Nuclear reaction and energy generation

group 4

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Introduction

Nuclear reaction is a process of particle nucleus or nucleus nucleus collisions resulting in rearrangment of nucleons inside the nuclei with eventually emission of nucleons and/or photonsand a different kind of nuclie. Although it involves change in energy like that of the chemical reaction,Nuclear reactions are very different from chemical reactions.In chemical reactions, atoms become more stable by participating in a transfer of electrons or by sharing electrons with other atoms. In nuclear reactions, it is the nucleus of the atom that gains stability by undergoing a change of some kind. There are two notable types of nuclear reaction: Nuclear fission and Nuclear fusion that we are going to discuss in our topic with their respective application with regard to energy the production.

nuclear fision

nuclear fission in simpler words can be defined as a nuclear reaction that involves the the splittiing of the nucleous of massive elements like that of Uranium and plutonium in to a lighter elements and other particles when bombarded by a neutron.

how it was discovered

In December 1938, physicists Lise Meitner and Otto Frisch made a startling discovery that would immediately revolutionize nuclear physics and lead to the atomic bomb. Trying to explain a puzzling finding made by nuclear chemist Otto Hahn in Berlin, Meitner and Frisch realized that something previously thought impossible was actually happening: that a uranium nucleus had split in two. After the neutron was discovered ,In 1934 Enrico Fermi bombarded uranium with neutrons, producing what he thought were the first elements heavier than uranium. Most scientists thought that hitting a large nucleus like uranium with a neutron could only induce small changes in the number of neutrons or protons.In December 1938, Hahn and Strassmann, experiments on bombarding uranium with neutrons, found what appeared to be isotopes of barium among the decay products.

changes occuring during the process

it is an exothermic reaction which can release large amounts of energy both as electromagnetic radiation and as kinetic energy of the fragments (heating the bulk material where fission takes place). Like nuclear fusion, for fission to produce energy, the total binding energy of the resulting elements must be greater than that of the starting element. this can be best understood through a consideration of the structure and stability of nuclear matter. Nuceli consist of nucleons(neutrons and protons), the total number of which is equal to the mass number of the nucleus. The actual mass of a nucleus is always less than the sum of the masses of the free neutrons and protons that constitute it. this difference is known as the mass defect.since mass is equivalent to energy (acording to the Einstein's Relativity Theory),theis mass difference is converted to energy.The corresonding difference in Energy is called the binding Energy.

Binding Energy: is the energy released during the formation of a nucleus from its constituent nucleons and would have to be supplied to the nucleus to decompose it into its individual nucleon components.
Example: the mass defect of helium atom is 0.030amu

•To calculate the total change in binding Energy

$$\Delta E = \Delta mc^2 \tag{1}$$

$$\Delta E = 5.0407 \times 10^{-29} \times (3 \times 10^8)^2 \tag{2}$$

$$\Delta E = 4.536 \times 10^{-12} J = 27.98 Mev$$

(this amount of energy is needed to overcome the nuclear force with in the nucleus of helium atom)

In fission, an unstable nucleus is converted into more stable nuclei with a smaller total mass This difference in mass, the mass defect, is the binding energy that is released.Hence binding energy per nucleon increases in the fission process.
for example: during the the fission of uranium 235
$\mathrm{U}_{235} + \mathrm{n}_1 \longrightarrow \mathrm{Ba}_{141} + \mathrm{Kr}_{92} + 3\,\mathrm{n}_1$
total mass of reactant=236.053amu
total mass of product=235.867

$$\Delta E = 3.09 \times 10^{-27} \times (3 \times 10^8)^2 \tag{3}$$

$$\Delta E = 2.781 \times 10^{-11} J \tag{4}$$

$$\text{about } 19.24 \times 10^{12} J \text{ for 1 mole uranium-235} \tag{5}$$

- This amount of energy is released when uranium-235 absorbs a neutron, which makes the products more stable having higher binding energy.

The chain reaction and critical mass

In a nuclear fission chain reaction, a free neutron interacts with the nucleus of an atom and causes that nucleus to split apart into two new, less massive nuclei. The ruptured nucleus in turn releases additional neutrons, which can cause additional nuclei to split, and so on. In the case of uranium-235, for example, each fission reaction produces two or three additional free neutrons, each of which may in turn strike additional nuclei and cause more to fission. A controlled chain reaction of this sort can be used to generate nuclear power; an uncontrolled chain reaction can result in a nuclear explosion. Chain reactions are initiated when a quantity of fissionable material, such as uranium-235 or plutonium, reaches **critical mass**.
The critical mass of a fissionable substance is the minimum amount of fissionable material that will support a self-sustaining chain reaction. At this mass the neutrons released as a product of one fission reaction can cause neighboring atoms to fission.

