ARIVAN AGARWAL

CLASS-11, DIV-B

ROLL NO: 14

NUCLEAR PHYSICS

Bombay Scottish School, Mahim

CERTIFICATE

This is to certify that Shri/Kumari __ARIVAN AGARWAL_______, a student of class __11-B___, Roll No:___14_, UID: ______________ has successfully completed the project work in Physics titled _____Nuclear Physics_____ for the Class XI practical examination as prescribed by the Council for the Indian School Examinations in the year 2021-2022. It is further certified that this project is the individual work of the candidate.

External Examiner
Internal Examiner

Head of the School

Date: 20/08/2021

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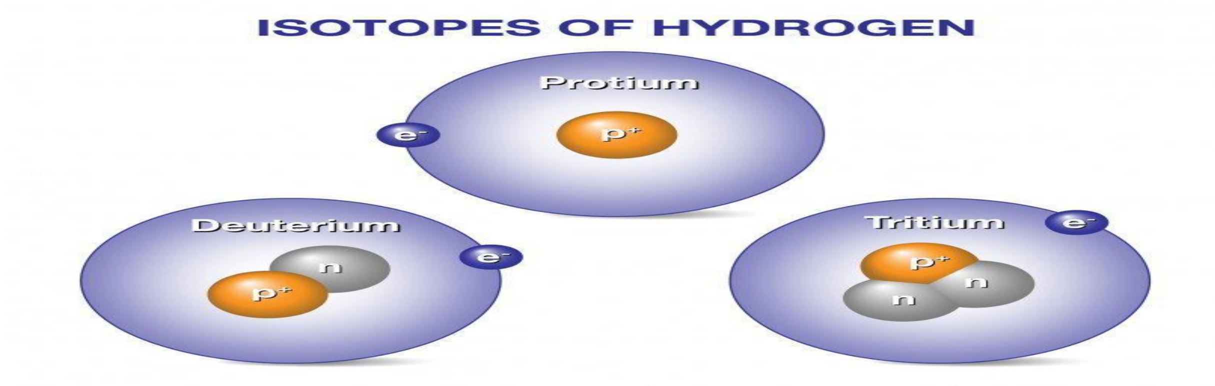
Every atom contains at its center an extremely dense, positively charged nucleus, which is much smaller than the overall size of the atom but contains most of its total mass. We will look at several important general properties of nuclei and of the nuclear force that holds them together. The stability or instability of a particular nucleus is determined by the competition between the attractive nuclear force among the protons and neutrons and the repulsive electrical interactions among the protons. Unstable nuclei decay, transforming themselves spontaneously into other nuclei by a variety of processes. Nuclear reactions can also be induced by impact on a nucleus of a particle or another nucleus. Two classes of reactions of special interest are fission and fusion which we will discuss later.

The nucleus of an atom has just two kinds of particles, protons and neutrons, which have approximately the same mass (the neutron is approximately 0.2 per- cent more massive). The proton has a charge of positive, and the neutron is uncharged.

The number of protons, Z, is the atomic number of the atom, which also equals the number of electrons in the atom. The number of neutrons that a nucleus has, N, is approximately equal to Z for light nuclei. For heavier nuclei, the number of neutrons is increasingly greater than Z. The total number of nucleons is called the nucleon number or mass number of the nucleus. The nucleon number or mass number A is the sum of the number of protons Z and the number of neutrons N: **A=Z+N.**

A particular nuclear species is called a nuclide. Two or more nuclides that have the same atomic number Z but have different values for N and A are called **isotopes**. For example-Hydrogen, has three isotopes: protium, 1H, whose nucleus is just a single proton; deuterium, 2H, whose nucleus is composed of one proton and one neutron; and tritium, 3H, whose nucleus is composed of one proton and two neutrons.



