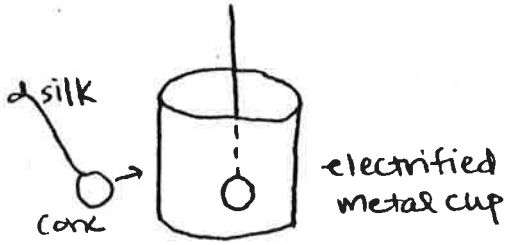


Figure 9.2 - Metal Cup Experiment

Metal Cup Experiment

1.Charge up a metal cup with a Leyden Jar.

2. Cork is attracted to the outside of the cup.

3. Cork is neither attracted nor repelled by the inside of the cup, even after contact.

Why not?

Franklin: "you require the reason, I don't know it."

Notes for Class 10

The Law of Electrical Force

Charged metal containers

No charge on interior surface

No electrical forces anywhere inside

Note parallel with Newton's discoveries

Figure 10.1 – Within a sphere, F_g cancels out

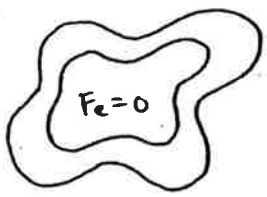


Figure 10.2 – irregularly shaped metal ring

Regardless of shape or amount of charge on the outside, no electrical charge inside.

Measurement of electrical forces:

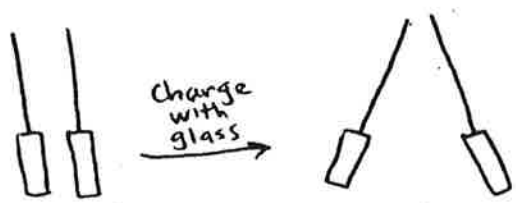


Figure 10.3 - Experiment 1

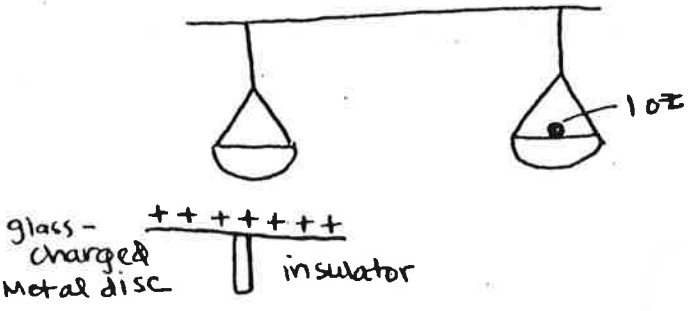


Figure 10.4 - Experiment 2

How does the force vary with distance?

Charles Coulomb (1736-1806)

Invents a new instrument

Figure 10.5 – Torsion Balance

$F = (kd^4/L)\theta$

$F \alpha \theta$

Notes for Class 11

The Law of Electrical Force

Review: $F_{torsion} = (kd^4/L)\theta$

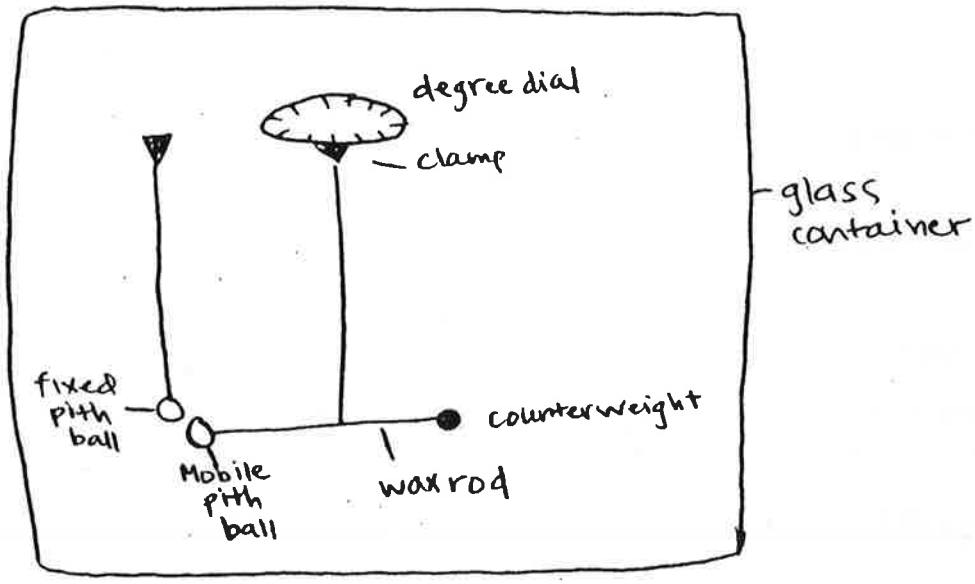


Figure 11.1 – Coulomb's Pith Ball Experiment

Electrify object, touch pith balls, they repel, ball that's mobile jumps away, wire twists.

Results of Experiment

Distance	Force
36°	36
18°	126 + 18 = 144
9°	567 + 9 = 576
[4.5°]	[576 x 4]

How does the force vary with distance?

$F \propto 1/R^2$

$F_e = K_e q_1 q_2 / R^2$

$F_g = G m_1 m_2 / R^2$

Notes for Class 12

Coulomb's Experiments (1785)

Review

F_c varies inversely with the square of the distance

The Electric Pendulum:

Review of Pendulum

Galileo: $T^2 \propto L$

Newton: $T^2 \propto L/F_g \propto L/(1/R^2) \propto R^2L \rightarrow T \propto R$

Pendulum 4000 miles from earth?

$F_g \propto 1/R^2 \rightarrow F = \frac{1}{4} F_g$

Double distance → double period

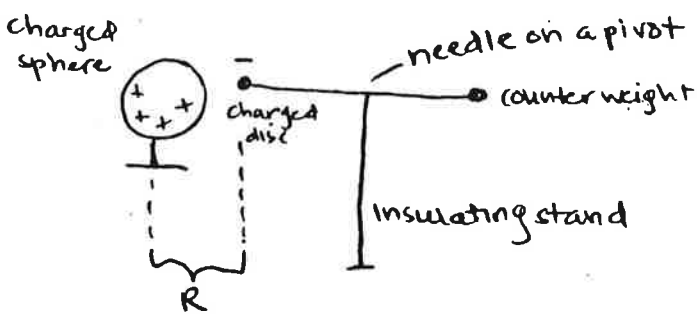


Figure 12.1 – Coulomb's Electric Pendulum

Coulomb shows that $T \propto R$.

$T \propto R$ is the result of $F \propto 1/R^2$.

Since $T \propto R$ for the electric pendulum, $F_e \propto 1/R^2$.

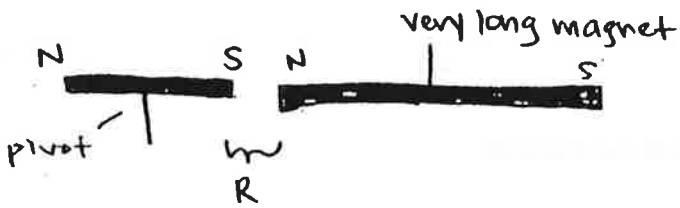


Figure 12.2 – Coulomb's Magnetic Pendulum

f = frequency = 15 swings per minute.

T = Period = 4 seconds (1 swing per 4 seconds)

$f \propto 1/T$

$T^2 \propto L/F_m$

$T^2 \propto 1/F_m$ (L is constant)

$F_m \propto (1/T)^2$

$F_m \propto f^2$

Notes for Class 13

Math and Magnetism

Equations and proportions.

$v = 32t$

$v \propto t$

$T^2 = 1.23\ L$

$T^2 \propto L$

$T^2 = 4\pi^2 L/g$

$T^2 \propto L/g$

Proportionality ignores constants: states relationship between two things that change.

$g = Gm_e/R^2$

$g \propto 1/R^2$

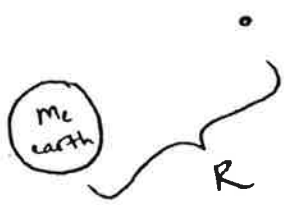


Figure 13.1

$T^2 \propto L/g \propto L/(1/R^2) \propto R^2 L$

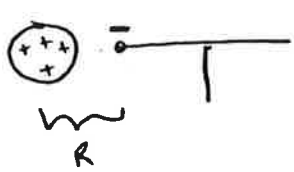


Figure 13.2 – Electric Pendulum

How does T vary with R?

Rx2→ Tx2

T∝R

If force falls off with the square of the distance, T∝R.

So, since T∝R for the magnetic pendulum, $F_m \propto 1/R^2$.

Coulomb's experiment on magnetic forces: how strong are they?

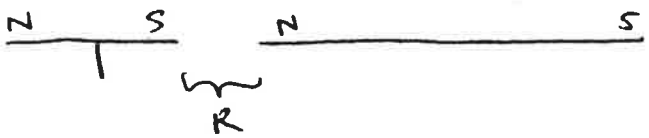


Figure 13.3 – Magnetic Pendulum

Results

Distance (R)	frequency
4 in.	43
8 in.	25
16 in.	18

Notes for Class 14

Coulomb's Experiments

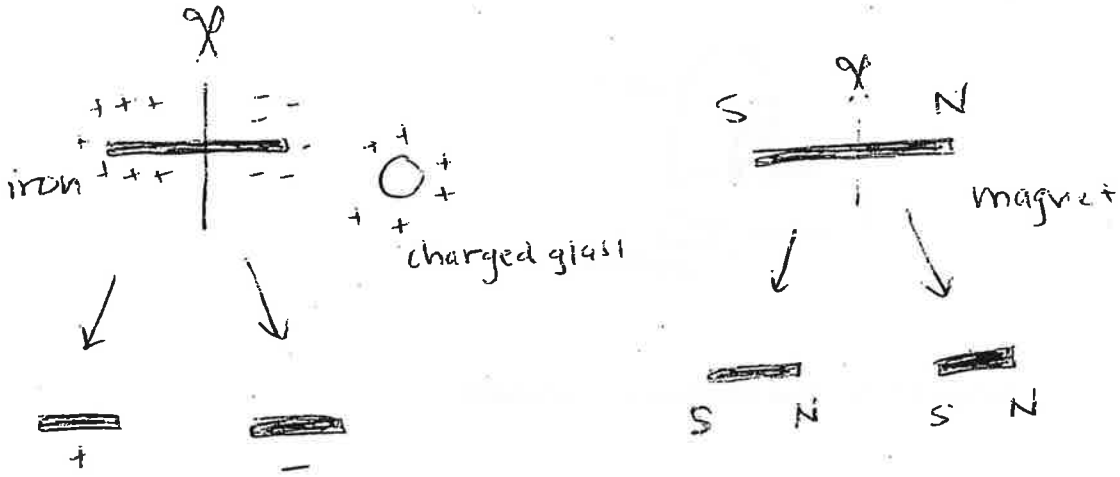


Figure 14.1 Difference between E & M

Results

R (inches)	frequency (swings/min)	Total F_m
4 in.	43	43^2
8 in.	25	25^2
16 in.	18	18^2

Total magnetic force = force of long magnet + force of earth

(15)

R (inches)	frequency (swings/min)	Force
4 in.	43	$43^2 - 15^2$
8 in.	25	$25^2 - 15^2$
16 in.	18	$18^2 - 15^2$

Conclusion: $F \propto 1/R^2$

3.

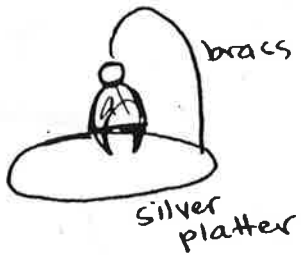


Figure 15.3 - Dead frogs on a silver platter

Platter must be a conductor

Wire and platter must be two different metals: "it takes two to tango"

Notes for Class 16

Galvani and Volta

Review

Galvani's theory of dead animals as Leyden jars

Alessandro Volta (1745-1827)

Invented the electric battery: "one of the most important inventions in all of history."

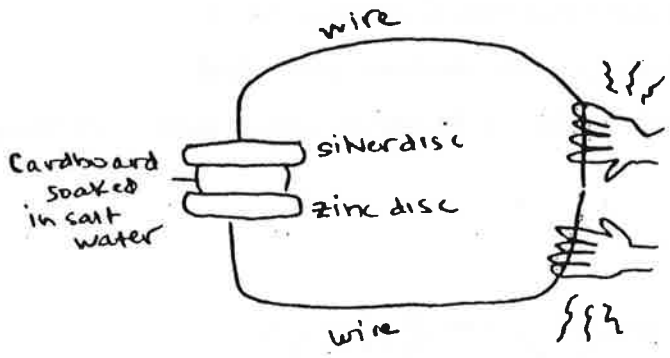


Figure 16.1 – Volta touches the wires together and feels a tingling sensation

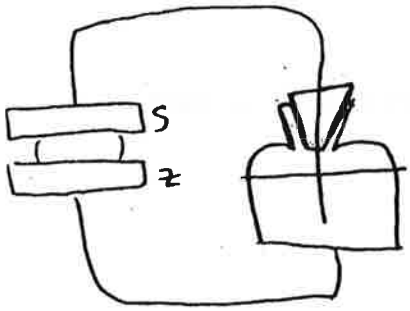


Figure 16.2 – Volta generates electricity without an animal.

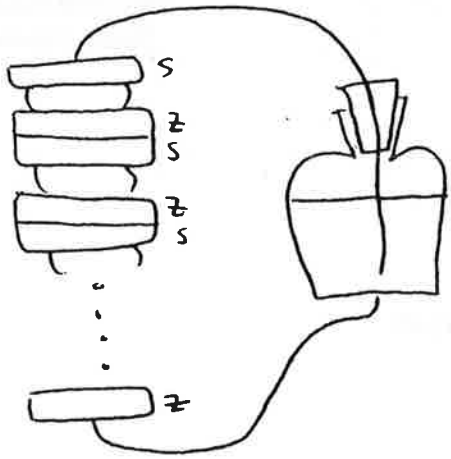


Figure 16.3 - Early electric battery

Experiments with different materials, develops sequence

Zinc,tin, lead, iron, copper, platinum, gold, silver

The further apart on this list the metals used in battery, the stronger the current

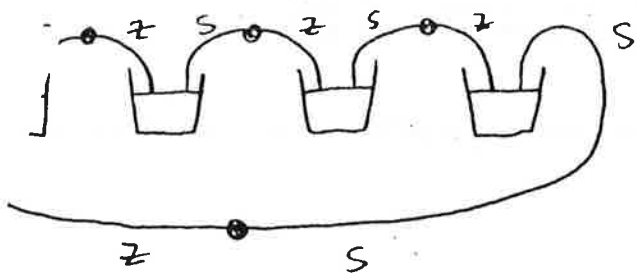


Figure 16.4 –Electric battery: alternative arrangement

Is there a connection between E and M?

Notes for Class 17

Review:

Electric battery

1. Increasing the stack of metal plates increases the electric current
2. Increasing the size of metal plates makes the current last longer

Can Franklin's theory explain the battery? No.

Hans Christian Oersted (1777-1851)

Wanted to understand the connection between E and M.

Will electric currents deflect the needle? No.

Figure 17.1 Electric current does not appear to exert a force on a magnet.

Accidental discovery

Compass below a current? Needle deflected west.

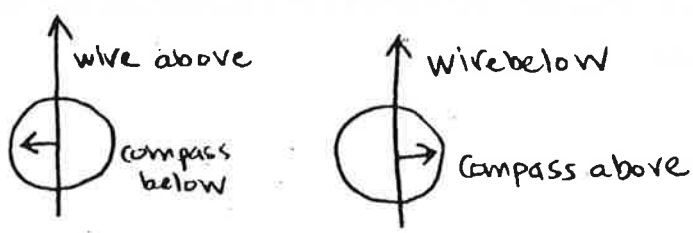


Figure 17.2 Electric current exerts a force on a magnet.

Notes for Class 18

Review

See. Figure 17.2

Electrodynamics

Oersted (cont'd)

Experiment 1: discovers that an electric current exerts a force on a magnet

Experiment 2 (1819): does a magnet exert a force back on a current?

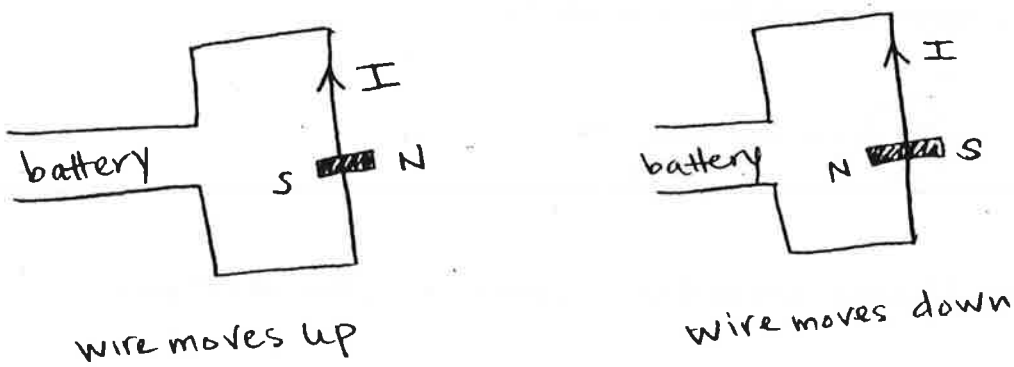


Figure 18.1 – Oersted's Experiment 2

Andre Ampere (1775-1836)

Experiment 1: effect of electric current on magnetic compass w/o earth's magnetic field.

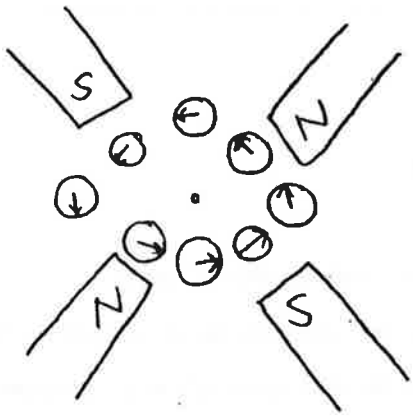


Figure 18.2 – Ampere's Experiment 1

Current coming out of paper: counter-clockwise

Current into paper: clockwise

"Right hand rule" #1: Point right thumb in the direction of the electric current; fingers will curl in direction of the circular magnetic force.

