NET, IAS, State-SET (KSET, WBSET, MPSET, etc.), GATE, CUET, Olympiads etc.: Science and Technology Nuclear Fusion

Nuclear Fusion

1. There are two types of fusionuncontrolled and controlled.In uncontrolled nuclear fusion, vast amount of energy in uncontrolled manner is released causing destruction onlythe hydrogen bomb is an example. Thus uncontrolled nuclear fusion is not of use for constructive purpose.In controlled nuclear fusion, the vast energy is released steadily so it can be used for peaceful purposes, say, the nuclear fusion reactors.
2. Hydrogen constitutes about 70% mass of the sun and other stars. The three isotopes of hydrogen (protium-1H1, deuterium-1H2, and tritium-1H3) and light isotope of helium (2He3) constitute the fuel of the nuclear fusion process.
3. Among all fuels, deuterium is the ideal and principal raw material for fusion reactors because:
4. Deuterium is non-radioactive, and inert and denser than hydrogen. So it is relatively easy and safe to produce, handle and store deuterium gas. Further, the by-products like oxygen formed during production of deuterium can be used in the medical field, sea diving, welding, etc. Tritium is radioactive so its production and storage involves radiation hazards. \
5. Deuterium is a renewable fuel as it is obtainable from water. This way, deuterium is as close as the nearest body of water. The ocean and other water bodies contain more than 25 million tons of deuterium. Thus, water bodies provide inexhaustible amount of deuterium as source of energy.
6. Burning of one deuterium nuclei through fusion produces about
7. 2 MeV energy (when deuterium alone is used as fuel) . So 18 g of water produces sufficient amount of heavy water and in turn sufficient deuterium to produce about 1022 MeV energy. If fusion reactors operate at 50% efficiency then 18 g ordinary water has capacity to produce about 222 KWH power sufficient to operate one cooler, one TV, one refrigerator, tube lights and electric bulbs for one month for a family.

Products of Nuclear Fusion

1. The products of nuclear fusion are vast amount of energy and some particles with by-product heliuman inert, non-polluting, non-radioactive and non-greenhouse gas. Helium finds many uses:
    a. As cryogenic rocket fuel
    b. In superconductivity as mercury on cooling by liquid helium becomes superconductive at 4 K
    c. For filling tyres of airships and balloons for meteorological observations as it is noninflammable with lifting power being equal to 92% of that of hydrogen gas
    d. Mixture of helium with oxygen is used for sea-divers for respiration, and in treatment of certain respiratory diseases like asthma
    e. For providing inert atmosphere in the welding of metals or alloys that are easily oxidized.

Hurdles in Nuclear Fusion

1. The energy intensity of renewable sources like wind, ocean, etc. Is very low. So, fusion is a renewable, clean commercial and limitless source of energy capable of meeting industrial and household power needs.
2. But then what is stopping us from using nuclear fusion as an energy source? Fusion involves some inherent problems like creation of plasma state, and fusion of positive charged nuclei against extremely high repulsion between them. To get the plasma state and to overcome nuclear repulsion during nuclear fusion, nuclei must be brought very close together not only by high pressure but also with high kinetic energies as required activation energy for fusion is very high. For this, a temperature about 108 K is required.
3. Nuclear fusion is possible in stars as temperature about 108 K is available in stars. On earth, it may be obtained by exploding a fission bomb as in hydrogen bomb. But, this way of fusion is an uncontrolled process that release uncontrolled energy leading to destruction.
4. For peaceful use of fusion energy, the nuclear fusion process has to be controlled. Till now, there is no available method of controlling the release of fusion energy. A controlled release of fusion energy is possible in a fusion reactor but its construction is problematic.
5. The main problem is the manufacturing of a container capable of containing hot plasma state under the required conditions of high temperature and high pressure. So far, there is no manufacturing material that can withstand 108 K temperature.

Developments in Fusion Technology

1. Considerable efforts have been made to accomplish controlled fusion. Scientists have been working for production of temperature of the order of 108 K and hot plasma without destroying the container itself and without letting the plasma to cool on touching the wall of the container.

2. The production of high temperature is based on electromagnetic and laser devices.In electromagnetic devices, the container is surrounded by strong and circular magnetic fields that repel the plasma and force and compress it away from the sides into center of the container. Further, the extremely dense flow of current within the plasma heats it up to enormously high temperature.
3. The high pressure and high temperature developed in the plasma state of fuel forces plasma particles to fuse together to produce helium nuclei and enormous energy in the form of heat. This is known as the 'Pinch Effect' On the basis of this effect, in experimental reactors, fusion has been observed for a fraction of a second. Three types of experimental reactors, namely magnetic bottle, tokamak and stellarator have been tried on the same principle i.e. … Magnetic containment and compression of plasma.
4. A major step taken towards imitation of stellar energy was the launch of International Thermonuclear Experimental Reactor (ITER) project at Cadarache in France. ITER will be designed for fusion of about 0.5 g of deuterium-tritium mixture in its approximate 840 sq m fusion reactor chamber to produce approximate 500 MW power sustained for up to 400 seconds. ITER is based around a hydrogen plasma torus operating at over 100 millions Kelvin temperature.
5. The project is anticipated to last for thirty years 10 years for construction, and 20 years for operation. The first plasma operation is expected in 2016, and a commercial fusion reactor is expected in 2050.

India and Fusion Technology

1. Several Indian research institutions are engaged in different components of fusion research. Some such institutions are the Bhabha Atomic Research Center (BARC) , Indira Gandhi Centre for Atomic Research (IGCAR) , Center for Advanced Technology (CAT) , Institute for Plasma Research (IPR) and Physical Research Laboratory (PRL) .
2. In 1989, India's indigenous tokamak named 'Aditya' was installed at IPR, Gandhinagar.In Aditya, plasta at about 5 million K can be generated, which however is not sufficient to trigger fusion.
3. India's electricity generation capacity would need to go up six to seven fold from the current installed capacity of around 1.15 lakh MW to between 7.8 – 9.6 lakh MW by 2031 – 32 (end of XV plan period) . To meet this requirement, India is trying to tap non-conventional energy resources including fusion reactor technology. *Courtesy: Science Reporter*