Magnetohydrodynamics and the Thermonuclear Problem

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At the first Geneva Conference, Dr. Bhabha made his famous prediction about the future of thermonuclear energy, and since then the possibility of the peaceful use of this energy has attracted a rapidly growing interest in the newspapers and also in scientific literature. It is the purpose of this and the following sessions to give a survey of the present situation.

The way which we have to go towards thermonuclear energy differs in some respects from the way which has led to the release of fission energy. The latter was opened by research in nuclear physics carried out as pure science. The objective was to gain knowledge of the structure of matter and not to achieve any technological results. In fact, it was not until the discovery of fission that technological aspects entered this field in a serious way.

As a comparison, it is of interest to see what is needed before we could hope to release fusion energy for peaceful purposes. This possibility does not depend on nuclear physics because the processes which possibly are of importance are very well known in nuclear physics. The main difficulty is to heat a gas to a very high temperature and to keep this gas confined during a sufficiently long time. The field of physics which we must study in order to be able to do so is magnetohydrodynamics and the physics of hot ionized gases, which is usually referred to as plasma physics. Magnetohydrodynamics is a combination of electromagnetism and hydrodynamics, and this means that we are facing the difficulties of electromagnetism multiplied by the difficulties of hydrodynamics. But the thermonuclear problem furthermore requires a combination of magnetohydrodynamics with plasma physics, which means that we have to multiply once again by the difficulties of plasma physics. Hence we are entering an extremely complicated, but also extremely rich and fruitful field, which is well worth our investigations even from the purely scientific point of view.

Up to quite recently magnetohydrodynamics was studied mostly because of its interest to astrophysics, where it is of basic importance. In fact, contrary to what was believed up to recently, ordinary hydrodynamics is applicable only to very few astrophysical problems, because under most astrophysical conditions the electrical conductivity is so great that there is generally a coupling between the mechanical motion and electromagnetic phenomena. In solar and stellar physics, the physics of interplanetary and interstellar space, and also in quite a few problems of the ionosphere and of the earth’s interior, we must introduce magnetohydrodynamics. Thus, in the whole universe, we leave to ordinary hydrodynamics only the lower parts of the planetary atmospheres and the seven seas.

This means that the thermonuclear problem is closely coupled with modern astrophysics. Progress towards the solution of the thermonuclear problem will necessarily be fruitful for astrophysics and, *vice versa*, progress in the concerned fields of astrophysics may be important also from the thermonuclear point of view.

Thus, summarized in a brief statement, fission energy was released as a result of purely scientific research carried out in order to investigate the atom and find the microscopic structure of our world. The progress towards thermonuclear energy is connected with astrophysics, the study of the macroscopic structure of our world.

There are at present a number of big projects aiming at the production of the necessary conditions for the release of thermonuclear energy. They are, of course, very important because they have directed interest towards the field and demonstrated its difficulties. But I think that of equal importance is an advance on a very broad front in magnetohydrodynamics and plasma physics, and I believe that this may lead to a great number of new projects. The field is rich in new possibilities, and we cannot be sure that any of the present lines of approach will lead to the best solution.

Capture of a Plasma by a Magnetic Field

As an example of what I mean I shall discuss one of the basic principles in the field. In order to make a thermonuclear reactor it is essential to keep heated gas enclosed during a certain time. The first question which should be decided is whether we should

1. confine the gas at first and then heat it,
2. heat it at first and then confine it, or
3. heat and confine it at the same time.

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Most thermonuclear projects seem to have chosen the first or, in some cases, the third alternative, in spite of the fact that from a technological point of view it may be an advantage to heat the plasma at first and then shoot it into a region of confinement where it will be used.

Let us discuss whether this could be an alternative to the present projects. This would be the case, for example, if we could shoot a heated plasma into a magnetic field in such a way that it is captured by the magnetic field. It has been argued that this is very difficult, if not impossible. A charged particle which is shot into a magnetic field from outside usually comes out of it again. Also, if we consider magnetic lines of force which are “frozen” into a plasma, we are tempted to conclude that the plasma could not be brought into a magnetic field from outside and captured by it. I think that we could learn from astrophysics that these objections are not watertight; for example, we can see what happens during magnetic storms and aurorae. This rather indicates that a magnetized plasma could be shot into and captured by the magnetic field. Certainly there are several conflicting theories about magnetic storms and aurorae but I think it is now fairly evident that a magnetic storm is caused by an extremely hot plasma which occupies parts of the geomagnetic field and is held captured by it during a considerable time. It is also very likely that this plasma has been shot into the geomagnetic field from the sun, where it has been heated by “solar activity” and magnetized by the solar magnetic fields.

Hence, from a study of these phenomena, we could conclude that in principle it is possible to shoot a heated plasma into a magnetic field and capture it there. This might be checked by laboratory experiments in which we simulate the geophysical phenomena. However, there may also be other and simpler methods for achieving the same results.

A possible method of capturing a plasma which is shot into a magnetic field is illustrated by Fig. 1a. An electric field is applied between the cylindrical electrodes A and B and a magnetized plasma ring is produced which drifts in the axial direction due to the action of the electric and magnetic fields. In a region NS, a radial magnetic field is produced between a magnetic pole S inside the inner electrode and an annular pole N outside the outer electrode. If the plasma ring has a sufficiently high conductivity and density it may carry the magnetic lines of force with itself as illustrated by Fig. 1b. When the ring proceeds further the lines of force will disrupt so that we obtain a configuration as shown in Fig. 1c. The original field between the electrodes is almost restored and a magnetized plasma ring is produced.

The ring is characterized by a longitudinal magnetic field which is wrapped up in field lines passing the hole of the ring. This structure is rather different from Bostick’s plasmoids, but is similar to the field configuration in Zeta. The temperature of the plasma ring is a function of the kinetic and thermal energy of the initial plasma and of the strength of the radial magnetic field. The dependence is rather complicated.

**Theoretical and Experimental Magnetohydrodynamics at Stockholm**

Finally, I should mention, as an example of the different possibilities which there might be in this field, the theoretical and experimental work which is done in Stockholm. As will be reported later by Professors Ohlin and Siegbahn, interesting investigations in this field are also going on in Uppsala.

During the last decade the magnetohydrodynamic research in Stockholm has consisted of a series of theoretical and experimental investigations. The experiments have been carried out in conducting liquids, mercury or liquid sodium, which are placed in strong magnetic fields. But, of course, experimental investigations of hot plasmas seem to be an even more fascinating field. Following a long series of investigations of relatively cool plasmas, presented by Dr. Lehnert at this Conference, we have now started a series of experimental investigations on hot plasmas, concentrating on the fundamental properties of the plasma. We are also trying to analyze in a more or less systematic manner possible new ways of approach to the thermonuclear problem. As an example I should like to mention the theoretical and experimental investigations by Dr. Lehnert about whether a plasma could...
be confined in a very simple way by the magnetic field of a circular loop of current. At first one would say "Yes, of course ", but, on second thoughts, one would say "No, not at all, because the leads to the loop will disturb the conditions "; but I think it has been demonstrated that there is a fair chance that the effect of these leads to the loop can be eliminated by the magnetic fields of the leads themselves. We have also started experiments with discharges of a few hundred kiloamps to produce fast-moving magnetized plasmas, in order to investigate whether they could be captured by magnetic fields in the way I have just discussed. Our investigations also cover other problems in magnetohydrodynamics with possible applications both to astrophysics and to the thermonuclear problem.

We have chosen this line of research because we believe that the way to solve the thermonuclear problem should be by an advance on a broad front in magnetohydrodynamics, plasma physics and astrophysics.