Notes for Class 19

Electric current and magnetic forces (Ampere)

Case 1: Magnetic force created by an electric current

RHR #1

Case 2: Force on the electric current exerted by an external magnetic force

RHR #2: Point fingers in direction of current, curl them in the direction of the external magnetic force; your thumb points in the direction of the force on the current.

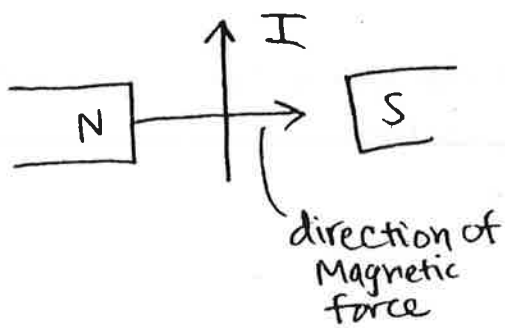


Figure 19.1 RHR #2: wire pushed into the board

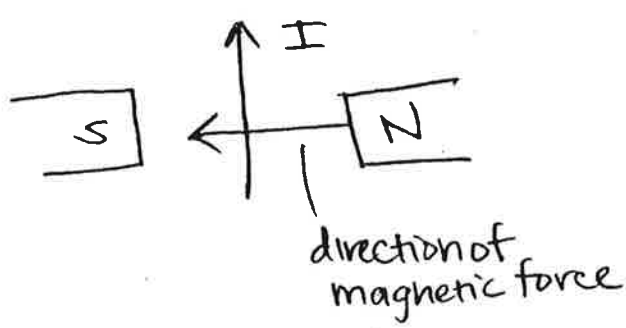


Figure 19.2 – RHR #2: Wire pushed out of the board

Ampere studies wire coils

(note: x = into the board, · = out of the board)

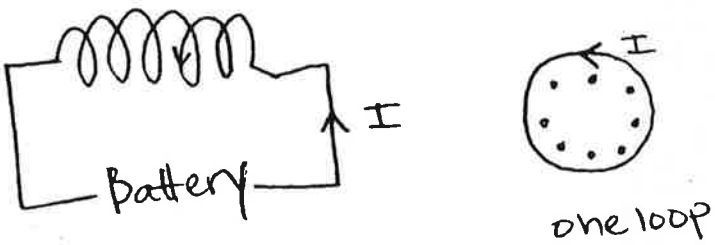


Figure 19.3 – RHR #1

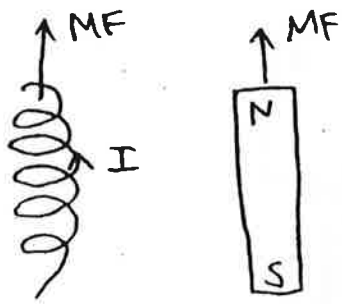


Figure 19.4 – RHR #1: Coil of wire with a current through it behaves exactly like a magnet

Rejects the idea that magnetic fluid and electric fluid are totally separate.

Notes for Class 20

Ampere's Electrodynamics

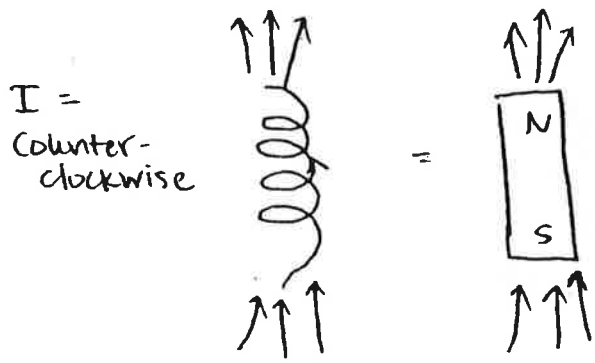


Figure 20.1 - A coil with a current through it acts just like a magnet

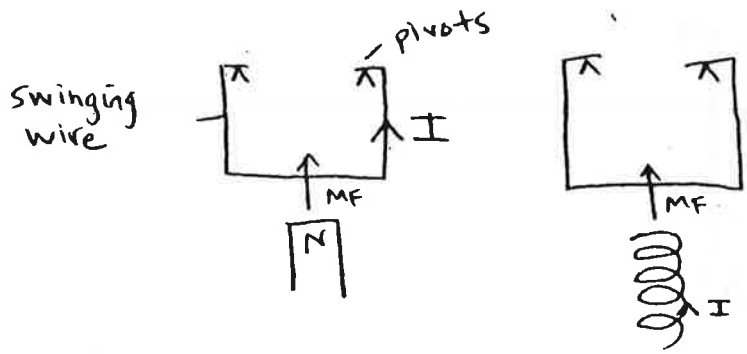


Figure 20.2 - Electric currents exert forces on other electric currents: wire is pushed out of the board

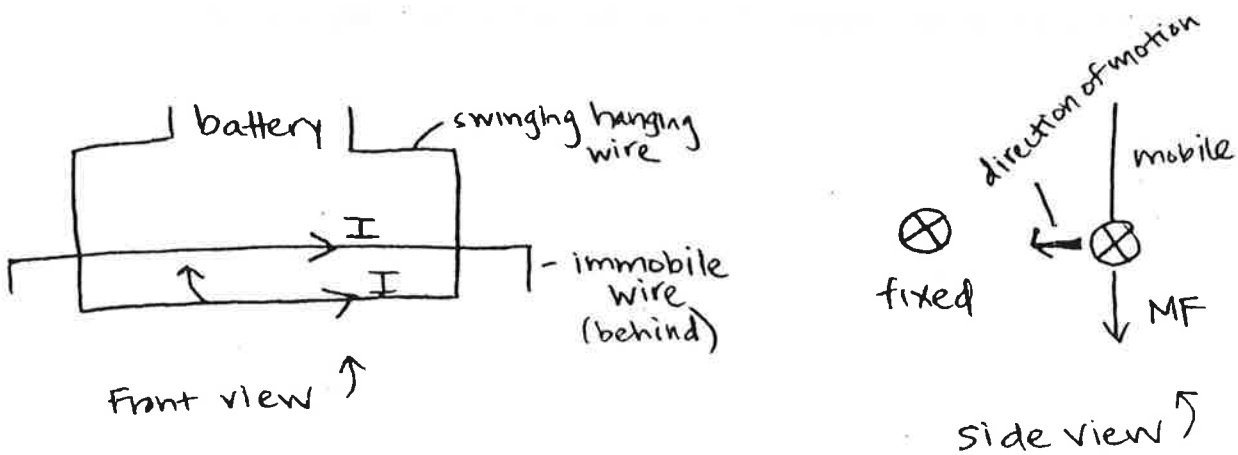


Figure 20.3 – Parallel currents attract each other.

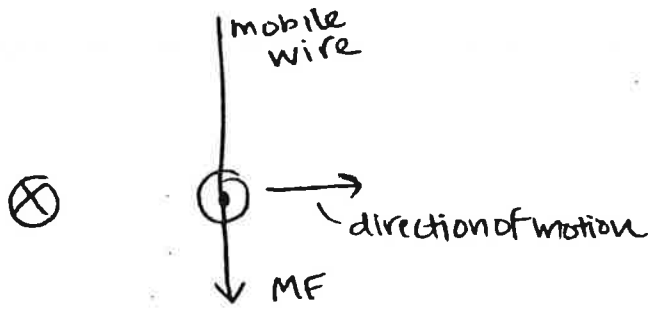


Figure 20.4 – Anti-parallel currents repel each other.

Search for the Mathematical Law

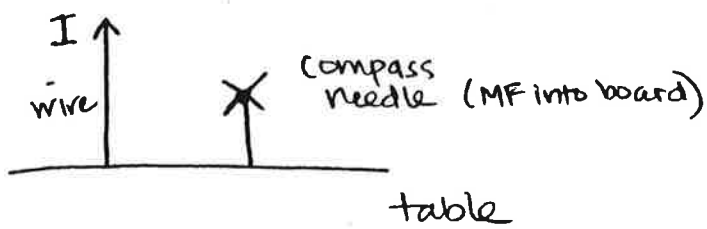


Figure 20.5 - Biot's experiment

Notes for Class 21

Ampere's electrodynamics

Biot's Experiment (1820)

(See Figure 20.5)

Coulomb showed: if $F \propto 1/R^2$, then $T \propto R$

Biot finds: $2R \rightarrow 1.4T$

$T^2 \propto R$

Biot proves: if $F \propto 1/R$, then $T^2 \propto R$

How does F vary with I?

$T^2 \propto 1/I$

$F \propto I/R$

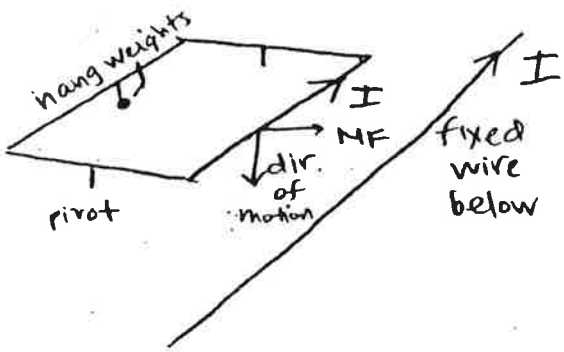


Figure 21.2 - Force between electric currents

Michael Faraday (1791-1867)

"the greatest experimental physicist in all of history"

Notes for Class 22

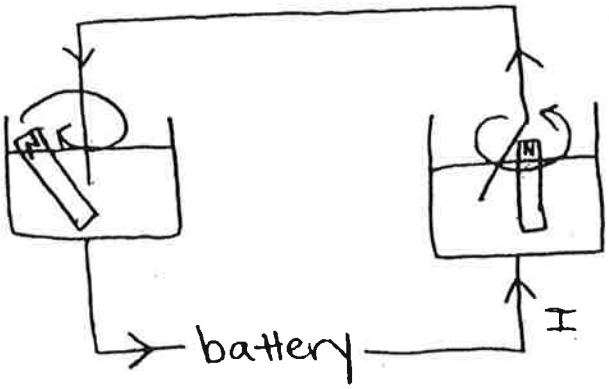


Figure 22.1 – Faraday's Rotation Experiment

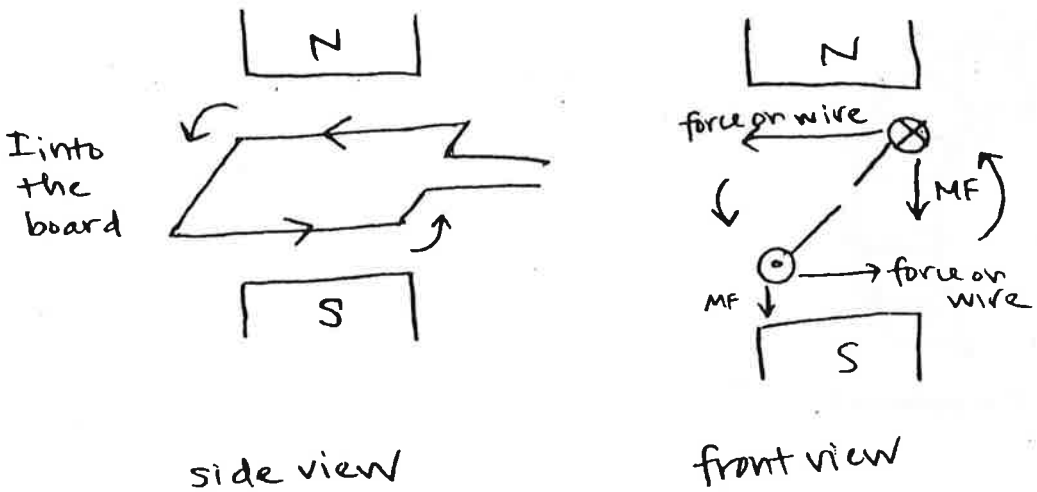


Figure 22.1 - Electric Motor

F∝I: How can we measure the force?

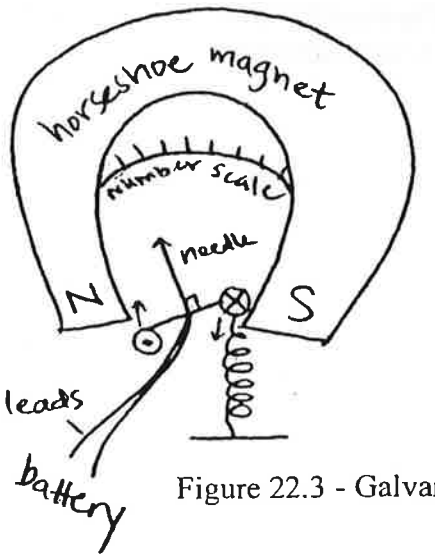


Figure 22.3 - Galvanometer

Joseph Henry

Used electric currents to make magnets

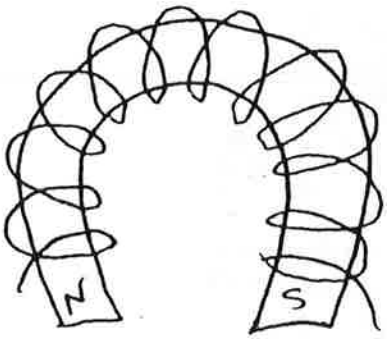


Figure 22.5 - Electromagnet

Notes for Class 23

Faraday: Fields and Currents

Electromagnets

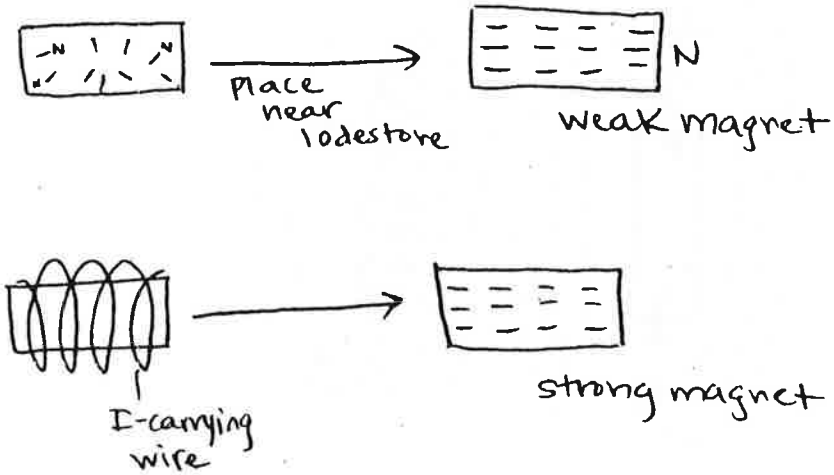


Figure 23.1- Ampere's magnet

Faraday's idea of "fields"

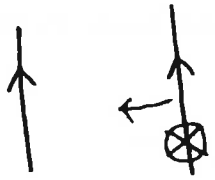


Figure 23.2 - "magnetic field" rather than magnetic force.

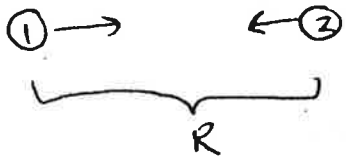


Figure 23.3 - $F = gm_1m_2/R^2$

Force on body = (property of body)x(field at location of body)

(m_1q_1I)

(See Figure 23.2)

Magnetic field is into the board, force on the wire is left.

Field direction ≠ force direction

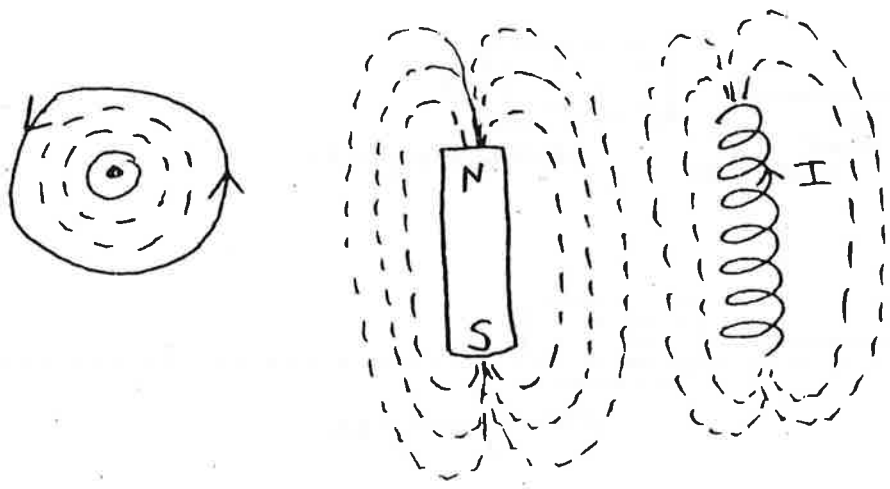


Figure 23.4 -Faraday visualizes magnetic fields using iron filings

Faraday's discovery of a new law

Faraday's to do list: "convert magnetism to electricity" (1822)

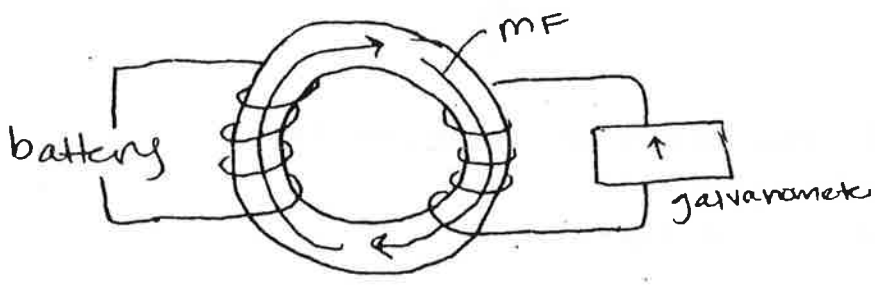


Figure 23.5 – Faraday's Experiment (1831)

Can produce a current by running a changing magnetic field through a coil.

Notes for Class 24

Faraday: Generating Electricity

Review

Experiment 1 (see Figure 23.5)

Experiment 2

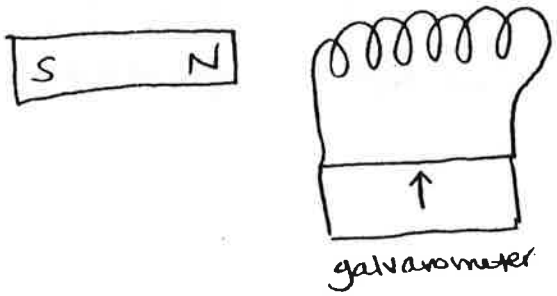


Figure 24.1

Move bar magnet into coil, needle deflects. Hold it there, current disappears. What direction is the current? Counter-clockwise.

