EMR = perpendicular electric and magnetic feilds

$v = c = 3.0 \times 10^8\ m/s$

$v = f\lambda \rightarrow c = f\lambda$. c is constant for all EMR

All EMR has accelerating charges, which cause the feilds to form
↳ different sources

PARTICLE
- Straight lines
- Travels through vaccuum
- Reflection

WAVE
- Diffraction
- Non-sharp shadows
- Wavelets
- Refraction (incident = refr + refl)
- Double slit experiment

Evidence of wave-particle duality (both are true)

Maxwell's predictions
- EMR is produced when a charge accelerates
- Frequency of charge moving = wave frequency
- All EMR travels at c, the speed of light
- Electric and magnetic components are perpendicular to each other as well as the direction of travel
- EMR follows all wave equations ($c = f\lambda$, etc)

Hertz proved these by switching the direction of an circuit (AC). This created a EMR wave, and used the hand rules to determine that the two components are perpendicular

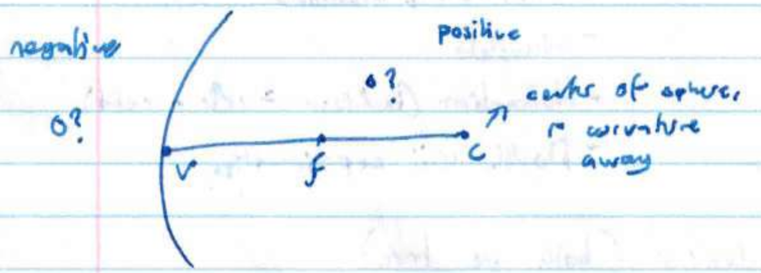
- He also created a standing wave by using a reflection, which allowed him to measure λ and c

Speed of light

- Galileo: two people turning on lamps a known distance apart
- Rømer: calculating the delay between two planets at different distances from the earth
- Fizeau-Focault: Spinning mirror. If the spinning mirror's frequency aligned with the (known) distance and speed, the light would always be visible
  - ↳ First accurate measure
  - ↳ Michaelson: 8-sided mirror turning

Reflection

- Incident = Reflected (regular surface)
- Flat mirrors create virtual images



- Rays coming in parallel to the mirror go through the focus (and ⇄)
- Rays going through the center go through the center

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

Focal point is halfway between vertex and center

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$m > 1$ enlarged
$0 < m < 1$ diminished
$m < 0$ inverted

Refraction

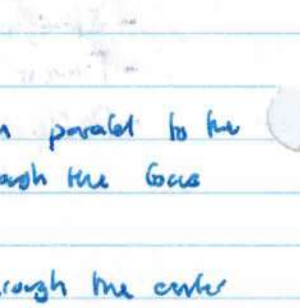
Snell's law

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1} = \frac{\lambda_1}{\lambda_2} = \frac{V_1}{V_2}$$

n is refraction index

refraction can change the color of light bc λ can change (f stays constant)

↳ $n_{air} = 1$
$V_{air} = c$



Prisms

Critical angle = angle where the angle of refraction is 90°
(light ray is trapped)
- → changes with different media
- → If incident angle > critical angle, the ray will reflect
  - → fibre - optic cable

Different wavelengths refract at different angles
- → shorter wavelengths refract more
- → the prism effect

Lenses

Use refraction to diver light rays
- → Diverging and converging lenses
- → Real images on other side of the lens, virtual on same side

Lensmaker's equation $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Diffraction

- Waves are made of many point sources which have concentric waves protruding from each point
- Diffraction: curving of light around openings (because of wavelets)
- Supports wave theory

- Double slit → interference caused by diffraction (creates orders of bright lines)

Small angles : $\lambda = \frac{xd}{nL}$ Precise formula: $\lambda = \frac{d \cdot \sin\theta}{n}$

Diffraction grating: many small slits (more precision for measuring λ)

