Topic 7 Atomic, nuclear & particle physics

7.1 Descrete energy and radioactivity

IB physicsnotes.wordpress.com

Date

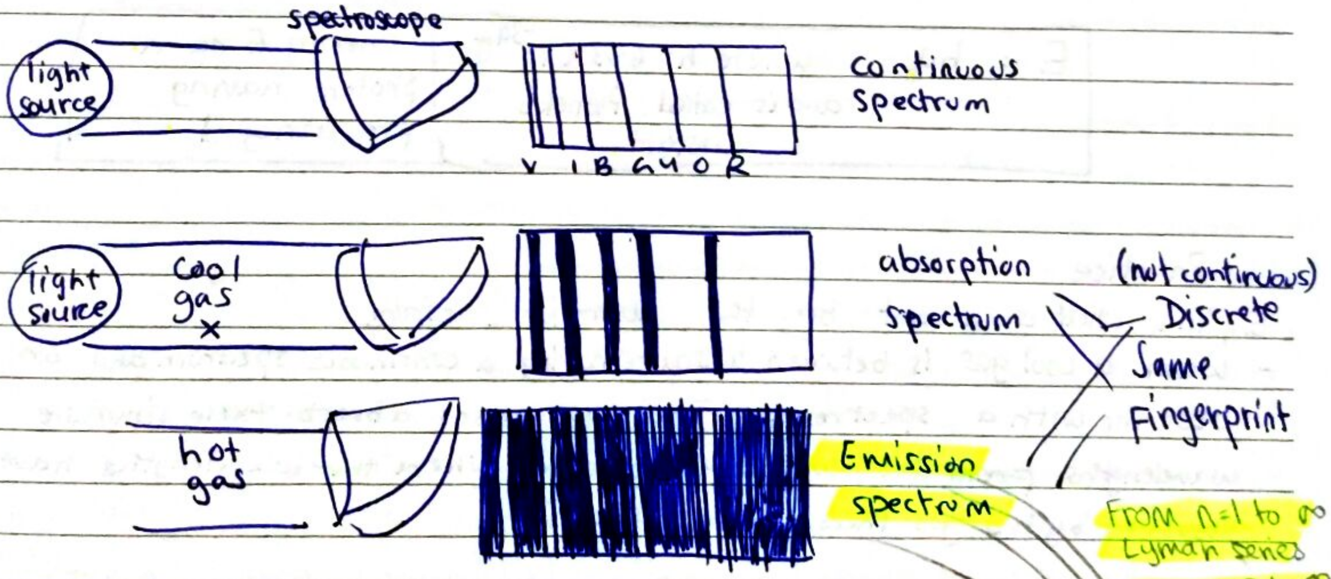
1) Discrete energy and discrete energy levels

- Electron of an atom can occupy certain discrete atomic energy levels.
- As electron jumps from one energy level to other, energy is absorbed or released. The energy is equal to the difference between the discrete atomic energy levels and is also quantized.
- Energy of a photon is dependent on its frequency. Therefore, only photons with frequencies which correspond to the differences between the atomic energy levels can be absorbed or released by an ~~atom~~ electron. These frequencies appear as spectral lines in the emission and absorption spectra.

  (Presentation)
- When a gas ~~is~~ in a tube and is subjected to a voltage, the gas ionizes, and emits light. Like tubelight
- If a photon of right energy strikes an atom, the electron jumps to a new energy level - "Excited" E.g. From 1 to 3.

  We can analyze the light by looking through spectroscope.

  Each element also has an absorption spectrum.



Transitions between energy levels

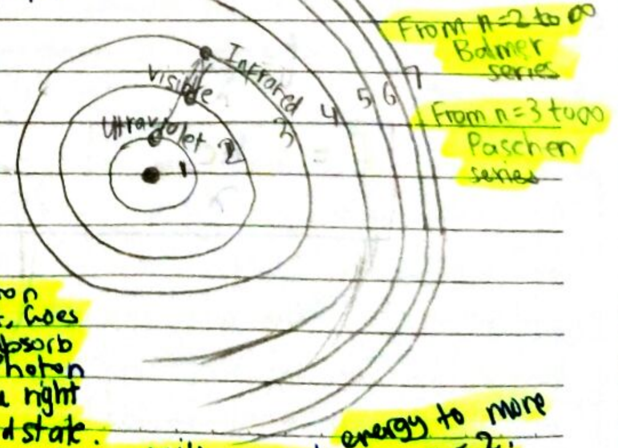
Principle quantum number (n) From 1 to ∞

Lyman series UV light

Balmer series Visible light

Electron unexcited → n = 1 first energy level

Paschen series Infrared radiation



Hydrogen's single electron could occupy many different energy levels, as shown.

Then photon strikes it. Goes to n=3. Absorb energy. Photon had just the right energy. Excited state.

De-excited when it emits a photon with enough energy to move to n = 2.

