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A FUTURE INTERNAL COMBUSTION ENGINE*

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A FUTURE INTERNAL COMBUSTION ENGINE

by

EDWARD TELLER

May 9, 1972

I might perhaps start by saying that I don't know as yet what I am going to tell you. For that reason I will listen very carefully and recommend the same to you.

Let me recall the Atoms for Peace Conference in 1958. At that time I had the really wonderful job to open up the discussion on controlled fusion. That project, which we call Sherwood, used to be secret. That it could be opened up was to a great extent due to the fact that a couple of years earlier Kurchatov in a speech in England did disclose a number of Russian results. We were very grateful to him. His initiative made the trend toward openness much more real.

We are now trying to make a similar step, not a terribly big one, toward openness.

Like the first speaker today I shall talk about rather simple things; in fact, so simple that I will not even use many formulae. I shall talk in terms of ideas. Indeed everything I shall say is already known to the experts. I shall present practically no news except that I hope to make it possible that a discussion should now go on in broader circles and therefore in a more fruitful manner.

First I shall speak about compression. There is a very simple law. It does not hold precisely but it is a good approximation and is very practical. This similarity law says qualitatively that if we use greater compression, then in order to get similar processes and similar efficiencies we need smaller amounts of material and, of course, we use smaller amounts of energy.

This is the secret of the modern internal combustion engine by which of course I don't mean an automobile. Instead of making a hydrogen bomb with, let us say, the use of "high octane" DT mixture, using DT at liquid density, we shall talk about the liquid 1,000-fold compressed. (I stick to the figure 1,000 because it has a simple cube root.) Let us therefore think of a droplet of liquid DT with a one millimeter diameter. We shall compress it ten-fold linearly and increase its density a thousand-fold. In order to make the functioning of this arrangement similar to the functioning of deuterium-tritium mixture at liquid density, we shall have to consider equal energies per particle equal velocities, and also equal disassembly velocities. For binary collisions, which are important in DT and produce α - particles and neutrons, the time between two such collisions will be cut by a factor 1,000. This means that the time scale must be reduced by a factor 1,000. If we want to have a similar situation with respect to disassembly we also have to cut the spatial scale by a factor 1,000.

I started with 10^{-1}cm, I compressed 10^{-2}cm and this is now the working fluid. This will be similar in its functioning to a DT mass 1,000 times bigger in diameter (because time scales and space scales have to be changed by this factor) that is, 10 cm. You see that the volumes are in the ratio 10^{9}. The masses however are in the ratio 10^{6} because 10^{-9} of the original 10 cm volume is present at 10^{3} times greater density. Therefore you can generally see that a change by a certain ratio in the density will give rise to reduction in mass by this ratio squared. A factor 1,000 in density means a factor one millionth in the mass. We can indeed hope for micro explosions, which make an internal combusion engine possible. I will look into the practical consequences in a very short time.

First I shall tell you, however, that this similarity law does not hold exactly. There are two main reasons , one of them completely unimportant and the other rather unimportant.

The completely unimportant reason is that we have to consider binary collision processes, where collisions occur at great distances and where shielding becomes important. In the appropriate well-known formulae logarithms appear. These logarithmic factors don't scale. They also are not terribly sensitive to conditions. In one case the factor is 10, in another case 20. The whole change is rather unimportant.

The second reason why the scaling is not strict is that it obviously does not apply to triple collisions. We have scaled in such a way that binary collision should behave properly. At greater densities triple collisions will become more important. There is one triple collision that is indeed important: that is the collision between a photon, an electron and a nucleus resulting in the absorption of the photon. The reverse process, the collision of an electron and a nucleus emitting a photon is a binary collision that scales; the absorption process does not scale.

This is an important correction as long as the temperature of the thermonuclear fluid is not more than a kilovolt. Then the absorption is strong enough to matter and fuel at a great density works a little better than we would have expected from the scaling law. But one kilovolt is not a terribly interesting temperature. We are really interested in 4 or 5 kilovolts and there the influence of this absorption becomes relatively small.