Polarization

Reducing an EMR wave to just one component by only letting that part thru

Quantum mechanics

- Blackbody: body that absorbs all EMR (emits as blackbody radiation)
- Difference between intensity and frequency of blackbodies
  → Cannot be explained by classical physics

- Planck: minimum amount of energy (per f) can be transferred by EMR
  $E = hf$ (h = planck's constant) (smallest piece = quantum)

→ energy is quantized, not continuous (particle model)(light particle = photon)

- Photoelectric effect: photons can knock electrons off of metal plates
  → elastic collision where photon is destroyed
  → threshold frequency (f_0): smallest frequency that causes the effect
  → energy needed to "snap off" e^- = work function (different for each metal)
  → $E = hf$ → $W = hf_0$
  → Threshold λ instead of f: convert using c = speed of light
  → Photoelectric effect can be used to ~~detect~~ create a current
  → $E_{k\,max}$ (electron) = q (elementary) · V_{stop} (voltage needed to stop current)
  → Photoelectric formula: $hf = E_{k\,max} + W = E_{k\,max} + hf_0$
  → Energy-frequency graph: y-int = work function, x-int = threshold f, slope = planck's constant

Compton

- Momentum of photons: $p = \frac{h}{\lambda} = \frac{hf}{c}$
- X-rays scatter electrons when they hit metals (compton effect)(momentum)
- $\Delta\lambda$ (x-ray) $= \frac{h}{mc}(1 - \cos\theta)$

De Broglie

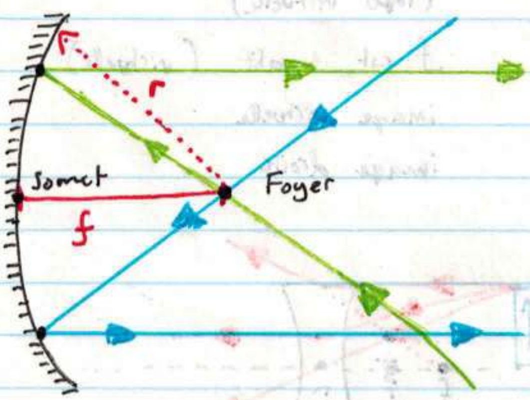
- Combined wave and particle formulae
- $\lambda = \frac{h}{mv}$ (De Broglie wavelength of a moving particle)
- Turn "solid" calculations into λ, f

13.4.1 Diagrammes de rayons [miroirs]

Image virtuelle + image de laquelle les rayons semblent provenir

Image réel - image de laquelle les rayons proviennent
↳ Peut être formé sur un écran

$m = h_i / h_o$ (m = grossissement, h_i = hauteur de l'image, h_o de l'objet)
↳ Orientation - inversé ou droite
↳ Magnification négatif = changement d'orientation

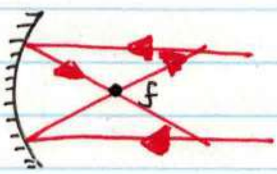


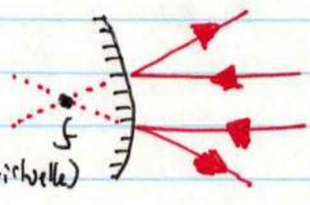
f = distance focale

r = rayon de courbure

Miroir Convergente

Miroir divergente





f est positif (avant)

image réel créé

image est inversé
(hauteur négatif)

f est négatif (arrière)

image virtuelle créé

image droite
(hauteur positif)

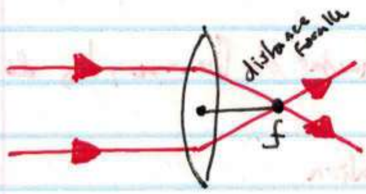
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad \text{(les lentilles minces)}$$

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \quad \text{(les lentilles minces)}$$

Les diagrammes de rayons [lentilles]

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}, \quad m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Lentille convergente



