5–28 Nuclear Physics

Nucleons:

Proton	Positive charge	$+e = 1.6 \times 10^{-19}\ C$	m_p	$= 1.6726 \times 10^{-27}\ kg$
Neutrons	Neutral charge	$q = 0$	m_n	$= 1.6749 \times 10^{-27}\ kg$

???? Mass difference between a proton & a neutron ($1.6749 \times 10^{-27} - 1.6726 \times 10^{-27} = 2.3 \times 10^{-30}$)

It is almost the mass of an electron. A neutron is made of a proton and an electron that have fused. This explains why the neutrons are neutral. As for the mass not quite adding up, see $E = mc^2$.

Atomic Mass Number	(A)	= # Nucleons			
Atomic Number	(Z)	= # Protons	${}^{A}_{Z}X$	${}^{12}_{6}C$	or just ${}^{12}C$
Neutron Number	($N = A\text{-}Z$)	= # Neutrons			

Isotopes: Same # of Protons, different # of Neutrons ${}^{12}_{6}C$ ${}^{13}_{6}C$ ${}^{14}_{6}C$

Unified Atomic Mass (u)

C-12	$= 12.00000\ u$	$1.00000\ u$	$= 1.66054 \times 10^{-27}\ kg$
$E = m c^2$		$100000\ u$	$= 931.5\ MeV$

Binding Energy: Total mass of a stable nucleus is less than the component protons and neutrons

He: lists as 4.002602 *u*, but when the protons, neutrons, and electrons are added separately it totals to: 4.032980 *u*

When *He* is formed some mass turns into energy: $\Delta E = \Delta m\, c^2$, ***Mass Defect*** $= \Delta m = 28.30\ MeV$

Total Binding Energy: Mass difference, amount of energy required in order to break the nucleus apart.

Average Binding Energy per Nucleon: Divide Total binding energy by the number of nucleons.

Highest for Iron: Requires the most energy to split this nucleus, most stable

Hydrogen:	Used in fusion,	Energy drops from ***Fe*** to ***H***.	Binding energy released: Powers stars
Uranium:	Used in fission,	Energy drops from ***Fe*** to ***U***.	Binding energy released: Nuclear power & bombs

Strong Nuclear Force: Force holding nucleons together

Radioactivity: Disintegration / decay of unstable nucleus. Certain isotopes are unstable and emit rays (radiation).

- The ***Electric Force*** acts over entire nucleus. It results from the repulsion of all the protons. Neutron are not involved in the electric force.
- The ***Strong Force*** is a short-range force. It holds the individual nucleons together. Both neutrons and protons attract due to this force.
- So adding more neutrons can help hold the nucleus together, since they do not contribute to the repulsive electric force. There is however an ideal amount of neutrons, not too many and not too few that each nucleus needs in order to be stable. If this number is out of balance the nucleus can deteriorate spontaneously.
- The larger the nucleus the greater the electric force. The distances become too large for the strong force to hold the nucleons together. The balance of force favors electric force.
- **Transmutation*:*** Occasionally parts of the nucleus are repelled out with great force and speed. When part of the nucleus is ejected the ***Parent nucleus*** changes into a ***Daughter nucleus***

Alpha (α) Decay: Results when an ***α Particle***, *He* nucleus $\boxed{{}^{4}_{2}He}$ is spontaneously ejected from the nucleus. The nucleons comprising the alpha particle are strongly bonded to each other and they eject as a single packet.

$${}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

Beta (β) Decay: Results when there are too many neutrons compared to the ideal number required to maintain the electric / strong force balance. A neutron is a proton and an electron that have been fused together. So if there are too many neutrons one of them can split, forming a new proton (adding to atomic number) and a nuclear electron, known as a ***β particle*** $\boxed{{}^{0}_{-1}e}$. This particle has a very low mass and picks up all the energy of this transmutation. It is ejected at an extreme speed. Being smaller and faster than the alpha particle it has more penetrating power and is thus a more hazardous form of radiation. ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + \bar{\nu}$. One by product of this reaction is a positron (anti-electron). The existence of this anti-matter particle lead scientists to postulate the existence of a fourth fundamental force, the ***Weak Nuclear Force***. Don't worry about the positron on this exam.

