32
NUCLEAR FISSION AND FUSION

32.1 INTRODUCTION

You know that the sun is continuously emitting an enormous amount of energy. It has been doing it for the last several billions of years and will continue to do so for billions of years to come. The source of this huge amount of energy emitted by the sun has ever puzzled human mind.

On August 6, 1945 an atomic bomb was exploded over Hiroshima, a large city of Japan. This explosion destroyed almost the entire city completely in a span of few seconds and lacs of lives were lost. It released an energy equivalent to that released by the explosion of a 20,000 ton TNT(tri nitro toluene) bomb. Much more powerful hydrogen bombs have been made whose destructive power is equivalent to several Mega tons of TNT. America, Russia and China have stockpiled large number of such bombs. The destructive power of their stock is so enormous that they can destroy the entire earth several times over.

The source of such colossal amount of energy are nuclear fission and fusion processes. The nuclear energy can also be used for production of cheaper electricity, which will improve the quality of human life. It will be interesting to know that the fission of 1 gm. of Uranium can supply 1 Mega Watt of power for 24 hours, where as a conventional thermal power plant will have to burn approximately 3 tons of coal for the production of this much electricity. In this lesson we will learn about the Nuclear Fission and Nuclear Fusion.

32.2 OBJECTIVES

After studying this lesson, you should be able to

- *differentiate between chemical and nuclear reactions;*
- *state the conservation laws as applied to nuclear and chemical reactions;*
- *write and balance nuclear reaction equation;*
- *explain the critical mass of fissile material;*
- *explain nuclear chain reaction;*
- *explain uncontrolled and controlled nuclear fission;*
- *explain moderator and its function;*
- *explain construction and working of a nuclear reactor; and*
- *explain the production of energy in stars;*

32.3 CHEMICAL AND NUCLEAR REACTIONS

(1) Chemical Reaction

We Know that all substances are made up of atoms. These have suitable number of electrons which are arranged in different orbits so as to possess the minimum potential energy. The outermost electrons in the atom are called valence electrons.

The atoms combine with other atoms or molecules (a group of atoms) and rearrange their valence electrons to further reduce their P.E. This change in P.E. is given out.

This process of interaction of atoms and molecules in which their valence electrons rearrange to form a new compound molecule with the release or absorption of energy is called chemical reaction. In this process the nucleus is not at all affected. Even the electrons in the inner orbits remain unaffected.

For example, the carbon atom reacts with oxygen as shown below by a chemical equation.

$$C + O_2 \rightarrow CO_2 + 4.08 \text{ eV} \qquad (32.1)$$

In this chemical reaction 4.08 eV energy is released for each reacting C atom. It is called the binding energy (B.E.) of CO_2 molecule. Such reactions in which energy is given out are called ***exothermic*** reactions.

This reaction can also be made to proceed in the reverse direction, if 4.08 eV of energy the B.E. of CO_2 molecule, is given to CO_2 under suitable conditions. The CO_2 molecule will break up into its constituents according to the following equation.

$$CO_2 + 4.08 \text{ eV} \rightarrow C + O_2 \qquad (32.2)$$

Such reactions, which take place only when energy is supplied from outside are called ***endothermic*** reactions.

As shown in equation (32.1), 4.08 eV energy leaves the system to form CO_2 gas. Therefore, mass of CO_2 molecule will be less than the total mass of C and O_2 by mass equivalent of 4.08 eV. Therefore, the loss of mass Δm is

$$\Delta m = \frac{4.08 \times 1.602 \times 10^{-19}}{9 \times 10^{16}} = 7.26 \times 10^{-36} \text{ kg} \qquad (32.3)$$

Such á small change in mass can not be detected, hence we say that the mass is conserved in chemical reactions, though change of mass does occur.

Alcohol undergoes chemical reaction with oxygen according to chemical equation given below.

$$C_2H_6O + 3O_2 \rightarrow 3H_2O + 2CO_2 + 14.17 \text{ eV} \qquad (32.4)$$

Here we see that 14.17 eV of energy is released per molecule of alcohol.

The important points to be noted in chemical reactions are

i) *Energy of the order of 10 eV is involved in these reactions.*

ii) *The energies of this order result in the change of mass of the order of 10^{-35} kg, which is extremely small and can not be detected. Hence we say that mass is conserved in chemical reactions.*

iii) *The total number of atoms of each type on the left hand side of the chemical equation is always equal to the total number of atoms of each type on right hand side.*

(2) Nuclear Reactions

In nuclear reactions, it is the nuclei of the reactants which interact with each other and not the electrons. They result in the formation of new elements. So, they are also called the transmutation of nuclei. In these reactions energies of the order of MeV are involved.

We know that atomic nucleus carry the entire positive charge of the atom. It is confined in an extremely small space. Hence the nucleus is surrounded by a strong electrostatic potential barrier also called the coulomb barrier as shown in fig (32.1). The coulomb barrier is about 3 MeV in height for carbon nuclei and 20 MeV for lead nuclei.