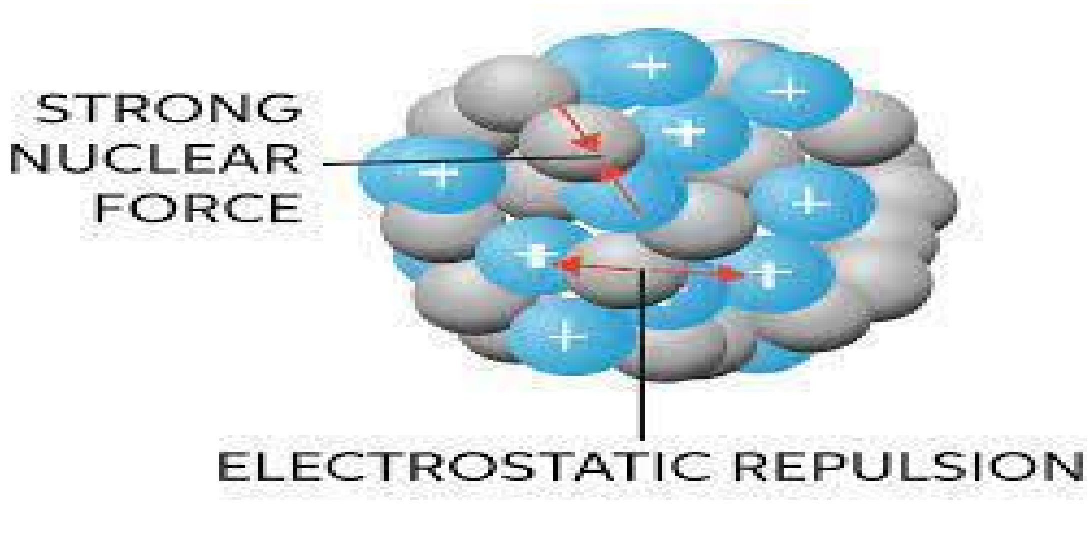
The masses of these particles are

Mass of a proton=1.007276 u = 1.672622 * 10-27 kg

Mass of a neutron = 1.008665 u = 1.674927 * 10-27 kg

Mass of an Electron = 0.000548580 u = 9.10938 * 10-31 kg

Nucleons exert a strong attractive force on other nucleons. This force, called the strong **nuclear force** or the hadronic force, is much stronger than the electrostatic force of repulsion between the protons and is very much stronger than the gravitational forces between the nucleons.



Nucleus size

Nuclei are spherical, with the nuclear radius—defined as the radius at which the density has fallen to half its central value—given approximately by

R = R0A^(1/3)

R0 = 1.2 fm and A is the mass number.

Nuclear spin and magnetic moments

Like electrons, protons and neutrons are also spin-1/2 particles. The magnitude of total angular momentum**'** I **'**of the nucleus is the vector sum of the individual spin and orbital angular momenta of all the nucleon.

Nuclear Angular Momentum

- Total nuclear angular momentum is --

$$I^{*} = \sqrt{I(I+1)}\hbar$$

- Nucear angular momentum z-axis projection

$$I_z = m_I \hbar \; ; \quad -I \leq m_I \leq +I$$

The spin quantum number I is an even or odd multiple of one-half depending on whether the number of nucleons is even or odd.

The angular momentum of the nucleus results in a nuclear magnetic dipole moment, usually expressed in units of the **nuclear magneton**.

STABILITY OF AN ATOM

For light nuclei, the greatest stability is achieved when the numbers of protons and neutrons are approximately equal. For heavier nuclei, instability caused by the electrostatic repulsion between the protons is minimized whenthere are more neutrons than protons. There are no stable nuclei for atomic number greater than 83.

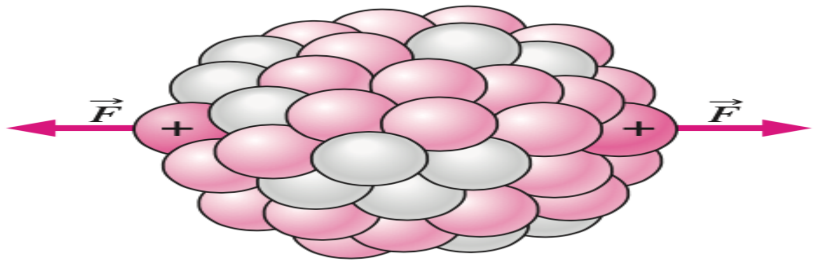


FIGURE 38.2 Two widely separated protons in a large nucleus experience significant electrical repulsion and negligible nuclear attraction.

