A Starter Lesson in Cold Fusion

This starter lesson is in the form of a science tutorial designed to provide a background for understanding cold fusion, a radiationless form of fusion energy, and its difference from other energy sources. It has been written for students and non-professional readers.

A Science Tutorial

There are now four distinct types of energy production: 1) chemical energy, that powers our cars and most of our civilization, 2) nuclear fission energy, as used to generate about 15% or our electricity, 3) plasma fusion nuclear energy, which powers the sun and most stars, and 4) cold fusion nuclear energy, which initially appeared as unexplained heat in the laboratory studies of a pair of experimenters. The three types of nuclear energy produce 10 million times as much heat per pound of fuel than occurs with chemical energy. How do these types of energy differ?

Protons and Electrons. The Hydrogen Atom

Nature has provided us with 2 types of stable charged particles, the proton and the electron. The proton is heavy, normally tiny, and has a positive charge. The electron is light, normally diffuse and fuzzy, and has a negative charge. The positive charge and the negative charge attract each other, just like the north pole of a magnet attracts the south pole of a magnet. When you bring 2 magnets together with the north pole of one facing the south pole of the other, they pull together, bang! When they bang into each other they release a little bit of energy in the form of heat, but it is too small an amount to easily measure. To pull the magnets apart you have to do work, which is another way of saying you have to use up energy. It's almost like pulling a rock back up a hill. Rolling the rock down a hill actually creates a little heat, and pulling the rock back up the hill takes energy.

In the same way the positive charge of the proton pulls on the negative charge of the electron and they stick together, releasing energy in the process. The simplest atom is a hydrogen atom, designated H. The hydrogen atom is nothing but one fuzzy electron hugging a compact proton. The proton is the nucleus of the hydrogen atom. If you knock the electron off the hydrogen atom you get a positive ion H^+, which is nothing more than a lone proton. An ion is the name applied to an atom or molecule that has lost or gained one or more electrons, hence is no longer electrically neutral.

Other Atoms

Other atoms (oxygen, nitrogen, iron, etc.) have different numbers of protons inside them, which means they all have different plus charges. The nucleus of the helium atom has 2 protons inside it, hence has plus 2 charge, and requires 2 electrons to neutralize its charge. When 2 electrons stick to it, it becomes a helium atom. The oxygen nucleus has 8 protons and has charge 8. When 8 electrons stick to it, it becomes an oxygen atom. The nitrogen atom has 7 electrons, while iron atoms have 26. But all the atoms are built more or less the same way, with a compact positively charged nucleus embedded in a cloud of fuzzy electrons. The fuzzy cloud surrounding the hydrogen nucleus is shown in Figure 1.2,1 The difference in size between the compact nucleus and the fuzzy electrons is enormous. The sun has a diameter only about 100 times that of the earth. The electron cloud in an atom has a diameter which is about 100,000 times that of the nucleus. This is a big number. If a proton was increased in size to be the width of a blade of grass and placed in the center of a football field, the electron cloud would enclose the whole football field. Cube these numbers to get the difference in volumes.

