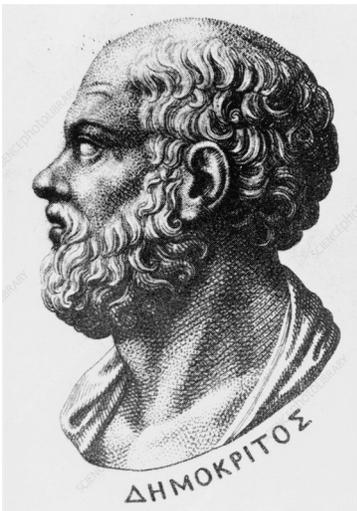


From Matter to Atoms

Democritus Theory of Matter

Democritus: Fifth Century BC (460 – 370BC)

If matter is divided into the smallest possible pieces you will eventually reach the smallest division of matter - "Atomos" – The atom





The Basic Elements

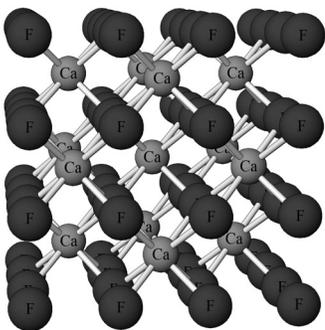
Prior to Democritus philosophers believed everything was made of Fire, Earth, Wind, Water, and Ether

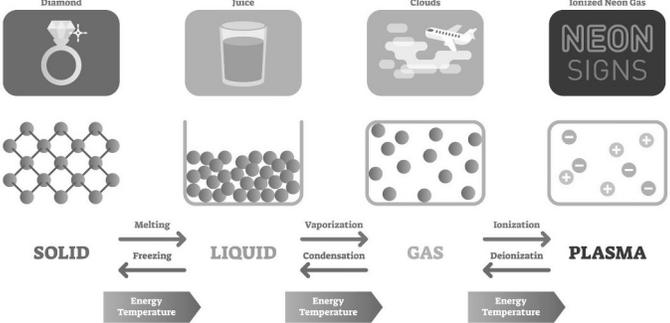
2

From Matter to Atoms

Preliminary Atomic Theories

Democritus (400BC): The Atom Greeks (200BC): States of Matter





3

From Matter to Atoms

Alchemy and The Chemical Reaction

Alchemy (1500s)

Alchemists believed gold could be **transmuted** (*changed*) from more common elements using fundamental characteristics of atomic theory.

A *chemical reaction* is a process in which atoms are changed (*rearranged*) to make new combination of atoms (*compounds and molecules*)

Alchemical Symbols

Three Principles



Sulfur Salt Mercury

The Four Elements



Fire Air Water Earth The Elements

Planets and Metals



Venus Jupiter Sun Mars Moon Mercury Saturn
Copper Tin Gold Iron Silver Quicksilver Lead

Alchemy defined the first elements / atomic symbols

4

From Matter to Atoms

Preliminary Laws of Matter

Law of Conservation of Matter

Matter is neither created or destroyed just rearranged in new ways

Law of Conservation of Mass

The physical mass of matter is constant

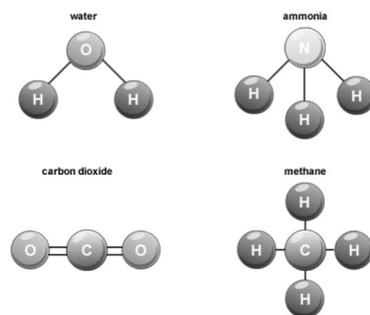
Law of Definite Composition (Proust's Law)

All combinations of atoms contain the same ratio (*by mass*) of all atoms that make up the matter

Compounds and Molecules

All combination of atoms are formed from existing atoms in definite proportions

Water is always 1 oxygen and 2 hydrogen [H₂O]



5

From Matter to Atoms

Dalton's Four Principles of the Atom

Matter and the atom is defined based on the basic principles of matter. His principles were:

First Principle of Atoms

All Matter is Made of Indivisible Atoms

Second Principle of Atoms

All Atoms of the same type have the same properties, including mass (*elements*)



John Dalton

English Chemist
1766 – 1844AD

6

From Matter to Atoms

Dalton's Four Principles of the Atom

Dalton used the scientific method in this principles and was the first to write down the basic ideas in his principles of matter

Third Principle of Atoms

Compounds and Molecules are combinations of two or atoms combined together

Fourth Principle of Atoms

A *Chemical Reaction* occurs when atoms are rearranged forming new atom combinations



John Dalton

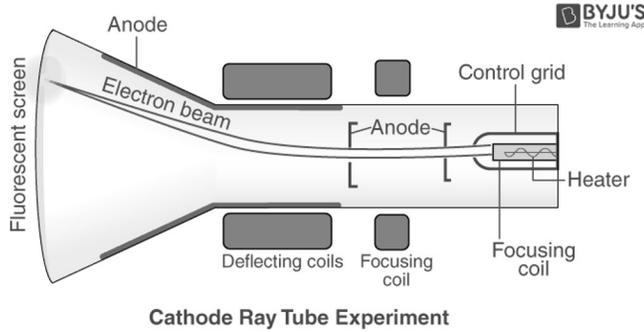
English Chemist
1766 – 1844AD

7

Subatomic Particles

Thomson's Cathode Ray Experiments

Thomson worked with Cathode "Canal" Rays in a vacuum to determine the energy and charge of e^-