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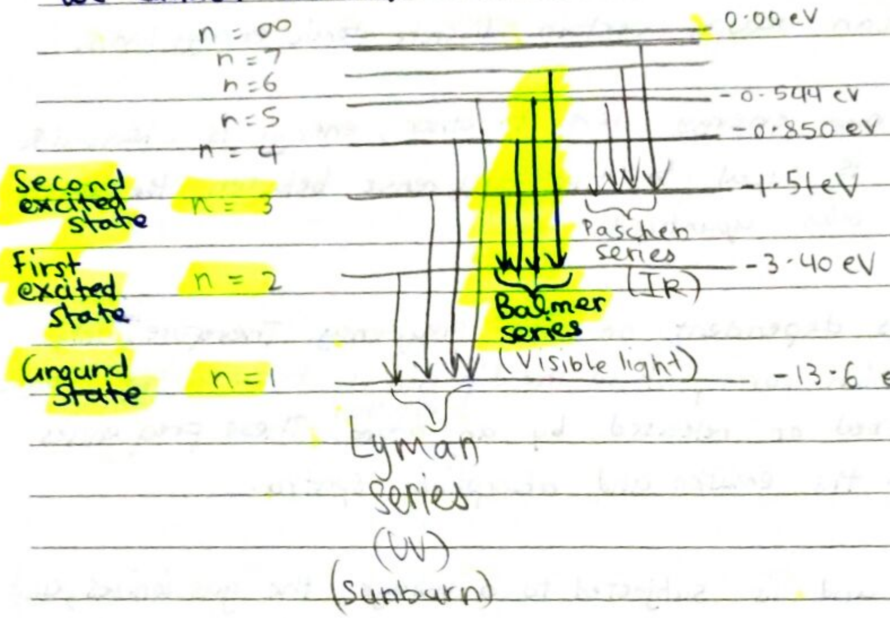
From an principal quantum number to a higher one, energy absorbed. Vice-versa.
The human eye is only sensitive to the Balmer series of photon energies (or wavelengths).
We cannot see any other series.



Because of wave-particle duality, we have discovered that light not only acts as a wave, having a wavelength λ and frequency f, but it acts like a particle (called a photon) having an energy E given by

$E = hf$ where $h = 6.63 \times 10^{-34}$ Js and is called Planck's constant.	energy E of a photon having frequency f

Practice

Explain what is meant by the absorption spectrum.

- When a cool gas is between a source having a continuous spectrum and an observer with a spectroscope. The cool gases absorb their signature wavelengths from the continuous spectrum. Where the wavelengths have been absorbed by the gas there will be black lines.

$$f = \frac{c}{\lambda}$$

$E = \frac{hc}{\lambda}$	energy E of a photon having wavelength λ

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Isotopes

Mass spectrometer is where an atom is stripped of its electrons and accelerated through a voltage into a magnetic field.

Charge of a hydrogen nucleus is e. Makes sense!

Scientists discovered hydrogen had 3 different masses. They postulated neutrons, that have a neutral charge, exist and add mass.

Nucleons:
- Proton. Charge = 1e or +1
- Neutron Charge = 0e or 0

Isotopes - a set of nuclei for a single element having different numbers of neutrons are called isotopes.

A particular isotope of a nuclide is called species or a nuclide.

Isotopes of an element have same chemical properties because an electron's chemistry is determined by electrons which determine on protons. Not neutrons

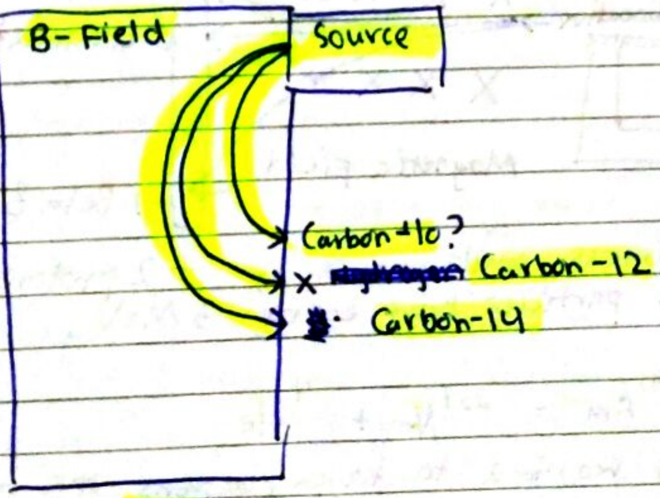
$A = Z + N$	Nucleon relationship

Nucleon number A
Proton number Z
Neutron number N

$^{1}_{1}H$ Hydrogen $^{2}_{1}H$ Deuterium $^{3}_{1}H$ Tritium

Radius is higher when mass is higher.

$R = R_0 A^{\frac{1}{3}}$



Nucleus diameter = 10^{-15} m

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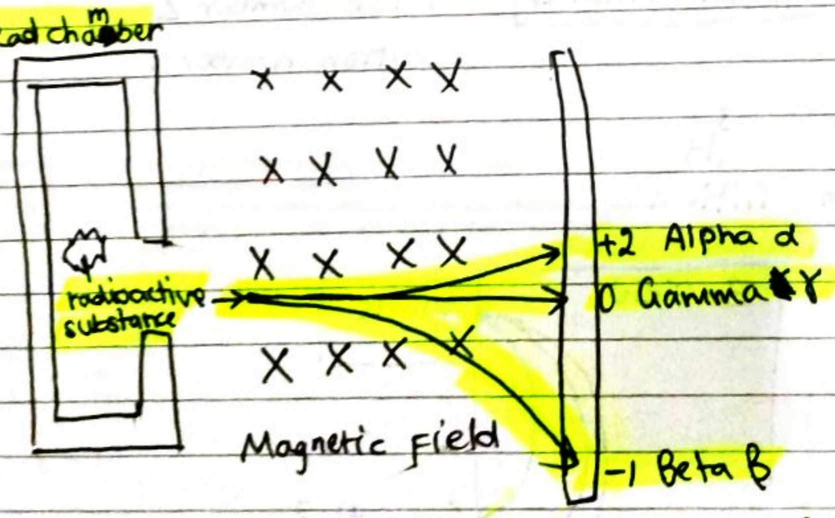
Coulomb force is repulsive. But, strong force overcomes the Coulomb force.

So, strong force must be very strong.