Gamma Rays: Electrons around the nucleus can be found in excited states. It turns out that nucleons can exist in excited states as well. If a nucleon drops to a lower energy state a tremendous energy is released, since the energy differences in the nucleus are huge. This results in the emission of extremely high energy photons.

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Half Life: Length of time for half of the sample to decay. See worksheet that follows this section.

Law of Conservation of Nucleon Number: Total # of nucleons remains constant

Nuclear Reactions: Nucleus is struck by a particle. Causes transmutation

Enrico Fermi: Neutrons most effective projectile particle. No charge, not repelled.

Fission

Hahn and Strassmann: Bombardment sometimes made smaller particles

Meitner and Frisch: Realized that Uranium split in two

Liquid drop model: Neutron added to nucleus increases energy. Increases motion of individual nucleons. Abnormal elongated shape. Short range Strong Force is weakened. Electric Repulsive Force dominates. 2 Fission Fragments result. Also some free neutrons are given off. Tremendous amount of energy released. Fission fragment plus neutron are substantially lower in energy than original U 235

Chain Reaction: 2 to 3 neutrons freed collide with other ^{235}U

Self Sustaining Chain Reaction: Nuclear Reactor

Moderator: Need slow neutrons, with the right speed

Enriched Uranium: To increase probability of ^{235}U fission

Critical Mass: Mass of fuel large enough to compensate for lost neutrons

Multiplying Factor: 1 or more neutrons must go to next reaction.

Subcritical: Less than one neutron goes on

Supercritical

Control Rods: Cadmium or Boron. Absorb neutrons

Delayed Neutrons: Come from fission fragments

Core: Fuel plus moderator. 2 - 4 % ^{235}U

Problems

Thermal pollution: Disposal of radioactive fission fragments. Radioactive interaction with structural components. Accidental release of radioactivity into atmosphere. Leakage of radioactive waste. Life time of 30 yrs due to build up of radioactivity. Earthquakes. Limited supply of fissionable materials

Breeder Reactor: Some neutrons produced are absorbed by ^{238}U. ^{239}Pu is produced, and is fissionable. So the supply of fuel can increase 100 times. However, Plutonium is highly toxic and can readily be used in bombs, and it involves a graphite moderator, as was used in Chernobyl.

Fusion: Building up nuclei

Sum of energy of nucleus is less than sum of energy of its component parts

Elements may be result of fusion in stars

Proton Proton Cycle

$$^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{1}H + e^{+} + \nu \qquad \textbf{0.42 } \boldsymbol{MeV}$$

$$^{1}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + \gamma \qquad \textbf{5.49 } \boldsymbol{MeV}$$

$$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + ^{1}_{1}H + ^{1}_{1}H \qquad \textbf{12.86 } \boldsymbol{MeV}$$

$$4\,^{1}_{1}H \rightarrow ^{4}_{2}He + 2e^{+} + 2\nu + 2\gamma$$

Carbon Cycle: Similar method in hotter stars, can make heavier elements

Thermonuclear Device: Fusion Devices

- Stars are under tremendous gravity
- Creates tremendous pressure
- High pressure means high temperature
- High temperature means particles collide violently

On earth high temperatures and densities not easily achieved

Fission Bomb can ignite Fusion Bomb: Thermonuclear Device or H bomb

Plasma: Need high density as well as temperature. Ordinary materials cannot contain plasma

Magnetic Confinement: Tokamak Reactor. **Break even point:** Output equals input

Inertial Confinement: Pellet of deuterium and tritium. Struck simultaneously by several lasers

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