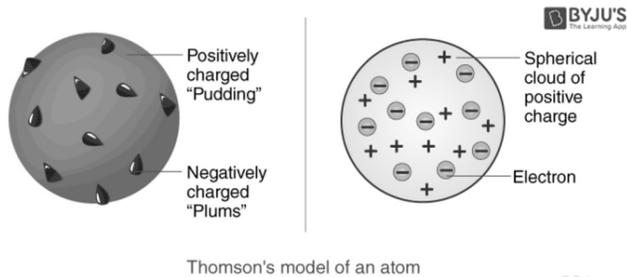
Joseph John Thomson
English Chemist
1856 - 1940AD

8

Subatomic Particles

Thomson's Plum Pudding Model

Thomson's discovery of the electron (e^-) led to the *plum pudding model*, e^- in an atom surrounded by a positive *matrix*



Joseph John Thomson
English Chemist
1856 - 1940AD

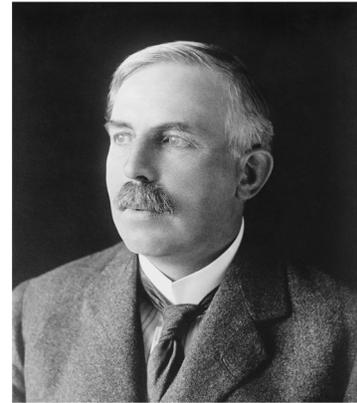
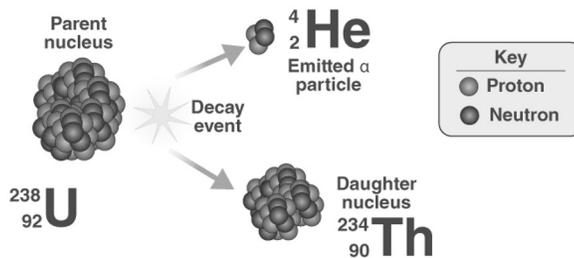
9

Subatomic Particles

Radiation and Alpha Particles

Rutherford separated nuclear radiation into three types of radiation. Alpha Decay (α), the weakest had 2 positive and 2 neutral particles

ALPHA DECAY OF URANIUM 238



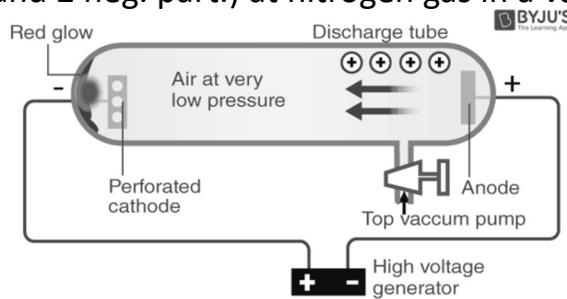
Ernest Rutherford
English Chemist
1871 - 1931AD

10

Subatomic Particles

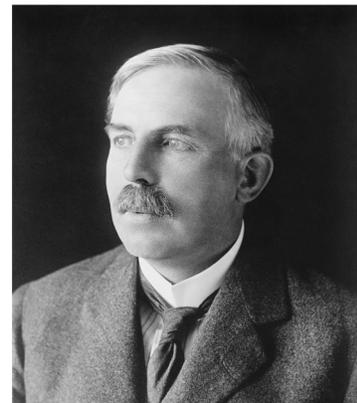
Rutherford's Nitrogen Experiment

Rutherford accelerated *shot* alpha particles (2 pos. and 2 neg. part.) at nitrogen gas in a vacuum.



Discovery of proton

The resulting particles were positive protons (p^+)



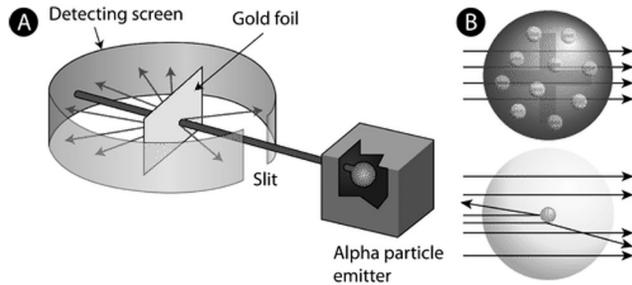
Ernest Rutherford
New Zealand Chemist
1871 - 1931AD

11

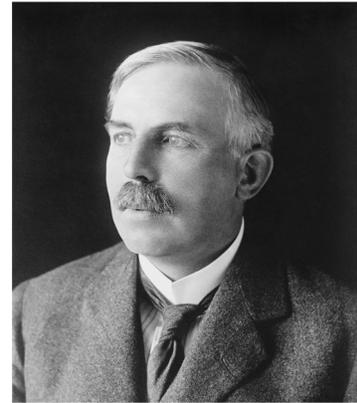
Subatomic Particles

Rutherford's Gold Foil Experiment

Rutherford accelerated *shot* alpha particles, charged helium atoms, at gold foil