	Strong force	Electromagnetic force	Weak force	Gravitational force
	Nuclear force	Light, heat & charge	Radioactivity	~~Gr~~ Free fall
	Strongest	→	→	Weakest
Range:	~~Extr~~ Very short	∞	Short	∞
Force carrier:	Gluon	Photon (Bosons)	~~Photon~~ Bosons W^+ W^- Z^0	Graviton

Radioactivity



When a nucleus emits an α, −2 protons & neutrons.
All alpha particles have energy 5 MeV.

$$^{241}Am = {}^{237}Np + {}^{4}He$$

Since, energy required to knock electrons off atoms is just about 10eV, one α can ionize a lot of atoms

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In β decay, a neutron becomes a proton and an electron is emitted.

$^{14}_{6}C \rightarrow ^{14}_{7}N + \bar{\nu} + ^{0}_{-1}e^{-}$, β^- Beta minus decay

$^{10}_{6}C \rightarrow ^{10}_{5}B + \nu + ^{0}_{1}e^{+}$, β^+ Beta plus decay

β particle is either electron or anti-electron (positron).

In contrast to α particles, β particles can have a variety of kinetic energies.

To conserve energy, another particle called a neutrino ν was created to carry the additional E_k needed to balance the energy.

β^+ produces ν (neutrino)

β^- produces $\bar{\nu}$ (antineutrino)

Electrons moving from an excited to a de-excited state release a photon.

~~When a nucle~~

Nuclei can also have excited states.

When a nucleus de-excites, it also release a photon. γ gamma decay.

$^{234}Pu^{*} \rightarrow ^{234}Pu + \gamma$

(⇝)

Penetration

- α, +2, relatively heavy, few cm of air, paper
- β, -1, smaller & lighter, few m in air, few mm in aluminium.
- γ, uncharged, high energy, few cm in lead, very long distance in air.
- ν, neutrinos, miles of lead.

Radiation causes damage by ionization in the living cells. All 3 particles energize atoms in living tissue to the point that they lose electrons & become ionized.

Background radiation is ionizing radiation that we are exposed to, including natural and artificial sources. Radon, CT scans

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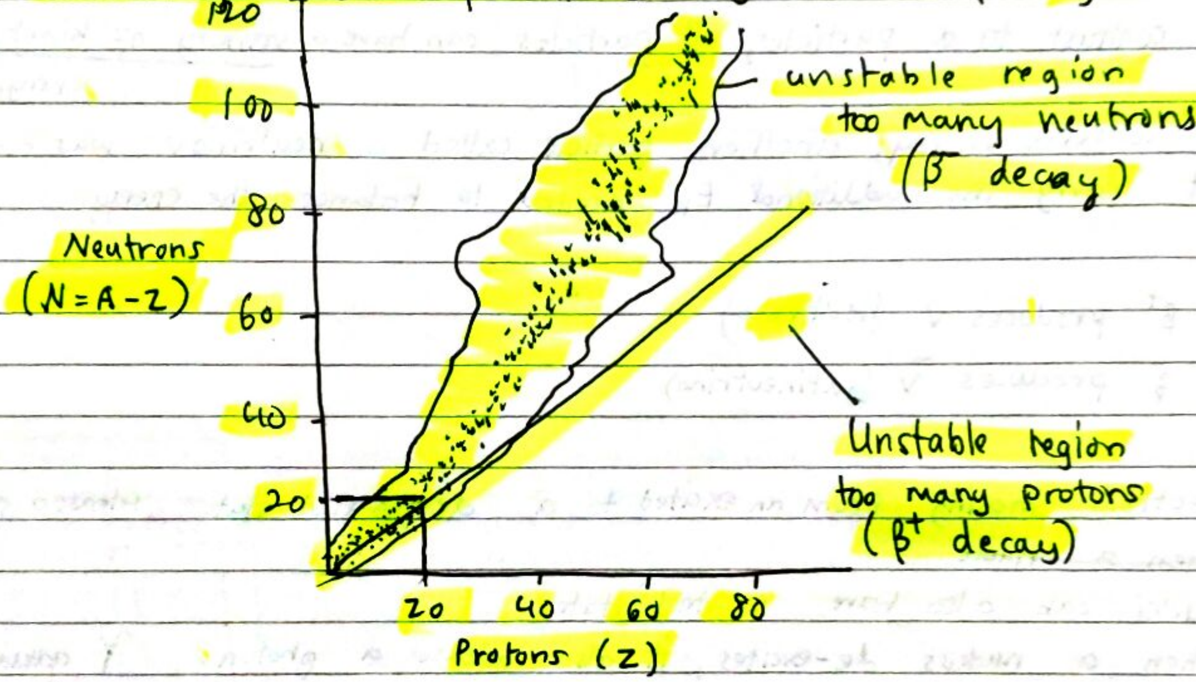
Radioactive decay

- Stable isotopes are for elements ~~have~~ with atomic numbers Z = 1 to 83.

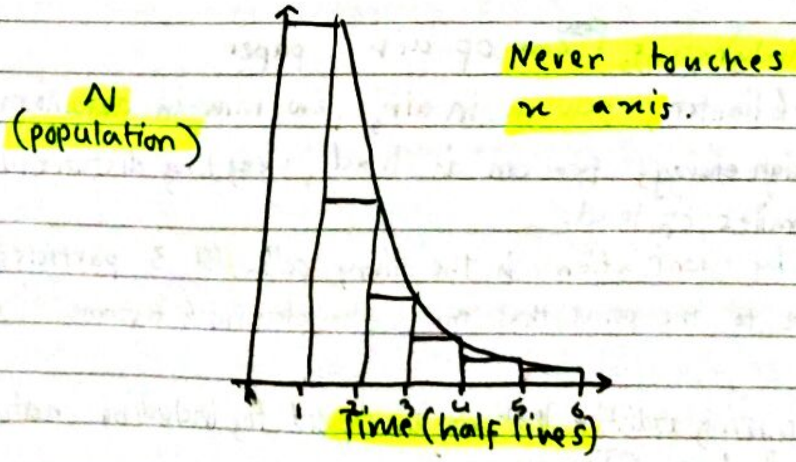
Up to Z=20, neutron-to-proton ratio is 1. Then, it gets bigger and grows with atomic number.