Lentille divergente

(foyer virtuelle)

f est positif (réel)

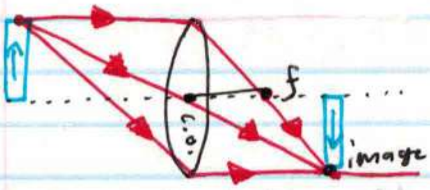
image réel

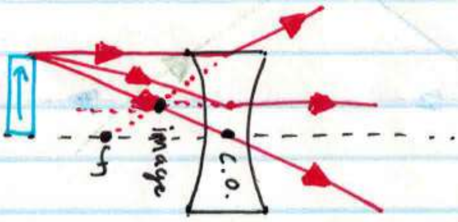
image inversé

f est negatif (virtuelle)

image virtuelle

image droite



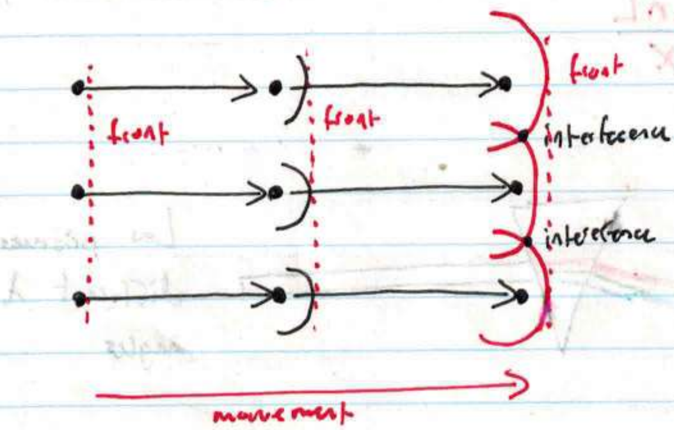


Diffraction et interference

Ventre - point d'interaction entre ces ondes [positif / constructif]

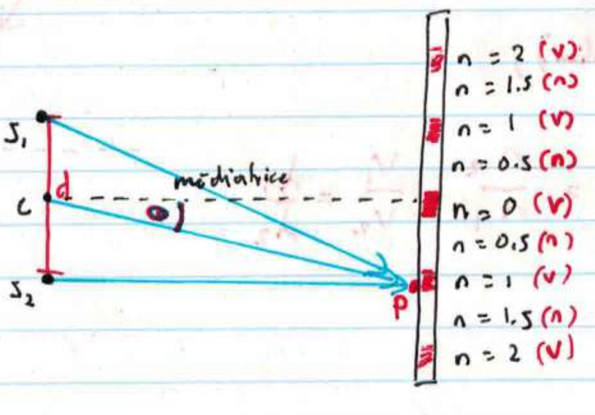
Noeud - point d'interaction entre ces ondes [negatif / destructif]

Principe de Huygens



Quand une onde se propage, les ondettes (ondes secondaires) se propagent d'une manière concentrique. Ils peuvent interferer avec eux-mêmes.

Experience de Young

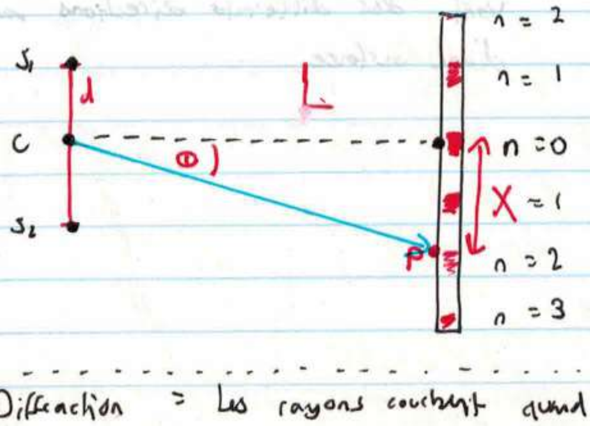


Quand il y a de l'interference constructif, une lumière forte est projeté sur l'écran (destructif = pas de lumière)