The delicate balance between neutrons and protons results in about 400 known stable nuclei, collectively called **nuclides.**

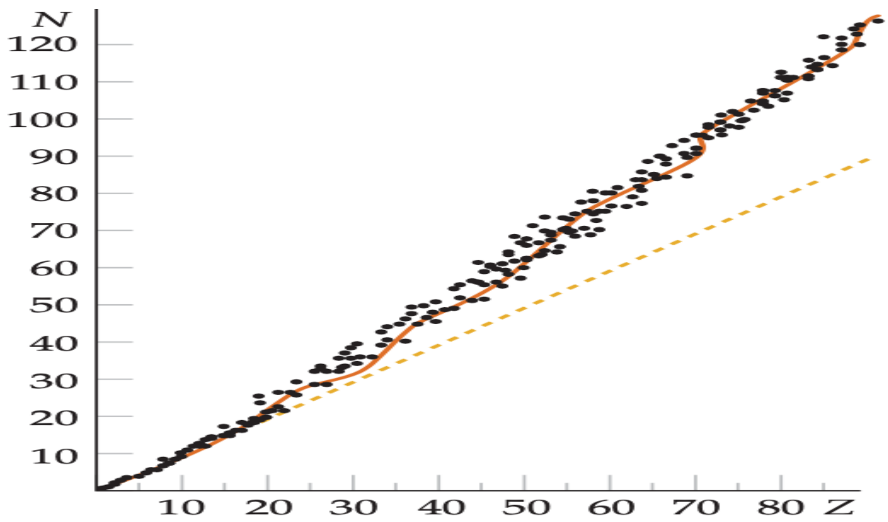
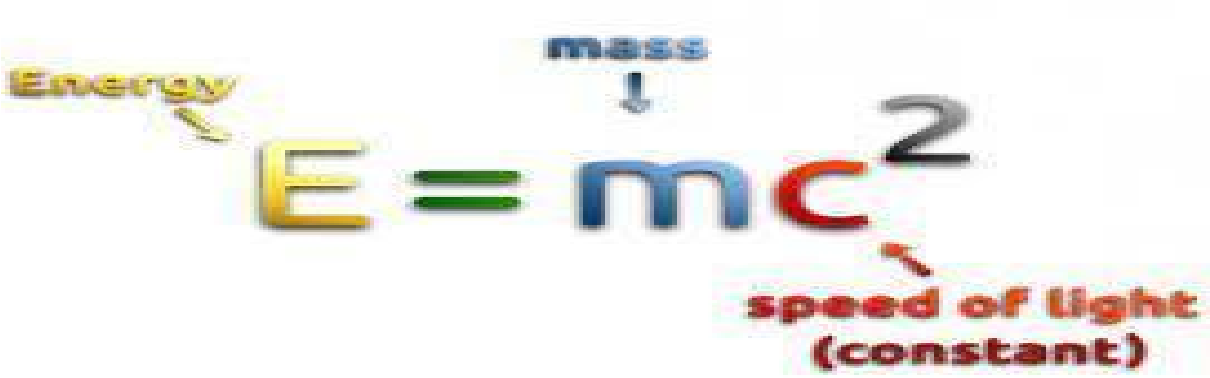


FIGURE 40-1 Plot of number of neutrons N versus number of protons Z for the stable nuclides. The dashed line is $N = Z$.

EINSTEIN'S MASS ENERGY EQUIVALENCE



BINDING ENERGY

Because energy must be added to a nucleus to separate it into its individual pro- tons and neutrons, the total rest energy E0 of the separated nucleons is greater than the rest energy of the nucleus. The energy that must be added to separate the nucleons is called the binding energy EB; it is the magnitude of the energy by which the nucleons are bound together. Thus, the rest energy of the nucleus is E0 - EB. Using the equivalence of rest mass and energy, we see that the total mass of the nucleons is always greater than the mass of the nucleus by an amount EB>c2 called the **mass defect**.

$$E_B = \left(ZM_H + Nm_n - {}^{A}_{Z}M\right)c^2 \quad \text{(nuclear binding energy)}$$

An important measure of how tightly a nucleus is bound is the binding energy per nucleon.

M-mass of the neutral atom

E-binding energy

The quantity in the parentheses is the mass defect

C: speed of light

Curve of binding energy

The curve of binding energy, a plot of binding energy per nucleon as a function of mass number A. The higher this quantity, the more tightly bound the nucleus is. The broad peak in the vicinity of **A = 60** shows that nuclei with mass numbers around this value are most tightly bound. That means it's energetically favorable for two lighter nuclei to join through the process of nuclear fusion, making a middle-weight nucleus. But heavier nuclei can reach a lower energy state if they split or fission into two middle-weight nuclei. We'll discuss fission and fusion later.