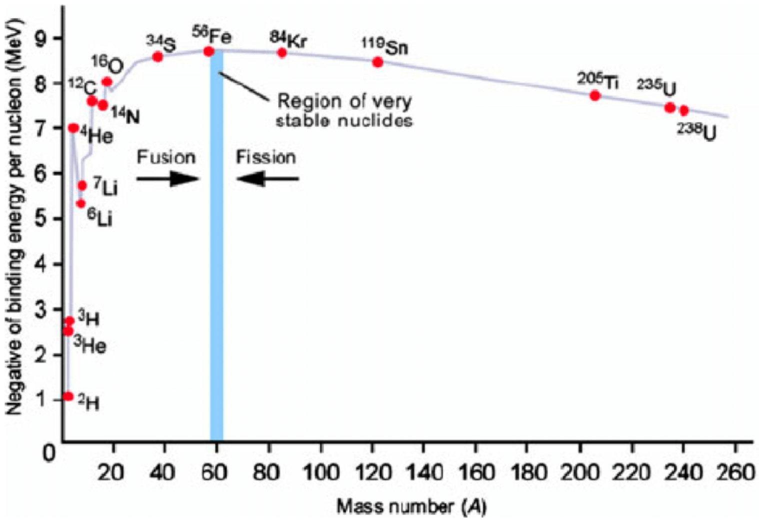

Figure 1: BEN-versus-mass graph

Application of nuclear fission

nuclear power plant

A nuclear power plant (NPP)is a thermal power station in which the heat source is a nuclear reactor. As is typical of thermal power stations, heat is used to generate steam that drives a steam turbine connected to a generator that produces electricity.Except for the reactor, which plays the role of a boiler in a fossil-fuel power plant, a nuclear power plant is similar to a large coal-fired power plant, with pumps, valves, steam generators, turbines, electric generators, condensers, and associated equipment.Nuclear power comes from the energy that is released in the process of nuclear fission,most nuclear power plants use enriched uranium as their fuel to produce electricity. This fuel contains greater amounts of a certain kind (or isotope) of uranium known as U-235.In fission, the nuclear fuel is placed in a nuclear reactor core and the atoms making up the fuel are broken into pieces, releasing energy. The neutrons that are released by one atomic fission go on to fission other nuclei, triggering a chain reaction that produces heat, radiation, and radioactive waste products. If uncontrolled, that chain reaction could produce so much heat that the nuclear reactor core itself could actually melt and release dangerous radiation. That's why power plants use "control rods" that absorb some of the released neutrons, preventing them from causing further fissions.The energy released from the fission of uranium atoms heats water, which produces steam. That's how we get electricity. The steam goes on to spin turbines, which then drive generators. It's the same basic principle used in coal or gas plants.

Uses of nuclear power

nuclear power is mainly used for electricity generation. The United States is the world's largest producer of nuclear energy, accounting for more than 30 percent of global nuclear electricity generation. Nuclear power plants could be used to

generate clean hydrogen to create ammonia and nitrogen for fertilizers. The hydrogen could also be used for steel refining or to develop synthetic fuels for cargo ships to drastically reduce its carbon.
•Main components of the Nuclear Power Plant
1:Core

The core of the reactor comprises all the nuclear fuel, which produces all the heat. It also contains low-enriched uranium (¡5 per cent U-235), control systems and structural materials. The core can consist of hundreds of thousands of individual fuel pins footprint.

2.turbine :The turbine converts heat from the coolant to electricity, just as it does in a fossil fuel plant.

3:Containment Containment is the structure that separates the reactor from the environment. These are typically dome-shaped, made from steel-reinforced and high-density concrete.

4:Cooling Towers

Some plants require cooling towers to dump excessive heat that cannot convert into electricity due to the thermodynamics laws. These are known as the hyperbolic icons of nuclear energy. They produce only clean water vapours.