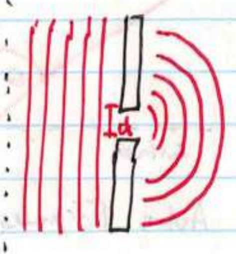
$$\lambda = \frac{d \cdot \sin(\Theta)}{n}$$

$n - \frac{1}{2}$ si destructif

→ Approximation



$$\lambda \doteq \frac{Xd}{nL}$$

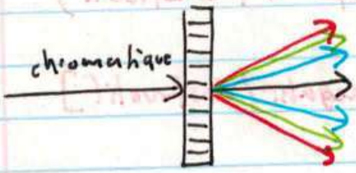


Plus fort
d est pr
a λ

Ceci est causé par le principe de Huygens

Diffraction = Les rayons courbent quand ils passent par un trou

Réseau de diffraction



Une reseau de diffraction comprend une surface avec beaucoup de lignes parallelles espaces egalement (comme young, mais plus de trous)

$$\lambda = \frac{Xd}{nL} \rightarrow d = \frac{\lambda n L}{X}$$

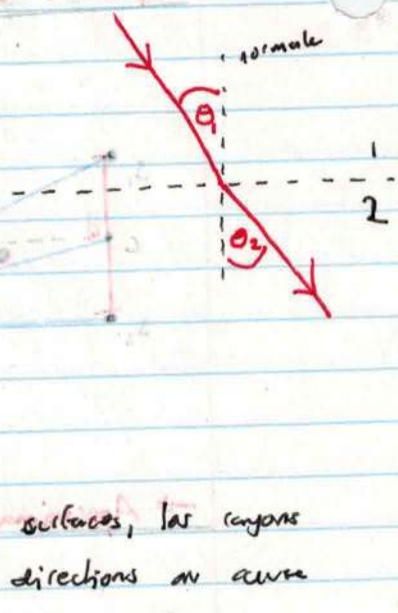
Prismes (réfraction)

Les prismes refractent les different λ a differentes angles

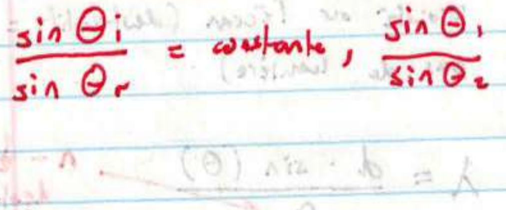
Réfraction

$n = \frac{c}{V}$ (n = indice de refraction),

$$\frac{\sin\Theta_i}{\sin\Theta_r} = \text{constante}, \quad \frac{\sin\Theta_1}{\sin\Theta_2} = \frac{n_2}{n_1} = \frac{V_1}{V_2} = \frac{\lambda_1}{\lambda_2}$$



Reflexion



$\Theta_i = \Theta_r$

Sur presque toute les surfaces, les rayons vont des differents directions au cause d'une surface

Autre Formules

$f = \frac{c}{\lambda}$ → vitesse de la lumière

Mechanique Quantique

Corps noir - une corps celeste qui absorbe toute energie electromagnetique qui entre en contacte

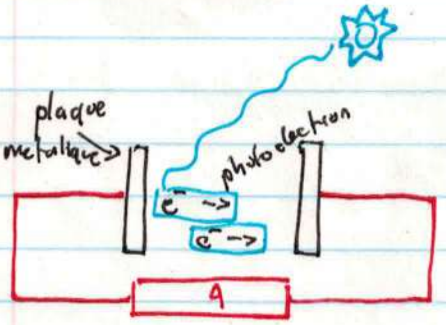
Quantum - plus petit quantité d'energie que possede une rayonnement d'une λ donné

↳ photon - un quantum de REM (particule lumière)