The alpha particles showed the atom to be basically empty except for a nucleus in the center



**Ernest
Rutherford**

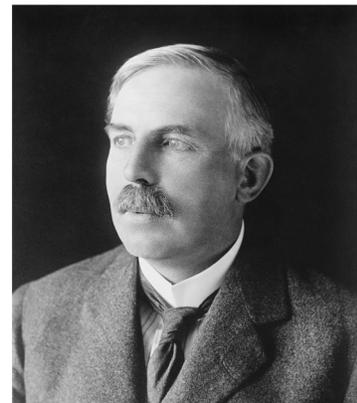
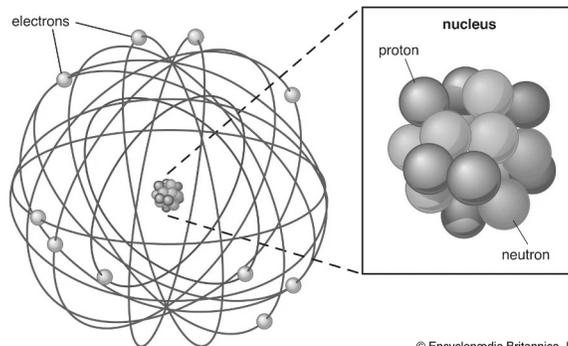
*New Zealand Chemist
1871 - 1931AD*

12

Subatomic Particles

Rutherford's Atomic Model

Strong positive center to the atom (*nucleus*) surrounded by negatively charged electrons (e^-)



**Ernest
Rutherford**

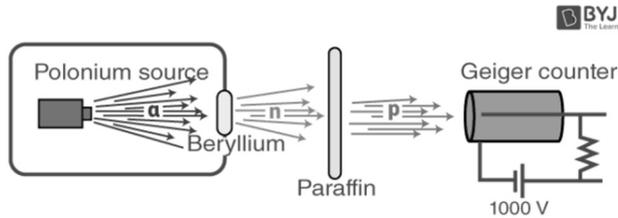
*New Zealand Chemist
1871 - 1931AD*

13

Subatomic Particles

Chadwick Alpha Particle Experiments

Chadwick observed a heavy byproduct of nuclear radiation without a charge



Discovery of neutron

BYJU'S
The Learning App

© Byjus.com



James Chadwick
English Chemist
1891 - 1974AD

The neutron (n^0) is a neutral charged particle balancing the protons (p^+) in the nucleus

14

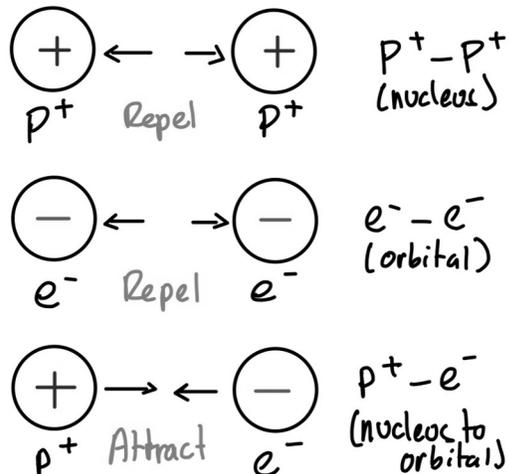
Subatomic Particles

Subatomic Particle Interaction

In the atom, subatomic particles interact based on their charges...

- Proton (+): Proton (+) - Repulsion
- Electron (-): Electron (-) - Repulsion
- Proton (+): Electron (-) - Attraction

Attraction pulls subatomic particles towards each other, while **repulsion** pushes subatomic particles apart in the atomic structure



15

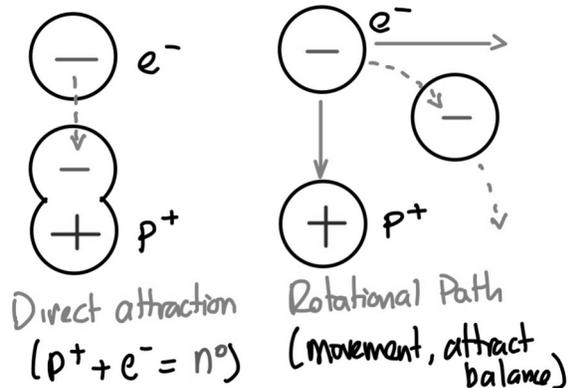
Subatomic Particles

Results of Interactions

Attracting particles will combine together when directly interacting

Proton (p^+) + Electron (e^-) = Neutron (n^0)

Within atoms, when subatomic particles attract the negative electron (e^-) will travel opposite that of the pull of the proton (p^+). This interaction leads to **circular e^- paths**