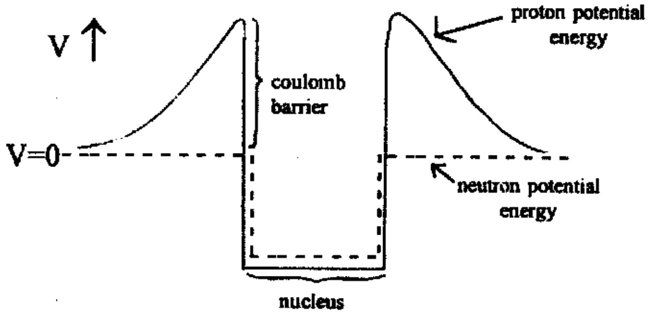

Fig. 32.1 : Proton and neutron potential energy near a nucleus.

Evidently, a charged projectile aimed at a nucleus is repelled back strongly by the coulomb barrier of the target nucleus. If the kinetic energy of projectile is not strong enough to cross over the barrier, it will come back with out producing any nuclear reaction. For a proton to enter the carbon nucleus and produce transmutation, it's energy should be 3 MeV or more. It is because of the large amount of energy involved in nuclear reactions that we do not observe these reactions in everyday life at ordinary temperatures and pressures.

The phenomenon of nuclear ***transmutation*** or nuclear reaction was discovered by Lord Rutherford in the year 1919. He was the first person to transform nitrogen into oxygen in the laboratory. He bombarded nitrogen gas with high energy α– particles obtained from a radioactive source. In this process new particles which were more penetrating than the incident α- particles were produced. These were established to be high energy protons. The transmutation is shown by the symbolic equation given below.

$$Q_1 + {}_2He^4 + {}_7N^{14} \rightarrow {}_8O^{17} + {}_1H^1 + Q_2 \qquad (32.5)$$

In this equation we see that the nuclei of two elements helium and nitrogen react to form oxygen and hydrogen nuclei. The energy Q_1 of incident α particles was 7.7 MeV. The energy Q_2 released in reaction was 6.5 MeV which was carried away by O and H nuclei.

Clearly this reaction required 1.2 MeV energy to be supplied from outside to take place. Therefore, it was an endothermic nuclear reaction.

Exothermic nuclear reactions also take place. For example when aluminum is bombarded by energetic alpha particles from radioactive source . The following nuclear reaction takes place and 10.7 Me V energy is released.

$$_{13}Al^{27} + {}_2He^4 + 7.7\,MeV \rightarrow {}_{14}Si^{30} + {}_1H^1 + 10.7MeV \quad (32.6)$$

Here we see that more energy is released than the input energy hence it is an exothermic reaction. There is a gain of nearly 3 MeV energy per reaction which is approximately 700,000 times the energy released in burning of one carbon atom. *But this reaction can't be used for production of energy because out of 125,000 incident alpha particles only one succeeds in producing the reaction.* Hence on the whole there is much more energy spent than produced.

Nuclear reaction can also be produced by protons, deuterons and neutrons. Out of these *neutrons are the best projectiles for producing nuclear reactions because they are neutral particles and they don't have to face the coulombian potential barrier*. Hence, even thermal neutrons can enter the target nucleus and produce nuclear reaction.

Some of the examples of nuclear reactions produced by these particles are given below.

$$_3Li^6 + {}_1H^1 \rightarrow {}_2He^3 + {}_2He^4 \quad (32.7)$$

$$_5B^{10} + {}_1H^2 \rightarrow 3\,{}_2He^4 \quad (32.8)$$

$$_5B^{10} + {}_0n^1 \rightarrow {}_3Li^7 + {}_2He^4 \quad (32.9)$$

Nuclear reactions also follow certain conservation laws like chemical reactions, which are given below.

The conservation laws for the nuclear reactions are

1. *The sum of the mass numbers of the reactants is always equal to the sum of mass numbers of the products. Refer equation (32.7) above, we see that $6 + 1 = 4 + 3$.*
2. *The sum of atomic numbers of the reactants is always equal to the sum of atomic numbers of the products. Refer equation (32.7) above, we see that $3 + 1 = 2 + 2$.*
3. *Nuclear reactions follow the law of conservation of energy. We know that mass is also a form of energy, therefore the sum of input kinetic energy plus the mass of the reactants is equal to the output kinetic energy plus the mass of the products.*
4. *Nuclear reactions also follow the law of conservation of momentum, which results in the distribution of kinetic energy among various product nuclei.*

Now, try to solve the following questions.

INTEXT QUESTIONS 32. 1

1. *Complete the following nuclear reaction equations*

   a) ${}_{9}F^{19} + {}_{1}H^{1} \rightarrow {}_{8}O^{16} + ?$

   b) ${}_{13}Al^{27} + {}_{0}n^{1} \rightarrow ? + {}_{2}He^{4}$.

   c) ${}_{90}Th^{234} \rightarrow {}_{91}Pa^{234} + ?$

   d) ${}_{29}Cu^{63} + {}_{1}D^{2} \rightarrow {}_{30}Zn^{64} + ?$

2. *Calculate the energy released in the nuclear reaction given below.*

   $${}_{5}B^{10} + {}_{1}D^{2} \rightarrow 3\ {}_{2}He^{4} + Q$$

   Given that nuclear masses of; Boron = 10.01294 amu; Deuterium = 2.014103 amu, and Helium = 4.002604 amu

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3. *${}_{7}N^{14}$ nucleus on bombarding with alpha particle produces ${}_{8}O^{17}$. Write the reaction equation and find the energy released.*
   Given that: Nitrogen mass = 14.003014 amu; Oxygen mass = 16.999138 amu; Helium mass = 4.002604 amu; Hydrogen mass = 1.007825 amu, and Energy of α particle = 7.7 MeV.