Loi de Planck : $E = nhf$

(E = energie, n = 1, 2, 3 etc, h = constante de planck, f = frequence)

Effet photoelectrique



Une rayonnement d'haut - intensité peut causer les electrons de separer d'une metal

Seuil de frequence : le plus petit frequence une onde peut avoir pour inciter l'effet

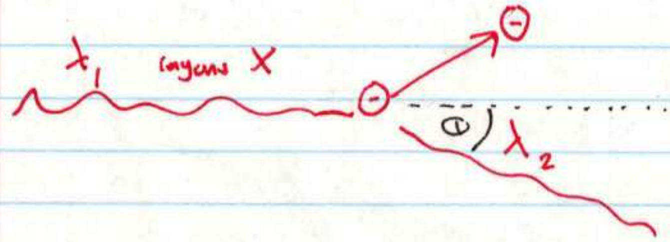
↳ Energie d'ionisation = energie minimale

$E = hf = E_c + W$ (travail) -> $E_{c\,max} = qV$ (charge, voltage)

Effet Compton

Diffusion Compton : diffusion de rayons X par des electrons

Effet compton : Variation de λ des rayons X diffusés



$p = \frac{h}{\lambda}$ (quantité de movement des rayons X)

$\Delta\lambda = \lambda_f - \lambda_i = \frac{h}{mc}(1 - \cos\theta)$

⚠ Quantité de movement applique

θ = angle de diffusion

De Broglie Hypothesis

$\lambda = \frac{h}{p} = \frac{h}{mv}$ pour les electrons ?

Principe de Heisenberg

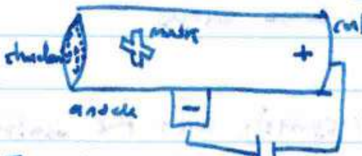
$\Delta x \Delta p = \frac{h}{2}$ → On ne peut pas savoir la quantité de mouvement et la position d'une photon

---

On peut representer le REM comme particule et/ou une onde

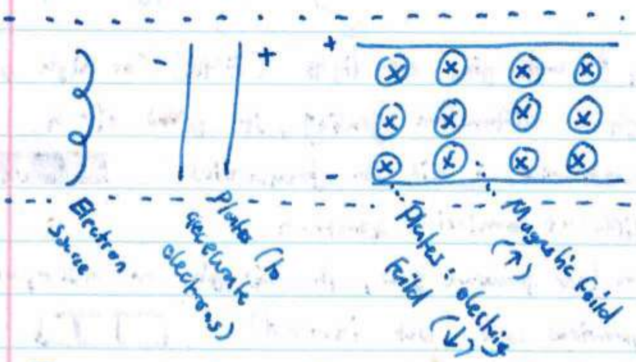
Atomic physics

- 1803: John Dalton proposed that everything is made of atoms
  - ↳ Used to explain chemistry
  - ↳ Solid sphere model: atoms cannot be subdivided
- Late 1800s: cathode rays showed that negatively charged particles were going from the cathode to the anode (if a high voltage was applied)
  - ↳ Cathode ~~[illegible]~~ ray tube:



→ Metal tube would gain a negative charge (proved 1895)

- J. J. Thompson cathode ray experiments
  - ↳ Proved that cathode rays were made up of negative charges
  - ↳ Showed that cathode rays could be deflected by magnetic fields
  - ↳ Charge to mass ratio: used a special CRT



If the magnetic and electric fields were equal, the electron would ~~not~~ move up or down

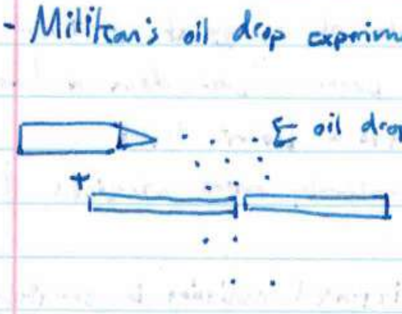
$F_e = F_m \rightarrow v = \vec{E}/B$

→ where v is speed of electron

$\frac{q}{m} = \frac{E}{B^2 r}$ → very high, because electrons have lots of charge