16

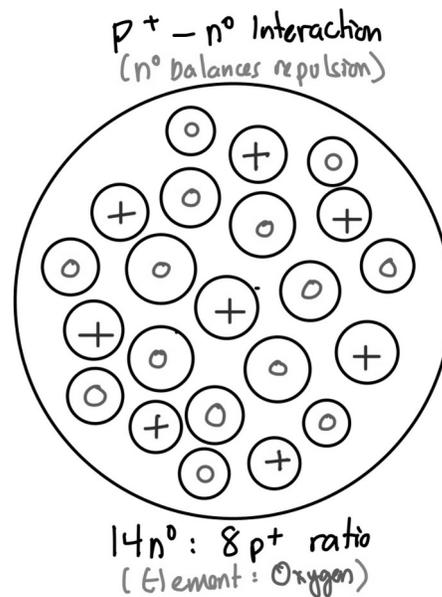
Subatomic Particles

Nucleus Interactions

The protons (p^+) within an atom repel other protons. To keep protons in the atom, neutrons (n^0) reduce the repulsion by sitting between the protons (p^+). This interaction is called

proton (p^+) – neutron (n^0) shielding

Shielding also affects the attraction between the protons (p^+) and electrons (e^-) within the atom



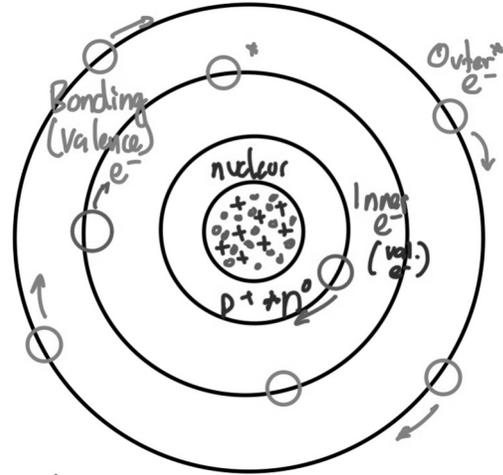
17

Subatomic Particles

Atomic Orbital Theory

In the *Bohr Atomic Model*, electrons travel around the atom in *orbits*, or circular paths due to the proton–electron interaction and shielding

Electrons fill around the atom in *quantized (numbered) levels*, known as *energy levels*. Electrons in the outer most level are known as *bonding, or valence electrons (e⁻)*. Lower level e⁻ are *inner electrons (e⁻)*



18

Subatomic Particles

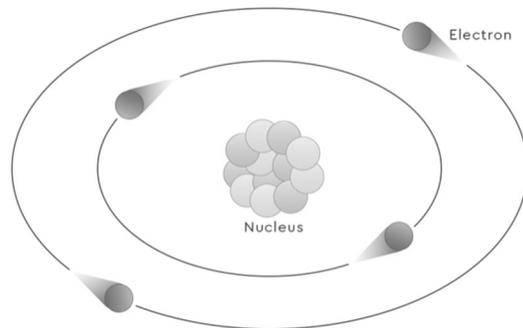
Uncertainty Principle

The *Heisenberg Uncertainty Principle* states that you can't know both the *position of a particle* and the particles momentum (p).

Momentum (p) is the multiplication of the particle mass and particle velocity (*speed*)

$$p = m \times v$$

Momentum can be described as the difficulty in changing particle direction



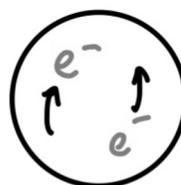
The *Heisenberg Uncertainty Principle* means we can't know the exact position of path of an electron (e⁻) in the orbit of an atom disproving the *Bohr Model* orbital pathways

19

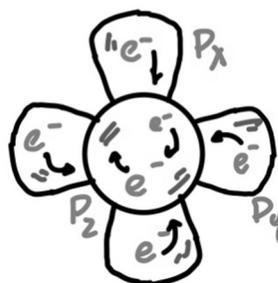
Subatomic Particles

Electron Cloud Theory

In the *modern atomic theory* electrons exist in areas within the atoms called *orbitals*. The orbitals are commonly labeled as s (*spherical*), p (*peanut*), d (*double peanut*), and f (*flower*) shapes. The p, d, and f orbitals contain many lobes, or suborbitals (p = 3, d = 5, and f = 7), with each suborbital containing up to 2 total electrons with opposite spins



s-orbital
(spherical)
2 e⁻, opp. spins



p-orbital
(peanut)
3 suborbitals
6 e⁻, opp. spins
2 e⁻ per sub.