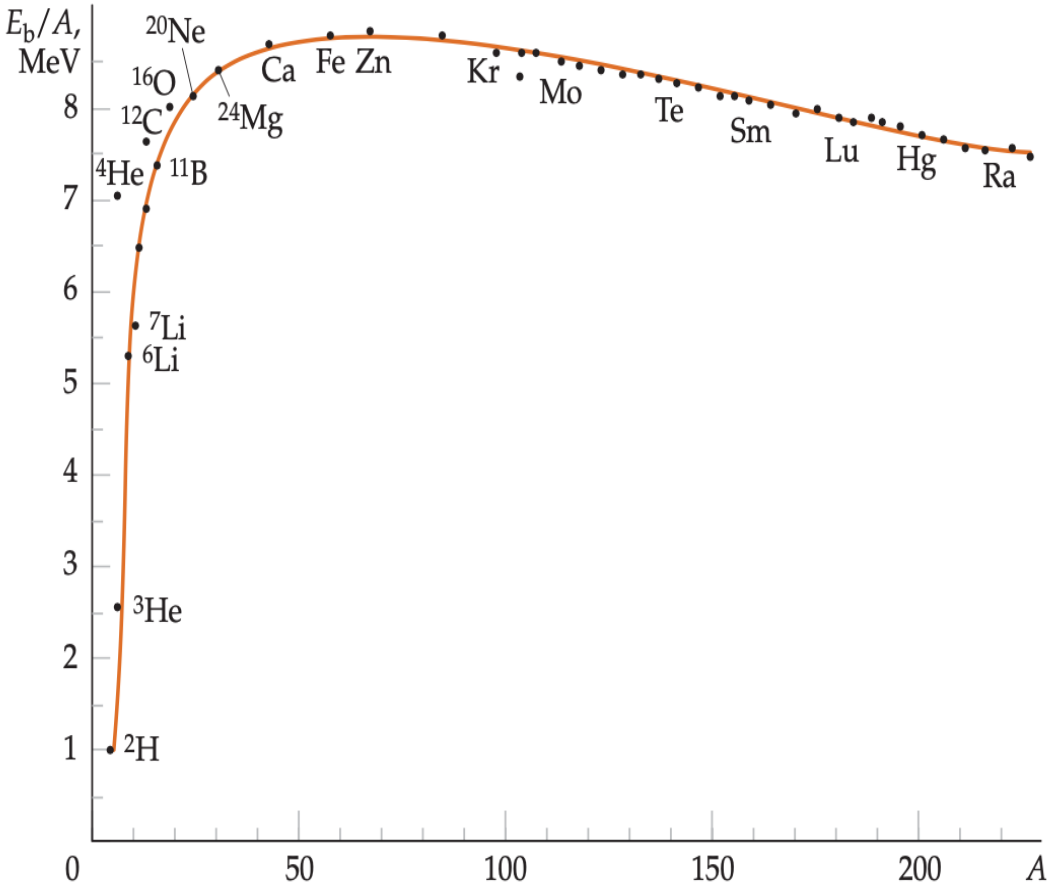


FIGURE 40-3 The binding energy per nucleon versus the nucleon number A. For nuclei that have values of A greater than 50, the curve is approximately constant, indicating that the total binding energy is approximately proportional to A.

What is Radioactivity?

Due to nuclear instability, an atom's nucleus exhibits the phenomenon of Radioactivity. Energy is lost due to radiation that is emitted out of the unstable nucleus of an atom.

Henry Becquerel discovered radioactivity by accident. A Uranium compound was placed in a drawer containing photographic plates, wrapped in a black paper. When the plates were examined later it was found that they were exposed! This exposure gave rise to the concept of Radioactive decay. Radioactivity can be seen in such forms

- Gamma Decay (Photons having high energy are emitted)
- Beta Decay (Emission consists of Electrons)
- Alpha Decay (Emission consists of Helium nucleus)

Radioactive Radiations

Following are the three radioactive radiations that are obtained from α, β, and γ rays:

X_{az}(mother nucleus) $\rightarrow Y_{a-4z-2}$(daughter nucleus) $+He_{42}$(αparticle)
X_{az}(mother nucleus) $\rightarrow Y_{az+1}$(daughter nucleus) $+e_{0-1}$(Beta radiation)
X_{+az}(mother nucleus) $\rightarrow$Yaz (daughter nucleus) +hf (gamma ray)