Rule: Current is always generated in the direction such that its magnetic field opposes the changing external field.

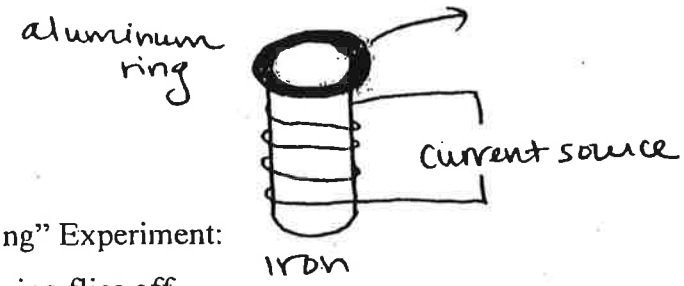


Figure 24.2 - "Flying Ring" Experiment:
Turn on current, ring flies off.

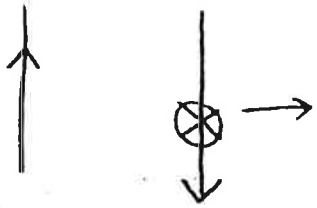


Figure 24.3 – anti-parallel I-carrying wires repel

Electric motor

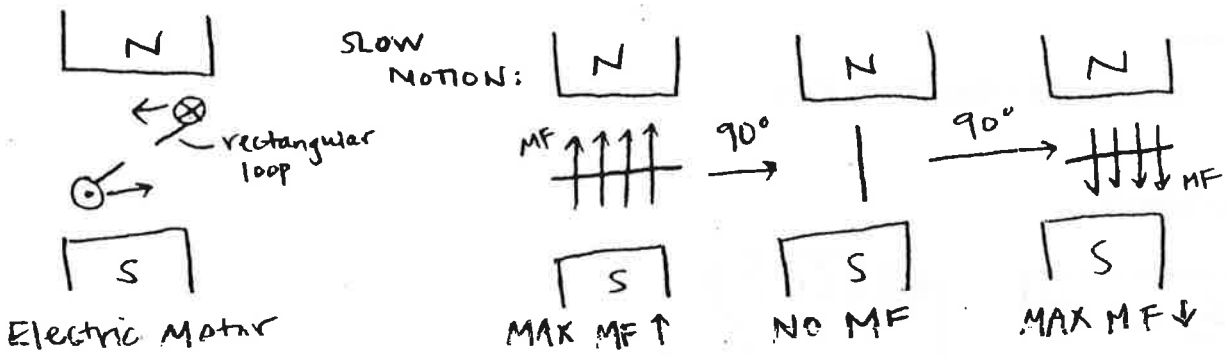


Figure 24.4 – Electric motor

Notes for Class 25

Generating Electricity cont'd

1. RHR for coils: Curl fingers in the direction of I, then thumb points in direction of magnetic field inside the coil.

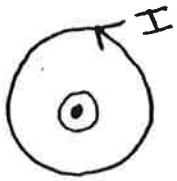


Figure 25.1 – RHR for coils

2. Faraday's Law:

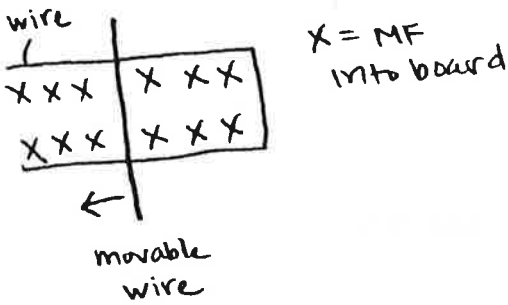


Figure 25.2

B = Strength of magnetic field

I = current

A = area of loop

Magnetic Flux through the loop = ϕ_B = BA

Figure 25.3 -Magnetic field lines

Magnetic flux = total Magnetic field lines through the loop

Rate of change of magnetic flux through a loop $\propto$ current generated in the loop.

Different ways to change the flux through a loop:

a) move magnet relative to a stationary loop.

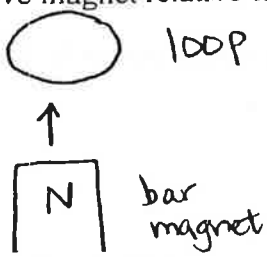


Figure 25.4

b)Rotate the loop: generates alternating current

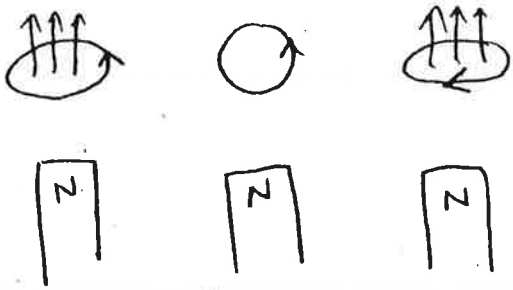


Figure 25.5

c) Move the loop relative to the magnet (same as A)

Electric resistance

Superconductors

Lower the magnet into the bowl

I flows in counterclockwise direction to oppose increase in flux.

I creates a MF in opposite direction.

Magnet is pulled out of the bowl; floats!

Figure 25.6 – Floating magnet

Notes for Class 26

Faraday's Laws and Summary

Review

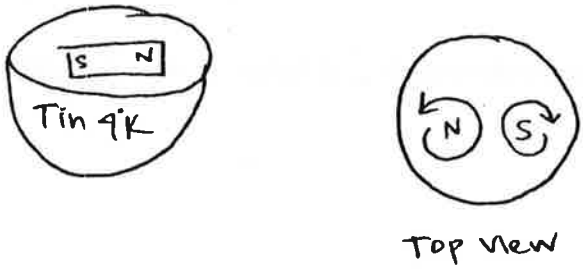


Figure 26.1 – Superconductors and magnets

Circular currents under poles of magnets push the magnet away.

Conductors

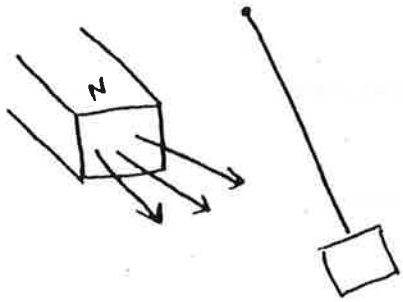


Figure 26.2 – Copper pendulum

Changing magnetic field in the presence of a conductor will cause currents to flow.

Current will flow in direction to oppose the change in magnetic field.

Application of Faraday's Law

Telephones: Sound → electrical signal→ sound

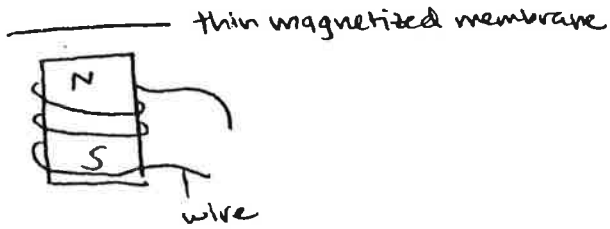


Figure 26.3 - telephone transmitter

Summary: Basic laws of electricity we've learned

1) Coulomb's Law

$F = K_e q_1 q_2 / R^2$

$F_1 = q_1 E_1$, $F_2 = q_2 E_2$

(Faraday rewrites C's Law using understanding of fields: $F_1 = q_1(K_e q_2/R^2)$ = electric field at q_1, given off by q_2)

2) Ampere's Law:

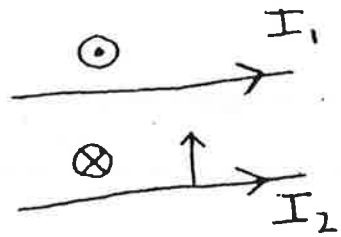


Figure 26.4 parallel current-carrying wires attract

$F = K_m L_1 L_2 I_1 I_2 / R$ (force between the wires)

$F_2 = L_2 I_2 \times B$

Look at a single charge

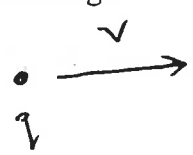


Figure 26.5 – charge with velocity v

$F = qvB$

Look at a single charge among others

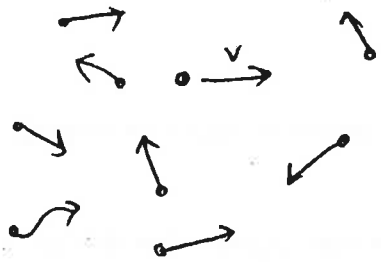


Figure 26.6

What is the charge on q_1?

$F = qE + qvB$

3) Faraday's Law

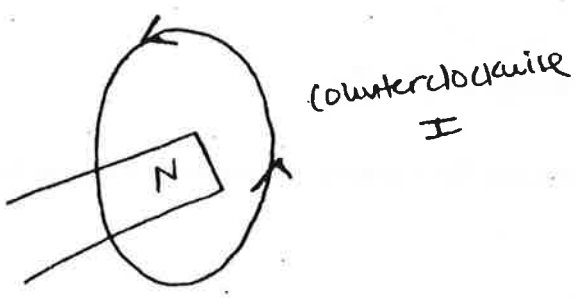


Figure 26.7 – visualize Faraday's Law

Notes for Class 27

E&M Summary Cont'd

1) Coulomb's Law (force between stationary charges)

2) Ampere's Law (currents cause magnetic fields, which exert forces on moving charges)

3) Faraday's Law:

Push magnet through loop, MF changes, creates current that opposes that change.

$\Delta\phi/\Delta t = I$ (resistance of loop)

Reminder: Flux = BA

What if we take the loop away?

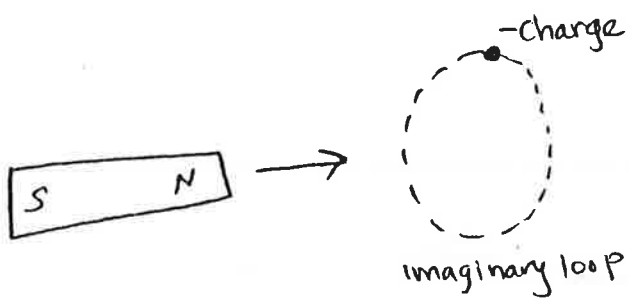


Figure 27.1 – a changing magnetic field causes a circulating electric field

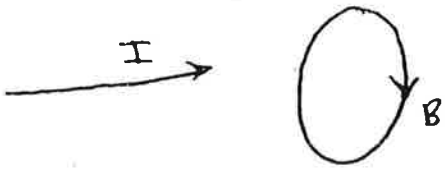


Figure 27.2 - Replace magnet with current-carrying wire

changing MF → circular EF

changing EF → circular BF

Light

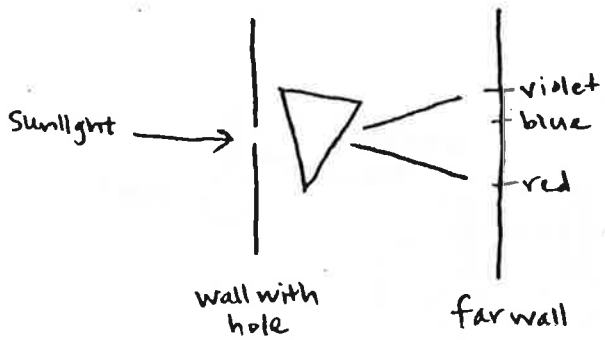


Figure 27.3 - Newton's Theory of colors (1687)

Notes for Class 28

Three Discoveries about light

1. William Herschel (1800)

   Experiment A: visible light.

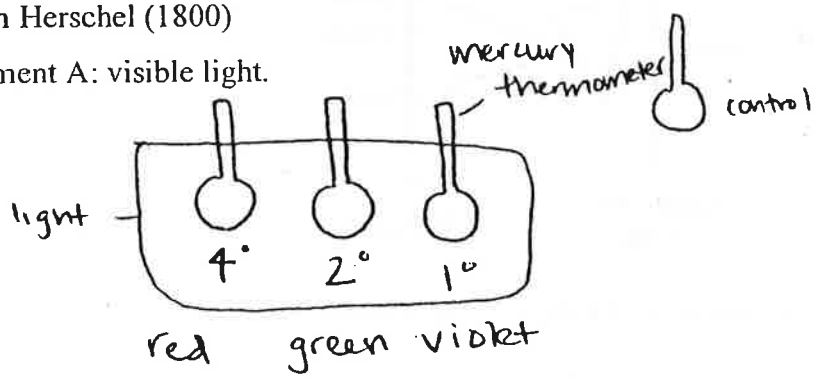


Figure 28.1 – Exp. A: Temperature increase after 10 minutes

Experiment B: infrared light.

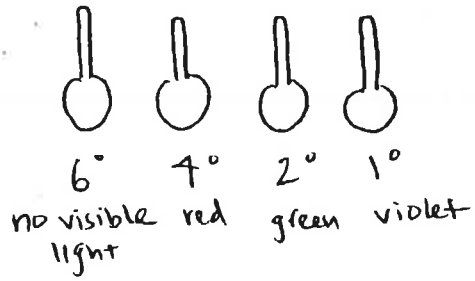


Figure 28.2 – Exp. B: Temperature increase after 10 minutes

Experiment C: ultraviolet light.

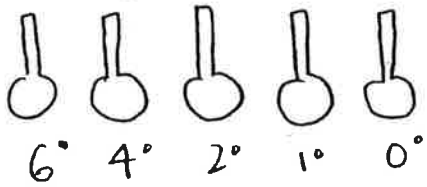


Figure 28.3 – Exp. C: Temperature after 10 minutes.

2. Johann Ritter (1800)

   Silver Nitrate becomes dark when light shines on it.

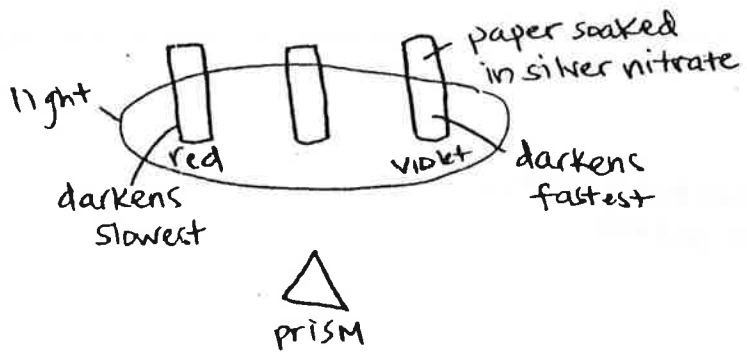


Figure 28.4 – Ritter's Experiment Step 1

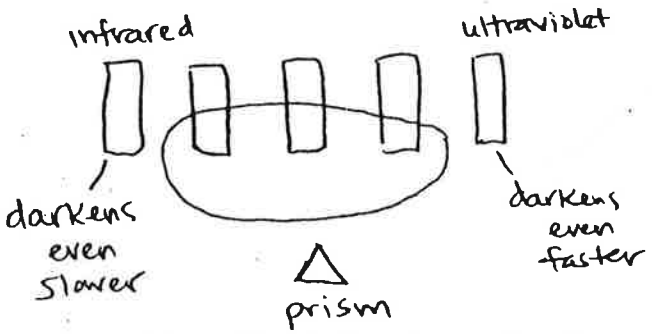


Figure 28.5 – Ritter's Experiment Step 2

3. Thomas Young (1801)

   Background

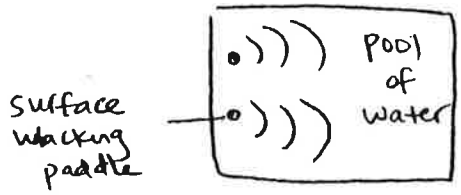


Figure 28.6 – Waves in water

Waves can add or subtract when they combine

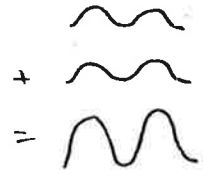


Figure 28.7 - combining "in phase"

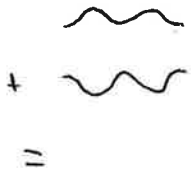


Figure 28.8 - combining "out of phase"