32.4 NUCLEAR FISSION

In the year 1938, Enrico Fermi, Otto Hahn and others irradiated uranium nuclei with neutrons to produce transuranic elements having Z greater than 92, which do not occur in nature. The incident neutrons were captured by the uranium nuclei and the neutron proton ratio increased in them. In reduceing this ratio, it became β active. A neutron changed into a proton and a β particle with few MeV energy was released according to equation:

$${}_{92}U^{238} + {}_{0}n^{1} \longrightarrow {}_{93}Np^{239} + {}_{-1}e^{0} + Q \qquad (32.10)$$

In this process a new transuranic element having atomic number 93 was produced as expected.

In the same year Otto Hahn, Meitner and Strassmann observed that sometimes elements of intermediate mass numbers were also produced followed by the release of nearly 200 MeV of energy. They were astonished to see the release of such a huge amount of energy, because in normal nuclear reaction few MeV energy is involved.

To explain this observation they suggested that on absorbing a neutron, the uranium nucleus splits up into two parts of intermediate masses. And as the B.E. per nucleon of nuclei of intermediate masses is nearly 0.9 MeV more than that of heavy nuclei like uranium, the energy released comes out to be nearly 200 MeV.

Fig. 32.2: Nuclear fission according to the liquid drop model

This process of splitting of atomic nucleus into two parts of nearly equal masses with the release of large amount of energy is called nuclear fission. The nomenclature **'fission'** was adopted from biology where division of a living cell into two parts is called fission of a cell.

Mechanism of Nuclear Fission

In the year 1939 Bohr and Wheeler gave the mechanism of nuclear fission and said that it was the U^{235} isotope of uranium which had undergone fission by thermal neutrons as shown by the nuclear reaction equation given below.

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + Q \qquad (32.11)$$

The neutrons emitted have energy in the range of 1 MeV and are called ***fast neutrons***. The fast neutrons, because of their high velocities, stay in the vicinity of uranium nucleus for a very short time, hence they are not as effective in producing fission in U^{235} as thermal neutrons whose energy is .03 eV. Fast neutrons having energy in excess of 1.1 MeV can however induce fission in U^{238} but to a very small extent.

The equation above gives only one of the several possible modes of fission of uranium nucleus. Different pairs of nuclei of intermediate masses are produced in fission of U^{235}. The number of neutrons emitted is also not always 3, sometimes it is less. The average number of neutrons produced per fission of U^{235} is 2.3.

Bohr and others explained this process of nuclear fission with the help of the ***liquid drop model*** of atomic nucleus. According to them, the atomic nucleus behaves like a liquid drop and has spherical shape. When a thermal neutron is captured by it, the B.E. of this neutron, which is 6.8 MeV for U^{235}, is released. This energy excites oscillations in the nucleus, which oscillates between spherical and dumb bell shape as shown in fig. (32.2). When the amplitude of these oscillations is large enough, the nuclear attraction, being short ranged, is reduced between the ends of the dumb bell. The repulsion between two positively charged ends of the dumb bell overcomes the ***weakand*** nuclear attraction and results in fission of the nucleus.

A substance which undergoes fission by thermal neutrons like U^{235} is called a fissile material. Other fissile materials are Th^{233}, U^{233}, U^{239} and Pu^{239}. All these have odd-even nuclei (odd Mass No. and even Atomic No.).

The energy released in the fission of U^{235} can be calculated by finding the mass defect produced by fission of nucleus as follows.
From the mass tables we have
Table 32.1:

Reactants		Products	Mass
mass of U^{235} mass of n^1	= 235.0439 amu = 1.008665 amu	Ba^{141} Kr^{92} $3 \times n^1$	= 140.9139 amu = 91.8973 amu = 3.025995 amu
Total **Mass**	= 236.052565 amu	Total	= 235.837195 amu
Thus, mass defect Energy released	= .2154 amu = .2154 × 931 $\simeq$ 200 MeV		

32.4.1 Chain Reaction

As we have seen above that when one neutron, called the parent neutron, is captured by U^{235} the nucleus splits up into two parts with the release of more than two neutrons called the ***daughter neutrons***. When the amount of uranium taken is small, the daughter neutrons escape the system and the reaction stops till another neutron from outside is captured. When the mass of fissile material is increased, some of the daughter neutrons fail to escape and induce fission. On increasing the mass still further, a self sustained nuclear chain reaction occurs. ***In a chain reaction the number of fissions produced by daughter neutrons in any generation is equal to or more than the number of fissions produced by parent neutrons in the previous generation.***

The minimum mass of a fissile material required to produce a self sustained chain reaction without any supply of neutrons from outside is called the critical mass. When the mass of fissile material is more than the critical mass such that 2 secondary neutrons emitted by each nucleus undergoing fission induce fission in next generation, a rapidly growing chain reaction is produced. It is shown in fig. (32.3).