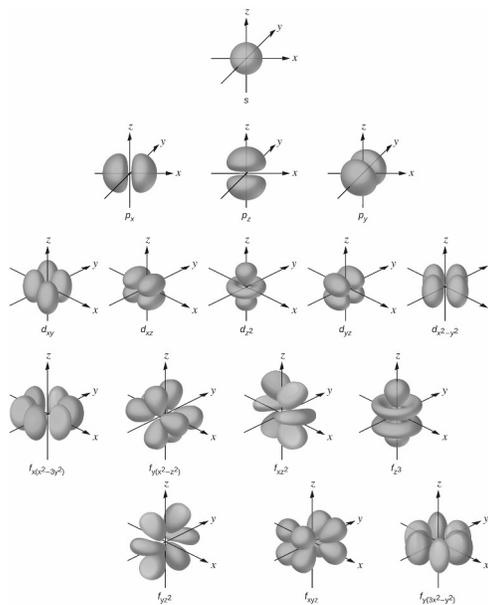
20

Subatomic Particles

Electron Filling in Orbitals

In the *modern atomic model*, electrons always fill the atom from the bottom up using a specific order, known as the *electron orbital filling order*.

Atoms need to *minimize energy*, with electrons closer to the atom being lower energy overall. The number of *total electrons (e⁻)* determines the filling of the atom overall



21

Role of Subatomic Particles

The modern atomic model contains protons, electrons, and neutrons (+, -, and neutral)

Protons

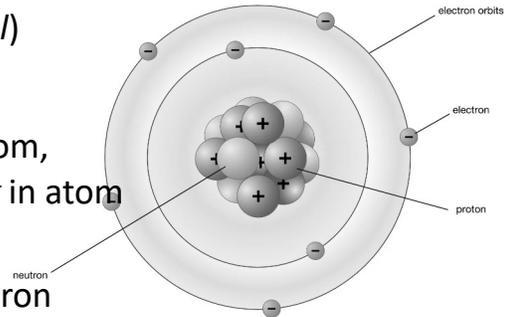
In nucleus (*center of atom*), identifies atom, provides attraction interaction holding e⁻ in atom

Electrons

Interactions between atoms due to electron transfer (*bonding*), absorbs extra atomic energy

Neutrons

Provides proton shielding, keep atom stable



22

Atomic Stability – Z-Ratio (n^o:p⁺ Ratio)

The Stability of an isotope of an atom is based on the relationship between protons (p⁺) and neutrons (n^o) in an atom. Atoms with too many or too new n^o will become unstable.

Z-Ratio

Ratio between the protons (p⁺) and neutrons (n^o) in the atom.

$$\text{Z-Ratio} = \frac{\#n^{\circ} (\text{neutrons})}{\#p^+ (\text{protons})}$$

Most stable isotopes of elements have the following ratios:

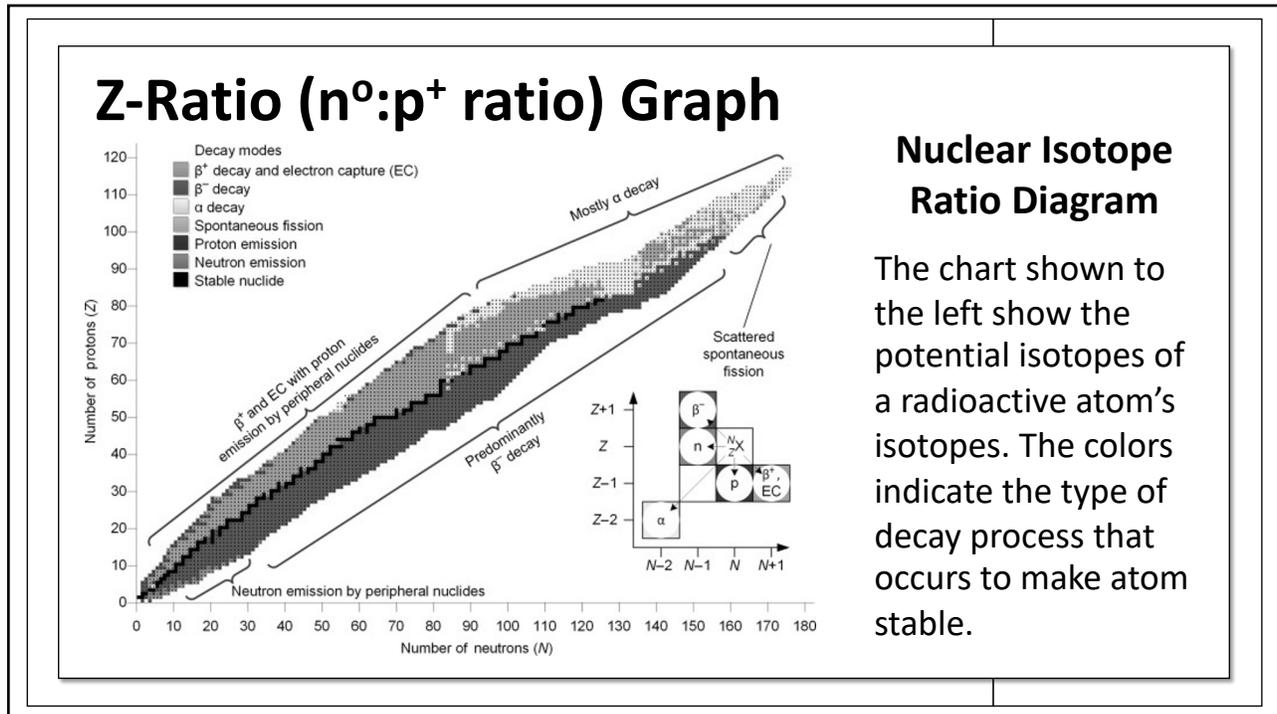
Small (1 – 20): 1.0 – 1.2

Large (55 – 82): 1.4 – 1.5

Medium (1 – 54): 1.2 – 1.3

No Stable Isotopes Above 82

23



Nuclear Isotope Ratio Diagram

The chart shown to the left shows the potential isotopes of a radioactive atom's isotopes. The colors indicate the type of decay process that occurs to make atom stable.