Nuclear reactors mostly depend on uranium to fuel a chain reaction. Uranium is a heavy metal that is common on Earth.Since nuclear fission generates radioactivity, a protective shield surrounds the core of the reactor. This containment absorbs radiation and prevents the release of radioactive material into the atmosphere. The aim of the steam turbine is to transform the heat stored in the steam into mechanical energy.An electrical generator transforms the mechanical power of the turbine into electrical energy. It uses low-pole AC synchronous generators with high rating capacity. The cooling system eliminates heat from the reactor core and transfers it to other parts of the station, where thermal energy is useful in generating power to perform other similar task.

Research Reactors

Research reactors are nuclear fission-based nuclear reactors that serve primarily as a neutron source. They are also called non-power reactors Research reactors are simpler than power reactors and operate at lower temperatures. They need far less fuel, and far less fission products build up as the fuel is used. On the other hand, their fuel requires uranium that is more highly enriched, typically up to 20 percent U-235, known as high-assay low-enriched uranium (HALEU), although some older ones still use 93 percent U-235. They also have a very high power density in the core, which requires special design features. Like power reactors, the core needs cooling, usually passively and only the higher-powered test reactors need forced cooling. Usually a moderator is required to slow down the neutrons and enhance fission. As neutron production is their main function, most research reactors also need a reflector to reduce neutron loss from the core.

useses of research reactor

Neutron beams are uniquely suited to studying the structure and dynamics of materials at the atomic level. Neutron scattering is used to examine samples under different conditions such as variations in vacuum pressure, high temperature, low temperature and magnetic field, essentially under real-world conditions. Neutron activation is the only common way that a stable material can be made radioactive. It is used to produce the radioisotopes, widely used in industry and medicine, by bombarding particular elements with neutrons so that the target nucleus has a neutron added. For example, yttrium-90 microspheres to treat liver cancer are produced by bombarding yttrium-89 with neutrons. **Neutron activation** is the only common way that a stable material can be made radioactive. It is used to produce the radioisotopes, widely used in industry and medicine, by bombarding particular elements with neutrons so that the target nucleus has a neutron added. For example, yttrium-90 microspheres to treat liver cancer are produced by bombarding yttrium-89 with neutrons. Research reactors can also be used for industrial processing. **Neutron transmutation doping (NTD)** changes the properties of silicon, making it highly conductive of electricity. Large, single crystals of silicon shaped into ingots, are irradiated inside a reactor reflector vessel. Here the neutrons change one atom of silicon in every billion to phosphorus. The irradiated silicon is sliced into chips and used for a wide variety of advanced computer applications. NTD increases the efficiency of the silicon in conducting electricity, an essential characteristic for the electronics industry.

In materials testing reactors (MTRs), materials are also subject to intense neutron irradiation to study changes. For instance, some steels become brittle, and alloys which resist embrittlement must be used in nuclear reactors.

Problems Posed by Nuclear Waste of Reactors

What is nuclear waste?Nuclear waste is radioactive waste, meaning that it spontaneously emits radiation. It usually originates from the by-products of nuclear reactions.Radioactive waste degrades with time, releasing alpha, beta, and gamma radiation that pose many health risks to the environment and most organisms, including humans.The remains of the nuclear reactor becomes nuclear waste, which is extremely lethal due to its radioactivity. As a response, researchers have found several ways to shield and isolate radioactive waste till it degrades completely.The controversy behind nuclear technology is due to the radioactive waste it creates. Some elements used in nuclear reactors have extremely long half-lives and must be shielded from humans and the environment for thousands of years. For example, plutonium-239, an isotope used in the production of nuclear weapons, has a half-life of 24,200 years while uranium-235 Hiroshima has a half-life of 700 million years. These elements emit large quantities of radioactivity that is extremely dangerous. Too much exposure can be followed by Acute Radiation Syndrome (ARS), which includes skin burns, nausea, vomiting, and eventually death within days if the exposure and dosage of radiation is high.
Half-life (symbol $t\frac{1}{2}$) is the time required for a quantity (of substance) to reduce to half of its initial value. The term is commonly used in nuclear physics to describe how quickly unstable atoms undergo radioactive decay or how long stable atoms survive.

Nuclear Fusion Reaction

Nuclear fusion, process by which nuclear reactions between light elements form heavier elements (up to iron). In cases where the interacting nuclei belong to elements with low atomic numbers (e.g., hydrogen [atomic number 1] or its isotopes deuterium and tritium), substantial amounts of energy are released. Fusion reactions between light elements, like fission reactions that split heavy elements, release energy because of a key feature of nuclear matter called the binding energy, which can be released through fusion or fission.in other words, the mass of the heavier nucleus thus produced is less than the total mass of the two lighter nuclei. This missing mass corresponds to energy released in the reaction.