Now I would like to ask the question, if we can for practical purposes scale, is it better to work at high densities or at low densities? I want to attack this problem from the point of view of the lasers (and not only for the reason that this is a laser conference) because we are going to use lasers to concentrate energy around the thermonuclear fuel and compress it as our colleagues from Moscow have indicated some time ago. It is not easy to produce the great energies required for the compression in the form of laser light and even more difficult to produce it in not very many picoseconds. This is required in order to have the energy available near the droplet.

Therefore the question has to be asked, what compression will need the least energy? It turns out that the stronger the compression, the smaller the mass and the less the energy required. Assume that you have an equation of state. The pressure is proportional to ρ^{γ} where γ is less than 3. At very high compressions it becomes 5/3. It is easy to see that the energy required will go as low as $\rho^{\gamma-3}$. Actually ρ^{-2} is contributed by the fact that the mass that you need is reduced by ρ^{-2} and $\rho^{\gamma-1}$ is contributed by straight integration that describes the compression. In the interesting case of $\gamma = 5/3$, $\rho^{\gamma-3}$ becomes $\rho^{-4/3}$. The higher the ρ value the less energy is needed.

So, why am I do modest? Why am I compressing a 1,000-fold and not a million-fold? Actually it would be better. But to continue to compress a droplet in a symmetric fashion and not break it up is slightly difficult.

Incidentally, I shall refrain for very good reasons (mostly reasons of ignorance) from telling you in detail how this compression is accomplished and how the energy is coupled into the droplet. Some of this will be done by my colleagues later in the afternoon and they asked me to ask you to stay for the last three speeches. Tell your friends to come also. This much for a commercial.

Now I want to mention a few factors which determine the mass with which we can operate. Of course, the less mass we could use, the better. But if we use very little mass, then we run into two difficulties. Number one, dissambly occurs before there is enough burning. Number two, the energy released by the thermonuclear reaction does not stay within the droplet. And here I have to talk for a moment about the energy balance within the droplet. First of all you lose energy to expansion. Secondly you lose energy to radiation. For high compression some of it is reabsorbed but in the interesting region not enough. The energy production must exceed these losses. Incidentally, the radiation is very easily calculated. All this however is only a part of the argument that determines the minimum size.

Another point is that the energy of the particles produced should be deposited within the droplet. This energy in the DT reaction is mostly given to neutrons of 14 MeV which escape with almost all their energy. A little less than 4 MeV is given to α - particles. These, you would imagine, stay in the droplet. It is not all that simple. Energetic α - particles are supposed to give their energies to colder electrons. But the electrons because of their smaller mass, even though they are relatively cold (a few kilovolts instead of a few MeV) move faster. It is unnatural to transfer energy from a slow particle to a fast particle. The right formulae can be derived easily, at least in first approximation, if one assumes that the usual energy loss occurs when the α - particles interact with the electrons that happen to be slower than the α -particles. The bulk of the electrons in the Maxwell distribution which move faster than the α - particle do not participate in the net energy exchange. This gives the right order of magnitude and is not implausible.

Incidentally, all of this and similar types of consideration become important again and again in the study of controlled fusion. They became very important in the attempts we have made and are still making in magnetically confined plasmas. The time of equilibration depends on these factors and this is very important also in the present case because when the laser heats the droplet, it heats in first approximation the electrons. The transfer of energy from electrons to the ions takes time which is not completely negligible.

Let me turn to one or two more interesting difficulties in connection with the compression problem. There are plenty of ways to couple the energy into the droplet. In fact, as the laser converges on this tiny droplet, the electric fields in the light wave become bigger than the electric fields in which electrons of the hydrogen atoms are moving. Therefore ionization occurs in a most straightforward manner. The phenomena which occur at these very high electric fields are not completely understood, certainly not by me, and a lot more study will be necessary. It may even happen that in the end in these high electric fields the phenomena will appear to be more simple.