Extra neutrons counteract the repulsive Coulomb force between protons by increasing the strong force but not contributing to coulomb force. Unstable region has isotopes with too many neutrons (β^- decay).



Decay process is random.

- Half-life - the time is takes for ~~a sample~~ half the total number of nuclei initially to decay. OR time it takes for the initial activity in a sample to half.



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Rather than measuring no. of nuclides left, we measure activity or decay rate.

Mostly using Geiger-Muller counter.

1 Bacquerels (Bq) = $\frac{1 \text{ decay}}{\text{second}}$ = 1 decay/sec	Bacquerel definition

Decay rate or activity A is proportional to population of radioactive nuclide N_0 in the sample.

$A \propto N_0$	Activity A

So, if population halves, Activity will half.

E.g. Activity decreases from X Bq to $\frac{X}{16}$ Bq in 80 minutes. What is the half-life of the substance?

$$N_0 \xrightarrow{(1)} \frac{1}{2} N_0 \xrightarrow{(2)} \frac{1}{4} N_0 \xrightarrow{(3)} \frac{1}{8} N_0 \xrightarrow{(4)} \frac{1}{16} N_0$$

4 half lives = 80 min

t_{half} = 20 min

Many examples in presentation.

7.2 Nuclear reactions

Unified Atomic Mass unit (u) is a standard unit of mass that quantifies mass on an atomic or molecular scale (atomic mass). One u is mass of 1 nucleon (either a single proton or neutron) and is equivalent to 1 g/mol. OR It is defined as one twelfth of the mass of carbon-12 atom in its ground state and is used to express masses of atomic particles. OR $\frac{1}{12}$ of the mass of one neutral atom of $^{12}_{6}C$.

$1u = 1.661 \times 10^{-27}$ kg $= 931.5 \text{ MeV} c^{-2}$	Unified atomic mass unit

E.g. 25.32 g of anything into AMU?

25.32×10^{-3} : ?

1.661×10^{-27} : 1u

$$\frac{25.32 \times 10^{-3}}{1.661 \times 10^{-27}} = ?$$

$= 1.524 \times 10^{25}$ u

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Mass defect and nuclear binding energy

$E = mc^2$ or $\Delta E = \Delta mc^2$ | Mass - energy equivalence

It means mass & energy are interchangeable.

1 mass of anything is? (If converted completely into energy)
$1 \times 9 \times 10^{16} = 9.00 \times 10^{16}$ Joules. ~~But, we can't~~

~~1 Meg~~ 1 Megaton TNT = 4.18400×10^{15} joules.

(Δm) Mass defect = difference in mass of reactants and products.

1) Find mass of reactants.
2) Find mass of products.
3) Find difference in mass.

E.g.

Particle	Mass (u)
Electron	0.000548
Proton	1.00727
^1H atom	1.007825
Neutron	1.008665
^4He atom	4.002603

Find mass defect in the following nuclear reaction:

$2(^1H) + 2n \rightarrow {}^4He$

Reactants

$2(1.007825) + 2(1.008665) = 4.03298$

Product

4.002603

~~$\Delta m = 4.03298 - 4.002603 = 0.030377\,u$~~

$\Delta m = 4.002603 - 4.03298 = -0.030377\ u$

$-0.030377 \times 1.661 \times 10^{-27} = -5.04562 \times 10^{-29}$ kg

$= -5.046 \times 10^{-29}$ kg.

So, the product has less mass than the reactants here.

- Binding energy E_b of a nucleus is the amount of work or energy that must be expended to pull it apart.

So, in previous example, the product was 5.046×10^{-29} kg lighter. We need to provide enough energy to make the additional mass of the constituents.

$E = 5.046 \times 10^{-29} \times 9.00 \times 10^{16} = 4.54 \times 10^{-12}$ J is the binding energy

So, ~~to~~ pull apart the ^4He to its constituents, 4.54×10^{-12} J are needed to create that extra mass and is thus the binding energy.

Date

$^4He + 4.54 \times 10^{-12} J \rightarrow 2(^1H) + 2n$

∴ ~~Du~~ Disassembling ^4He will require energy.

Reverse process yields the same energy:

$2(^1H) + 2n \rightarrow {}^4He + 4.54 \times 10^{-12} J$

∴ Assembling ^4He will release energy.

E.g. Radium-226, natural radioactive decay, emission of an alpha particle to form radon (Rn). Calculate released energy in joules.

Radium : 226.0254 u
Radon : 222.0176 u
α particle : 4.0026 u

$^{226}Ra \rightarrow {}^{222}Rn + {}^4\alpha$

Reactant: 226.0254u ~~× 1.661 ×~~

Product: 222.0176 + 4.0026u = 226.0202u

$\Delta m = 226.0202 - 226.0254 = -0.0052$

~~0.002~~ $-0.0052 \times 1.661 \times 10^{-27} = -8.6372 \times 10^{-30}$ kg

$\Delta E = (8.6372 \times 10^{-30})(9.0 \times 10^{16})$
$= 7.77 \times 10^{-13} J$

- Binding energy per nucleon of a nucleus is binding energy E_b divided by the number of nucleons A. E_b/A

E.g. Binding energy per nucleon of ^4He?