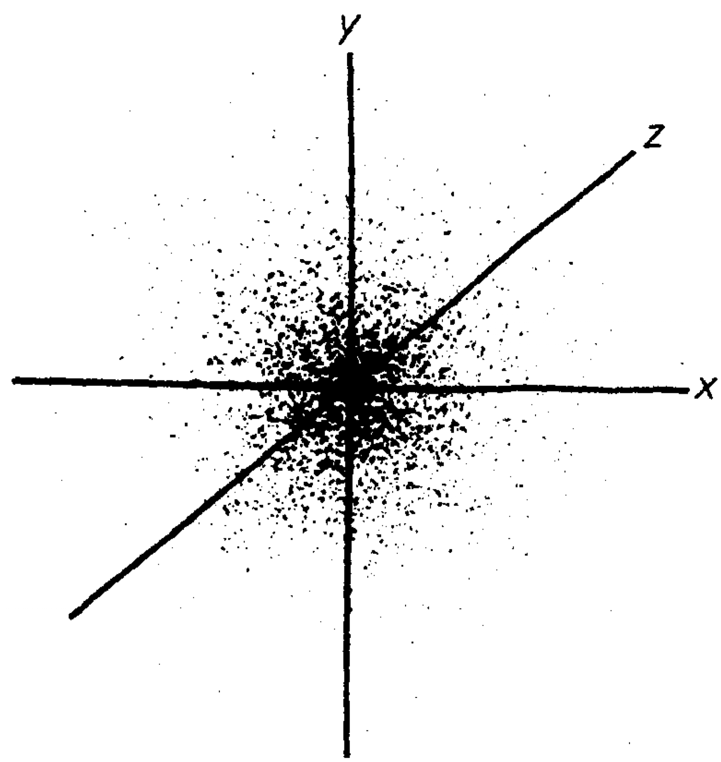

Fig. 1.2,1 A hydrogen atom consists of a proton embedded in a fuzzy cloud of electron charge. This figure is a computer plot of electron density taken from "Chemistry, experimental foundations" by R.W. Parry, L.E. Steiner, R.L. Tellefsen,. and P.M. Dietz (Prentice Hall, Inc., Englewood Cliff, NJ, 1970).

Chemical Energy

The atoms, all electrically neutral, can actually join with each other and release more energy. This is another way of saying that they can join into more stable configurations. The negatively charged electrons in an atom try to configure themselves so as to get as close as possible to their positively charged nucleus, but their fuzzy nature requires that they take up a certain volume of space. However, if they join together with the electrons of another atom they can usually find a tighter configuration that leaves them closer to their positively charged nuclei. For example, 2 hydrogen atoms can join together into a more compact configuration if each hydrogen atom contributes its electron to a 2-electron cloud, which the separate protons share. In this manner they form a grouping of the 2 electrons in a single cloud, together with the 2 isolated protons spaced apart from each other but still within the electron cloud. The result is a heat-producing chemical reaction in which 2 H atoms combine to form a hydrogen gas molecule. The H_2 configuration is the hydrogen molecule, and when you buy a tank of hydrogen gas, H_2 molecules is what you get. Furthermore, the 2 electrons of the H_2 molecule and the 8 electrons of the O atom can find a still more compact configuration by combining their electrons to create the water molecule, plus heat. The water molecule is really a single cloud of electrons in which are embedded the three point-like nuclei to form a minimum energy configuration. So when we burn oil or coal, we change the configuration of the electrons to produce more stable arrangements of point-like nuclei embedded in electron clouds, liberating heat. So much for chemical energy.

Strong Force and Neutrons

We have slid over one point. How does Nature construct a nucleus containing two or more protons in the first place? After all, each of the protons has a positive charge, and the positive charges repel each other very strongly when they are separated by a tiny distance, equal to the distance across a nucleus. The repulsion of like charges is just like the repulsion between the north poles of two magnets when they are pushed together the wrong way. Something must overcome this repulsion, or else the only kind of atoms we would have would be those of hydrogen. Fortunately, this is not what we observe. The answer is that there is a second kind of force which acts on protons. This is the strong nuclear force. The nuclear force is a very strong attraction but requires particles to almost sit on each other to have any effect. It is often called "the strong force". Also, there is a second kind of heavy particle, which is just like a proton, except that it has no positive or negative charge. It is not pushed away by the proton's plus charge. This other kind of particle is called the neutron, since it is electrically neutral. A peculiar fact of life is that it exists in stable form only inside a nucleus. When not in the nucleus it changes into a proton, an electron and a very light anti-neutrino in about 10 minutes. But it lasts forever inside a nucleus.