24

Nuclear Decay Processes

NUCLEAR DECAY *Whither be your way?*

α I'm stuffed! \rightarrow Now I'm α -okay!

alpha particle
+
smaller nucleus

Want to swap out a nucleon? - Be my guest!

β^+ beta-plus decay
too many neutrons!

different element
+ $e^- + \bar{\nu}_e$
electron
antineutrino

β^- beta-minus decay
too many protons!

different element
+ $e^+ + \nu_e$
positron
neutrino

This arrangement's so uncomfortable! Just relax!

γ \rightarrow

Nuclear Decay

Unstable Isotopes are isotopes that have a z-ratio outside the stable range for the element.

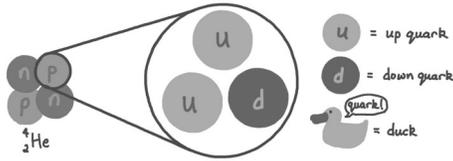
Most common nuclear decay processes include:

Alpha Decay – Atom too large
Beta Decay (+) – Too many n^0
Beta Decay (-) – Too many p^+

25

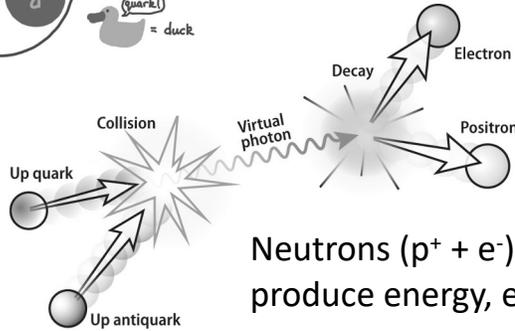
Energy of Subatomic Particles

UP QUARKS AND DOWN QUARKS



Subatomic Particles Contain Energy

All particles are made of individual particles called quarks and antiquarks.



Neutrons ($p^+ + e^-$) break down to produce energy, electrons, and protons

26

Nuclear Decay Processes

Type	Nuclear equation	Representation	Change in mass/atomic numbers
Alpha decay	${}^A_ZX \rightarrow {}^4_2\text{He} + {}^{A-4}_{Z-2}Y$		A: decrease by 4 Z: decrease by 2
Beta decay	${}^A_ZX \rightarrow {}^0_{-1}e + {}^{A}_{Z+1}Y$		A: unchanged Z: increase by 1
Gamma decay	${}^A_ZX \rightarrow {}^0_0\gamma + {}^A_ZY$		A: unchanged Z: unchanged
Positron emission	${}^A_ZX \rightarrow {}^0_{+1}e + {}^{A}_{Z-1}Y$		A: unchanged Z: decrease by 1
Electron capture	${}^A_ZX + {}^0_{-1}e \rightarrow {}^{A}_{Z-1}Y + \gamma$		A: unchanged Z: decrease by 1

Additional Decay Processes

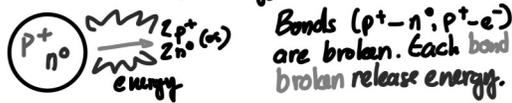
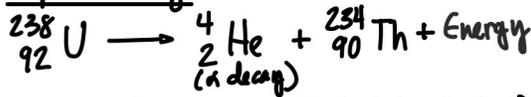
In addition to Alpha and Beta decay additional decay processes can occur including **gamma radiation, positron emission, and electron capture**

27

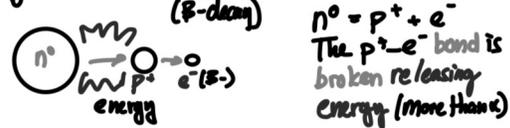
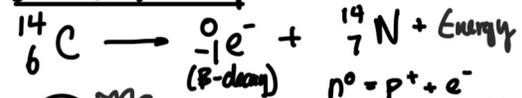
Nuclear Energy

Nuclear Energy is the energy (heat or light) produced through the decay (breakup) of unstable isotopes during the nuclear decay process.

Alpha Decay



Beta (β^-) Decay



Energy between Subatomic Particles is released with these particles decay (break apart). Alpha Decay break 4 subatomic particle bonds, while in Beta Decay, a neutron breaks apart into a proton and beta particle. More particle bonds broken = more energy produced.

28

Gamma Radiation

Gamma Radiation is a byproduct of other nuclear decay processes (such as alpha and beta decay)

A **Gamma Ray** is a small high energy packet of light (photon) that is produced due to extra energy of an excited atom.