$E_b = 4.54 \times 10^{-12} J$

$\frac{4.54 \times 10^{-12}}{4} = 1.135 \times 10^{-12}$ J/nucleon

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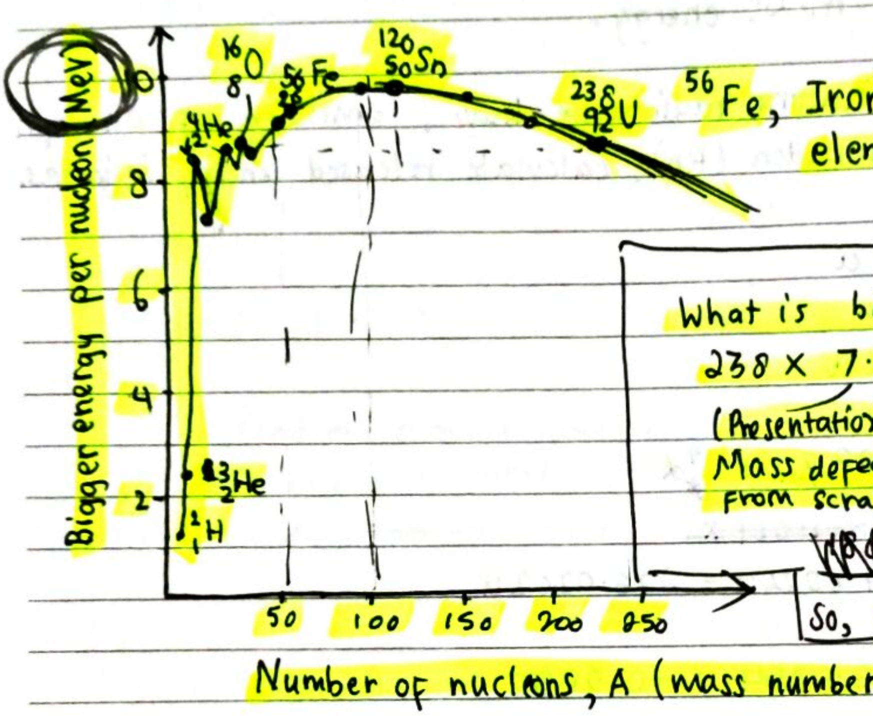
- Instead of looking at total binding energy of nuclei, we usually look at binding energy per nucleon.

- Bigger the binding energy per nucleon, the more stable the nucleus.
  - The bigger the binding energy per nucleon, the less likely a nucleus will be to want to lose one of its electrons. Thus, more stable, by definition.



^{56}Fe, Iron-56 is the most stable element.

What is binding energy of Uranium-238?

238×7.6 MeV $=$ 1800 MeV.

(Presentation)

Mass defect of uranium if assembled from scratch?

1.661×10^{-27} kg $= 931.5$ MeVc^{-2}

So, $\frac{1800\text{ MeV}}{c^2} = \Delta m$

1800 MeV$c^{-2} = \Delta m$

$\frac{1800}{931.5} \times 1.661 \times 10^{-27} = \Delta m$

Mass defect $= 3.21 \times 10^{-27}$ kg

Example

^{54}Fe has a mass of 53.9396 u. A proton (with electron) has a mass of 1.00782 u and a neutron has a mass of 1.00866 u.

a) Find the ~~binding energy~~ mass defect of iron-54 in MeVc^{-2}.

^{54}Fe: $A = 54$, $Z = 26$, $N = 28$

Reactants:

$26(1.00782) + 28(1.00866\text{ u})$

$26.20332 + 28.24248$

$= 54.4458$ u

Product:

53.9396 u

$\Delta m = 54.4458\text{ u} - 53.9396\text{ u} = 0.5062$ u

~~$0.5062 \times 1.661 \times 10^{-27} = 8.408 \times 10^{-28}$~~

~~$E = 8.408 \times 10^{-28} \times 9.00 \times 10^{16}$~~

~~$E = 7.57 \times 10^{16}$ J~~

~~or $\frac{7.57 \times 10^{16}}{1.661 \times 10^{-27}} \times 931.5 = 4.24 \times 10^{35}$ MeV~~

$E = mc^2$

MeV $= mc^2$

$\frac{\text{MeV}}{c^2} = m$, $0.5062 \times 931.5 = 471.5$ MeVc^{-2}

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b) Find the binding energy per nucleon of iron-54.

$$\frac{471.5}{54} = 8.7 \text{ MeV/nucleon}$$

. This is consistent with graph.

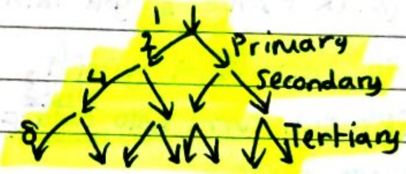
The c^{-2} is cancelled, ($E = mc^2$).

Nuclear fission and nuclear fusion

- Nuclear fission is the splitting of a large nucleus into 2 smaller (daughter) nuclei.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow \left(^{236}_{92}U^{*}\right) \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\left(^{1}_{0}n\right)$$

Triggered by a single neutron, two neutrons released. These neutrons will split other nuclei. So, we have a chain reaction.



Exponential growth

- Nuclear fusion is the combining of 2 smaller nuclei into one large nucleus.