Nuclear Fusion

The neutron and the proton very strongly attract each other once they get close enough together, and then they combine to form a highly stable pair called a deuteron, which we designate D^+. The single deuteron, when it combines with a single electron, forms the heavy hydrogen atom called deuterium, designated D. A second nuclear reaction, called **fusion**, occurs when two deuterons make contact. When they can be forced together so as to make contact, the 2 deuterons fuse, making a doubly charged particle. The grouping of 2 protons and 2 neutrons is even tighter than the proton-neutron grouping in the deuteron. When neutralized by 2 electrons, the new particle is the helium atom, designated He. Larger groupings of neutrons and protons exist in nature and serve as the nuclei of carbon, nitrogen, oxygen, and iron, etc. atoms. All of these groupings are made possible by the strong force, which is felt between protons and neutrons only when they are in contact or share the same nucleus-size volume of space.

Nuclear Fission

Normal nuclear energy power plants are powered by nuclear **fission** energy, not **fusion** energy. During the early history of the universe massive stars were formed. In the explosion of these massive stars, lots of different types of nuclei were formed and exploded back into space. Second and later generation stars and planets were formed from this mix, including the sun. In the explosion process probably every possible stable configuration of protons and neutrons was produced, plus some almost-stable groupings, such as the nucleus of the uranium atom. There are actually 3 different types of uranium atom nuclei, called uranium-234, uranium-235, and uranium-238. These "isotopes" differ in their number of neutrons, but they all have 92 protons. The nuclei of all uranium atoms can go to a lower energy configuration by ejecting a helium nucleus, but this process occurs so rarely that the Earth's uranium has already lasted over 4 billion years.

The uranium nuclei are unstable in another way. In general, groupings of protons and neutrons are happiest if they have about 60 protons-plus-neutrons. The uranium nuclei contain more than three times this number. So they would like to split in two, which would release a lot of heat. But nature doesn't provide a way for them to split apart. They have to first go to a higher energy configuration before splitting in two. However, one of the three forms of uranium nucleus found in nature called uranium-235 and designated ^{235}U, gains the needed energy if it captures a neutron. The energized nucleus that results from neutron capture then splits apart with the release of an enormous amount of energy, and incidentally with release of additional neutrons. The additional neutrons can then split more uranium-235 nuclei, keeping the reaction going. This is what happens in nuclear power plants, where the heat, which is the end product of the nuclear splitting process, is used to boil water, generate steam, and turn electrical generators. (One also gets lots of radioactive products, which are a nuisance to dispose of safely and constitute an environmental hazard lasting many human generations.)

Hot Fusion

We are now also in a position to understand hot fusion (plasma fusion) nuclear energy. As mentioned in lesson 5, the groupings of protons plus neutrons is most stable when the numbers of neutrons and protons approximate those found in the nucleus of an iron atom. Just as uranium has too many neutrons plus protons to be comfortable, so the light elements like hydrogen, helium, carbon, nitrogen and oxygen have too few. If the nuclei can be made to make contact under proper conditions, they can combine to create more stable groupings, plus heat. This is the process of fusion. Nature has found a way of doing this in stars like the sun. All Nature has to do is heat compressed hydrogen hot enough and wait long enough and plasma fusion will occur. If Nature were to start with deuterium, which already has a paired proton and neutron, the task would be relatively easy in a star. Temperature is a measure of how much speed an atom of a given type has as it bangs around inside a cloud of such atoms. The higher the temperature, the higher the speed and the closer the atoms get to each other momentarily during a collision. In a star the temperatures are high enough that all the electrons quickly get knocked off the atoms, so one is really dealing with a mixed cloud of electrons and nuclei, called a plasma. At very high temperature the nuclei occasionally get close enough during collisions for the pulling-together short range nuclear force to turn on. Then the nuclei can stick together and go to a lower energy grouping of protons plus neutrons, releasing heat.

