CONTROLLABLE THERMONUCLEAR REACTIONS BY MEANS OF GAS DISCHARGES*

THEORETICAL and experimental work in atomic and nuclear physics has in recent years led to searches for new ways of utilising atomic energy for peaceful purposes. Of these, special mention may be made of thermonuclear reactions, where the energy contained in the nucleus of the atom is emitted, not by the fission of heavy atomic nuclei of uranium or thorium, but as a result of deuterium or tritium, which are rare varieties of hydrogen. Deuterium is found in nature and can be extracted in large quantities from water by electrolysis. Tritium can be obtained in atomic reactors by bombarding lithium with neutrons.

In the hydrogen bomb it has been possible to create conditions for converting deuterium into helium. This is precisely a thermonuclear reaction. But in order to make it a controllable reaction it is necessary to find ways to ensure that it shall not be in the nature of a powerful and destructive explosion.

Thermonuclear reactions can arise only if the temperature of a substance is so high that when nuclei collide as a result of their thermal movement, there is a possibility of overcoming the mighty electrical forces of repulsion existing between the nuclei. The excitation of thermonuclear reactions in deuterium or in a mixture of deuterium and tritium is of particularly great interest, as in this case the temperature required to produce a noticeable effect is lower than when other substances are used. However, even in this most favourable case, in order to come even near the threshold of thermonuclear reactions, the temperature of the substance has to be raised to some millions of degrees. At that temperature, deuterium can exist only in the form of plasma —a medium composed of electrons and bare atomic nuclei divested of electron shields.

The amount of energy that must be concentrated in the plasma for its temperature to rise to heights at which thermonuclear reactions can become sufficiently intense is relatively small. At a temperature of a million degrees, the thermal energy accumulated in one gram of deuterium is only a few kilowatt-hours. Therefore, if a method were invented for heating the plasma so as to ensure the preservation of the accumulated thermal energy, it would then be possible to cause intensive thermonuclear reactions. The chief difficulty, however, is precisely that of precluding heat losses, which already at a temperature of some tens of thousands of degrees become so large that without thermal insulation a further rise of temperature becomes a practial impossibility.

When a very dense substance is heated, yet another serious obstacle arises. It is necessary to overcome in some way the enormous mechanical forces that arise owing to pressure increasing with temperature. In trying to heat solid or liquid deuterium, one finds that already at 100,000° C the pressure exceeds a million atmosphere Therefore, in a substance of high density a thermonuclear reaction can only be induced for a very brief space of time and such a process will be in the nature of a short pulsation or weak explosion. This makes it necessary to conduct experiments with gaseous deuterium.

But in heating deuterium, it is essential to prevent its particles, which assume high velocities, from dispersing on all sides, carrying the thermal energy to the walls of the vessel in which they are contained. For this, it is necessary to devise an experiment making it possible to retain the particles in the plasma, that is to say, to deprive them of the possibility of transmitting heat to the walls.

One idea that has arisen in connection with this problem is to use a magnetic field for thermal insulation of the plasma. This was first suggested in 1950 by Academician A. D. Sakharov and by Academician I. E. Tamm. They have shown that a magnetic field can play the part of an "invisible wall", restricting the plasma and creating thermal insulation. A magnetic field fundamentally changes the nature of the movement of the charged particles, *i.e.*, electrons and nuclei, in the plasma. They cease to move in straight trajectories and begin to move in spirals with a small radius. Using a common figure of speech, it can be said that they are imprisoned in the plasma like a squirrel in a cage. Having lost its freedom of movement, the particle, if there is a

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magnetic field, can no longer carry energy away from the plasma.

The magnetic field required for thermal insulation can be created by passing a sufficiently strong electric current—a current of some hundreds of thousands of amperes—through a rarefied gas. If an electric discharge more powerful than any lightning is created in the gas then, on the basis of theoretical considerations, it may be expected that the substance in the discharge chamber will for some millionths of a second be compressed into a thin plasmic cord severed from the walls of the chamber and heated to a very high temperature. If such a discharge takes place in deuterium, then, given a sufficiently strong current, we should observe the emission of neutrons produced as a result of the thermonuclear reaction.

On the basis of these considerations Soviet physicists organised experiments to study powerful electric discharges in gases. In these experiments they investigated phenomena arising when strong currents are passed through hydrogen, deuterium and other gases at various degrees of rarefaction The peak current reached two million amperes, and the instantaneous energy released in such brief discharges in some of the experiments was more than ten times as great as the capacity of the Kubiyshev Hydro-Electric Station For such experiments, however, it is not enough to have installations that make it possible to concentrate such vast energy. It is also necessary to have highly efficient apparatus of various kinds to record the development of processes in the plasma that last for some millionths of a second. High speed oscillographs, ultra-high-speed motion picture filming, cameras with electrically powered shutters, and electronic computors—all this complex arsenal of modern experimental physics was used in studying the properties of the plasma heated by an instantaneous impulse current.

Briefly, the experiments have shown that by passing a current of several hundred thousand amperes through a rarefied gas it is actually possible to heat the plasmic cord that is formed to a temperature of the order of a million degrees centigrade. No one had previously succeeded in obtaining such a temperature in laboratory conditions. A higher temperature is achieved only in a hydrogen bomb. In that case, however, the investigator dare not risk coming within less than a few kilometres from the explosion. In the experiments reported here the thin streak of the heated plasma contained inside the discharge chamber is not dangerous because it consists of only a small amount of substance.

A result of these investigations that is no less interesting was the discovery in 1952, of the emission of neutrons and high energy X-rays from the discharge. True, the neutron emission in this case cannot be regarded as a result of thermonuclear reaction, since it is evidently conditioned in the main by some new and previously unknown processes in the plasma. It appears that the phenomena taking place in the plasma are very much more complex than the simplified picture produced in the initial theoretical constructions.

The facts obtained experimentally have upset many conventional conceptions about the properties of plasma, which gained currency as a result of many years of investigation of gaseous discharges in ordinary conditions. The plasma in the discharge chamber goes through rapid and successive compressions and expansions, during which the substance alternately converges on the centre of the discharge chamber and disperses to the walls with an enormous speed reaching 100 kilometres per second. In the process, very high electric potentials—which, perhaps, are one of the basic reasons for the appearance of neutrons and penetrating X-rays—form in the plasma for a short time.

Only further investigations will be able to provide an answer to the question whether it is possible by proceeding along this path to approach the creation of a controllable thermonuclear reaction of high intensity. At the same time, it is necessary to study other trends in solving this basic problem. Of considerable interest, in particular, is the study of the possibility of obtaining a thermonuclear reaction in continuous processes of long duration.