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

To do this, you must overcome the repulsive Coulomb force and get them close enough together that the strong force takes over.
Stars use their immense gravitational force to overcome the Coulomb force.
In our fusion reactors, precise & strong magnetic fields are used to overcome the Coulomb force.

See the E_b/A graph again.

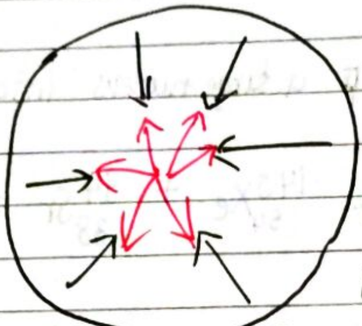
- Nuclear fusion occurs with elements below Fe because joining smaller nuclei forms bigger ones, which are higher on the graph. (thus more stable).
- Nuclear fission occurs with elements above Fe because splitting bigger nuclei forms smaller ones, which is higher on the table (thus more stable).

In stars:

Gravitational force squishes hydrogen nuclei together overcoming the repulsive Coulomb force.

The energy released by fusion prevents the gravitational collapse from continuing.

Gravitation and radiation pressure reach equilibrium



They balance each other.

Different elements keep evolving, and different fusions occur.

Mass keep decreasing according to $E=mc^2$.

So, new equilibrium is established between gravity & radiation pressure and the star grows!
(Makes sense if you think pressure and area)

As star evolves along fusion side of E_b/A graph, runs out of fuel and gravity wins. It shrinks. Stars like sun turns into white dwarf and slowly cool down. Gravity not strong anymore to fuse nuclei.

For more massive stars, gravity enough to fuse elements all the way up to iron in E_b/A graph.
when it is completely iron, radiation ceases. Gravity is not balanced. Star becomes smaller into a neutron star. This is called an iron catastrophe.

For even massive star, enough gravity to overcome neutron barrier to collapse. Collapse continues.
Star becomes a black hole. (extremely dense body.
Gravitational force is so strong that even light cannot escape it!)

We cannot see it directly.

7.3 The Structure of Matter

Date

An elementary particle has no internal structure.

Three divisions of elementary particles:

Force carriers

Particles that allow compatible particles to sense and react to each other's presence through exchange of these carriers.

4 Force Carriers

- Strong: 1.0, arbitrary value for comparison. Strongest of all interactions
- Electromagnetic: 0.01, 10^{-2}
- Weak: 0.000001, 10^{-6}
- Gravitational: 10^{-39}

Hideki Yukawa: Theory of exchange forces

All forces are due to the exchange of particles between like elementary particles.

O $\overset{2}{\text{protons}}$ ()

The protons exchange photons & repel each other because of this exchange. (Electromagnetic)

Electromagnetic force long range because photons "live" until absorbed.

Strong force short range because ~~short~~ gluon has short life.

Exchange particles whose range of influence is limited are called virtual particles. Strong & Weak carriers. Only exist within their range of influence.

Quarks

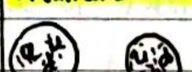
Quarks are the heavier, tightly bound particles that make up particles like (protons & neutrons, lambda, omega, delta, sigma)

Scientist proposed, all strong-force particles were made of 3 fundamental particles called quarks.

All quarks have strangeness no. 0 except strange quark (-1).

Charge	Quarks			Baryon no.
$\frac{2}{3}e$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}e$	d	s	b	$\frac{1}{3}$

Proton is uud.
Neutron is udd.



Every particle has antiparticle with same mass, but ~~different~~ opposite quantum numbers.
$\bar{p}$ (antiproton), same mass, charge = -1
Antielectron charge = +1
They have different chemical properties, so same charge is not ~~same~~ meaning antiproton is electron.

matter + antimatter → annihilation + energy

Antiquarks: $\bar{u}\,\bar{d}\,\bar{c}\,\bar{s}\,\bar{t}\,\bar{b}$

Not enough space.
Hadron, Baryons, Mesons
Conservation of Baryon no.
Conservation of strangeness
Quark confinement
Next page

Leptons

Leptons are the lighter, more loosely bound particles like electrons.

Next page after quark confinement.

Date :

Hadron, Baryons and Mesons

Hadron is a particle that participates in the strong force.

Baryon is made of 3 quarks (qqq). Antibaryon ($\bar{q}\bar{q}\bar{q}$)

Meson is made up of a quark and an antiquark ($q\bar{q}$).

Since quarks participate in strong force, and since baryons & mesons are made of quarks, baryons & mesons are hadrons.

Proton = uud ; $\frac{2}{3}+\frac{2}{3}-\frac{1}{3}=+1$, charge
Neutron = udd, $\frac{2}{3}-\frac{1}{3}-\frac{1}{3}=0$, charge

Both are hadrons.

Conservation of Baryon number

Baryon number B of a quark is $+\frac{1}{3}$. B of Antiquark is $-\frac{1}{3}$.

Quark: $B=+\frac{1}{3}$ Antiquark: $B=-\frac{1}{3}$	quark (q) or antiquark ($\bar{q}$) baryon number B

E.g. Baryon number of proton and antiproton? Baryon number of meson?

proton = uud = $+\frac{1}{3}+\frac{1}{3}+\frac{1}{3}=+1$

Anti proton = $\bar{u}\bar{u}\bar{d}$ = $-\frac{1}{3}+-\frac{1}{3}+-\frac{1}{3}=-1$

Meson = $q\bar{q}$ = $+\frac{1}{3}+-\frac{1}{3}=0$

Like charge, baryon number is conserved in all reactions.

Conservation of strangeness

Strangeness number S of a baryon is related to the number of strange quarks the particle has.