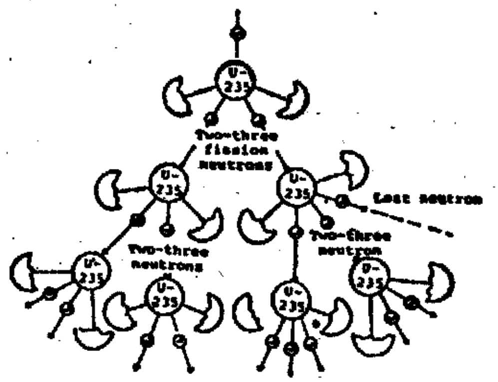

Fig. 32.3 : Nuclear Chain reaction

The ratio of the number of daughter neutrons inducing fission in any generation to the number of parent neutrons in previous generation is called 'neutron multiplication ratio k. If $k < 1$, then the fission reaction dies away. If $k = 1$, then the fission reaction continues indefinitely at a constant power level. If $k > 1$, then the reaction grows exponentially till the system explodes. The chain reaction can be controlled as well as un controlled.

i) Controlled Chain Reaction

In a controlled chain reaction multiplication ratio k is controlled by changing the number of daughter neutrons available in any generation. In this case we can change the power level, keep it constant or stop the reaction as desired. This is achieved in a nuclear reactor about which we will study below.

ii) Uncontrolled Chain Reaction

In an uncontrolled chain reaction the value of k is kept as much above one as possible. The reaction grows exponentially to the explosive level. It is achieved for making a nuclear bomb.

32.4.2 Nuclear Reactor

A nuclear reactor or atomic pile is a device to produce controlled chain reaction. The first nuclear reactor was made by E. Fermi at the University of Chicago USA. Chain reaction was realized in it on Dec. 2, 1942.

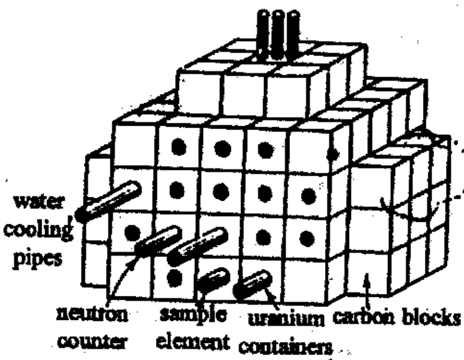

Fig 32.4: Uranium pile of carbon blocks used to produce pintanium - 239 and many other vadio active atomic nuclei

It was a huge structure assembled from rectangular blocks of extremely pure graphite. Large number of cylindrical rods of natural uranium encased in aluminum tubes called ***fuel rods*** were inserted in the holes in structure in a regular pattern as shown in fig.32.4. The graphite blocks slow down the fast secondary neutrons by collision and reduce their energy to thermal level between emission and next collision with U^{235} to produce fission. It requires nearly 110 collisions with carbon nuclei to get slowed down to thermal level. The graphite used is called a ***moderator***. ***A moderator is a material used in a nuclear reactor to slow down the fast neutrons.***

Some cadmium rods were also inserted at different points. These are called ***control rods***. Cadmium absorbs large number of neutrons. When the rods are fully inserted they absorb all neutrons and fission stops. When they are slowly pulled out the number of neutrons producing fission increases and we say the power level of pile rises. When the required power level is reached the control rods are slowly inserted so that only one secondary neutron per atom undergoing fission is able to produce fission in each generation. Under this condition the fission will neither grow nor die. The pile runs at constant power level and emit huge amount of energy and radiation consisting of mainly neutrons and gamma rays. The whole assembly was enclosed by a thick concrete wall on all sides to stop radiation from escaping the pile. The control rods and fuel rods are moved by remote control.

Other substances used as moderator in later piles are heavy water and ordinary water. In India we produce heavy water at Nangal in Panjab for use in our reactors. Our first research reactor named APSRA was set up at Bhabha Atomic Research Centre, Trombay. It used enriched uranium as a fuel and water as moderator. It was used for research purposes. Our second research reactor was Canada–India Reactor. It was also set up at Trombay. The other Indian Reactors at Tarapur, Kalpakkam, Kota & Narora set up for power generation use heavy water as moderator.

Intext questions 32. 2

1. *Why a U^{238} nucleus becomes β active after absorbing a neutron ?*

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2. *In a nuclear fission*
   i) Atomic nucleus breaks into two parts. ii) Proton breaks into two parts.
   iii) Neutron breaks into two parts. iv) Electron breaks into two parts.