There is an international hot plasma fusion nuclear energy program, which is an attempt to carry out this process in the lab using deuterium and mass-3 hydrogen (whose nucleus is a compact grouping of 1 proton and 2 neutrons) as the gas. Hot fusion requires that the gas plasma be contained at temperatures of hundreds of millions of degrees, which can be done with the help of magnetic fields, but only for 1 or 2 seconds. The hope is to contain the gas for longer times. During the period of high temperature containment nuclear reactions occur during collisions. The main form of energy release is ejection of high energy neutrons and protons. The proton energy quickly converts to heat. The neutron energy can also be converted to heat, but makes the equipment highly radioactive. It then becomes difficult to repair the equipment, which could make hot fusion a poor candidate for commercial power production. In any case hot fusion power is a dream that is still probably at least 50 years away. It has been impossible to keep the hundred million degree gas away from the container for more than 1 second. Electrical instabilities occur in the plasma gas. In the most successful experiment a power output of 16 Megawatts was achieved for less than 1 second, and the fusion energy produced was less than the energy used to heat and confine the gas. But most scientists view hot fusion as the only way to achieve fusion power. Plasma fusion produces less radioactivity than fission power, is relatively environmentally benign, and has a virtually limitless fuel supply on earth. (more than a billion years at present energy usage rates).

Cold Fusion

Cold fusion promises a less costly and non-radioactive way of releasing nuclear fusion energy. Cold fusion relies on a different way of letting the protons and neutrons in one nucleus make contact with those in another nucleus, so that the nuclear force can bring them into a more stable configuration. Nuclei have sometimes been modeled like drops of liquid. For water droplets to combine, they must make contact. The same joining together occurs with nuclei. The requirement for any nuclear reaction to occur is that the reacting nuclei either make contact or come to share the same volume of space. The sharing condition is called particle overlap. In plasma fusion particle overlap is brought about briefly by banging the nuclei together so as to overcome momentarily the repulsion of the two positive charges which try to keep the particles apart. In cold fusion particle overlap conditions are achieved by making deuterium nuclei act as extended fuzzy objects like electrons in a metal, instead of like tiny points. The fuzziness is dictated by the famous Heisenberg uncertainty principle. When an electron is part of an atom, its fuzzy volume is called an "orbital". The conduction electrons in a metal are in very extended orbitals. Cold fusion occurs when the deuterons are in metal-type electron "orbitals".

A cold fusion reactor, i.e., an apparatus that promotes cold fusion, makes deuterons behave like electrons in a metal. When a heavy hydrogen atom is added to a metal, it loses its electron to the metal. The deuteron moves into the metal and occupies a position where it is surrounded by the metal atoms. The metal atoms are in an ordered array, which is embedded in a sea of electrons, called the "fermi sea". The atoms make room for the deuteron and the fermi sea neutralizes the deuteron's positive charge. Each deuteron has its own little volume. This is **not** the form of hydrogen that supports cold fusion. To get two or more deuterons to share the same volume one most go one step further. In a metal, electrical current is carried by the fermi-sea electrons, which act more like vibrating matter waves than like point particles. This behavior is part of the famous wave-particle duality of quantum mechanics. If electrons did not become very extended objects inside solids, there would be no transistors and no present day computers.

The wave-like form of electron inside a metal is called a "quasiparticle". The secret of cold fusion is that one needs quasiparticle deuterons. This need for quasiparticle geometry has not been recognized. Once a quasiparticle deuteron is created, its positive charge is shared between many local volumes. The deuteron has been "partitioned". The repulsion force between two such deuterons is enormously reduced and no longer keeps the deuterons cleanly separated. The nuclear strong force comes into play, pulling the partitioned deuterons together to form a stable helium nucleus in quasiparticle form. Nuclear reaction energy heats the metal without release of dangerous radiation.

To study cold fusion the experimenter has to entice some of the deuterons to assume the quasiparticle form. The cold fusion experiments discussed in this paper demonstrate the radiationless release of cold fusion heat. Five years ago no one knew how to do it reliably. New materials in the form of clusters of metal atoms called nanometals have greatly improved reliability. Since cold fusion promises more than a billion years of energy without the problems of global warming or radioactivity, an urgent effort should be made to learn how to make commercially affordable heaters.