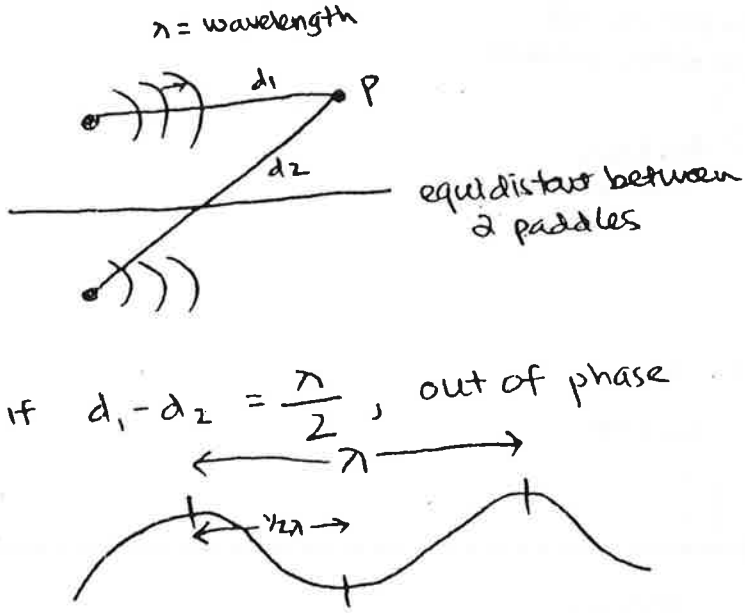


Figure 28.9 – mathematics of waves

Notes for Class 29

Young's Experiment

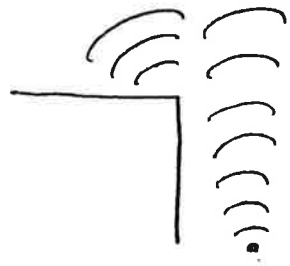


Figure 29.1 - water waves bend around corners

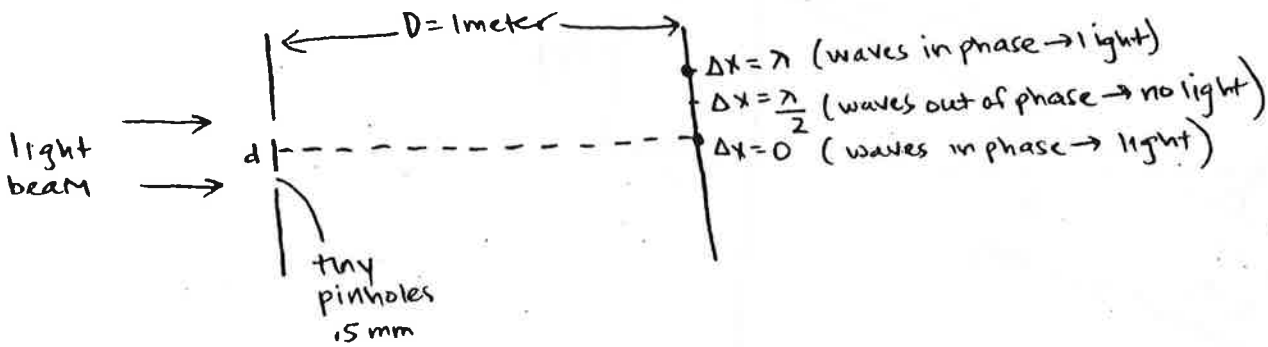


Figure 29.2 Young's Experiment

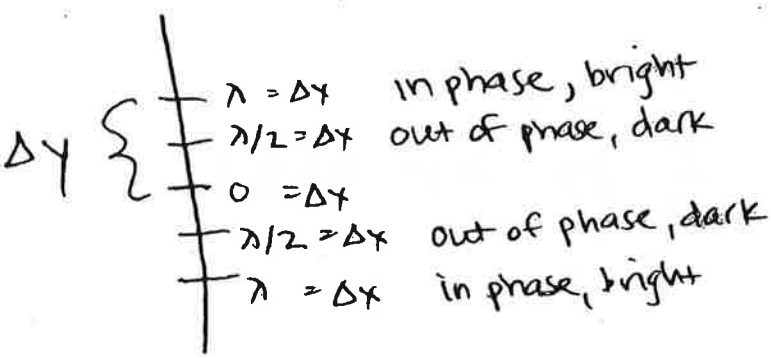


Figure 29.3 Young's results

Δy = distance between adjacent bright spots

$\Delta y = \lambda(D/d)$

Calculate the wavelength of green light:

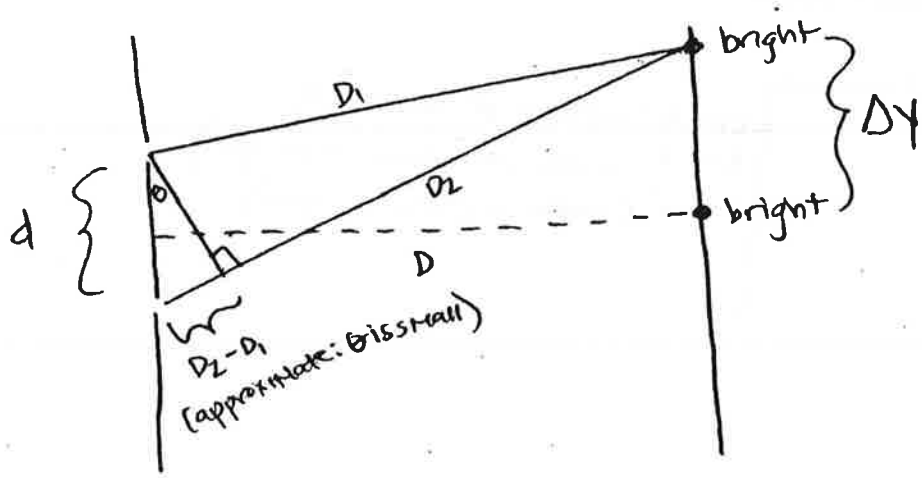
$\Delta y = \lambda(D/d)$

1.1 mm = λ(1 meter/.5 mm)

1.1 mm = λ(2000)

550 nm = λ

How did Young figure this out?



At bright spot: $D_2 - D_1 = \lambda$

$$\therefore \frac{\Delta Y}{D} = \frac{D_2 - D_1}{d} = \frac{\lambda}{d} \Rightarrow \Delta y = \lambda\left(\frac{D}{d}\right)$$

Figure 29.4 – Young's proof

Visible Spectrum:

	Red	Orange	Yellow	Green	Blue	Violet
λ	670 nm			550 nm		430 nm

Notes on Class 30

Speed of Light (revisited)

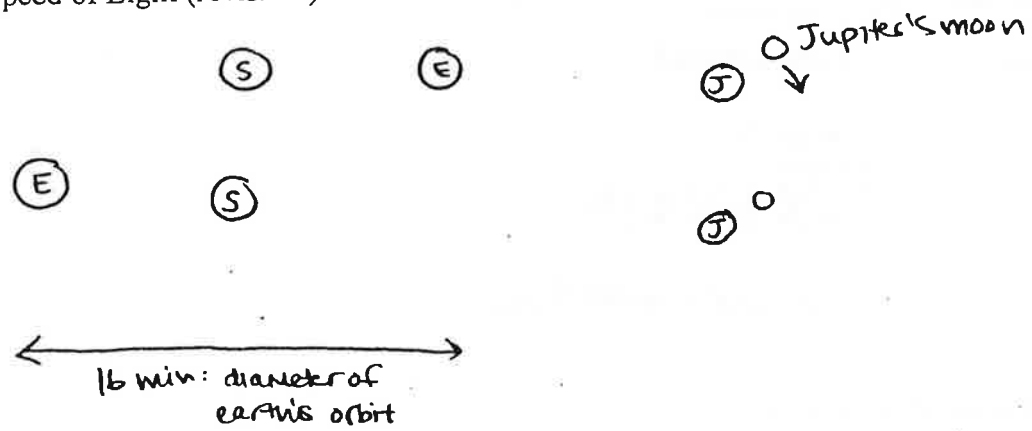


Figure 30.1 – Jupiter's moons

Estimated speed of light = 140,000 mi/sec

Louis Fizeau (1849)

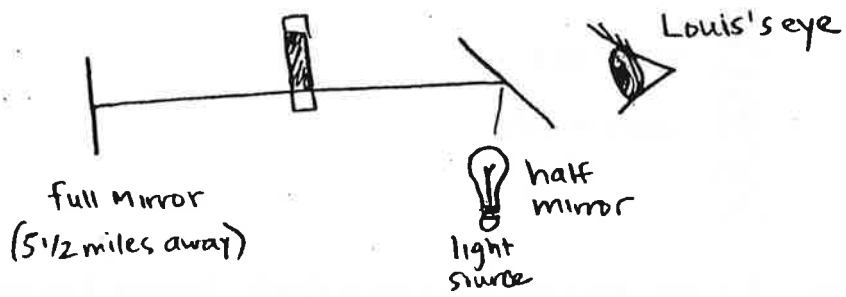


Figure 30.2 – Fizeau's Experiment

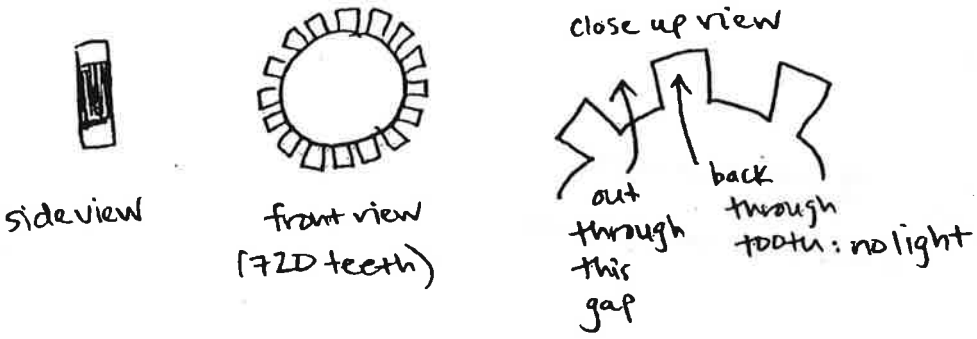


Figure 30.3 – Fizeau's Wheel

Result: light is blocked at 12 revolutions/second.

$$\text{Speed} = \frac{\text{distance}}{\text{time}} = \frac{11 \text{ miles}}{\text{time interval}}$$

$$= \frac{11 \text{ miles}}{\left(\frac{1}{12}\right)\left(\frac{1}{720}\right)\left(\frac{1}{2}\right)\text{sec}}$$

$$= 190{,}000 \text{ miles/sec}$$

Figure 30.4 - Fizeau's Calculation

Actual speed of light = 186,000 mi/sec.

Types of Waves

1. Slinky wave

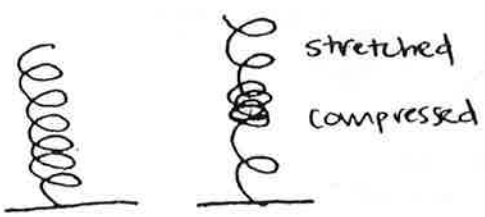


Figure 30.5 – Longitudinal wave: vibrating motion is along the direction of the wave.

2. Rope wave:

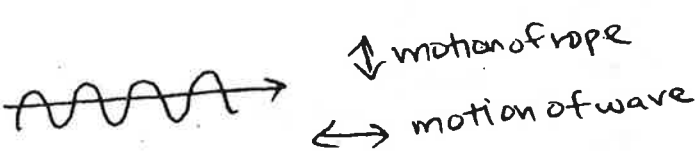


Figure 30.6 - Transverse wave: vibrating motion is in direction transverse to the wave propagation.

Notes for Class 31

Types of Waves (cont'd)

1. longitudinal wave
2. transverse wave

What kind of a wave is light?

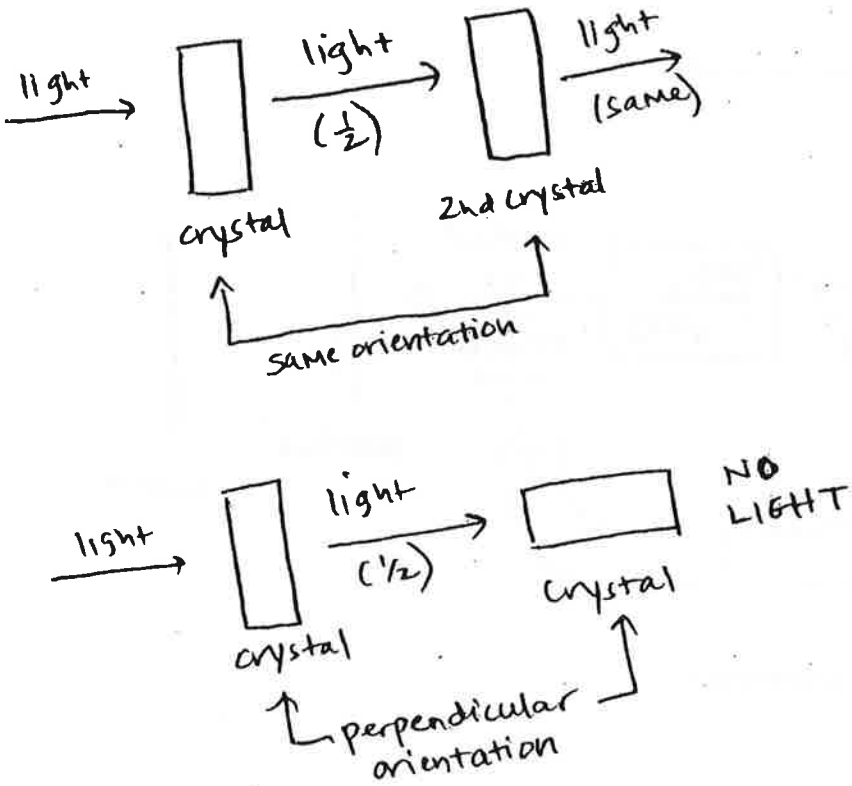


Figure 31.1 - Light can be polarized

Light is a transverse wave.

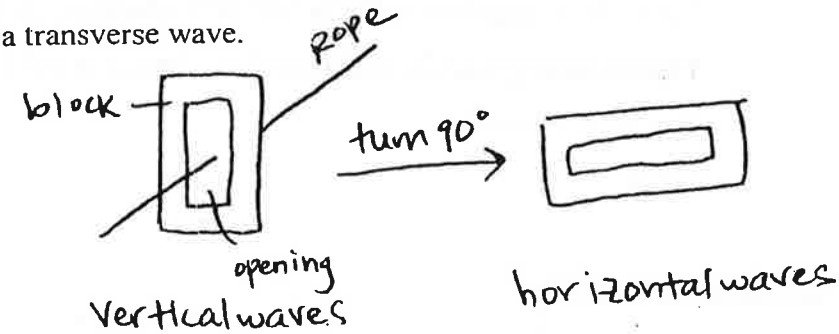


Figure 31.3 - Transverse waves in two directions, both perpendicular to propagation of the wave.

Notes for Class 32

Back to E & M

Review

Can we connect E & M to light?

Faraday's discovery (1845)

Experiments with materials: no results.

Uses lead borate glass

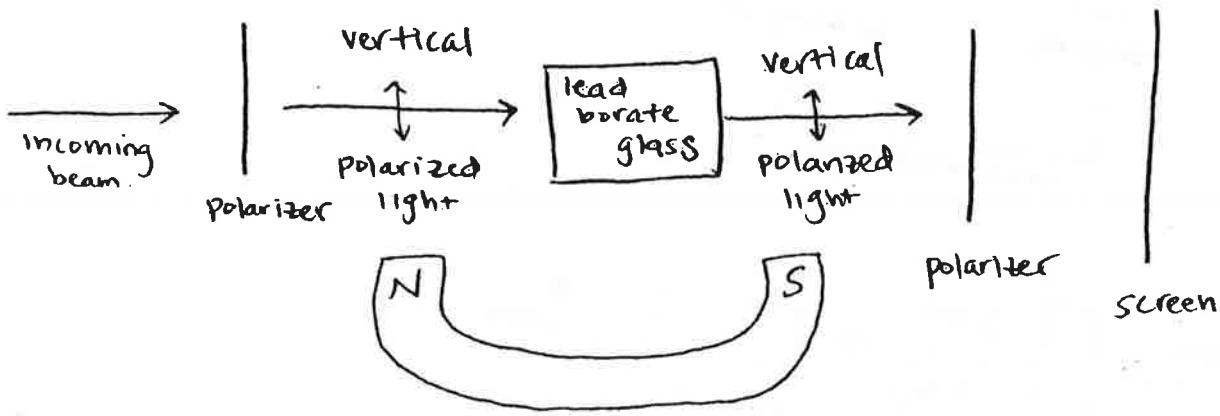


Figure 32.1 – Faraday's Experiment

Light rotates!

How much depends upon:

Strength of magnetic field (2x MF→2x change in pol.)

Thickness of glass (2x thickness→2x change in pol.)

Nature of material

Color

James Clark Maxwell (1831-1879)

"greatest theorist of the 19th century" completes theory of E&M

Discovery of "missing term"

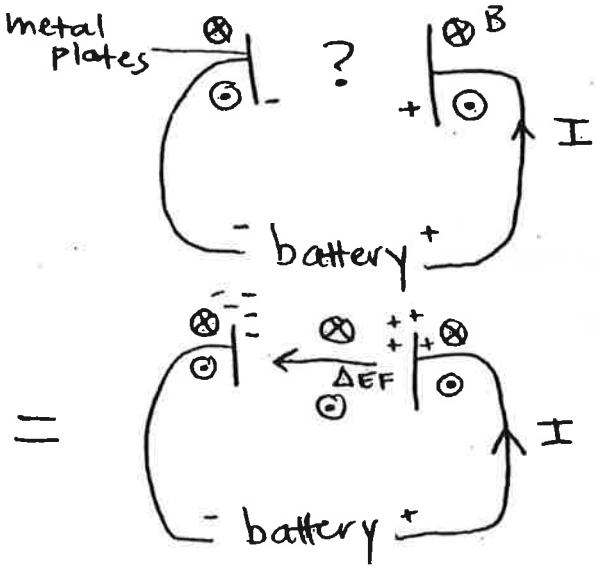


Figure 32.2 Maxwell's Discovery

Changing EF between plates → MF

Notes for Class 33

Maxwell's Discovery of the "missing term" cont'd

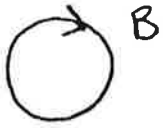


Figure 33.1 – Circulating magnetic field

Two ways to generate a circulating MF

1. Electric current flowing through the loop
2. Changing EF through the loop

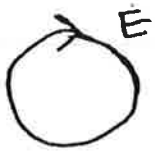


Figure 33.2 – Circulating electric field

One way to generate a circulating EF

1. Changing MF through the loop

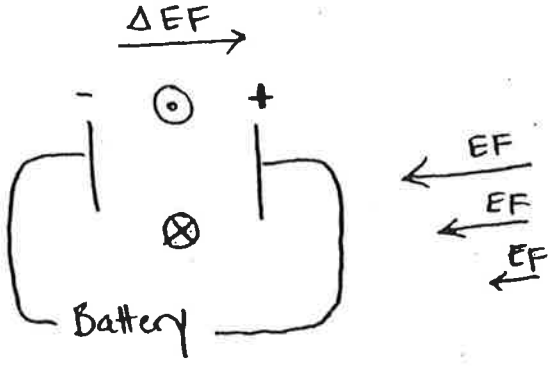


Figure 33.3 – Magnitude of EF decreases until neutral

Relates EF to MF mathematically, finds:

0 = non-zero!

Maxwell's Second Great Discovery

Figure 33.4 - Result of shaking a charge

Shake a charge→ change MF →change EF→ change MF ....

Shake a charge→electromagnetic wave!

$$\text{Speed} = \sqrt{2\frac{K_e}{K_m}}$$

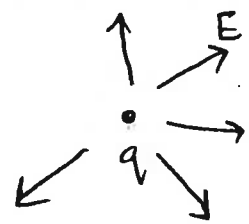
$$= \sqrt{\frac{\cancel{2}\cdot 9(10)^9}{\cancel{2}(10)^{-7}}}$$

$$= \sqrt{9(10)^{16}}$$

$$= 3(10)^8$$

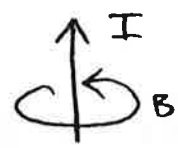
$$= 3\times 10^8 = 300{,}000{,}000 \text{ m/sec}$$

$$= 186{,}000 \text{ mi/sec !!}$$



$$E = \frac{K_e q}{R^2}$$

$$(K_e = 9\times 10^9)$$



$$B = \frac{K_m I}{R}$$

$$(K_m = 2\times 10^{-7})$$

Figure 33.5 – Speed of an electromagnetic wave

LIGHT IS AN ELECTROMAGNETIC WAVE!