3. *Select the fissile material*
   i) U^{238} ii) Ba^{141} iii) Pu^{239} iv) C^{12}

4. *Amount of energy released in a nuclear fission is*
   i) 1 MeV ii) 10 eV iii) 200 MeV iv) 10 keV

5. *In fission of U^{235}*
   i) α particles are emitted ii) β particles are emitted
   iii) Protons are emitted iv) Nuclei of intermediate mass are emitted

6. *Power level of a reactor is 1 watt. Find the number of U^{235} nuclei undergoing fission per second.*

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7. *Find the amount of U^{235} consumed in an atomic explosion equivalent to 20,000 tons of TNT. Given that 1 gm. of TNT gives 1k cal.*

32.5 NUCLEAR FUSION

Let us have a look at the nuclear BE/A (binding energy per nucleon) graph fig. 31.1 of the previous lesson once again. We observe that BE/A of heavy nuclei is less than that of intermediate mass nuclei by nearly 0.9 MeV/A. This difference provided the 200 MeV energy released in fission reaction. At the other end of this graph again we find a large difference in BE/A

The BE/A of some light nuclei are given below.

Table 32.2 : BE/A of some nuclei

Nucleus	*Mass in amu*	*BE in MeV*	*BE/A MeV/A*
H^1	1.007825	0	0
D^2	2.014103	2.22	1.11
T^3	3.016049	8.482	2.827
He^3	3.016029	7.718	2.573
He^4	4.002603	28.295	7.074
Li^6	6.015126	31.991	5.332
Li^7	7.015982	39.244	6.541

From the difference in BE/A we conclude that tremendous amount of energy can be released if medium weight nuclei are synthesized from lighter nuclei. One such example would be

$$_1D^2 + {}_1D^2 \rightarrow {}_2He^4 + Q$$

The total BE of reactants $= BE_1 = 2 \times 2.22 = 4.44$ MeV

The Total BE of product $= BE_2 = 28.295$ MeV

Hence, $Q = (BE_2 - BE_1) \sim 24$ MeV

Thus, we see that energy released per nucleon in this reaction is 24/4 that is 6 MeV which is nearly 7 times the energy released in nuclear fission.

But the process of fusion is not that simple because both the deuterons are positively charged. When we try to bring them together to fuse into one nucleus they repel each other very strongly and the reaction is ordinarily impossible.

To achieve this reaction the deuterons have to be heated to nearly 10 million degree K so that they can collide with each other with sufficient kinetic energy to over come the repulsion and get fused into a helium nucleus.

The process of fusing two light nuclei to form a heavier nucleus with the release of tremendous amount of energy is called the nuclear fusion or thermonuclear reaction.

The gaseous reactants can be heated to such high temperatures either by nuclear fission or by passing very high electric current discharge through the gas. But the problem of maintaining this temperature continuously and containing it has not yet been solved fully. The controlled thermonuclear reaction necessary for exploiting this source of energy has not been achieved so far. The research laboratories the world over are busy to tackle these problems.

Almost inexhaustible amount of deuterium is present in the ocean. If this process is harnessed our energy problem will be solved forever. We will get an endless supply of cheap electricity without any pollution.

32.5.1 Energy in the Sun and Stars

The stars like our sun are very massive objects. They have been continuously emitting tremendous amount of energy for the last billions of years. The mass equivalent of energy emitted by the sun is approximately 3 million tons per second.

Such a huge amount of energy can't be obtained by the burning of conventional fuels like coal. Nuclear fission can also not be the source of this energy because heavy elements do not exist on the sun in large quantity. The sun mainly consists of hydrogen and helium gases.

Huge mass of sun produces extremely strong gravitational field. The gravitational pull compresses its constituent gases to enormous pressure resulting in the rise of temperature to millions of degrees K at its center. It has been estimated that the temperature at the center of sun is 20 million degree K. At such high temperatures and pressures thermonuclear reaction sets in resulting in the release of large amount of energy

Bethe proposed that fusion of hydrogen into helium progresses through the ***Carbon-Nitrogen cycle*** given below.

$$ {}_6C^{12} + {}_1H^1 \rightarrow {}_7N^{13*} \rightarrow {}_6C^{13} + {}_{+1}e + Q $$

$$ {}_6C^{13} + {}_1H^1 \rightarrow {}_7N^{14} + Q $$

$$ {}_7N^{14} + {}_1H^1 \rightarrow {}_8O^{15*} \rightarrow {}_7N^{15} + {}_{+1}e + Q $$

$$ {}_7N^{15} + {}_1H^1 \rightarrow {}_8O^{16*} \rightarrow {}_6C^{12} + {}_2He^4 + Q $$

Nuclei marked '*' are in excited state.

From these equations we see that ${}_6C^{12}$ atom which was used during the first reaction has been regenerated in the last reaction of the C-N cycle. It acts only as a catalyst. The net effect of the cycle is

$$ 4\,{}_1H^1 \rightarrow {}_2He^4 + 2\,{}_{+1}e + Q $$

The overall result of this cycle is fusing of four hydrogen nuclei into a helium nucleus with the release of two positrons and 26.8 MeV of energy. ***The tremendous amount of energy released in the thermonuclear nuclear reaction is the source of energy of stars.*** The quantity of hydrogen in sun is sufficient to keep it shining for nearly 8 billion years.

Bethe's C-N cycle does explain the enormous amount of energy emitted by the sun but this is not the only process going on there. Other possible thermonuclear nuclear processes must also be taking there.