- Thompson's plum pudding model: Small, negatively charged [electrons] floating in a clump of positively charged material

- Militkan's oil drop experiment: measuring the fundamental charge



→ Some of the oil drops would fall through the hole in the positive plate and enter $\vec{E}$

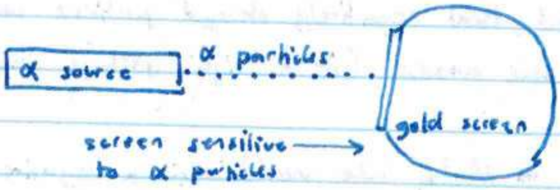
→ They would usually accelerate to the negative plate if charged positively (as per usual)

→ However, if they were charged negatively, they might enter a situation where $F_g = F_e$

→ Derived to $q = mgd/V$

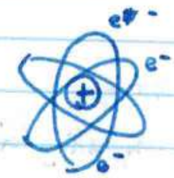
→ The experiment showed all q was a multiple of one charge: 1.6×10^{-9} C

- Alpha particles (α^{2+}) (He^{2+}) are released by some radioactive materials
  - ↳ These particles move at high speeds (2.5×10^7 m/s)
- Gold foil experiment: alpha particles scatter when they pass through gold foil. The scatter at different frequencies at different angles



  - → If thompson's model was correct, there would be minimal scattering.
  - → However, some of the particles scatter at large angles

- Rutherford's planetary model: accounts for the irregularity with the scattering



  - → α^{2+} might get repelled by e^- at the exterior
  - → However, it wasn't compatible with Maxwell's EMR theory
    - → The electrons aren't creating EMR. (which they should be if accelerating)

Because electrons change energy level

- Spectroscopy: if a gas is heated, it will give off light (EMR) (or high voltage)
  - ↳ If this light goes through a diffraction grating, it gives off a discrete spectrum (not continuous): discrete frequencies 
  - ↳ Every element has a different emission spectrum
  - ↳ If light shines through a low pressure gas, it will give an absorption spectrum (same as the previous one, but inverted) 
- Balmer's formula: $\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$
  - ↳ λ = wavelength, R_H = Rydberg's hydrogen constant, n_f and n_i = energy level
  - ↳ Thus: electrons have energy levels: amounts of energy at particular positions
  - ↳ EMR is released when an electron looses power (goes down a level)
  - ↳ EMR is absorbed when an electron gains a power level
  - ↳ When an electron goes down many power levels, more energized UV radiation is emmitted
  - ↳ When it goes down less, less energized infrared radiation is emmitted
  - ↳ Rutherford figured out the radius of H ($n=1$) and the energy to ionize hydrogen
  - ↳ $r_n = n^2 r_1$ where r is radius and n is power level
  - ↳ $E_n = \frac{1}{n^2}E_1$ where E is energy and n is power level
  - ↳ Can be used with $E = \frac{hc}{\lambda}$ and $E = hf$

- Bohr's model still couldn't explain all of the experimental data
  - ↳ Why don't electrons emit EMR in their energy levels
  - ↳ Only works for hydrogen.
  - ↳ Brightness and spacing of emission lines
- Bohr's model could be joined with quantum mechanics: de Broglie's equations
  - ↳ Electrons can be thought of like waves where λ is a multiple of the circumference (r dependent, which is n dependent)
    - ↳ If not a multiple, the waves would add together (destruction)
  - ↳ Electrons = standing waves
  - ↳ Because it's not accelerating, EMR theory doesn't apply
  - ↳ Quantum model explains all elements: more protons in core → more force on electron → smaller radius → different λ