Notes for Class 34

Electromagnetic Waves

Review

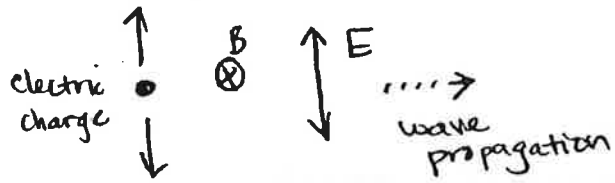


Figure 34.1 – Electromagnetic wave propagation

$$E = \frac{k_e q}{R^2}$$

$$B = \frac{k_m I}{R}$$

$$c = \sqrt{2\frac{k_e}{k_m}} = 186{,}000 \text{ mi/sec}$$

Figure 34.2 – Speed of an electromagnetic wave

How can we prove that light is an electromagnetic wave?

Properties of Light

1. Law of reflection: $\theta_i = \theta_r$

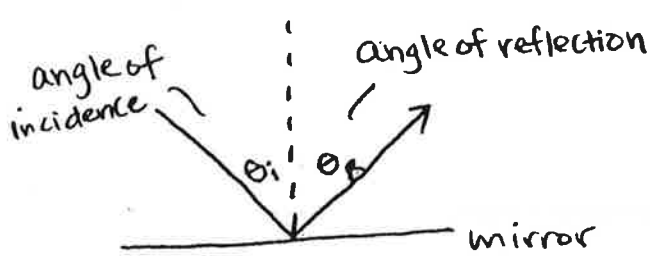


Figure 34.3

2. Law of refraction (1620s): $\sin\theta_i = n \sin\theta_r$

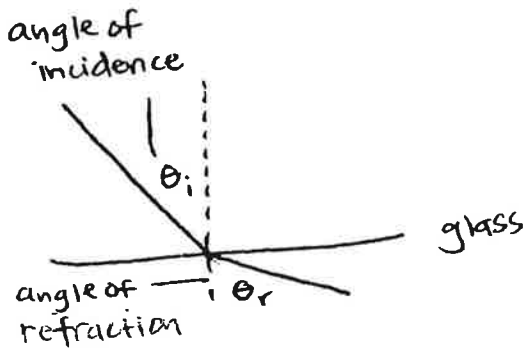


Figure 34.4

n depends on material

3. Light is a wave (Young)
4. Transverse wave: light can be polarized
5. Speed of wave = 186,000 mi/sec

Heinrich Hertz (1857-1894)

Experimental proof that EM waves are light (1889)

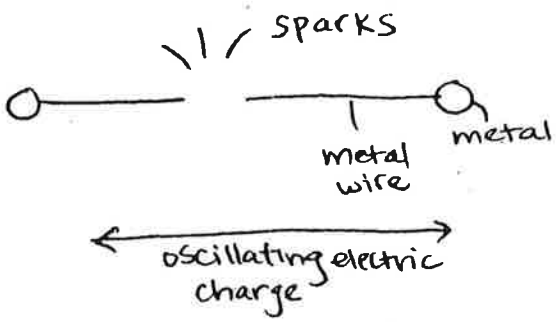


Figure 34.5 – Hertz's experiment

1. oscillate charges
2. spark-gap detector

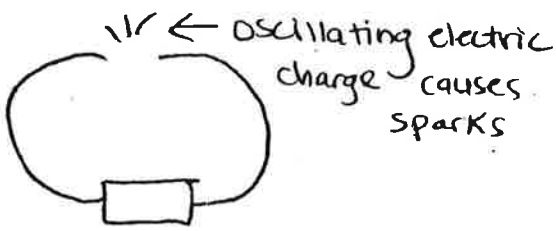


Figure 34.6

Notes for class 35

Hertz's Experimental Discovery of EM Waves

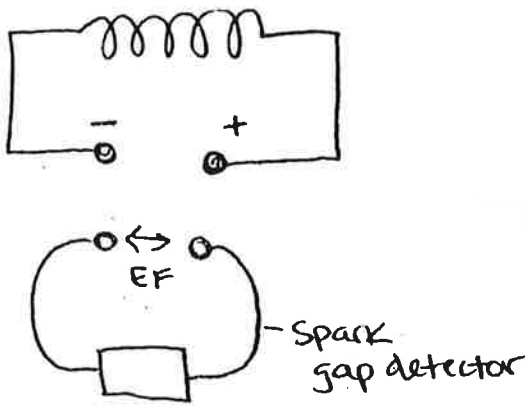


Figure 35.1 - Hertz's EM transmitter

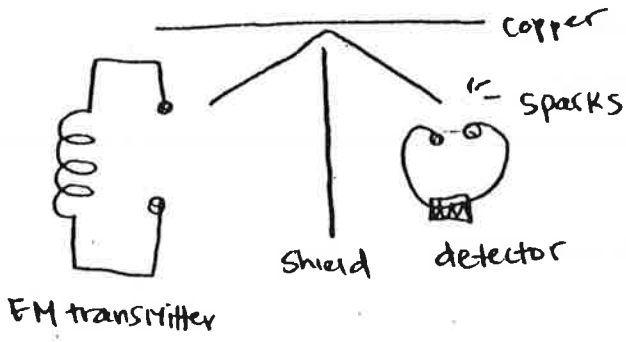


Figure 35.2 – Hertz tests reflection

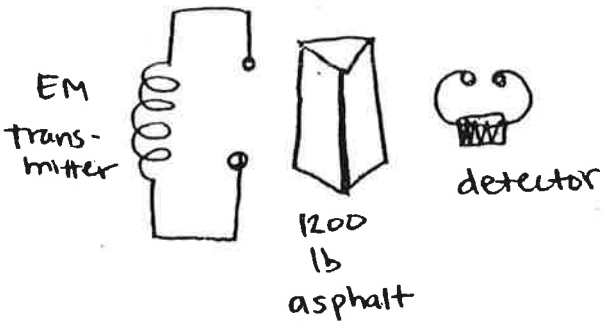


Figure 35.3 – Hertz tests refraction

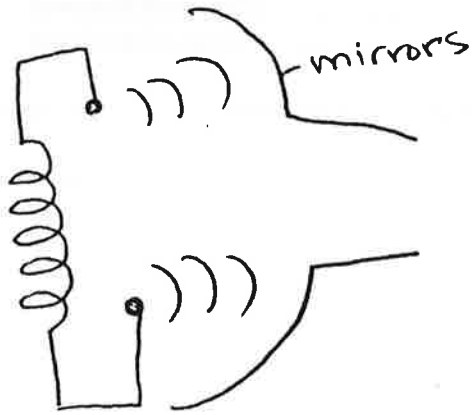


Figure 35.4 – Hertz tests interference

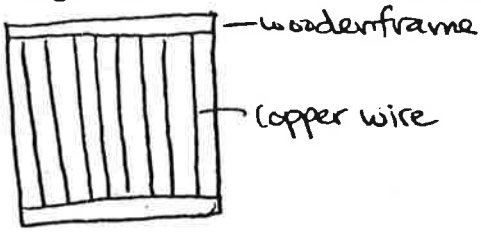


Figure 35.5 – Hertz's polarizer

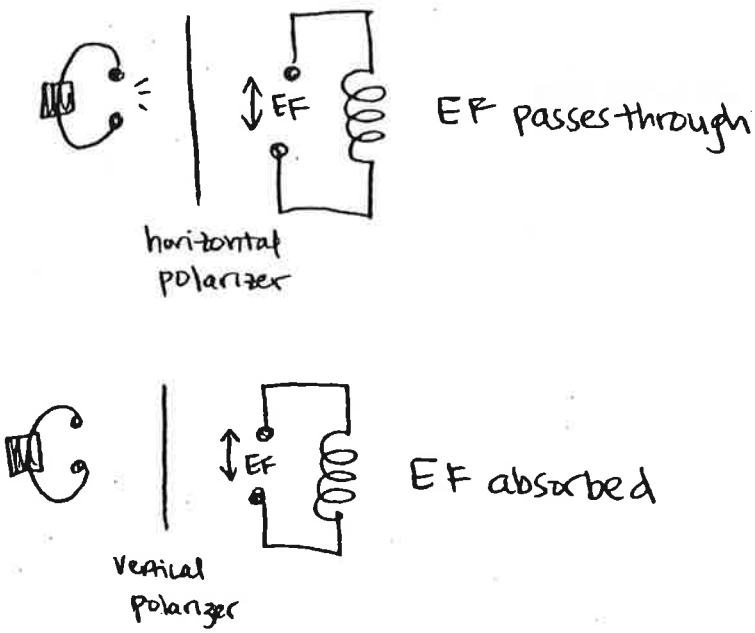


Figure 35.6 – Hertz tests polarization

Speed =186,000 mi/sec? Yes

Electromagnetic Spectrum

Radio, Microwave, Infrared, Visible, Ultraviolet, X-rays, Gamma

Notes for Classes 36 & 37

Brief History of Electrical Technology

1800 Electric battery (Volta)

1830s Electric generator and motor (Faraday)

1840s Telegraph (Morse)

S: • • •

O: - - -

SOS: • • • - - - • • •

1886 Trans-Atlantic cable

1859 Rechargeable battery (Plante)

1867 Dry cell battery (Leclanche)

1876 Telephone (Bell)

1879 Electric lightbulb (Edison)

1896 Niagara Falls: first major electric power plant

1901 Radio (Marconi)

1909 Tungsten filaments

1911 Electric starters for cars

1947 Black and white television

1948 Transistor

Notes for Class 38

Early History of Chemistry

By 1000 B.C.

Metals: gold, silver, copper, lead, tin, iron, mercury

Dyes: blue (indigo plant), purple (shellfish glands), red (insect guts)

Pottery

Glass

665 A.D.

"Greek Fire"

c.1300 A.D.

Distilling techniques

Sulfuric and Nitric acids discovered

Gunpowder: charcoal + sulfur+ saltpeter

John Mayow (1641-1679):

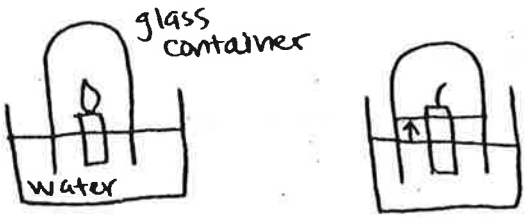


Figure 38.1 – Candle burns air

Concludes: Air is a mixture of two gases-- one that burns, one that doesn't.

Varies his experiment: sulfur and mice

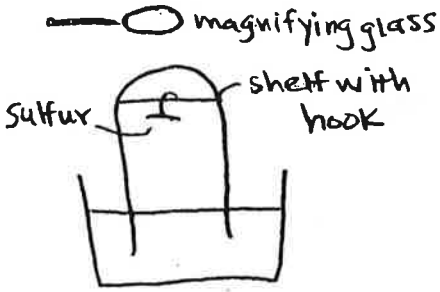


Figure 38.2 – Sulfur needs air to burn

Notes for Class 39

18th Century Chemistry

Stephen Hale:

Invented an apparatus for collecting gases (1727)

Figure 39.1 – Water remains in an inverted water bottle

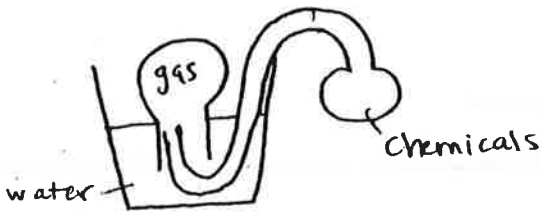


Figure 39.2 – Hale's gas collector

Joseph Black:

Discovered a new gas: "fixed air" (1754)

Magnesium carbonate + heat → magnesium ore + gas

Properties of this gas:

No respiration or combustion

Plants love it

Once plants have been in it, respiration and combustion are possible

"fixed air" is CO_2!

Chalk + heat → "quicklime" + CO_2

($CaCO_3$ + heat → CaO + CO_2)

Joseph Priestley:

Discovered oxygen (1774)

Rusted mercury + heat → pure mercury + gas

Properties of this gas:

Burns vigorously

Great for breathing

Mice love it

This gas is oxygen ("fire air").

Henry Cavendish:

Discovered Hydrogen (1776)

Iron filings + sulfuric acid→ gas

Properties of this gas:

Burns

Can't breathe it

Very light

Gas + oxygen + electrical spark→ water

Notices: 2 volumes Hydrogen + 1 volume Oxygen → 2 volumes steam

Notes for Class 40

Early Chemistry

Review

Priestley and Cavendish

No theoretical understanding!

Antoine Lavoisier (1743-1794)

An element is a pure substance that cannot be decomposed by any chemical process.

If A + B → C + D, mass of reactants = mass of products

So: If A + heat → B + C, and $M_A = M_B + M_C$, A is a compound.

Refuted quantitatively the idea that elements can disappear or miraculously change into other elements:

1. Water Residue experiments:

   Glass + ~~water~~ + heat→ glass + ~~water~~ + residue

   Glass + heat → glass + residue

   Finds: glass decreases in weight by the exact weight of residue!

2. Burning Phosphorus in a closed container: air doesn't disappear!

   Volume of air decreases by 20%, weight of phosphorus increases by weight of that "disappeared" air

Notes for Class 41

Antoine Lavoisier (1743-1794)

Experiments:

1. Water residue
2. Burning phosphorus
3. Rusting metal:

   Rusted metals are heavier than pre-rusted metal (tin, lead, mercury)

4. Black's experiments

   Carbon (charcoal) + oxygen + heat → "fixed air"

   Concludes: "fixed air" is a compound of carbon and oxygen.

   3 grams C combines with 8 g O.

5. Cavendish's experiments

   2 Hydrogen + 1 Oxygen → water

   8 grams H + 1 gram O → water

   (note: H is light! 2 Liters H weighs 8x less than 1 liter O)

6. Lavoisier's mistake: hasty generalization

   Noticed: O + C→ acid, O + S → acid, O + P → acid

   Concluded: O is the "acid former"

   (note: Hydrogen is the real "acid former": discovered when mercuric acid was analyzed)

Founder of chemistry (compare with Newton)

Major Book = Elements of Chemistry (1789)

Elements v. compounds

Reforms language of chemistry ("green lion of mars" becomes "hydrochloric acid")

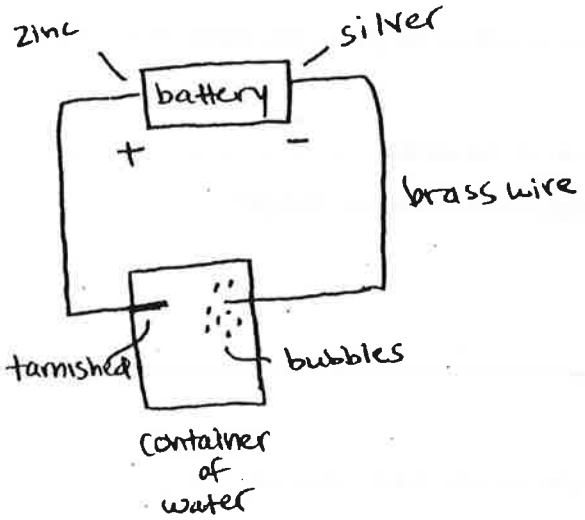
Lavoisier's tragic end: "the Republic has no need for learned men" (1794)

Notes for Class 42

Post-Lavoisier Chemistry

Nicholson and Carlisle (1800)

Decomposition of water by electrolysis:



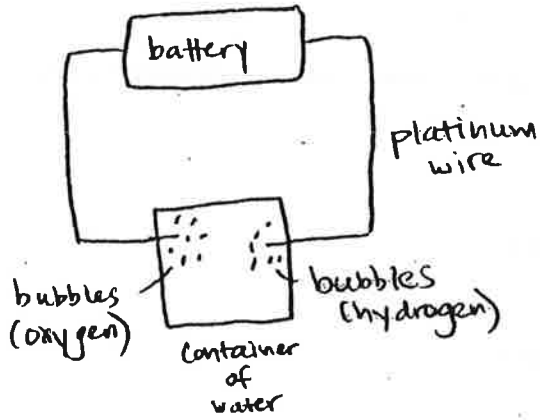


Figure 42.1 – Decomposition of water by electrolysis

Linked chemistry and electricity

Joseph Proust

Law of Definite Proportions (1799)

Evidence

a) 1 g H + 8 g O → 9 g H_2O

2 g H + 8 g O → 9 g H_2O + 1 g H

(can't make "hydrogen-enriched" water!)

b) 3 g C + 8 g O → 11 g CO_2 ("fixed air")

c) 4 g Copper + 1 g O → 5g black compound

8 g Copper + 1 g O → 9 g reddish brown compound

Law: Different samples of a compound always contain the same elements in the same proportion by mass.

e.g. water is always 8:1 (Oxygen : Hydrogen) by weight

Fixed air is always 3:8 (Oxygen : Carbon) by weight

John Dalton (1766 1844)

Review: Democritus (400 B.C.): matter is made of atoms. No proof!

Dalton: first scientific evidence for atomic theory

Notes for Class 43

Dalton's Chemistry

Law of Multiple Proportions (1803)

Evidence

1. 4 g Copper + 1 g O → black ore
   8 g Copper + 1 g O → red ore

2. 3 g C + 8 g O→ "fixed air"
   3 g C + 4 g O → different gaseous carbon/oxygen compound

3. 3 g C + 1 g H → methane ("marsh gas")
   6 g C + 1 g H → olefiant gas ("ethane")

4. Nitrogen/oxygen compounds (clincher)

   1.75 g N combines with:

   1 g O → Laughing Gas (N_2O)
   2 g O → Clear gas formed by lightning (NO)
   3 g O → Blue liquid (N_2O_3)
   4 g O → Brown gas (NO_2)
   5 g O → white powder (N_2O_5)

   Why are they in exact integer multiples?