INTEXT QUESTIONS 32. 3

1. *200 MeV energy is released on fission of one U^{235} nucleus & 26.8 MeV energy is released in fusion of 4 protons. Which process releases more energy per unit mass?*

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2. ${}_1H^1 + {}_3Li^7 \rightarrow {}_2He^4 + Q$. *Evaluate Q*.

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3. ${}_1H^2 + {}_1H^2 \rightarrow {}_1H^3 + {}_1H^1 + 4\,MeV$.; *Find the mass of Tritium.*

32.6 APPLICATIONS OF NUCLEAR ENERGY

As you know the Energy released in nuclear fission and fussion is called nuclear energy. The amount of energy released in these processes is so enormous that even nature has used this energy to provide eternal shine to stars.

Man needs energy for all economic activities in life. The amount of energy consumed per capita is a measure of advancement of a nation. The conventional sources of energy are depleting very fast and may exhaust completely in next 50 years. So the nuclear energy is the only important substitute for this important commodity.

The nuclear energy can be employed both for constructive as well as destructive purposes as any other boon of nature. We shall discuss both these applications.

32.6.1 Peaceful Applications

One of the most important peaceful application of this energy is the *generation of electricity* for feeding the energy starved homes and industry of today. For this purpose the nuclear reactor described earlier is modified to run at higher power level. In India 235 MW pressurized heavy water reactors (PHWR) are adopted for use at various Nuclear Power Plants. In these reactors natural uranium is used as a fuel and heavy water as moderator. The heat generated is extracted from the reactor by circulating either the low melting point metal like sodium or high boiling point hydrocarbon through the reactor core. The heated liquid is passed through a heat exchanger where it generates steam at high pressure. The steam is used to run steam turbines which are coupled to the electrical generators to produce electricity. The steam after running the turbines is condensed back to water by cooling in condenser and re-circulated in the heat exchanger for continuous running of the generator as shown in fig. (32.5).

One of the main advantage of nuclear power plant is that the fuel is not required to be fed continuously like gas or coal in a thermal plant. It does not *discharge smoke or ash in the atmosphere like the conventional power houses*. On the other hand the fuel once loaded in a reactor runs for nearly 6 months at a stretch. Because of this property nuclear power plants have been used to power huge ships and submarines. They produce electrical energy at a much cheaper rate of nearly Rs. 0.70 p per kwh where as in a thermal power plant it costs more than Rs. 1 per kwh.

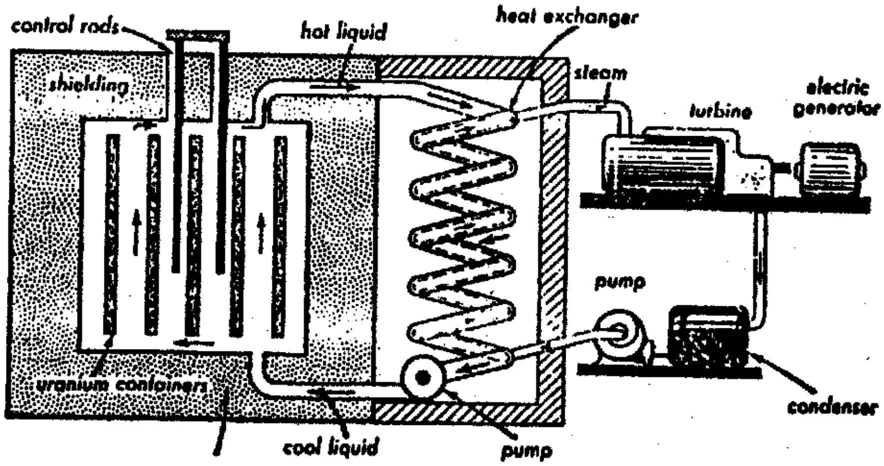

Fig. 32.5: Schematic diagram of one type of nuclear power plant

The used fuel of a reactor is highly radioactive because a large number of radio isotopes including $_{94}Pu^{239}$ are produced in it. India has developed its own facility to treat this used fuel and extract from it $_{94}Pu^{293}$ and other *radio isotopes which find wide application in agriculture, medicine, industry and research.* $_{94}Pu^{239}$ is a fissile material and is used as a fuel in making new reactors. The left over part of the used fuel is highly radio active and dangerous. To avoid its spreading in atmosphere and water sources, it is converted into glass and embedded deep in the earth.

At present India has nuclear power plants at Kalpakkam, Kota, Narora and Tarapur. The fuel elements are prepared at Jadugoda in Orisa. The heavy water is also produced in our own country at various fertiliser plants. India has a plan to produce 10,000 MW nuclear power by the end of this century.

32.6.2 Destructive Applications

(i). Atom Bomb

The making of an atom bomb is an example of the destructive application of nuclear energy. During the times of world war- II the pressing need to make an atom bomb is responsible for the rapid development of nuclear energy technique which would have otherwise taken a much longer time.