- The nucleus of an atom can determine its properties.
  - ↳ Made up of protons (atomic number Z) and neutrons (neutron number N)
  - ↳ Protons have a charge of +e, neutrons have a charge of 0
  - ↳ Each element has a specific number of protons and neutrons ($^{A}_{Z}X$)
    - ↳ Elements can have multiple numbers of neutrons (isotopes)
  - ↳ The number of neutrons controls how stable an atom is.
  - ↳ The neutron is held together by the strong nuclear force
    - ↳ Counteracts the electrostatic force (p^+ and p^+)
    - ↳ Only acts over very small distances
  - ↳ Binding energy: Energy it takes to separate the nucleons so that the strong nuclear force doesn't apply
    - ↳ Equation: $E = mc^2$ (energy in Joules)
    - ↳ Separate nucleons have more mass than ones that are together
    - ↳ The difference between the mass of the nucleus and its components is the mass defect (Δm)

- Atomic mass can be measured using the atomic mass unit (u)
  - ↳ 1 u = 1/12 the mass of C-12

- Some (radioactive) elements emit EMR under all conditions
  - ↳ This radiation comes from the nucleus
  - ↳ IF the nucleus is unstable, it will decay into a stable nucleus
  - ↳ This can even change the element (transmutation)
- Earnest Rutherford found three types of radioactive decay
  - ↳ Alpha (α): deflected as positive in a magnetic feild (weak)
  - ↳ Beta (β): deflected as negative particle in a magnetic feild (stronger)
  - ↳ Gamma (γ): not deflected in a magnetic feild (very strong)
- Conservation of nucleons: the number of nucleons stays the same during decay

- Alpha radiation: 2 protons and 2 neutrons leave the nucleus (α^{2+})
  - ↳ The same as a helium nucleus ($^{4}_{2}He$)
  - ↳ ex. $^{168}_{77}Ir \rightarrow {}^{4}_{2}\alpha + {}^{164}_{75}Re$ ....› $^{164}_{75}Re$ = daughter particle
  - ↳ The change in mass (products - reactants) is released as energy ($E = mc^2$)
    - ↳ Mostly kinetic energy of the atoms
- Beta radiation^{-}: A neutron becomes a neutron and electron (negative decay)
  - ↳ proton stays in the nucleus, electron ($^{0}_{-1}\beta$) leaves the atom
  - ↳ neutrons are just electrons and protons stuck together)
  - ↳ $^{46}_{20}Ca \rightarrow {}^{0}_{-1}\beta + {}^{46}_{21}Sc + \bar{v}$
    - ↳ $\bar{v}$ is a neutral antineutrino (used for conservation of momentum)
- Beta radiation^{+}: The antimatter equivalent of negative beta decay (β^{+})
  - ↳ Antineutron → positron + antielectron + neutrino
  - ↳ ex. $^{40}_{19}K \rightarrow {}^{0}_{1}\beta + {}^{40}_{18}Ar + v$
- Inverse beta decay: proton-rich nucleus absorbs inner electron
  - ↳ $p^{+} + e^{-} \rightarrow n^{0} + v$
  - ↳ ex. $^{83}_{37}Rb + {}^{0}_{-1}e \rightarrow {}^{83}_{36}Kr + v$
- Gamma decay: releasing energy in form of EMR (no particles)
  - ↳ A gamma burst is produced if the atom needs to let off energy

- IF the daughter nucleus is unstable, a decay series can happen
  - ↳ ex. $^{236}_{90}Th \rightarrow {}^{222}_{88}Ra \rightarrow {}^{222}_{89}Ac \rightarrow {}^{218}_{87}Fr \rightarrow {}^{214}_{85}At$

- Radiation is a health risk because it can cause genetic damage and ionize cells
  - ↳ Gamma is the most dangerous, then Beta, then alpha