An excited atom when extra energy is added to an atom after a particle decays into a more stable isotope



The positron (e^+) decay above excites the new atom Ne-22, which then quickly releases the energy as a gamma ray particle

29

Effects of Nuclear Radiation

The **energy of radiation** is based on the mass of the radiation particle and the energy of the particle itself.

Alpha Decay

4 Subatomic Particles
High Energy, High Mass
Large Size

Lowest Penetration
Stopped by Paper

Beta Decay

Proton and Electron
Lower Energy, Low Mass
Small Size

Medium Penetration
Stopped by Aluminum

Gamma Decay

Photon from Atom
Low Energy, No Mass
Smallest Size

High Penetration
Not Stopped

Penetration of nuclear decay is based on the relationship between the **particle energy** and the **size** of the particle itself.

30

Dangers of Nuclear Radiation

Nuclear Radiation procedures energy that can have dramatic effects on the body through simple exposure to radiation. The most common health effects of radiation include:

- Mutations or Changes in Cells of DNA
- Cancers and Changes in Cell Growth
- Radiation Sickness

People / Workers in the following areas are at greater risk: Radiologists, Nuclear Power Plant Workers, Cancer Doctors

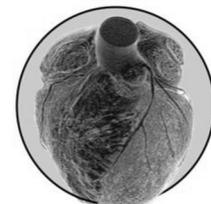
CT Scans



Nuclear Workers



Natural Background Radiation

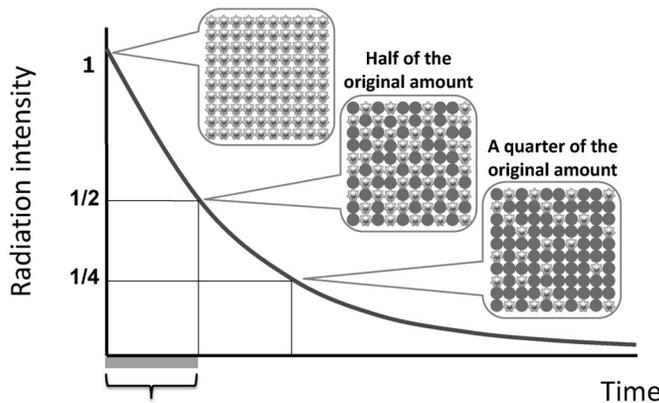


Nuclear Medicine

31

Nuclear Decay Rate

Based on the stability each isotope of an atom has a chance to decay every moment of time.

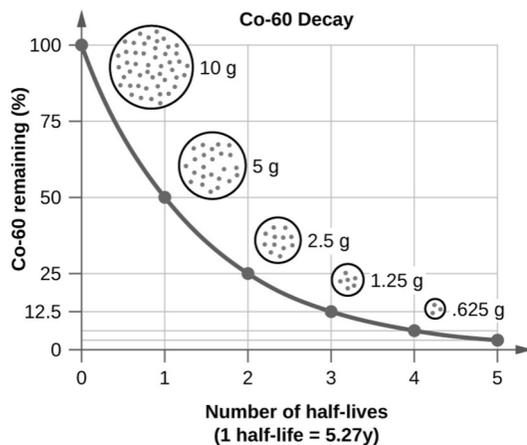


Each isotope will decay over time, the rate starting fast (*more particles can decay*) then slowing down (*less particles to decay*) over time as the sample decays. The decay rate is based on the **stability of the atoms** in the sample.

32

Nuclear Half Life

The time for particles to decay is based on the stability of particles



The **Half-Life** of a particle is the time it takes for half (50%) of the particles to decay from the original isotope state.

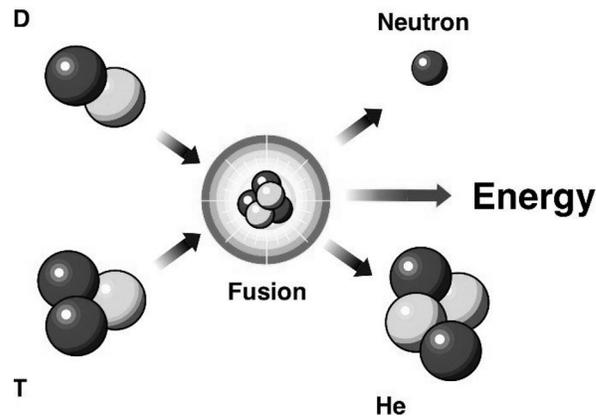
More Stable = Longer Half Life
Less Stable = Shorter Half Life

Nuclear Decay is an *inverse function* with a negative slope

33

Fusion

Fusion is the process where *small isotopes* combine under pressure together to produce larger atoms with lots of energy



Production of Elements

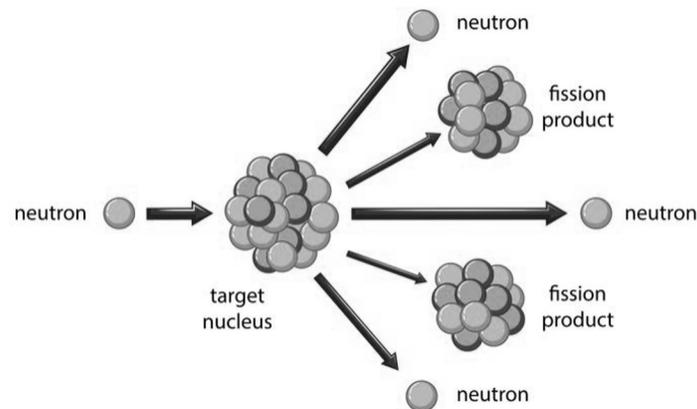
Elements can be *transmuted* to other elements through the process of fusion.