An atom bomb is made of a very thick walled strong steel tubular vessel. The working of an atom bomb is based on nuclear fission reaction. Two sub critical pieces of a fissile material like Uranium - 235 or Plutonium -239 are fixed inside the tube at the two ends. A highly explosive material is filled behind one of the two pieces of the fissile material. A neutron source is fixed near the other piece as shown in fig.32.6. Normally the assembly is sub critical and no explosive nuclear fission can takes place. When we want to explode it, the explosive material is ignited. This explodes and the piece of fissile material on this side strike the other piece with an immense force and a block of super critical fissile material is formed. In this block the fission reaction starts which grows very rapidly in an exponential manner. The container is very strong and it takes a few micro seconds to explode. During this time nearly one kilogram of fissile material undergoes fission thereby releasing a tremendous amount of energy and creating an immense explosion. For a few micro seconds center of the sun comes near the site of explosion and every thing burns. Due to the immense explosion a huge shock wave spreads which wipes out every thing in an area of few km radius around the center of explosion. Every thing around the center of explosion is irradiated with an immense flux of gamma rays, neutrons and particles of strongly radio active substances created during fission. Nothing is left to be killed or destroyed.

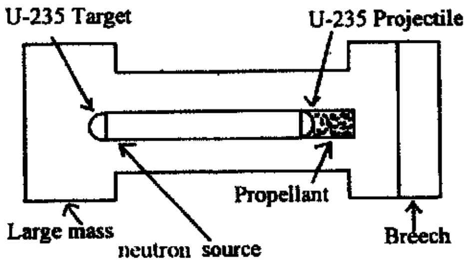

Fig. 32.6: Adiagram of suggested atomic bomb mechanism

(ii) Hydrogen Bomb

The hydrogen bomb is another destructive application of nuclear energy. The working of a hydrogen bomb is based upon nuclear fusion reaction. We know that nuclear fusion reaction can only be achieved if the reactants are heated to nearly 10 million degree K. Such a high temperature is produced in an atomic explosion. Therefore an atomic explosion is exploited for making a hydrogen bomb.

An atomic bomb is made as described earlier. It is surrounded by a thick layer of some substance like 'LiD' which contains heavy hydrogen 'Deuterium'. Then the whole assembly is enclosed in another strong bomb made of extremely strong steel. The atom bomb is ignited from outside by electrical device. This explosion raise the temperature of heavy hydrogen and other constituents of the covering layer of the atom bomb to several million degrees K. At this temperature deuterium and lithium are fully ionized and get converted into plasma. Their nuclei start hitting each others with immense kinetic energy and thereby getting fused with each other as shown in the equations below.

$$_1D^2 + {}_1D^2 \rightarrow {}_2He^4 + 24\ MeV$$

$$_1D^2 + {}_3Li^7 \rightarrow 2\,{}_2He^4 + {}_0n^1 + 15\ MeV$$

From the equations we see that tremendous amount of energy is released in these reactions. Both these reactions and the fission reaction proceeds at extremely fast rate and grow to full strength within a span of few micro seconds. The energy equivalent to that released in the burning of 1 million Ton of TNT is produced resulting in an explosion of tremendous intensity. This type of bomb has very large destructive power, but it is cleaner than the atomic (fission) bomb of same intensity. Thermonuclear bomb doesn't spread that much harmful radio activity in the surrounding.

INTEX QUESTIONS – 32.4

1. *What is the power of reactors used for power generation in our country?*

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2. *What substances are used to extract heat from reactor?*

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3. *What type of reactors are used in India for power generation ?*

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4. *How much U^{235} undergoes fission in an atomic bomb which releases energy equivalent to 20,000 tons of TNT. (Given that 1 gm of TNT gives out 1000 calorie of heat).*

32.7 WHAT YOU HAVE LEARNT

- It is the valence electrons which take part in chemical reaction and not the nucleus and the energy involved in a chemical reaction is of the order of 10 eV
- Total number of atoms of each type on LHS of a chemical equation = the total number of atoms of each type on RHS of the equation. Change of mass in a chemical reaction is negligible.
- In a nuclear reaction the atomic nuclei interact and a new element is formed.
- The phenomenon of trasmutation was discovered by Lord Rutherford in 1919.
- Energy involved in nuclear reaction is of the order of MeV. Because the energy involved in a nuclear reaction is of the order of MeV measurable change of mass takes place.
- The sum of atomic numbers on LHS of a nuclear reaction equation = the sum of

atomic numbers on RHS of equation.