I would however like to warn of one difficulty. As the light falls upon the plasma that is produced the electrons and the nuclei are accelerated in the opposite directions. The electrons move in the same phase. One of the ways how we can produce temperatures is by nonlinear instabilities. Disorder appears in the motion of the electrons. But this disorder at first is not complete. Great numbers of electrons are still moving together, probably with higher frequencies. These then can emit light coherently and therefore with high intensity. In the surrounding of the droplet the plasma is less dense and in equilibrium most energy should appear as radiation. The danger of energy loss to radiation is serious.

Now let us assume that the compression and the fusion work. Let us get to the engine. What can we do? We could make internal combustion engines, in fact, power stations of a few hundred megawatt. They would have enough fuel for any time to come. The energy production would be clean and very safe.

There are some slight engineering difficulties. Let me mention to you a couple.

One version that I heard described would have hundred explosions per second, droplets being hit hundred times a second by lasers not necessarily in the same place. I don't want to confine the exploding plasma. One might do it but it is a little difficult. Let's make it as simple as possible and just exploit the neutrons that escape. But to keep droplets in the focus of the lasers is more difficult. Furthermore, the vessel must withstand hundred explosions per second, each equivalent to a few pounds of TNT. Tens of billions of them should occur before the machine needs readjustment. That is not quite easy.

Let's try again. The other extreme would be to use explosions equivalent to 10^{17} ergs which is two and a half tons of TNT equivalent. Then you need only one explosion in ten seconds. The vessel has to withstand without fatigue a few times ten million explosions. The engineering still has some problems.

Very much to the disappointment of my colleagues, I do not expect this to happen before I am either in heaven or in a considerably lower place. I hope that something else will happen sooner. This may seem to you a little fantastic altho I know of some very interesting investigations of these possibilities at Los Alamo the use of this internal combustion engine for space propulsion. If we have thermonuclear explosions that go on at temperatures in the neighborhood of 10 kilovolts, there the natural velocities with which the plasma would leave is approximately 10^8 cm/sec. In the crazy language of the engineers, this means a specific impulse of 10^5. If you intend to accelerate your vessel to one thousands of light velocit this actually could be done in a few days with an engine of many thousands of mega watts. We could get to Mars in a week, the round trip would be two weeks. The astronaut would have to be heavily shielded against the neutrons. We would have some difficulty with heat rejection problems; we would have difficulty in recapturing some of the energy to drive the lasers; the latter I am not so afraid of because I hope to have magnetic fields regulating the flow of the plasma and this magnetic field being pulsed by explosions could generate electric currents which in turn could drive the lasers. Actually only a fraction of the heat will have to be rejected, but even that heat rejection problem is serious. I want to confess to you that Los Alamos did assume only to go to one three-thousands of light velocit What they talk about is more modest and more feasible.

Is this not a little crazy to talk about space propulsion before talking about power stations? I claim that it isn't. Both of them are crazy, but space propulsion is more feasible for two reasons. Your apparatus needs to last a very much shorter time, and you are allowed to pay for it, allowed to put work into it, many thousand times more than if you tried to do something in an economic way for power production on the earth. I think therefore that there is an outside chance that in this century astronauts will use this kind of internal combustion engine.

I want to say with all kinds of emphasis that I hope that this will be attempted by a concerted international effort. Opening our minds to such cooperation is the right step.

I want to conclude by discussing a question that many have asked. If you don't have soon a real machine, when will you have a demonstration, a real proof that the laws of thermonuclear burn can be used efficiently? Well, I won't give you an answer, but I will give you my definition of a pessimist and of an optimist. A pessimist is a man who is always right, but does not get any enjoyment out of it. An optimist is a person who imagines that the future is uncertain. Virtue in this case is on the side of the optimist. I want to be an optimist and I want to believe that the demonstration will succeed sometime in the 1970's, perhaps even early in the 1970's.