S = # antistrange quarks − # strange quarks	Strangeness S

E.g. Lambda zero particle (Λ^0) is a baryon having quark combo (uds). What is its charge? What is its strangeness?

Charge = $+\frac{2}{3}-\frac{1}{3}-\frac{1}{3}=0$

Strangeness = $0-1=-1$

E.g. When a K^- meson collides with proton, $K^- + p \rightarrow K^0 + K^+ + X$. (X: not determined.)

Particle	Quark structure
K^-	$s\bar{u}$
K^+	$u\bar{s}$
K^0	$d\bar{s}$

(a) State whether K^- particle is hadron, lepton or exchange particle?

Hadron because composed of quarks.

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b) State quark structure of the proton.

uud

c) Quark structure of particle X is sss. Show that reaction is consistent with the theory that hadrons are composed of quarks.

$$K^- + p \rightarrow K^0 + K^+ + X$$

$$s\bar{u} + uud \rightarrow d\bar{s} + u\bar{s} + X$$

$$s + ud \rightarrow d\bar{s} + u\bar{s} + X$$

$$s + d \rightarrow d\bar{s} + \bar{s} + X$$

$$s \rightarrow \bar{s} + \bar{s} + X$$

$$\bar{s} + \bar{s} + sss = s$$

So, X = sss

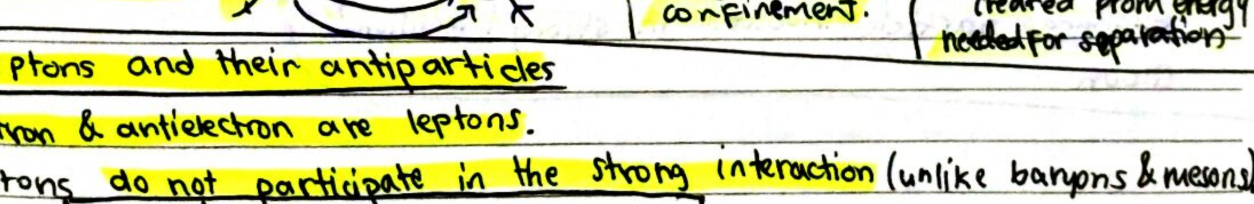
Quarks are balanced on each side. ~~and reaction can be written.~~

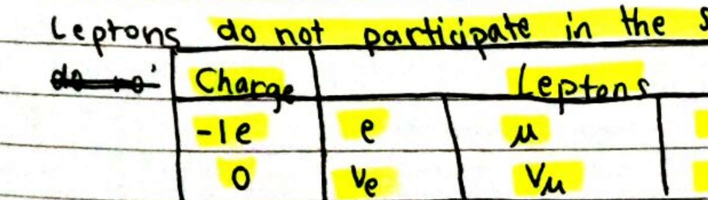
Quark Confinement

Quark confinement means we cannot ever separate a single quark from a baryon or meson.

Because of the nature of the strong force holding the quarks together, we need to provide an energy that is proportional to the separation.

Eventually, the energy is so vast that a new quark-antiquark pair forms and all we have is a meson, instead of an isolated quark.





q and q̄ structure are very different e⁻ & e⁺, leading to quark confinement.

Leptons and their antiparticles

Electron & antielectron are leptons.

Leptons do not participate in the strong interaction (unlike baryons & mesons).

Charge	Leptons		
-1e	e	μ	τ
0	ν_e	ν_μ	ν_τ

All leptons have lepton no of 1 and antileptons have lepton number of -1.

- The leptons interact only via the electromagnetic force carrier, the photon.
- leptons, unlike quarks, do not react to the gluon.
- Quarks react to both gluon and photon
- 6 leptons:

Leptons W-6			
	ν_e Elect. neutrino	ν_μ Muon neutrino	ν_τ Tau neutrino
	e electron	μ Muon	τ Tau

Lepton number

Lepton: L = +1	Lepton & antilepton number L
Antilepton: L = -1	

Lepton numbers must be conserved by generation.

Electron $L_1 = +1$
positron $L_1 = -1$
proton $L_1 = 0$
antimuon neutrino $L_{11} = -1$
electron neutrino, L = 1

Leptons have baryon no. 0.
~~Baryons have~~
Hadrons have lepton number 0.

$p \rightarrow n + e^+ + \nu_e$ Feasible
B = 1 → 1 + 0 + 0
L = 0 → 0 + −1 + +1
Charge = +1 → 0 + (+1) + 0

$n \rightarrow p + e^- + \bar{\nu}_\mu$ Not Feasible.
B: 1 → 1 + 0 + 0
L: 0 → 0 + $^{+}1_{1}$ + $^{-}1_{11}$ (L must be conserved by Family)
Charge: 0 → +1 −1 +0

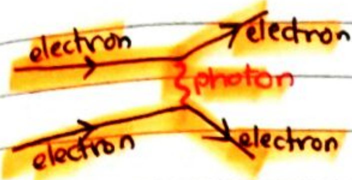
Family Lepton number

Lepton	Charge, Q	L_e	L_μ	L_τ
e^-	−e	+1	0	0
ν_e	0	+1	0	0
μ^-	−e	0	+1	0
ν_μ	0	0	+1	0
τ^-	−e	0	0	+1
ν_τ	0	0	0	+1

Practice
Exchange particle involved in strong interaction?
Gluon

Exchange particles

Why does an electron exert an electric force of repulsion on another electron?