- The sum of mass numbers on LHS of a nuclear reaction equation = the sum of mass numbers on RHS of equation.
- The splitting of heavy nuclei into two nearly equal parts is called nuclear fission and Energy involved in a fission reaction is ~ 200 MeV.
- Transuranic element is produced when a heavy nucleus absorbs a neutron and emits β particle.
- BE of extra neutron absorbed by U^{235} nucleus is released & excites oscillations in it, which result in fission.
- Energy of fast neutrons ~ 1 MeV and that of thermal neutrons is ~ .03 eV.
- Neutrons don't face coulombian repulsion while hitting a nucleus.
- On the average 2.3 neutrons are emitted on fission of U^{235}
- Fast neutrons pass through the neighbourhood of U^{235} in a very short time therefore they fail to induce fission in it. Neutrons of energy > 1.1 MeV induce fission in U^{238}.
- Substances that undergo fission are called fissile substaus. Th^{233}, U^{233}, U^{235}, U^{239} & Pu^{239} are fissile materials.
- Chain reaction occurs when more than 1 daughter neutron induce fission for each fission induced by a parent neutron in previous generation.
- Neutron multiplication ratio '*k*' is equal to the ratio of number of neutrons inducing fission in a generation to the No. of neutrons which induced fission in previous generation. For a chain reaction to take place k > or = 1 .
- For a controlled chain reaction $k = 1$. for an uncontrolled chain reaction $k > 1$, and For an atomic explosion k >>1.
- Nuclear reactor is a device to produce controlled chain reaction.
- Moderator is the material which reduces the kinetic energy of fast neutron by collision. Carbon, water and heavy water are used as moderators.
- India's first research reactor at Trombay was 'APSRA'.
- In a nuclear fusion two light nuclei are fused into one.
- For producing nuclear fusion the reacting nuclei must be heated to nearly 20 million degree K to gain sufficient kinetic energy to overcome the coulombian potential barrier.
- In stars energy is produced by nuclear fusion reaction.
- In C-N cycle 4 H atoms fuse to form 1 He atom & emit 2 positrons + 26.8 MeV energy. C only acts as a catalyst.
- Mass equivalent of energy emitted per second by the sun is 3 million Tons per second.
- Amount of H consumed in the sun is nearly 400×10^6 m Ton per second.
- Fusion reaction was started at the centre of the sun because of intense heating of gases due to immense compression under its own weight.
- Electrical energy generated in nuclear power plant is cheaper.
- Indian power reactors are 'PHWR' type They use heavy water as moderator and natural uranium as fuel.
- U^{238} in fuel changes into Pu^{239} which is as good a fissile material as uranium 235.
- From nuclear reactor's burnt fuel we get a large number of radio isotopes which find application in agriculture, medicine and industry.
- Heavy water is produced in our fertilizer plants.
- In an Atomic Bomb two sub-critical masses of fissile material are kept apart. For exploding it the two pieces are pressed against each other to make it super critical.
- On exploding an atomic bomb the temperature at its centre rises to approximately 100 million degree K.

The amount of U^{235} undergoing fission in a 20,000 Ton TNT capacity bomb is nearly 1 kg. The energy released by the first Hydrogen Bomb was equivalent to that released by 1 Mega Ton of TNT.

32. 8 TERMINAL QUESTIONS

1. How does a nuclear reaction differ from a chemical reaction ?
2. What is the use of moderator and absorber in a fission reactor ?
3. On the basis of BE per nucleon versus mass number curve explain nuclear fission and nuclear fusion reactions as the source of energy.
4. What is a nuclear reaction? State the conservation laws obeyed in nuclear reactions. Give 3 examples of nuclear reactions.
5. What are endothermic and exothermic nuclear reactions? Illustrate your answer with one example of each.
6. What is a nuclear fission? Give an example to illustrate your answer.
7. What is critical mass of a fissile material?
8. What is neutron multiplication factor? How is it defined?
9. What is a moderator? How does it function? How many collisions a fast neutron has to undergo to get thermalized in graphite?
10. Find the mass of U^{235} consumed to generate 100 mega watts of power for 30 days.
11. Heavy hydrogen undergoes the the following fusion reaction

    $_1D^2 + {_1D^2} \rightarrow {_2He^4} + 24$ MeV.

    Find the amount of heavy hydrogen used in producing the same energy as above. Compare the two results.
12. What is nuclear fusion? Write an equation of nuclear fussion to support your answer.
13. What is the source of energy in the sun? How is it generated? Illustrate with an example.
14. Describe the construction of an atomic reactor.
15. Describe the construction and working of an atom bomb.
16. Describe the construction and working of hydrogen bomb.
17. Calculate the energy released in a fusion reaction

    $3\,(2He^4)\ {_6C^{12}}$

    Given, the mass of on α-particle = 4.00263 amu.

ANSWERS TO INTEXT QUESTIONS

Intext Questions 32.1

1. a. $_9F^{19} + {_1H^1} \rightarrow {_8O^{16}} + {_2He^4}$;

   b. $_{13}Al^{27} + {_0n^1} \rightarrow {_{11}Na^{24}} + {_2He^4}$

   c. $_{90}Th^{234} \rightarrow {_{91}Pa^{234}} + {_{-1}e^0}$;

   d. $_{29}Cu^{63} + {_1D^2} \rightarrow {_{30}Zn^{64}} + {_0n^1}$

2. 17.9 MeV

3 $_7N^{14} + {_2He^4} \rightarrow {_8O^{17}} + {_1H^1}$, 6.5 MeV.

Intext Questions 32.2

1. Due to increase of n/p ratio above the natural ratio its stability decreases. To decrease the ratio to attain more stability it emits a ß particle.
2. i 3. iii 4. 200 MeV. 5. iv. 6. 1.01 Mev.

Intext Questions 32.3

(1) 0.84 MeV , 6.7. MeV (2). 17MeV (3) 2.01 MeV.

Intext Questions 32. 4

1. 235 MW; 2. Sodium metal & Hydrocarbon; 3. Pressurized Heavy Water Reactor; 4. nearly 1 kg.