Man-Made elements heavier than Uranium (U) can be formed through fusion with protons and neutrons

34

Fission

Fission is the process where a *fissionable* atom is split by the interaction of the atom by a free neutron (n^0).



Fissionable Isotopes

Uranium-235 (*uncommon*) and Plutonium-239 can undergo fission.

Uranium-238 (*common*) can be converted to U-239 when hit by neutrons, then converted to Pu-239

35

Use of Fission

Fission produces a chain reaction process that can produce a large amount of energy due to repeated spitting of atoms.

Controlled Fission

Fission is used to produce power in a nuclear reaction using the fission process of quickly boil water and produce large amounts of energy. The leftover radioactive fuel is collected (*from nuclear rods*) and is stored in waste collection for generations

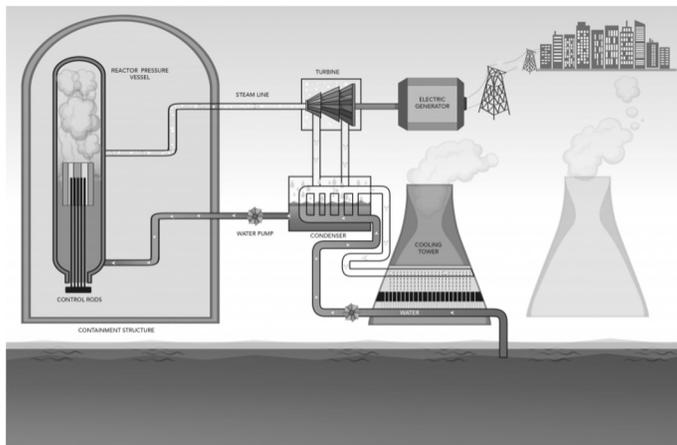
Uncontrolled Fission

Fission is also used to make large amounts of energy in an uncontrolled manner to destroy material is a nuclear weapon. In a nuclear reactor a *nuclear meltdown*, or uncontrolled heat production accident, can lead to similar effects to a nuclear bomb

36

Nuclear Power

Production of Power (*Electricity*) through *nuclear fission*



Nuclear Fission occurs in a reaction chamber when fuel rods undergo fission and boils water to turn turbines which produce electricity

Control rods absorb extra n° to control the rate of nuclear fission and heat

37

Nuclear Waste

Nuclear waste from reactors need to be stored in long term storage



Large Silos (*cylinders*) are used to safety store spent nuclear fuels.

Nuclear fuels after fission contain highly radioactive isotopes that remain a major hazard for thousands of years.

38

The Nuclear Power Debate

Nuclear power has its pros and cons over the use of more conventional energy production methods, including renewable sources

Pros of Nuclear Power

- No greenhouse gas (CO₂) production during the energy production process
- Larger amount of available energy for other alternate energy sources (*like electric cars*)

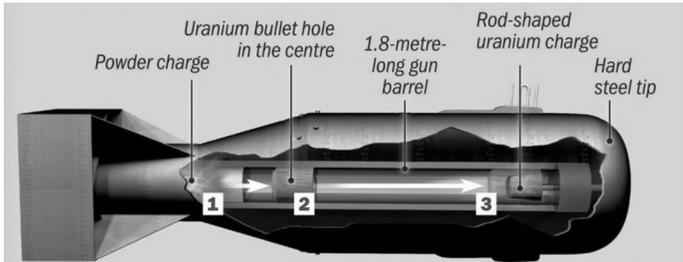
Cons of Nuclear Power

- Pollution due to nuclear fuel mining and purification
- The risk of nuclear meltdown
- The risk to wildlife due to the fuel cooling process, such as heating of water sources
- The need to store nuclear waste over time

39

Nuclear Weapons

Weapon (*bomb*) made by creating an uncontrolled fission reaction



Explosions split atoms

- 1** At the back was a 38.5 kg projectile filled with uranium. As the powder charge is activated it shoots through the bomb.
- 2** The uranium projectile flies through the strong 10 cm diameter gun barrel.
- 3** In the bomb tip is a further 25.5 kg of uranium. The clash with the projectile unleashes enough energy for the nuclear reaction to began.

Nuclear weapons contain a small *bullet* of a neutron producing isotope that is shot into a large uranium-235 tip. The uranium *bullet* sets off an uncontrolled fission reaction making uncontrolled heat