Law:

When two elements combine to form more than one compound, the weights of one element that combine with identical weights of the other are in simple multiple proportions.

e.g. Copper/oxygen compounds:

Cu_2O (red) has an 8:2 weight ratio,

CuO (black) has a 4:1 weight ratio

So: each Cu atom is 4x as heavy as each O atom.

e.g. carbon/oxygen compounds:

CO_2 has a 3:8 weight ratio,

CO has a 3:4 weight ratio,

So: each C atom is ¾x as heavy as each O atom

Conclusion: every atom within an element weighs the same.

Law of Combining Volumes:

2 Hydrogen + 1 Oxygen → 2 steam

1 Nitrogen + 3 Hydrogen → 2 Ammonia

Notes for Class 44

Early 19th Century Chemistry

How to make laughing gas:

Humphrey Davy (c. 1798)

Step 1: Aluminum chloride salt (white powder found in nature) + water + lye (whitish chalky material) → salty water + Ammonia gas.

Step 2: Ammonia gas + Nitric acid → Ammonium nitrate (solid)

Step 3: Ammonium nitrate + heat → nitrous oxide + steam

Step 4: cool down Nitrous oxide → Laughing gas + water

Law of Combining Volumes cont'd:

2 Hydrogen + 1 Oxygen → 2 steam

1 Nitrogen + 3 Hydrogen → 2 Ammonia

1 Hydrogen + 1 Chlorine → 2 Hydrogen Chloride (HCl)

"nice, round numbers"

Why would gases only combine in small integer ratios?

Equal volumes of gases must contain equal numbers of atoms.

What is the structure of water? (2 H + 1 O → 2 steam)

Assume water is H-O

Expect: 1 H + 1 O → 1 steam

Assume water is H_2-O

Expect: 2 H + 1 O → 1 steam

Assume water is H_2-O and that H has is H_2, O gas is O_2

Expect: 2 H_2 + 1 O_2 → 2 steam

1 hydrogen (H_2)+ 1 chlorine (Cl_2) → 2 Hydrogen Chloride (HCl)

1 Nitrogen (N_2) + 3 hydrogen (H_2) → 2 ammonia (NH_3)

2 nitrous oxide (N_2O)→ 2 nitrogen (N_2) + 1 Oxygen (O_2)

Notes for Class 45

Terminology of Chemistry

All samples of a substance have identical chemical and physical properties.

e.g. pure water

A mixture is two or more substances, each of which retains its specific properties.

e.g. salt water, milk, gunpowder

An element is a substance that cannot be decomposed by a chemical change.

A compound is a substance composed of two or more elements; it can be decomposed.

An atom is the smallest particle of an element that can enter into a chemical combination.

Note: different from the Greeks' idea of atom as the ultimate particle which can't be broken down.

A molecule is two or more atoms bonded together.

e.g. O_2, H_2, N_2, NH_3, CO_2

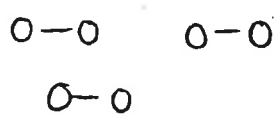


Figure 45.1 – Oxygen molecules

Notation

$\mathbf{1}\ N_{\underline{2}} + \mathbf{3}\ H_{\underline{2}} \rightarrow \mathbf{2}\ NH_{\underline{3}}$

Coefficients identify the number of molecules

Subscripts identify the number of atoms in the molecule.

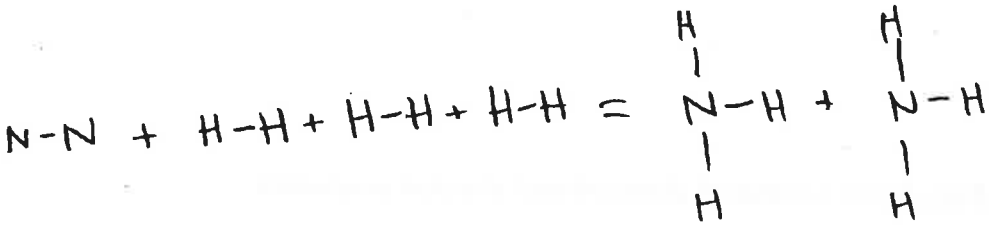


Figure 45.2 – $N_2 + 3H_2 \rightarrow 2NH_3$

Joseph Gay-Lussac (1808)

Law of Combining Volumes

The volumes of gases involved in a reaction can always be expressed as a ratio of small whole numbers.

Avagadro's Law (1811):

Equal volumes of gases contain equal numbers of molecules

More evidence for the Atomic Theory:

Humphrey Davy (1814)

Burn a diamond, it becomes graphite. Both are carbon!

Relative weights of elements

Element	Atomic Weight
H	1
C	12
N	14
O	16
Sodium (Na)	23
Aluminum (Al)	27
Chlorine (Cl)	35
Copper (Cu)	64
Silver (Ag)	108
Lead (Pb)	208

So: O = 16x H, C = 12x H, Pb = 208x H

Introduction to heat

Calorie: heat needed to raise the temperature of one gram of water by 1° C.

Notes for Class 46

Chemistry and Heat

Allotropes: same element existing in different forms.

Carbon:	diamond (3-D lattice)
	Graphite (2-D planes)
Phosphorus:	white (P_4)
	red (chain)
Oxygen:	normal (O_2)
	Ozone (O_3)

Isomers ("equal parts")

C_2H_6O: Ethanol (boiling pt. 78°, explosively reacts with Na)

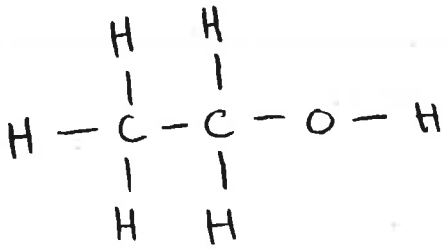


Figure 46.1- Ethanol

Methyl ether (boiling pt. -24°, doesn't react with Na)

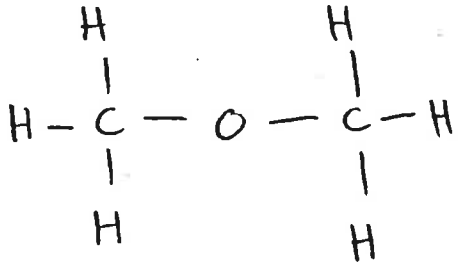


Figure 46.2 - Ether

HOCN: Cyanic acid (H-O-C-N)

Fulminic acid (H-O-N-C)

Notes for Class 47

Heat

Example 1:

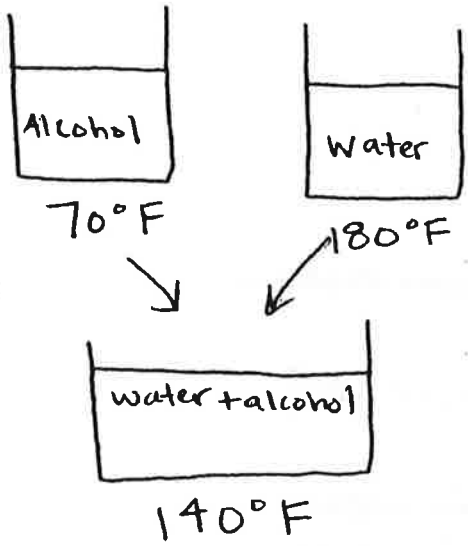


Figure 47.1 - More energy is needed to change the temperature of water.

Example 2:

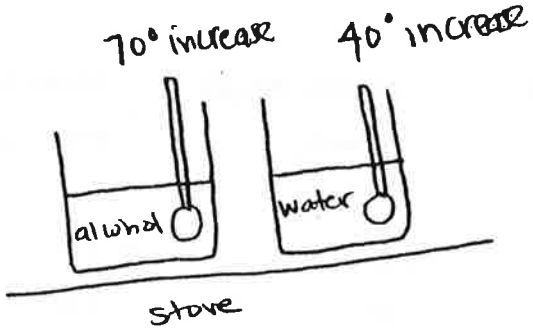


Figure 47.2 - Alcohol heats faster than water.

Different materials require different heats to raise their temperature.

Specific heat of a substance is the amount of heat required to raise the temperature of one gram of it by 1° C. (unit = cal/gram°C)

Specific heat of water = 1.

Specific heat of alcohol = 4/7 $\simeq$ .6

Metal	Specific Heat (Cal/g°C)
Aluminum	.22
Copper	.093
Silver	.056
Lead	.030

Dulong and Petit (1819)

1 mole = number of atoms in 1 gram of hydrogen.

How many atoms are in 16g oxygen? 1 mole.

Recall atomic weight chart:

1 mole of Hydrogen atoms weighs 1g.

1 mole of Nitrogen atoms weighs 14g.

1 mole of Carbon atoms weighs 16g.

1 mole of lead atoms weighs 207g.

Metal	Specific Heat (cal/g°C)	Atomic Weight (g/mole)	Molar Specific Heat (cal/mol°C)
Aluminum	.22	27	5.9
Copper	.093	64	5.9
Silver	.056	108	6.1
Lead	.030	207	6.2

Specific heat x Atomic Weight = Molar Specific heat

(cal/g°C) x (g/mole) = (cal/mol°C)

Note: all ≈ 6!

Notes for Class 48

Dulong-Petit Law (1819)

Different samples of elements that contain the same number of atoms will have the same heat capacity.

For most elements, molar specific heat = 6 cal/mol°C.

"striking evidence for atoms"

Faraday's Law of Electrolysis

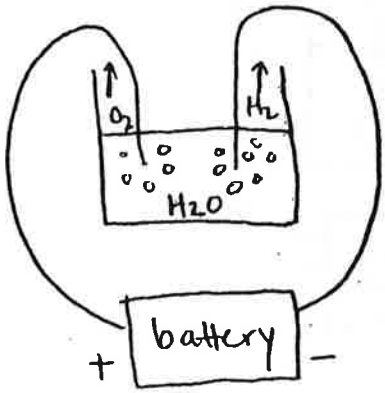


Figure 48.1 – If one collects 1g H gas, one will collect 8 g O gas.

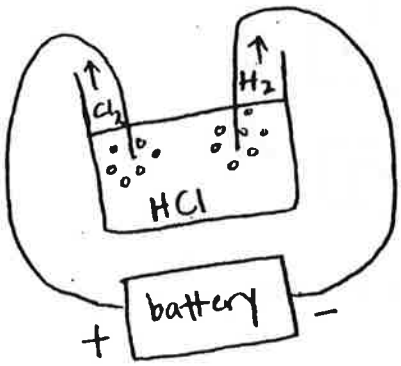


Figure 48.2 - If one collects 1g H gas, one will collect 35 g Cl gas

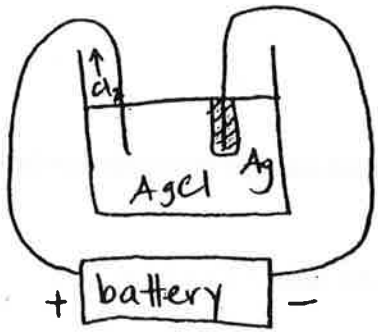


Figure 48.3 – If one collects 35 g Cl gas, one will collect 108 g Ag

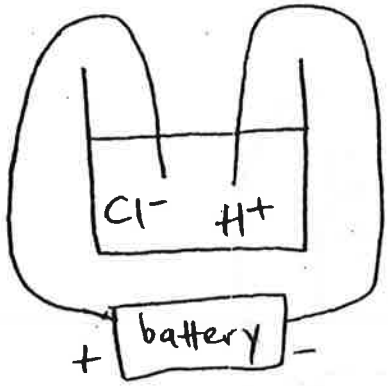


Figure 48.4 – $HCl \rightarrow H^+ + Cl^-$

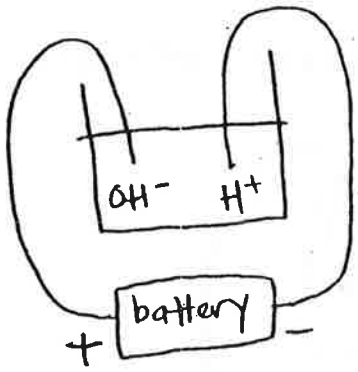


Figure 48.5 – $H_20 \rightarrow H^+ + OH^-$

Law: the number of atoms undergoing chemical change at each electrode is proportional to the quantity of electricity that passes through the solution.

Notes for Class 49

Electrolysis and Batteries

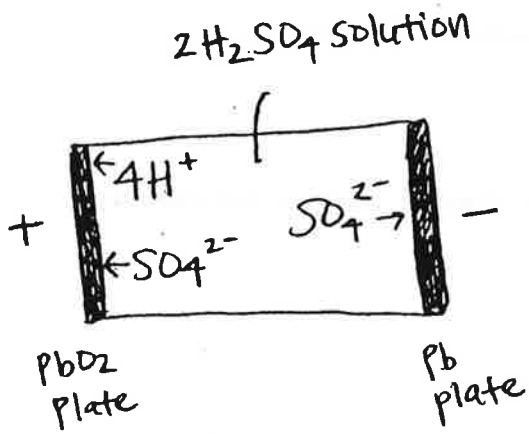


Figure 49.1 – Car battery interior: $2H_2SO_4 \rightarrow 4H^+ + 2SO_4^{2-}$

Positive electrode:

$PbO_2 + 4H^+ + SO_4^{2-} \rightarrow PbSO_4 + 2H_2O$ + 2 positive charges

Negative electrode:

$Pb + SO_4^{2-} \rightarrow PbSO_4$ + 2 negative charges

Evidence for Atoms: Summary

1. Dalton's Law of Multiple Proportions (1803)

   (See Class 43)

2. Law of Combining Volumes: gases (1808)

   (See Classes 44 & 45)

3. Existence of allotropes (1814) and isomers (1827)

   (See Class 46)

4. Dulong-Petit Law of Molar Heat Capacities (1819).

   (See Classes 47 & 48)

5. Faraday's Law of Electrolysis (1832)

   (See Class 48)

Note: all these discoveries within a 30-year span.

Is the atomic theory proven at this point?

All evidence so far from chemistry, physical evidence still needed.

Heat

2 competing views:

Heat as a fluid

Heat as atoms set in motion

Notes for Class 50

Heat

Background

1. Count Rumford's experiments boring cannons (1798)

   Not quantitative: source of motion (horse) not measurable.

2. Humphrey Davy melts ice with friction (c. 1800)

   Rub ice cubes together in a vacuum? They melt.

   No air, the motion must be causing the heat.

James Joule (1818-1889)

Interested in "conversion processes", i.e. chemical reactions→ electricity→ heat→ motion.

Experiment 1 (1840)

Recall Faraday's electric generator (rotate coil in a strong magnetic field→ alternating current)

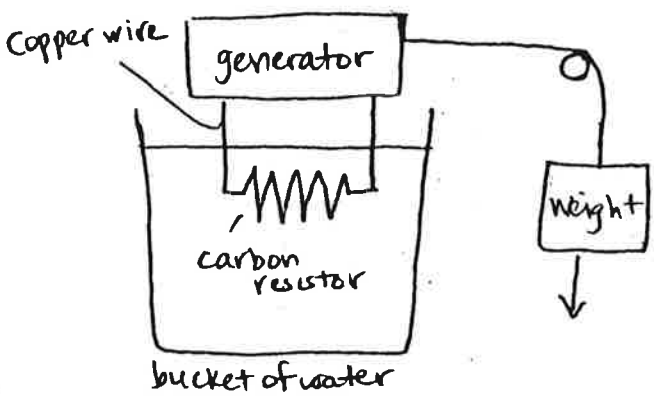


Figure 50.1 Experiment 1

Weight falls→ coil turns and generates current→ resistor heats up→ water temperature increases.

Or: Motion→ electricity→ heat.

Joule quantifies this relationship:

Heat = (change in water T)(heat capacity of water) = I^2R = (weight)(height fallen)

No longer, "when my horse trots around, things heat up"

Notes for Class 51

Heat

Review Experiment 1: Relate motion to electricity to heat

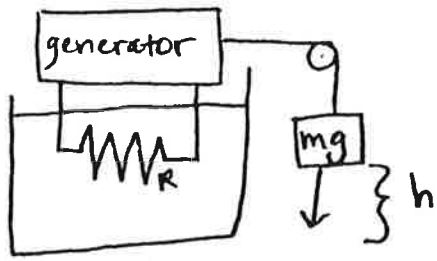


Figure 51.1 – Joule's Experiment 1

Heat = $m_w C\Delta T = I^2R = mgh$

So: 2x Current → 4x temperature increase

2x resistor → 2x temperature increase

Experiment 2: Relate motion to heat by eliminating the middleman (1845)

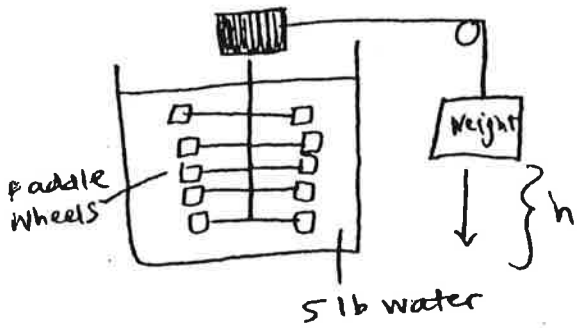


Figure 51.2 – Joule's Experiment 2

typical experiment:

weight = 40 lb

height = 100 ft

water = 5 lb

Result:

4000 ft-lb will raise the temperature of 5 lb water by 1° F.

Or: 800 ft-lb will raise the temperature of 1 lb of water by 1° F.

Replace water with oil? Same relationship:

Heat = $\mathbf{M_0 C \Delta T = I^2 R = mgh}$

Notes for Class 52

Atomic Theory of Gases

Background (Review)

Charles' Law (1785):

$PV \propto (T_c + 273) \propto T_k$

Proportionality constant depends on type and mass of gas

J.J. Waterston (1845): wanted to understand gases in terms of the atomic theory.