~~Electrochemistry~~ Half-lives

- The half-life of an element is the amount of time it takes for half of the element to transmute into something else
  - ↳ Half-lives can range from 10^{28} s (10^{21} years) to 10^{-22} s
- The activity of a smaple measures the decays / per second
  - ↳ Measured in Becquerels (Bq) = decay/s
  - ↳ This changes as the sample gets older

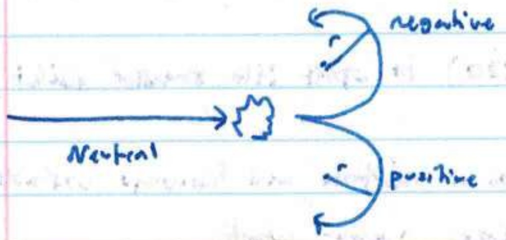
Half-life formula: $N = N_0 \left(\frac{1}{2}\right)^n$ where n is the number of half-lifes

- Fission: causing a large nucleus (A > 120) to split into smaller nuclei
  - ↳ This releases energy
  - ↳ Can start when a nucleus absorbs a neutron and becomes unstable
  - ↳ Used in nuclear reactors, produces nuclear waste
- Fusion: causing smaller nuclei to stick together into a large nucleus
  - ↳ This releases energy
  - ↳ Makes safe by-products (unlike fission)

- Critical nuclear reaction: where every reaction causes the same reaction <u>once</u>
  - ↳ This is because neutrons are reactants and products
- Supercritical: when every reaction causes the same reaction multiple times
  - ↳ If more (2x) neutrons are produced than consumed
  - ↳ This is the reaction behind atomic bombs and nuclear meltdowns
- Subcritical: The reaction will eventually die out
  - ↳ If less neutrons are produced than consumed
- Nuclear reactors use moderators to slow down the reaction (so the chain can happen) and heavy water so that no neutrons get absorbed

- Proton-proton chain: H and H combine to form He and γ radiation
  - ↳ This is the reaction that takes place in our sun
  - ↳ It is hard to replicate on earth due to the high pressures and temperature
  - ↳ Uncontrolled fusion is used in thermonuclear bombs
  - ↳ We can perform fusion, but not when $E_{in} > E_{out}$

- Cloud chamber: a chamber supersaturated with water vapor
  - ↳ Charged particles can ionize some of the water
  - ↳ The path of the particle could be observed this way
- Bubble chamber: a chamber with liquefied gas at low pressure
  - ↳ Same concept: path is visible (due to gas-state gas)
- Chambers are often use with electric and magnetic fields
- Chambers can't detect neutral particles
- When particles follow circular tracks, we can use $F_m = F_c$



- We can use the third hand rule to determine which particle is positive and negative
- The charges have to add up to 0

- Antimatter: same as matter, but charges are reversed (e^+, p^-, $\bar{n}$, $\bar{\nu}$)
  - ↳ When antimatter and matter collide, they annihilate and produce energy
  - ↳ Energy produced is defined by $E = mc^2$
  - ↳ $e^- + e^+ \rightarrow 2\gamma$

- It turns out that there are many fundamental particles (particle zoo) (categories:
  - ↳ Leptons: don't interact with the strong nuclear force (half-integer spins)
  - ↳ Hadrons: Interact with the strong nuclear force
    - ↳ Mesons: integer spins (bosons)
    - ↳ Baryon: half-integer spins (fermions)
  - ↳ Spin: Quality of particles (similar to momentum)
  - ↳ Mass unit: MeV/c^2 (from $E = mc^2$)

- Quarks: sub-atomic particles with fractional charges (/3)
  - ↳ Every particle is made of (3) quarks that add up to its charge
  - ↳ Up $= 2/3\,e$, down $= -1/3\,e$, ~~strange = -1/3e, charm~~
  - ↳ Conservation of (fractional) charge is still applied w/ quarks
  - ↳ Negative beta decay: down quark → up quark
  - ↳ Positive beta decay: up quark → down quark