Laws of Radioactivity

- Radioactivity is the result of the decay of the nucleus.
- The rate of decay of the nucleus is independent of temperature and pressure.
- Radioactivity is dependent on the law of conservation of charge.
- The physical and chemical properties of the daughter nucleus are different from the mother nucleus.
- The emission of energy from radioactivity is always accompanied by alpha, beta, and gamma particles.
- The rate of decay of radioactive substances is dependent on the number of atoms that are present at the time

Alpha Decay

Alpha decay is a type of radioactive decay where the unstable atomic nuclei emit a helium nucleus (alpha particle) and in the process transforms into another more stable element. The particle ejected out, the alpha particle, consists of four nucleons and they are two neutrons and two protons. Alpha radiation reduces the ratio of protons to neutrons in the parent nucleus, bringing it to a more stable configuration.

$$^{235}_{92}\mathrm{U} \longrightarrow \underbrace{^{4}_{2}\mathrm{He}}_{\alpha \text{ particle}} + {}^{231}_{90}\mathrm{Th}$$

Beta Decay

In beta-minus decay, an energetic negative electron is emitted, producing a daughter nucleus of one higher atomic number and the same mass number. An example is the decay of the uranium daughter product thorium-234 into protactinium-234:

$$^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + \underbrace{^{0}_{-1}\mathrm{e}}_{\beta \text{ Particle}}$$

Gamma Decay

A nucleus changes from a higher energy state to a lower energy state through the emission of electromagnetic radiation (photons). The number of protons (and neutrons) in the nucleus does not change in this process, so the parent and daughter atoms are the same chemical element

$$^{99m}_{43}\mathrm{Tc} \longrightarrow {}^{99}_{43}\mathrm{Tc} + \underbrace{^{0}_{0}\gamma}_{\gamma \text{ ray}}$$

Advantages of radioactivity are:

- The most important use is **carbon dating**. The unstable isotope 14C, produced during nuclear reactions in the atmosphere that result from cosmic-ray bombardment, gives a small proportion of 14C in the CO2 in the atmosphere. . When a plant dies, it stops taking in carbon, and its 14C b- decays to 14N with a half-life of 5730 years. By measuring the proportion of 14C in the remains, we can determine how long ago the organism died.
- Gamma rays are used to kill cancerous cells and hence used in radiotherapy.
- Cobalt-60 is used to destroy carcinogenic cells.
- Gamma rays are used in scanning the internal parts of the body.
- Gamma rays kill microbes present in food and prevent it from decay by increasing the shelf life.
- Age of the rocks can be studied using radioactive radiations by measuring the argon content present in the rock.
- Tritium 13H2, a radioactive hydrogen isotope, is used to tag molecules in complex organic reactions; radioactive tags on pesticide molecules, for example, can be used to trace their passage through food chains.

Disadvantages of radioactivity are:

- High dosage of radioactive radiation on the body might lead to death.
- Radioactive isotopes are expensive.
- In mild cases it results in a burn, as with common sunburn.
- Greater exposure can cause very severe illness or death by a variety of mechanisms, including massive destruction of tissue cells, alterations of genetic material, and destruction of the components in bone marrow that produce red blood cells.

Nuclear Reaction Energy

When two nuclei interact, charge conservation requires that the sum of the initial atomic numbers must equal the sum of the final atomic numbers. Because of conservation of nucleon number, the sum of the initial mass numbers must also equal the sum of the final mass numbers. In general, these are not elastic collisions, and the total initial mass does not equal the total final mass.

The difference between the masses before and after the reaction corresponds to the reaction energy, according to the mass–energy relationship $E = mc2$. If initial particles A and B interact to produce final particles C and D, the reaction energy Q is defined as:

$Q = (1MA + MB - MC - MD2)\ c^2$ (reaction energy)

When Q is positive, the total mass decreases and the total kinetic energy increases. Such a reaction is called an **exothermic reaction**.

When Q is negative, the mass increases and the kinetic energy decreases, and the reaction is called an **endothermic reaction.**

NOTE: In an endothermic reaction, the reaction cannot occur at all unless the initial kinetic energy in the center-of-mass reference frame is at least as great as the threshold energy which is the minimum kinetic energy to make an endothermic reaction undertake.

The Reaction with a neutron

The most likely reaction between a nucleus and a neutron that has an energy of more than about 1 MeV is scattering. However, even if the scattering is elastic, the neutron loses some energy to the nucleus because the nucleus recoils. If a neutron is scattered many times in a material, its energy decreases until the neutron is of the order of the energy of thermal motion kT, where k is Boltzmann's constant and T is the absolute temperature. The neutron is then equally likely to gain or lose energy from nucleus when it is elastically scattered. A neutron that has an energy of the order of kT is called a thermal neutron.