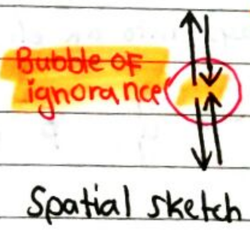


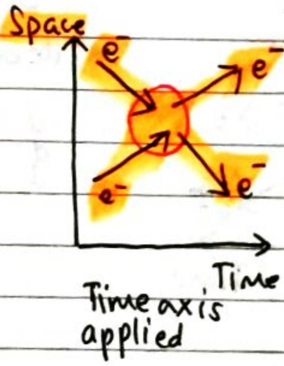
Particle physics interprets an interaction between two particles as the exchange of a particle between them. In case of electromagnetic interaction, the particle is photon. One electron emits it & one absorbs it. The emitted photon carries momentum, so the electron that emits it experiences change in ~~electron~~ momentum, ie experiences a force. Similarly, absorbing electron has momentum change and it experiences a force.

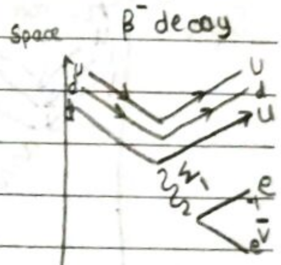
Feynman Diagrams

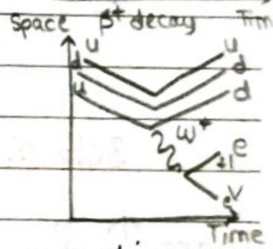
Graphic representation of particle interactions that predicts probabilities of the outcome of particle collisions.

Space & time.









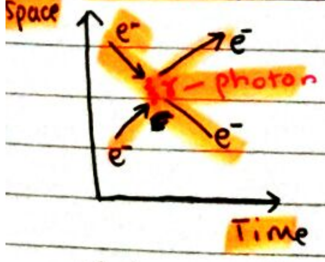
"Bubble of ignorance" is the actual place in the plot ~~where~~ that exchange particles do their thing.

Particles →

Exchange (force) particles : Photons, W^+, W^-, Z^0: ~~~~ (Electromagnetic or weak exchange)

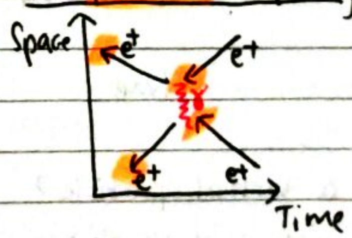
Gluons ∂∂∂∂∂ (strong exchange)

Repulsion of 2 electrons

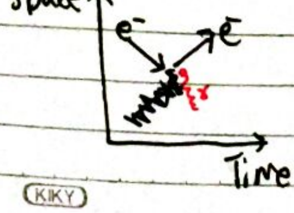


Antimatter points backwards

Two positrons repelling

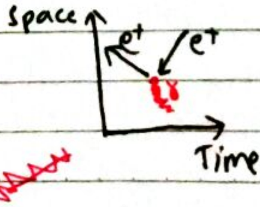


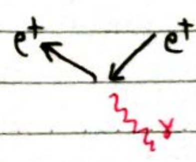
Electron emitting photon



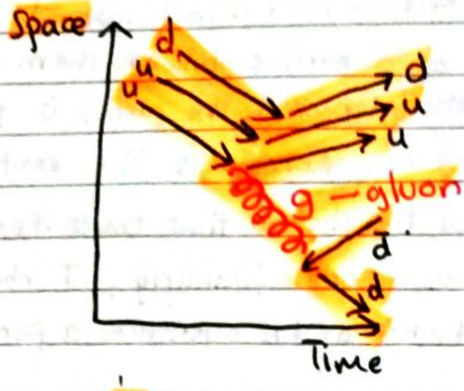
The photon direction follows electron (bad diagram)
Should be like this:

Positron emitting photon

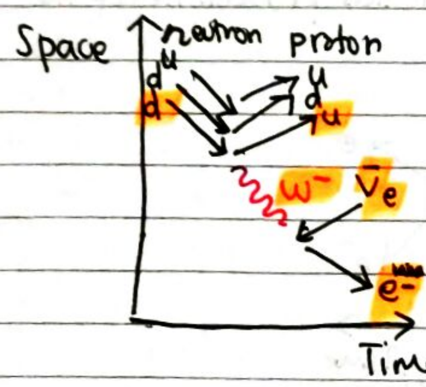




- up quark of a proton (uud) emits a gluon.
- The gluon decays into d quark and $\bar{d}$ quark.
- Quark cannot exist by themselves. So, quickly annihilate



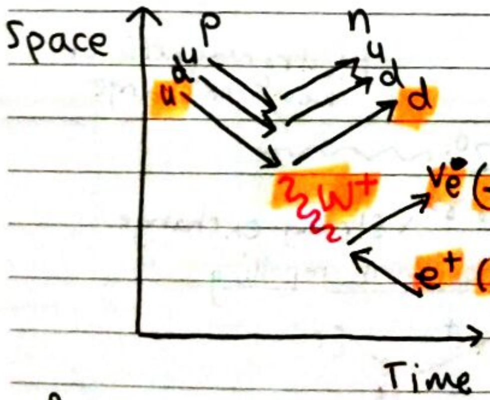
Beta minus decay



Down quark emits W^- particle that decays into an electron and anti-neutrino.

udd → uud β^- decay

Beta plus decay



It is neutrino (not antineutrino) to conserve ~~Lepton~~ Lepton number.

Practice

What is a virtual particle?

Particle with very short range of influence.

Date

The Higgs Particle

Standard Model → quarks, leptons & exchange particles

↓

Higgs particle : a neutral particle required to exist by the theory of the standard model.

~~Why do ele~~ It gives the elementary particles their mass.

The Higgs particle is responsible, through its interactions, for the mass of the particles of the standard model, in particular the masses of the W and the Z.

KIKY