Simple atomic model: "perfect superball model"

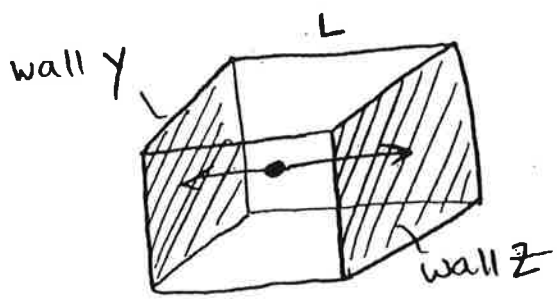


Figure 52.1 – Suberball bouncing between walls Y and Z

Calculate pressure on wall Z:

$P = \text{force} / \text{area}$

$= \text{force} / L^2$

$= ma / L^2$

$= m\Delta v / L^2 \Delta t$

Δv = change in velocity on impact

$\Delta v = 2v$

Δt = time between impacts

$d = vt = 2L$ (d = distance traveled between impacts)

$t = 2L/v$

$\Delta t = 2L/v$

$P = m\Delta v / L^2 \Delta t$

$= m(2v)/L^2(2L/v)$

$= mv^2/L^3$

$= mv^2/V$ (V = volume)

$PV = mv^2$

$\mathbf{PV = mv^2 (N/3)}$ (3 walls total, N/3 = number of atoms hitting wall Z)

Fantasy or science? Does this capture what's going on in a gas?

Notes for Class 53

Atomic Theory of Gases

Scientists know: $PV \propto T$

Waterston's theory: $PV = mv^2 (N/3)$

Does Waterston's result make sense?

Consider Newton's physics.

Figure 53.1 - (weight)(height) = $(\frac{1}{2})mv^2$ = kinetic energy (KE)

Consider collision between two bodies:

$$KE_{before} = (\tfrac{1}{2})m_1v_{1b}^2 + (\tfrac{1}{2})m_2v_{2b}^2$$

$$KE_{after} = (\tfrac{1}{2})m_1v_{1a}^2 + (\tfrac{1}{2})m_2v_{2a}^2$$

$$KE_{before} = KE_{after}$$ (according to Newton's physics)

Consider "cubic energy":

$$CE_{before} = (\tfrac{1}{2})m_1v_{1b}^3 + (\tfrac{1}{2})m_2v_{2b}^3$$

$$CE_{after} = (\tfrac{1}{2})m_1v_{1a}^3 + (\tfrac{1}{2})m_2v_{2a}^3$$

Waterston's Gas Law:

$PV = (N/3)\, mv^2 = (2N/3)$(average KE per molecule)

$PV \alpha$ average KE per molecule

Charles' Gas Law:

$PV \propto T_k$

Implication: **$T_k \propto$ average KE per molecule**

What does this new idea—that T_k is the kinetic energy of molecules—explain?

1. Charles' Law of Gases
2. Avagadro's Law (equal volumes = equal no. molecules, or $V \propto N$)

$$PV = (2N/3)(KE)$$

$$PV \propto N(KE)$$

$$PV \propto NT$$

$$V \propto N \text{ (at constant T and P)}$$

3. Conservation of heat

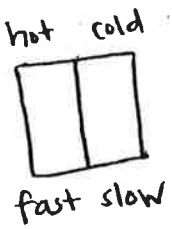


Figure 53.2 - Lead bricks

Lead bricks: fast atoms bump into and speed up slow atoms; eventually all move at the same speed. Heat is transferred, not lost.

Notes for Class 54

Atomic Theory of Gases

KE of molecule = T. What does this idea explain? (cont'd)

1. Charles' Law
2. Avogadro's Law
3. Dulong-Petit Law of Heat Capacities
4. Joule's conversion of external motion to heat
5. Relation of speed of molecules to speed of sound

Speed of air molecules?

$$PV = (N/3)\, mv^2$$

Rewrite: $v^2 = 3PV/Nm$ (Nm = total mass of gas. P, V, and Nm are measurable)

V = 480 meters/sec = 1000 mph (Way too fast!)

Figure 54.1 - JJ blindfolded in the Colosseum.

Notes for Class 55

Atomic Theory of Gases

JJ in the Colosseum: Smartest move = big steps as fast as he can.

Diffusion:

Rate depends on "mean free path" = l

l = distance a molecule travels before colliding with another molecule

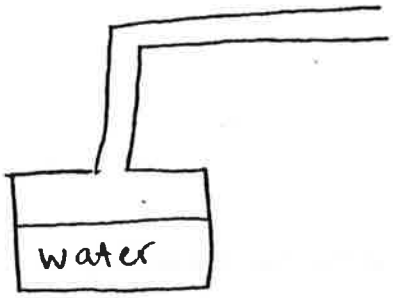


Figure 55.1 – Boil water, see how long steam takes to get to the open end

Size of molecules (Loschmidt, 1865)

1. l_{steam} = 500 nm.
2. Volume of steam = 1500 x volume of water

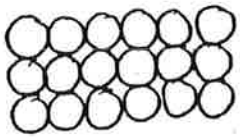


Figure 55.2 – Molecular model of water

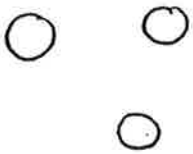


Figure 55.3 – Molecular model of steam

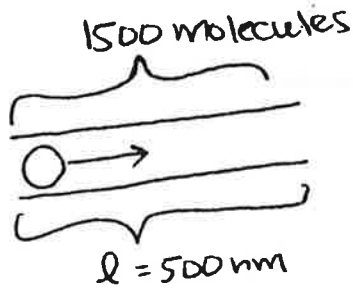


Figure 55.4 – Diameter of one H_2O molecule = 500 nm/1500 = 1/3 nm.

How do we know this is true?

James Clark Maxwell

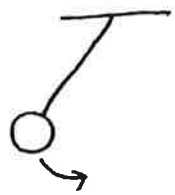


Figure 55.5 - Pendulum

Notes for Class 56

Maxwell's Analysis of the effect of air density on pendulum motion

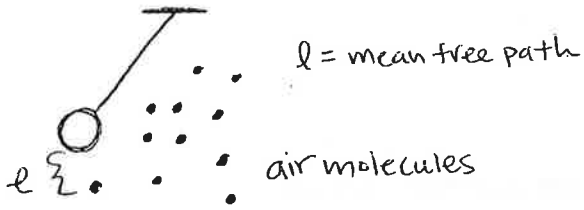


Figure 56.1

Only molecules within *l* (one mean free path) contribute to the damping of the pendulum.

Summary of Evidence for Atoms

From Chemistry:

1. Law of Multiple Proportions (Dalton, 1803)
2. Law of Combining Volumes (Gay-Lussac, 1808)
3. Allotropes and Isomers (Davy 1814 et al.)
4. Law of Electrolysis (Faraday, 1832)

From Physics:

5. Law of Heat Capacities (Dulong-Petit 1819)
6. Relationship between heat and motion (Joule, 1845)
7. Law of Gases (Waterston, 1845)
8. Atomic Theory of Gases explains diffusion, heat conduction, and damping due to air resistance (Maxwell, 1867)

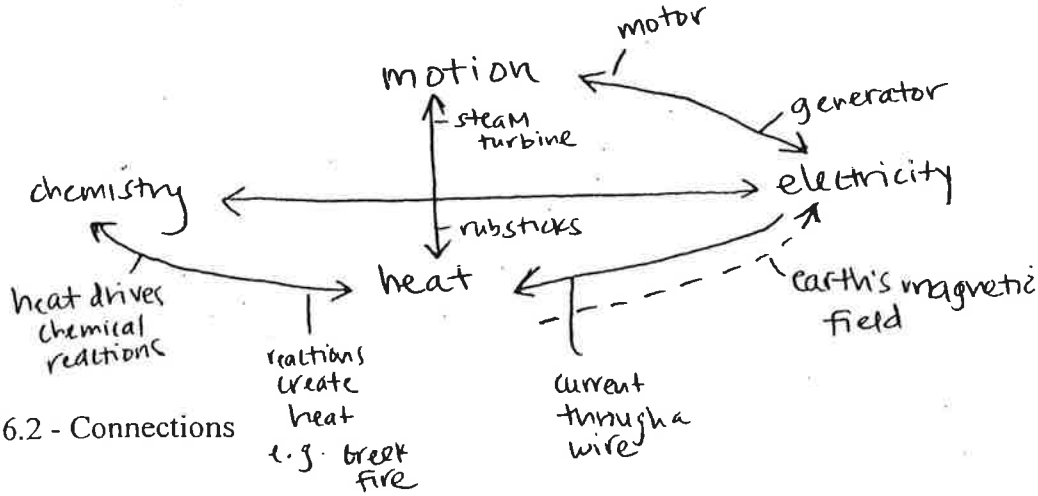


Figure 56.2 - Connections

Notes for Class 57

Review

(See Figure 56.1)

Progress in Chemistry: Discoveries leading to the periodic table

Valence: The highest number of atoms that an element can join to.

Carbon combines with at most 4 other atoms, e.g. CH_4, CCl_4, CH_2Cl_2

Nitrogen combines with at most 3 other atoms, e.g. NH_3

Oxygen combines with at most 2 other atoms, e.g. H_2O

Hydrogen combines with 1 other atom, e.g. H_2, HCl

The "valence" is the number of hooks an atom has for attaching to other atoms.

C = 4, N = 3, O = 2, H = 1, Cl = 1, Na = 1

In CO_2 (O=C=O), C uses all 4 hooks.

Elements can be characterized as "electropositive" or "electronegative."

e.g. Cl^-, Na^+

Group: Scientists found that atoms with the same type and same valance have similar properties, e.g. H^+, Na^+, K^+, Li^+ all react explosively with water.

Notes for Class 58

The Periodic Table

Dimitri Mendeleev (1st version 1869)

Basic Properties:

Electrical properties: which electrode attracts the element?

Valence: number of "hooks"

Group: Valence 1, electropositive

Element:	H,	Li,	Na,	K,	Rb
Atomic Weight:	1	7	23	39	85

Group: Valence 1, electronegative

Element:	F	Cl	Br	Iodine
Atomic Weight:	19	35	80	127

Group: Valence 3, electronegative

Element:	Boron	Al	Indium (In)
Atomic Weight:	11	27	115

Big gap in atomic weight between Al and In!

M's prediction:

Atomic weight = 68

Metal

Density = 6 g/cm^3

Low melting point

X_2O_3

Discovered in 1875 (Gallium)

Atomic weight = 70

Metal

Density = 6 g/cm^3

Low melting point 30°C

Ga_2O_3

Group: Valence 4, neutral

Element:	Carbon (C)	Silicon (Si)	Tin (Sn)
Atomic Weight:	12	28	119

Big gap in atomic weight between Si and Sn!

Mendeleev's Prediction

Atomic Weight = 72

Density = 5.5 g/cm^3

grey metal

XO_2

XCl_4

Low boiling point

Discovered in 1886 (Germanium)

Atomic Weight = 73

Density = 5.4 g/cm^3

grey metal

GeO_2

$GeCl_4$

Low boiling point 83°

"it's like this guy's psychic!"

Spectroscopy

Light	Violet	Blue	Green	Yellow	Orange	Red
Wavelength	430 nm……			570 nm……		690 nm

Notes for Class 59

Spectroscopy (1859)

Gustav Kirchhoff

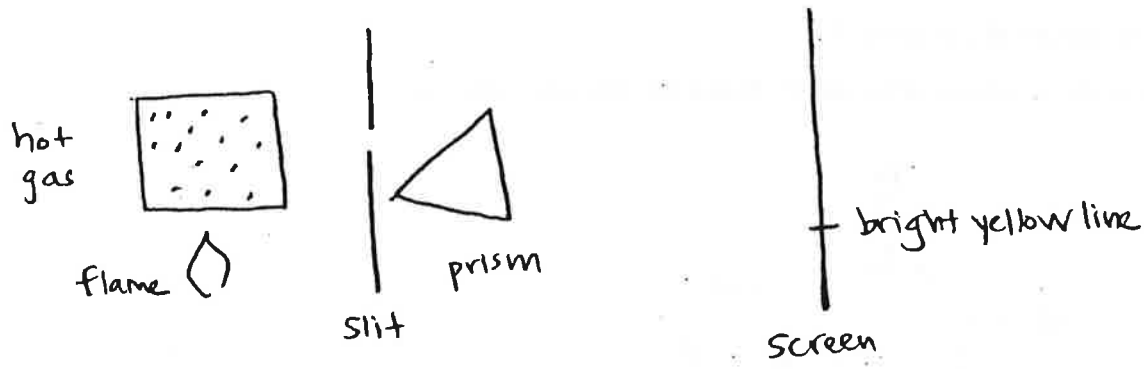


Figure 59.1- Kirchhoff's experiment

Each element emits light at unique characteristic wavelengths (gases)

e.g. 1 bright yellow line at 570 nm = Sodium

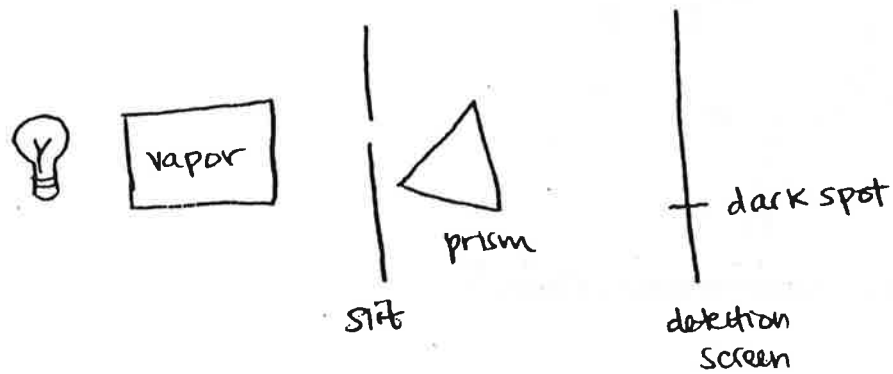


Figure 59.2 – Modified experiment

Dark lines where bright emission lines used to be, due to absorption

Auguste Comte (1798-1857)

What are stars made of?

Notes for Class 60

Molecular Structure

Friedrich Kekule (1858)

Benzene (distilled from "coal tar") = C_6H_6

How to use all of the hooks?

What is the structure of benzene? Benzene, dibromobenzene

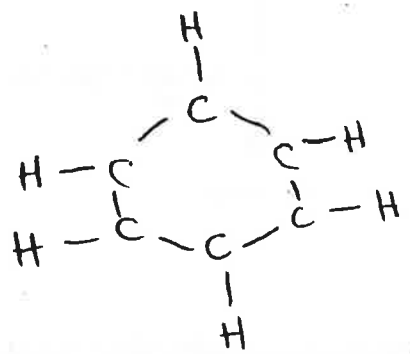


Figure 60.1 – incorrect structure of benzene

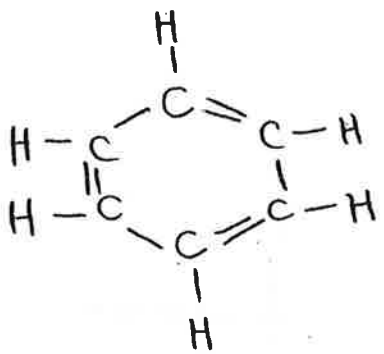


Figure 60.2 – correct structure of benzene

Explanation of isomers

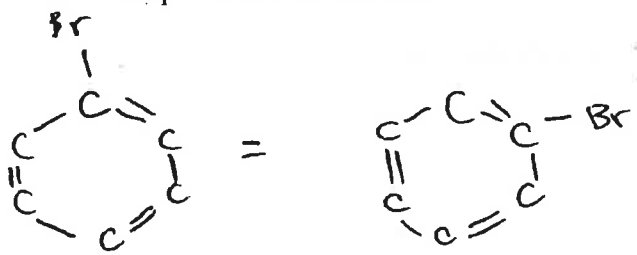


Figure 60.3 – Monobromobenzene has no isomers

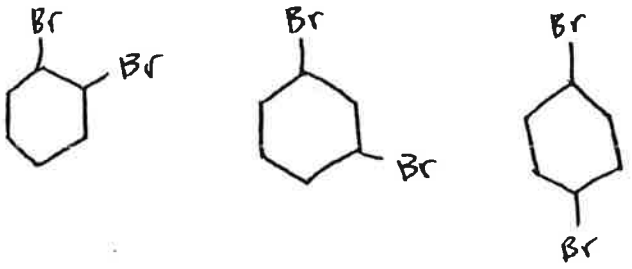


Figure 60.4 – Dibromobenzene has three isomers

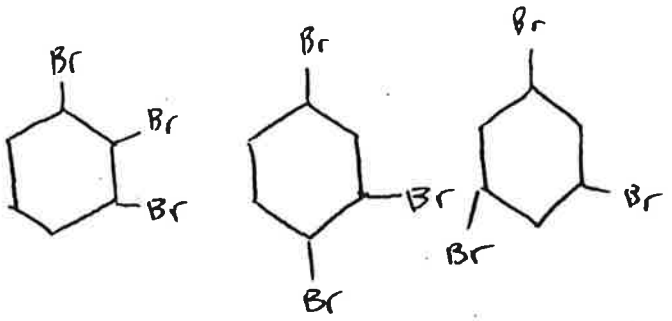


Figure 60.5 – Tribromobenzene has three isomers

Problem Case: CH_2Cl_2

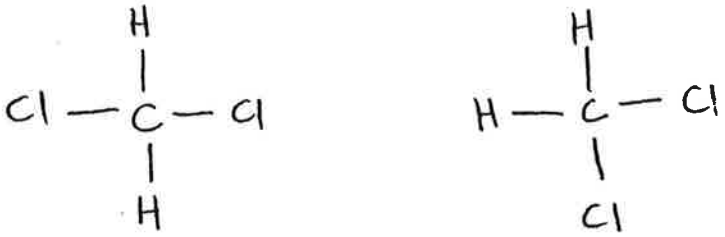


Figure 60.6 – Predicted isomers of CH_2Cl_2

No experimental evidence for 2 isomers!

2-dimensional diagram is inadequate.