NUCLEAR FISSION

Nuclear fission is a process in which an unstable nucleus splits into two nuclides and emits neutrons. Two types of fission reactions are possible: spontaneous fission and induced fission.

Spontaneous fission occurs in some radionuclides, at least one of which, californium-252, occurs naturally. These radionuclides are extensively used as neutron sources.

In induced fission, when a fissionable nucleus, such as uranium, captures neutron it goes into an unstable state and eventually breaks into two heavy parts. In this process it also emits some neutrons. The two heavier particles are known as fission fragments. The reaction can be written as:

$FM+n \rightarrow FF1+FF2+(2-4)n$,- where FM represents fissionable material (such as $U92235$), n is the neutron, and FF1 and FF2 are the two fission fragments.

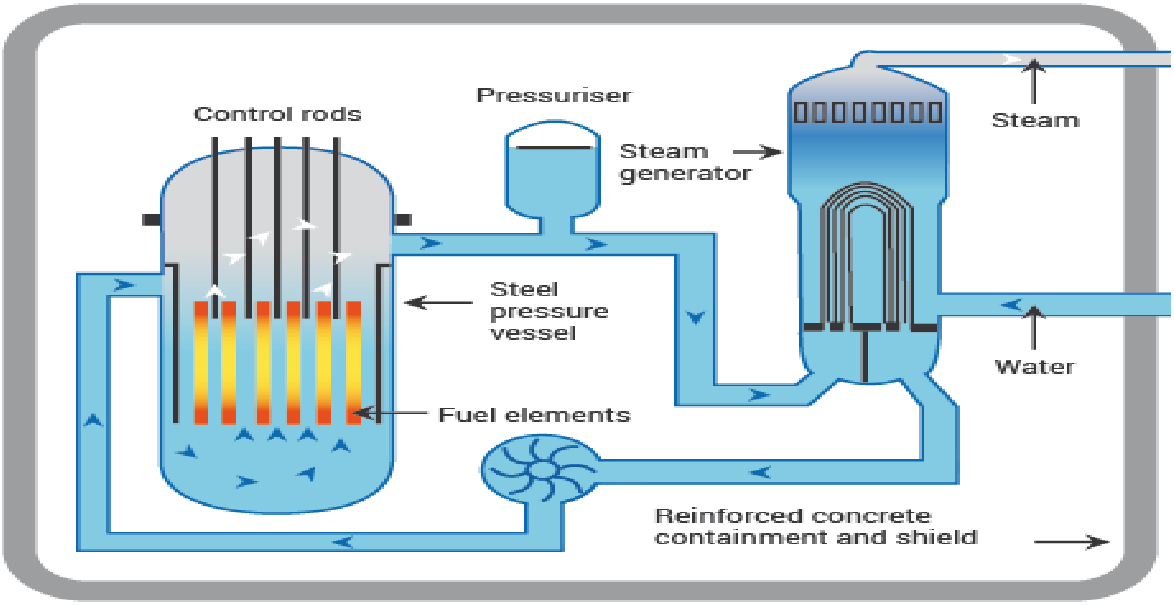
As an example, let us have a look at how uranium-235 fissions.

$$^{235}_{92}U + 2n \rightarrow ^{236}_{92}U \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2n$$

Uranium-236 is an unstable isotope of uranium that eventually breaks up into fragments and releases two neutrons.

NOTE-A nuclear chain reaction, which could be controlled to release and harness immense amounts of energy for electric power through nuclear fission. If the system is designed such that, on average, exactly one neutron from each fission event triggers another event, then the fission energy can be released in a slow and controlled manner. This is the basic operating principle of the nuclear reactor.

Components of a nuclear reactor are:
-Fuel,moderator,coolant,control rods, pressure vessel, containment.



NUCLEAR FUSION

For two nuclei to undergo fusion, they must come together to within the range of the nuclear force, typically of the order of 2 * 10^-15 m. To do this, they must overcome the electrical repulsion of their positive charges. In a **nuclear fusion** reaction, two or more small light nuclei come together, or *fuse,* to form a larger nucleus. The binding energy per nucleon after the reaction is greater than before. The total mass of the products is less than that of the initial particles as there is some mass deficiency that is released as energy, and the quantity of energy released follows Einstein's formula: E = mc^2, in which E is the energy in joules, m is the mass difference in kilograms, and c is the speed of light.