•there are two basic types of nuclear fussion reaction
those that preserve the number of protons and neutrons and (D-T fussion) and those that involve a conversion between protons and neutrons(H-H fusion). Reactions of the first type are most important for practical fusion energy production, whereas those of the second type are crucial to the initiation of star burning.

D-T fusion-involves the combination of a deuterium nucleus and a tritium nucleus to produce a helium–4 nucleus and a free neutron.

•general reaction-

$\mathrm{D} + \mathrm{T} \longrightarrow \mathrm{He} + \mathrm{n}\,\cdot$

before the reaction there are two protons and three neutrons. The same is true on the right.

practical energy generation requires the D-T reaction for two reasons: first, the rate of reactions between deuterium and tritium is much higher than that between protons; second, the net energy release from the D-T reaction is 40 times greater than that from the H-H reaction.

H-H fusion- involves the fusion of two hydrogen nuclei to form deuterium

$\mathrm{H} + \mathrm{H} \rightarrow D{+}\beta^{+}{+}\nu$

here represents a positron and v stands for a neutrino. Before the reaction there are two hydrogen nuclei (that is, two protons). Afterward there are one proton and one neutron (bound together as the nucleus of deuterium) plus a positron and a neutrino (produced as a consequence of the conversion of one proton to a neutron).

Stellar Nucloesynthesis

Stellar nucleosynthesis is the process by which elements are created within stars by combining the protons and neutrons together from the nuclei of lighter elements. All of the atoms in the universe began as hydrogen. Fusion inside stars transforms hydrogen into helium, heat, and radiation. Heavier elements are created in different types of stars as they die or explode.

•Fusion reactions in stars

The simplest type of atom in the universe is a hydrogen atom, which contains a single proton in the nucleus (possibly with some neutrons hanging out, as well) with electrons circling that nucleus. These protons are now believed to have formed when the incredibly high energy quark-gluon plasma of the very early universe lost enough energy that quarks began bonding together to form protons (and other hadrons, like neutrons). Hydrogen formed pretty much instantly and even helium (with nuclei containing 2 protons) formed in relatively short order (part of a process referred to as Big Bang nucleosynthesis).

As this hydrogen and helium began to form in the early universe, there were some areas where it was denser than in others. Gravity took over and eventually these atoms were pulled together into massive clouds gas in the vastness of space. Once these clouds became large enough, they were drawn together by gravity with enough force to actually cause the atomic nuclei to fuse, in a process called nuclear fusion. The result of this fusion process is that the two one-proton atoms have now formed a single two-proton atom. In other words, two hydrogen atoms have begun one single helium atom. The energy released during this process is what causes the sun (or any other star, for that matter) to burn.

It takes nearly 10 million years to burn through the hydrogen and then things heat up and the helium begins fusing. Stellar nucleosynthesis continues to create heavier and heavier elements until iron.

why does the nucloesynthesis processs stops on iron?

This is because, elements up to and including iron are produced exothermically (a process that releases energy) by fusion reactions in stars. On the other hand, producing elements heavier than iron in this way would be endothermic (a process that absorbs energy) Iron is the most stable of all atoms with higher binding energy per nucleon.from the graph of BEN we can obesrve that binding energy of elements increase up to iron means when atoms lighter than Iron fuses the are becoming more compact and smaller in mass than what they are before the fussion process (means they release energy)however, after Iron the binding energy per neucleon began to drop and the elements become more and more massive so,producing heavier elements than iron requires energy.The fusion of iron atoms only happens in events like Supernova and Hypernova explosions.

The proton proton chain

The sun is a huge volume of gases that are mostly hydrogen. The massive hydrogen provides billion of years of incessant fuel for solar nuclear fusion to continuously produce a huge amount of energy. proton-proton chain, chain of thermonuclear reactions is the chief source of the energy radiated by the Sun and other cool main-sequence stars.it involves series of reactions in which hydrogen nucleus is converted to helium nucleus with in the core of the sun. The first step in all the branches is the fusion of two protons into a deuterium. As the protons fuse, one of them undergoes beta plus decay, converting into a neutron by emitting a positron and an electron neutrino.