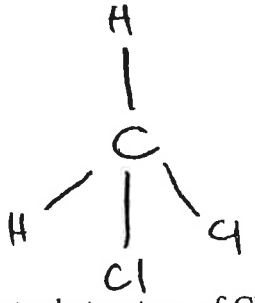


Figure 60.7 – Actual structure of CH_2Cl_2

More mystery cases:

Lactic acid

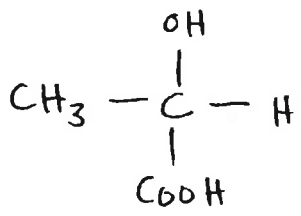


Figure 60.8 – Lactic acid

Notes for Class 61

Molecular Structure

Lactic Acid (See Figure 60.8)

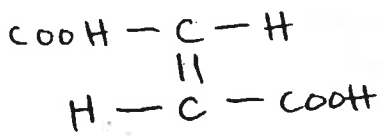


Figure 61.2 -Fumaric acid

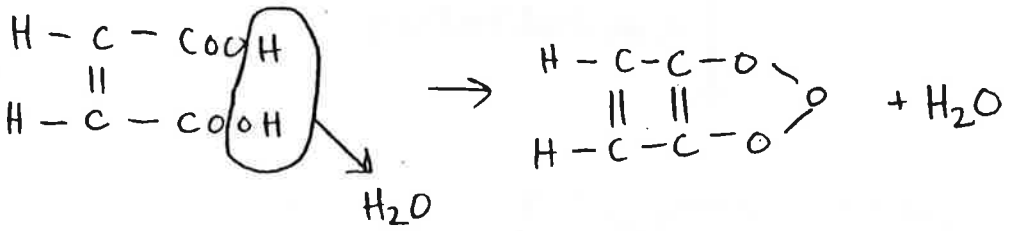


Figure 61.3 - Maleic Acid

Understand complicated compounds in terms of molecular structure.

Our study of chemistry is complete!

What is an atom?

Discovery of the electron

William Crookes (1879)

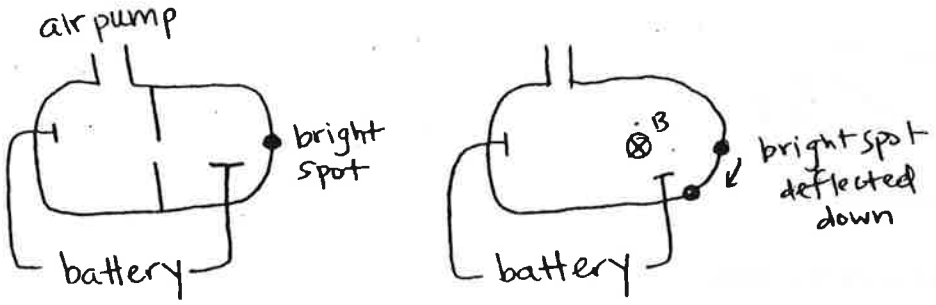


Figure 61.4 – Crookes' experiment

Bright spot deflected down = evidence that he's seeing negatively charged particles.

Notes for Class 62

Discovery of the Electron

J.J. Thompson (1897)

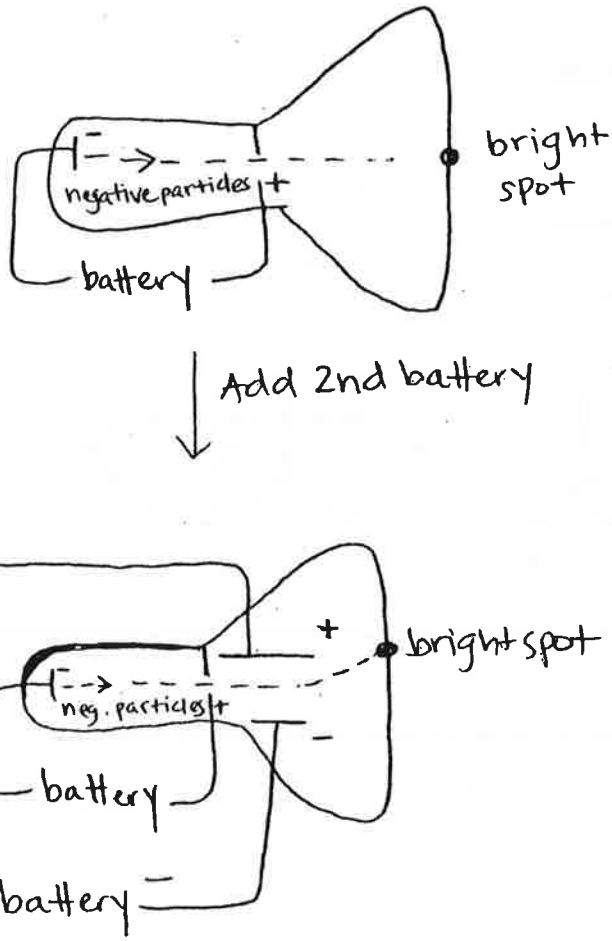


Figure 62.1 – Thompson's experiment

What's happening between the plates?

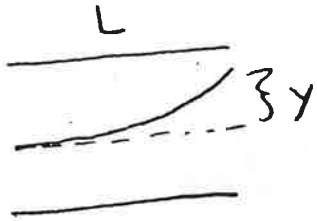


Figure 62.2 – Between the plates

Recall Galileo's Law of Freefall:

$h = \frac{1}{2} gt^2$

$y = \frac{1}{2} at^2$

v = speed of negative particles

$t = L/v$

$y = \frac{1}{2} a(L/v)^2$

$y = \frac{1}{2} a(L^2/v^2)$

Newton's 2nd Law: $F = ma = qE$

$a = qE/m$

$y = \frac{1}{2} (qE/m)(L^2/v^2)$

$q/m = (2yv^{2)}/(EL^2)$

now: charge is in terms of things that can be measured, except v. how will he determine v?

$F = qE + qvB$

Arrange magnets to cancel out the force of the E field, such that no deflection occurs.

No deflection at $F = 0$.

So: $F = qE + qvB = 0.$

$E = vB$

$v = E/B$

$q/m = 2yE/L^2B^2$

$q/m = 1.76 \times 10^{11}$ coulombs/kg

Notes for Class 63

Discovery of the electron (1897)

$q/m = 2yE/L^2B^2$

$q/m = 1.76 \times 10^{11}$ coulombs/kg

$q/m = 10^{15}$ "balloon sparks"/g

Robert Millikan (1909)

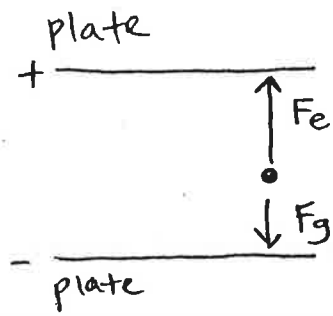


Figure 63.1 – Loitering electron

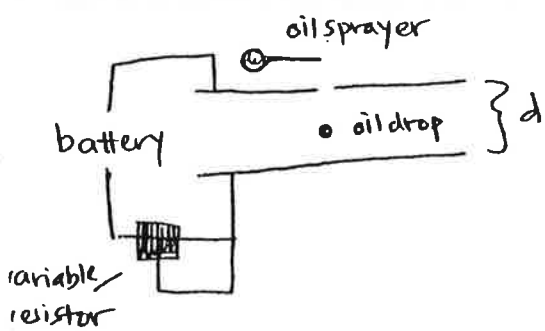


Figure 63.2 – Millikan's Experiment

$F_e = F_g$

$qE=F_g$

$q(V/d) = mg$ (V = voltage)

$q = (dg/V)m$

$m= 4/3\pi r^3\rho$ (ρ = mass density g/cm^3)

$q = n(1.6 \times 10^{-19}$ coulombs)

Notes for Class 64

Electrons

Charge of an electron = 1.6×10^{-19} coulombs

Mass of an electron = 9.1×10^{-31} kg

Revisiting Faraday's Electrolysis Experiment

current = 1.12 amps
time = 1 day
mass Na = 23 g

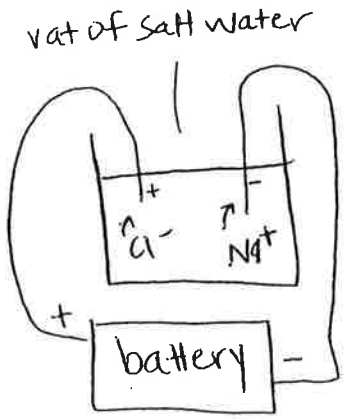


Figure 64.1

Atmospheric Electricity and Lightning

Earth is an electric battery

Earth's surface is negatively charged

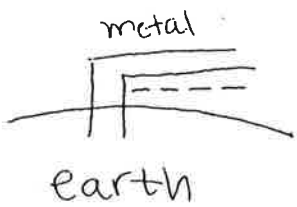


Figure 64.2

Earth's atmosphere is positively charged.

Total current flowing from atmosphere down to ground = 1800 amps.

Notes for Class 65

Atmospheric Electricity

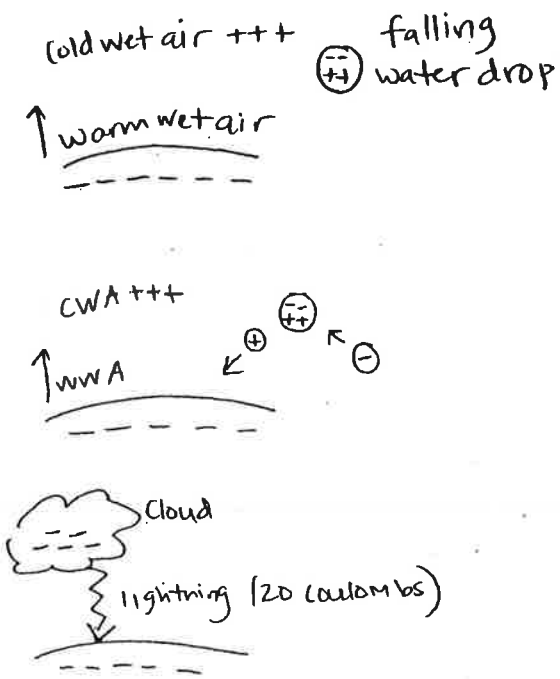


Figure 65.1 Lightning

Discovery of the Atomic Nucleus

Antoine Becquerel (1896)

Notes for Class 66

Discovery of the Atomic Nucleus

Review

Becquerel: uranium spontaneously emits something

Pierre and Marie Curie (1898): other elements also emit something (Polonium, Radium, Thorium)

Ernest Rutherford

"that's the last potato I'll ever dig"

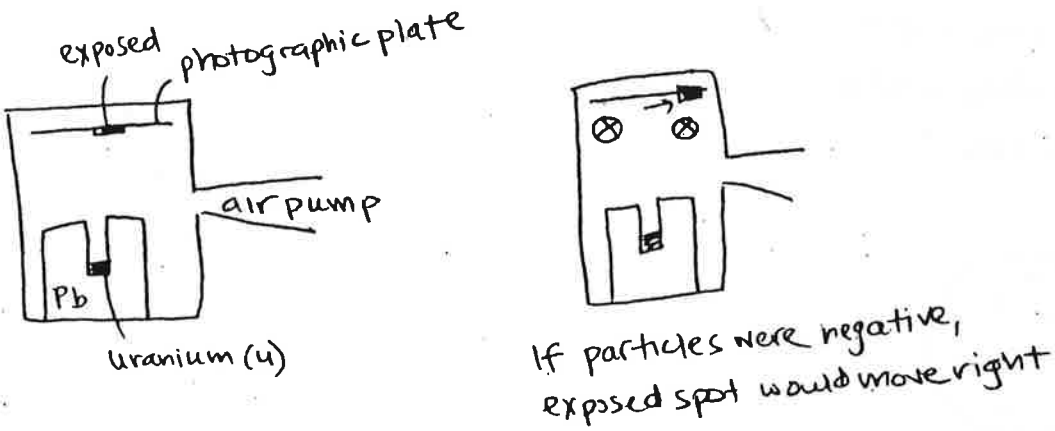


Figure 66.1 - Experiment 1 Setup

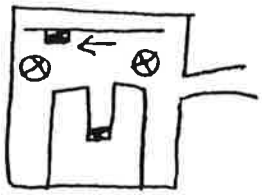


Figure 66.2 – Experiment 1 Result: Particles are positive

discovers that Uranium emits positive particles (alpha particles).

Experiment 2:

Thompson's mass/ratio experiment, but this time with α particles rather than electrons

$(q/m)_{\alpha} = (q/m)_{electron}\ (1/3672)$

Experiment 3:

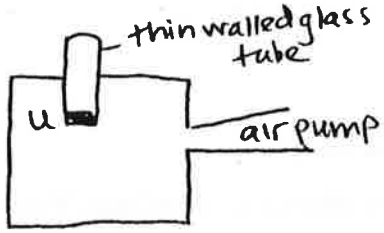


Figure 66.3 – Experiment 3

Container fills with Helium.

How does the mass of an α compare to that of an e?

$(q/m)_\alpha = (e/m)_e\,(1/3672)$

$(2e/m)_\alpha = (e/m)_e\,(1/3672)$

$m_\alpha = 2(3672)m_e$

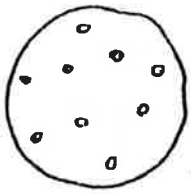


Figure 66.4 - Thompson's atomic model (raisin muffin)

Notes for Class 67

Discovery of the Atomic Nucleus (cont'd)

Ernest Rutherford tests Thompson's model.

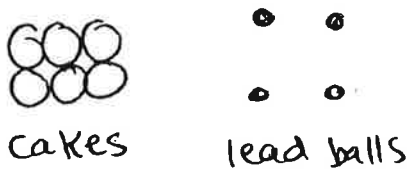


Figure 67.1 – Mr. Harriman's analogy

Experiment 4

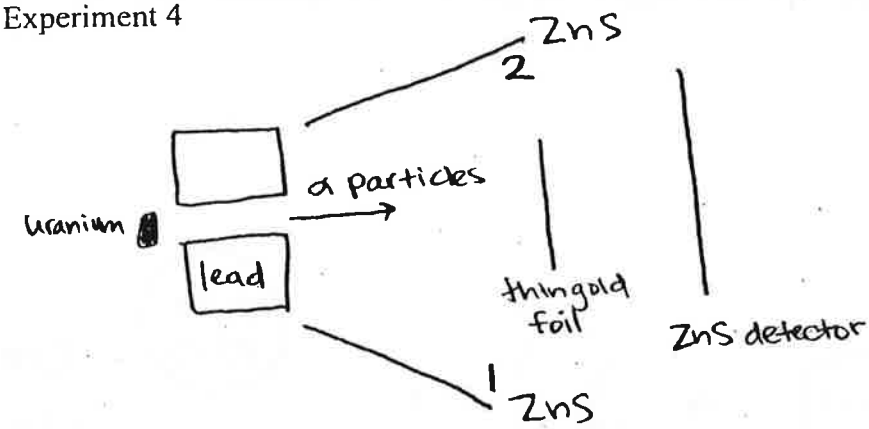


Figure 67.2 - Shoot α particles at gold foil.

Thompson's model is wrong.

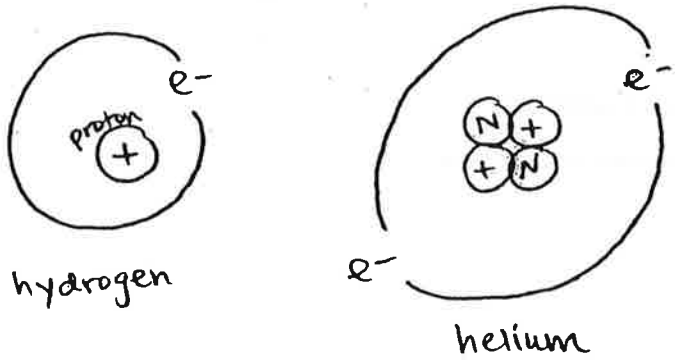
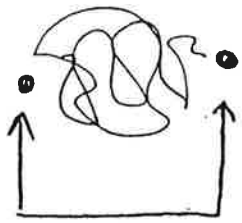


Figure 67.3 - Solar system model

Problems with big atoms

Uranium: 92 protons

143 neutrons



e^- repulsion > nuclear attraction

Figure 67.4 - Uranium

Unstable nucleus: protons "want to fly off"; force of repulsion > force of attraction.

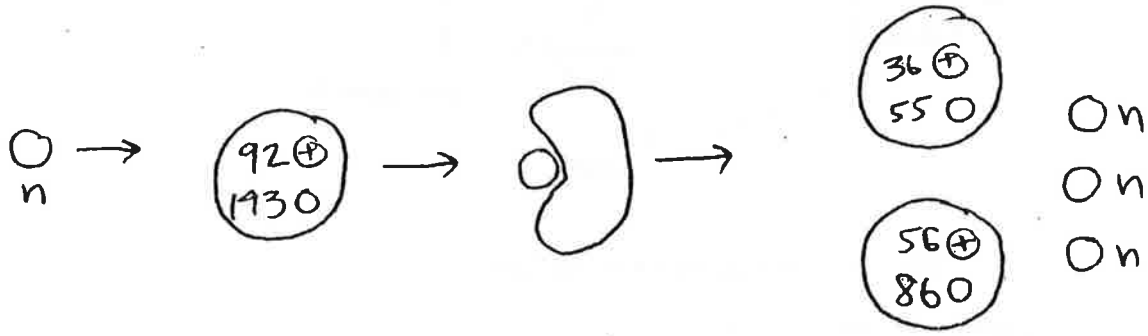


Figure 67.5 – Fission of uranium

releases energy (dynamite x 7 million)

Notes for Class 68

Nuclear Bombs

(see Figure 67.5)

Chemical reactions: combine atoms

Nuclear reactions: change the nucleus

break nucleus apart (fission)

combine two nuclei (fusion)

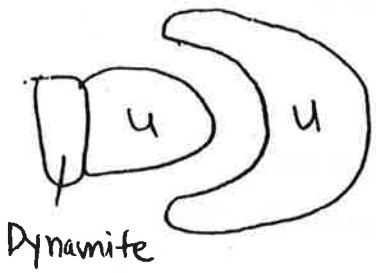


Figure 68.1 – Nuclear bomb schematic

Two types of Uranium:

U235 (1%)

U238 (99%)

Sun as "huge nuclear fusion explosion"

Notes for Class 68 & 69

Harriman's Top Ten List: Great Discoveries in the History of Physics

1. Thales: Natural Science (600 BC)
2. Aristarchus: Size and distance of moon (280 BC)
3. Archimedes: Application of math to the physical world (240 BC)
4. Galileo: Law of Pendulum Motion (1604)
5. Newton: Universal Gravitation (1666)
   "single greatest insight in all the history of science"
6. Newton: The mathematics of colors (1669)
7. Galvani and Volta: Electric current (1800)
8. Faraday: Relationship between electricity and motion (1831)
9. Maxwell: Relationship between electromagnetism and light (1864)
10. Rutherford: The structure of the atom (1910)