beginning of May. It only took about 40 days for the physics community to consider the new claims, test them experimentally, and then announce loudly to the world that they had been carefully weighed and rejected.

Following this rejection, physicists have treated cold fusion rather badly. For example, Professor John Huizenga of Rochester University was selected to be co-chair of the DOE ERAB committee that met to review cold fusion and issue a report. Shortly afterward, he wrote a book entitled Cold Fusion, The Scientific Fiasco of the Century, in which he discusses the claims, the experiments, and the extreme skepticism with which the new claims were greeted. Robert Park discusses the subject in his book entitled Voodoo Science. You can find many places where physicists and other scientists happily place the cold fusion claims together with claims of psychic phenomena.

A Science Tutorial

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First it is important to recognize that there are 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) hot fusion nuclear energy, which powers the sun and most stars;
4) cold fusion nuclear energy, which appears as unexplained heat in a few experimenter's laboratory studies and which most scientists believe is impossible.

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? To understand this question you need to know some chemistry and physics.

Lesson 1

Nature has provided us with two 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 large 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 two 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 result is a hydrogen atom, designated H. A hydrogen atom is nothing but a 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 the original 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.

Lesson 2

As you know, nature has provided us with more than one type of atom. We have oxygen atoms, nitrogen atoms, iron atoms, helium atoms, etc.. How do these atoms differ? The answer is that they all have different types of nuclei (plural of nucleus, from the Latin). And these different nuclei all 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, and the iron atoms something like 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 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 on an atom has a diameter which is about 100,000 times that of the nucleus. Cube these numbers to get the difference in volumes.

Lesson 3

We now are in a position to understand what chemical energy is. 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 electrons in an atom try to configure themselves so as to get as close as possible to their 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 beloved 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 $H + H => H_2$. (The => means "goes to" or "becomes".) 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 H_2O, 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 reconfigure the electrons to produce more stable configurations of point-like nuclei embedded in electron clouds, liberating heat. So much for chemical energy.

Lesson 4

We have slid over one point in the above discussion. How does Nature make 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 nuclear force. The nuclear force is very strong but requires particles to almost sit on each other to have any effect. 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. Anyway, 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 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. The new particle, when neutralized by 2 electrons, is the nucleus of 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 very strong nuclear force, which is felt between particles only when they are in contact or share the same nucleus-size volume of space.

Lesson 5

We can now understand normal nuclear energy, which is really nuclear fission 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. But 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.)

Lesson 6

We are now also in a position to understand hot 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 hot 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. 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. Hot fusion nuclear energy 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 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. But most scientists view hot fusion as the only way to achieve fusion power. Hot fusion produces less radioactivity than fission power, is environmentally benign, and has a virtually limitless fuel supply on earth (many millions of years at present energy usage rates).

Lesson 7

So now we come to cold fusion. Cold fusion may provide an easier 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. The requirement for any nuclear reaction to occur is that the reacting nuclei occupy the same volume of space. This condition is called particle overlap. In hot 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 fuzzy objects like electrons in atoms, instead of like tiny points. When either light or heavy hydrogen is added to a heavy metal, each hydrogen "atom" occupies a position inside the metal where it is surrounded by heavy metal atoms. This form of hydrogen is called interstitial hydrogen. With interstitial hydrogen the electrons of the hydrogen atom become part of the pool of electrons of the metal. Each hydrogen nucleus oscillates back and forth through a negatively charged electron cloud provided by the electrons of the metal. They can be thought of as moving back and forth like the pendulum in a grandfather clock. This vibration exists even at very low temperature, due to a peculiarity of a branch of physics called quantum mechanics. The vibration is called zero point motion. The nucleus then becomes a fuzzy object, like the electrons in an atom. But this amount of fuzziness is not enough to permit a hydrogen nucleus to make contact with another hydrogen nucleus. To get two or more hydrogen nuclei to share the same volume one must go one step further. In a metal electrical current is carried by electrons that act more like vibrating matter waves than like point particles. If electrons did not become wave-like inside solids, there would be no transistors and no present day computers. This wave-like kind of electron is called a Bloch function electron. The secret of cold fusion is that one needs Bloch function deuterons. One needs wave-like deuterons inside or on the surface of a solid in order that two or more deuterons share the same volume of space. But once the Bloch function deuterons are created, the nuclear force comes into play and the protons and neutrons making up the deuterons can rearrange themselves into the more nuclearly stable Bloch function helium configuration, with release of heat. To study cold fusion the experimenter has to force deuterons to assume the wave-like form and keep them in the wave-like state. Cold fusion experiments demonstrating release of excess heat show that this can be done. But at present no one knows how to do it reliably. Since cold fusion promises millions of years of energy without the problems of global warming or radioactivity, a real effort should be made to learn how.

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