$^{1}\mathrm{H}+^{1}\mathrm{H} \longrightarrow {}^{2}\mathrm{H} + \mathrm{e}^{+} + \nu_{\mathrm{e}} + 0.42\mathrm{Mev}$

this reaction is initiated by the weak nuclear force. the deuteron produced in the first stage can fuse with another proton to produce the stable, light isotope of helium,$^{3}\mathrm{He}$

$^{2}\mathrm{H}+^{1}\mathrm{H} \longrightarrow {}^{3}\mathrm{He} + \gamma + 5.493\mathrm{MeV}$ This process initiated by the strong nuclear force rather than the weak force so its extremely fast by comparison to the first step to the extent that each newly created deuterium nucleus exists for only about one second before it is converted into helium-3. Once the helium-3 has been produced, there are four possible paths to generate.

•The p–p I branch

$^{3}\mathrm{He}+^{3}\mathrm{He} \longrightarrow 4\mathrm{He} + 2^{1}\mathrm{H} + 12.859\mathrm{MeV}$

•The p–p II branch
$3\text{He}+{}^{4}\text{He} \longrightarrow {}^{7}\text{Be} + \gamma + 12.859\text{MeV}$
${}^{7}\text{Be} + \text{e} \longrightarrow 7\text{Li} + \nu_{\text{e}} + 0.861\text{MeV}$
$7\text{Li} + 1\text{H} \longrightarrow 2{}^{4}\text{He} + 17.35\text{MeV}$
the p–p III is rare almost (0.3 percent) it involves the fussion of ^{3}He with preexisting ^{4}He to form beryllium-7 which undergoes further reactions to produce two helium-4 nuclei.
•The p–p IV branch
${}^{3}\text{He}+{}^{1}\text{H} \longrightarrow {}^{4}\text{He} + \text{e}^{+} + \nu_{\text{e}}$
Comparing the mass of the final helium-4 atom with the masses of the four protons reveals that 0.7 percent of the mass of the original protons has been lost. This mass has been converted into energy, in the form of kinetic energy of produced particles, gamma rays, and neutrinos released during each of the individual reactions. The total energy yield of one whole chain is 26.73 MeV. Energy released as gamma rays will interact with electrons and protons and heat the interior of the Sun. Also kinetic energy of fusion products (e.g. of the two protons and the 4 2He from the p–p I reaction) adds energy to the plasma in the Sun. This heating keeps the core of the Sun hot and prevents it from collapsing under its own weight as it would if the sun were to cool down.

Hydrogen Bombs vs Atomic Bombs

Hydrogen Bombs

hydrogen bomb,is a weapon whose enormous explosive power results from an uncontrolled self-sustaining chain reaction in which isotopes of hydrogen combine under extremely high temperatures to form helium in a process known as nuclear fusion. The high temperatures that are required for the reaction are produced by the detonation of an atomic bomb. In a thermonuclear bomb, the explosive process begins with the detonation of what is called the primary stage. This consists of a relatively small quantity of conventional explosives, the detonation of which brings together enough fissionable uranium to create a fission chain reaction, which in turn produces another explosion and a temperature of several million degrees. The force and heat of this explosion are reflected back by a surrounding container of uranium and are channeled toward the secondary stage, containing the lithium-6 deuteride. The tremendous heat initiates fusion, and the resulting explosion of the secondary stage blows the uranium container apart. The neutrons released by the fusion reaction cause the uranium container to fission, which often accounts for most of the energy released by the explosion and which also produces fallout (the deposition of radioactive materials from the atmosphere) in the process.

Atomic Bombs and How they work

There are two naturally-occurring isotopes of uranium. Natural uranium consists mostly of isotope U-238, with 92 protons and 146 neutrons (92+146=238) contained in each atom. Mixed with this is a 0.6 percent accumulation of U-235, with only 143 neutrons per atom. The atoms of this lighter isotope can be split, thus it is "fissionable" and useful in making atomic bombs. Neutron-heavy U-

238 has a role to play in the atomic bomb as well since its neutron-heavy atoms can deflect stray neutrons, preventing an accidental chain reaction in a uranium bomb and keeping neutrons contained in a plutonium bomb. U-238 can also be "saturated" to produce plutonium (Pu-239), a man-made radioactive element also used in atomic bombs. Uranium is not the only material used for making atomic bombs. Another material is the Pu-239 isotope of the man-made element plutonium. Plutonium is only found naturally in minute traces, so useable amounts must be produced from uranium. In a nuclear reactor, uranium's heavier U-238 isotope can be forced to acquire extra particles, eventually becoming plutonium.