Here are three examples of energy-liberating fusion reactions, written in terms of the neutral atoms:

$$^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{2}_{1}\mathrm{H} + \beta^{+} + \nu_{e}$$

$$^{2}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + \gamma$$

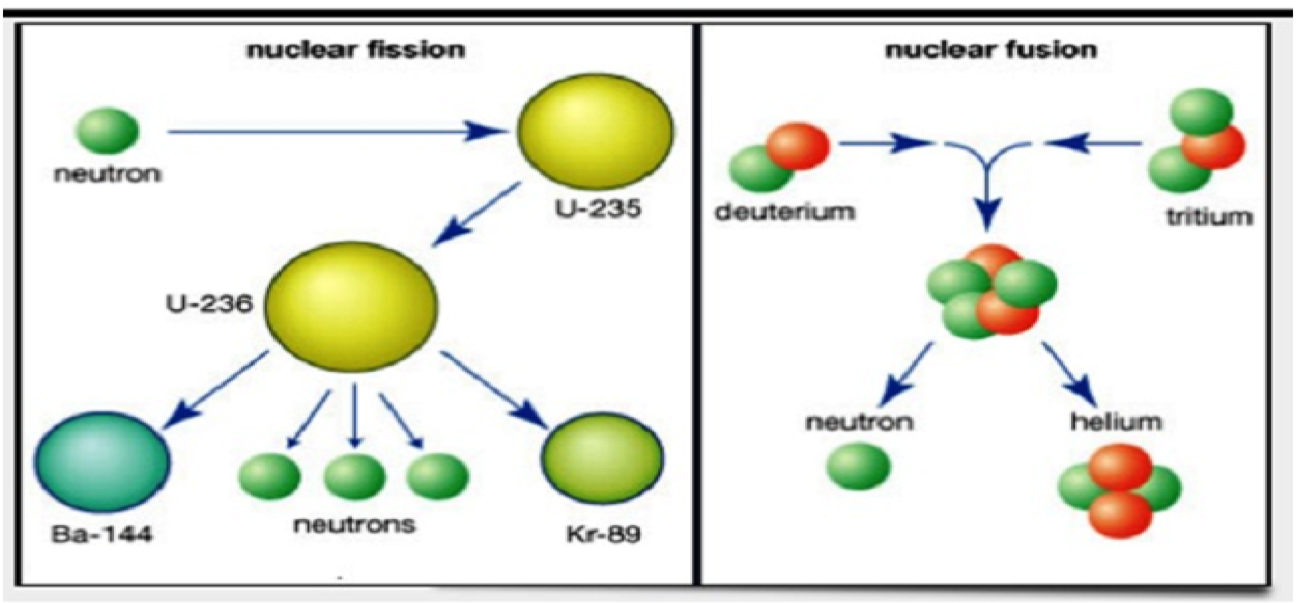
$$^{3}_{2}\mathrm{He} + {}^{3}_{2}\mathrm{He} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H}$$

In the first reaction, two protons combine to form a deuteron 1^{2}H2, with the emission of a positron 1b^{+}2 and an electron neutrino.

In the second, a proton and a deuteron combine to form the nucleus of the light isotope of helium, ^{3}He, with the emission of a gamma ray.

Now double the first two reactions to provide the two ^{3}He nuclei that fuse in the third reaction to form an alpha particle 1^{4}He2 and two protons.

Nuclear Fission and Nuclear Fusion



DIFFERENCES BETWEEN NUCLEAR FISSION AND FUSION

Nuclear fission	Nuclear fusion
In fission, a heavy nucleus splits into two smaller nuclei of nearly equal masses.	In fusion, two smaller nuclei fuse together to form a heavier nucleus.
The energy available per fission is much large as compared with that available per fusion.	The energy available per fusion is much less.
The energy released per unit mass of material is much less as compared with that released in fusion.	The energy released per unit mass of material is much greater.
It does not require extremely high temperature, so it can be carried on the earth.	It requires extremely high temperatures, so it can't be carried on the earth. It is possible in sun & stars only.
The reacting mass has to be divided up into small (i.e. critical) masses.	Any large mass may be used.
It is a quick process.	This occurs, in several stages & considerable time may lapse in between initial & final stages.
The products of fission are radioactive & hence pose a hazard for life.	The products of fusion are non radioactive & so do not pose any hazard for life.
The sources of fissionable material (like uranium, thorium, plutonium) may vanish some day.	The source of fusion reaction namely protons are present in an immense quantity in the hydrogen of air & water of ocean.

APPLICATIONS OF NUCLEAR FISSION AND NUCLEAR FUSION

Abundant fuel supply - Deuterium can be readily extracted from seawater, and excess tritium can be made in the fusion reactor itself from lithium, which is readily available in the Earth's crust. Uranium for fission is rare, and it must be mined and then enriched for use in reactors.

Safe - The amounts of fuel used for fusion are small compared to fission reactors. This is so that uncontrolled releases of energy do not occur. Most fusion reactors make less radiation than the natural background radiation we live within our daily lives.

Less nuclear waste - Fusion reactors will not produce high-level nuclear wastes like their fission counterparts, so disposal will be less of a problem. In addition, the wastes will not be of weapons-grade nuclear materials as is the case in fission reactors.

Nuclear reactors use the heat from nuclear reactions (reactions due to nuclear fission) in the nuclear fuel to boil water. Just as in conventional power stations, the steam from the boiling water makes a turbine spin, which in turn makes the generator turn and thus produces electricity.

It is used in a nuclear bomb where the energy released is fast and uncontrolled.

LIMITATIONS OF NUCLEAR FISSION AND NUCLEAR FUSION

Tragic events such as Chernobyl and Fukushima show us just how dangerous the process of nuclear fission can be. This creates a radiation-exposure event that can be dangerous to human and animal health.

Nuclear fission can create clean-burning energy, but the radioactive waste products can be very harmful to the environment. Without proper disposal sites, toxic waste dumps can damage a regional environment for hundreds of years.

It can also be the foundation of powerful weapons that create mass casualties. The atomic bombs, which start with the same fission reaction, that were dropped in Japan killed up to 226,000 people over a 4-month period.

From 2002-2008, the cost of a new nuclear plant rose from $2 billion to $9 billion per unit in the United States. Costs in Canada and Europe are even higher for new plants.

Although nuclear fission creates a clean-type of energy, like fossil fuels, it is not a renewable energy resource with our current technologies.

LATEST DEVELOPMENTS IN NUCLEAR PHYSICS

Partial dynamical symmetry versus quasi dynamical symmetry examination within a quantum chaos analyses of spectral data for even–even nuclei

4D-imaging of drip-line radioactivity by detecting proton emission from 54mNi pictured with ACTAR TPC

Evidence of a sudden increase in the nuclear size of proton-rich silver-96

On the interpretation of annual oscillations in 32Si and 36Cl decay rate measurements

CONCLUSION

Nuclear physics is a discovery-driven enterprise motivated by the desire to understand the fundamental mechanisms that account for the behavior of matter; the new knowledge of the nuclear world has also directly benefited society through many innovative applications. The report recommendations will ensure a thriving and healthy field that continues to benefit society from new applications at an accelerating pace.

The world was in political turmoil when fission was discovered in 1938. Compounding the troubles, the possibility of a self-sustained chain reaction was immediately recognized by leading scientists the world over. The enormous energy known to be in nuclei, but considered inaccessible, now seemed to be available on a large scale.

Of course, not all applications of nuclear physics are as destructive as the weapons described above. Hundreds of nuclear fission power plants around the world attest to the fact that controlled fission is both practical and economical and have plethora of advantages. Given growing concerns over global warming, nuclear power is often seen as a viable alternative to energy derived from fossil fuels.

The idea of Mutually Assured Destruction (MAD) keeps the “Commies” from starting WWIII. Now that the threat of “rouge” nations has been brought into the spotlight, people are beginning to realize that there are fanatics, willing to die, if it means that all “unbelievers” die with them. Although we cannot put the nuclear genie back in the bottle, we can build an effective defense against it. And after the events of September 11, we must! Use the nuclear energy quite responsibly.

ACKNOWLEDGMENT

I extend my thanks to my physics sir Mr. Pandey, for guiding me in the completion of this project. This project was possible because of his constant support and guidance. Further, I acknowledge our principal, Mrs. George, for providing me with this opportunity. I also thank the senior academic coordinators, Ms. Thomas for supporting and organizing the academic program. Finally, I thank my parents for their continued encouragement.

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