of singularities in the correlation function of the phase of the superconducting "wave function" at different points[22,24]).

The problems touched upon at the end of the report are not sufficiently clear, but are mentioned here in order to draw attention to them and to emphasize the necessity for carrying out a wide range of theoretical and experimental investigations connected with surface excitons.

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E. K. Zavoĭskiĭ. Energetics in Fast Thermonuclear Processes. If we were to speak about the immediate prospects of thermonuclear power, the year 2000 is the year we should have in mind. It is estimated that by this time the world's demand for all forms of fuel will be 10^{21} J/year. With that end in view, we shall probably have to construct 1000, 3×10^{10}-W thermonuclear plants. A plant of such power will burn ~ 1 cm^3 of D-T mixture per second.

According to current ideas, a stationary thermonuclear plant of such power must have a confining magnetic field of not less than 10^5 G for a plasma of density 10^{15} cm^{-3} at a temperature of 10^8 degrees. Hence, we find the volume of the plasma to be 3×10^9 cm^3. If a toroidal trap is used for the thermonuclear reactor, then the minor diameter of the torus will not be less than 10 m, and the length of the internal axis of the torus $\sim 10^2$ m. Although facilities of such scale is common, the entire gigantic chamber is filled from the beginning by a strong magnetic field, which is subsequently expelled from and pressed to the walls of the chamber by the hot plasma. Note that (for the scale) the thermal energy of the plasma of the reactor is sufficient for heating up 10 tons of copper to 1000°C. The state of the system should be stable to such a degree that the plant can operate for many years without a single sudden major violation of the equilibrium between the plasma and the magnetic field. Indeed, a rapid destruction of this equilibrium will lead to the penetration of the magnetic field into the region occupied by the hot plasma, and this will generate inside the chamber and in the solenoids producing the magnetic field surges of power equivalent to a blast of 20 tons of demolition explosives. Should such a blast destroy the wall of the torus, up to 8 g of tritium can immediately enter the atmosphere. The equilibrium can be destroyed by the development of a macroscopic plasma instability connected, for example, with "arcing," a rapid cooling of the plasma owing to local vaporization of the metal of the torus wall, stripping of metallic particles from the walls of the chamber, the breakdown of the power supply for the magnetic field (the short-circuiting of the solenoid coils), etc. Until completely reliable safeguards are found, a thermonuclear plant with magnetic confinement will be a considerable hazard for the surrounding district, and each accident on such a scale will bring about a considerable economic loss. In this situation, if we also consider the many other unsolved problems of plasma confinement and heating, then the construction of 1000 such plants before the year 2000 seems unlikely.

An alternative to the "stationary" thermonuclear power is microexplosions, which will have a special area of application. The physical basis for obtaining an energetically advantageous thermonuclear reaction in an explosion is the following well-known observation: a rapidly heated condensed target will, during the disintegration time $\tau = r_0/c_s$, where r_0 is the target radius and c_s is the disintegration rate, have time, according to the Lawson condition, $\tau N_0 = 10^{14}$, where N_0 is the concentration of nuclei in the target, to liberate a larger amount of energy than was expended in heating up the D-T mixture.

Two possible ways of accomplishing the heating of the microtargets to thermonuclear temperatures have recently been proposed. What is contemplated here is the use of superpower laser pulses of light and relativistic electron beams. Although, as is well-known, the necessary energy and power have not for the present been attained in either method, there is no doubt now that they can be obtained. If we succeed in constructing laser or electron-beam devices which will operate periodically without disruption, then this should essentially change our ideas about the role of fast thermonuclear processes in power engineering in the near future. This report will be devoted to a discussion of this problem.

The production of thermonuclear energy from microexplosions should not be considered as a maneuver for circumventing the temporary difficulties encountered in the application of the stationary thermonuclear process: the microexplosions allow, in principle, the realization of the reactions: 1) the thermonuclear chain reaction; 2) the D-D reaction; 3) the D-He^3 reaction; 4) the combined reactions of D-T, D-D, and D-He^3 with certain light nuclei and fissionable elements.

Owing to the simplicity and complete safety, the microexplosions will, apparently, be a better fuel for long-distance space rockets, and will subsequently be the universal means by which experiments of diverse scale will be performed in outer space.

Microexplosions also allow the production under laboratory conditions of extreme (with respect to density) states of matter, will be superpowerful neutron sources, etc. The burning of small thermonuclear charges can also be used for carrying out blasting operations, for imparting the requisite relief to a locality, and for changing a climate. In the more distant future, when we begin to use for microexplosions the D-D, D-He^3, and combined reactions, possibilities will open up for an economic optimization of thermonuclear energetics with allowance for complete radiation safety over long periods. It is possible that through this will be solved one of the most important problems of the wide-scale use of nuclear-fusion energy.

What are the major technical problems that must be solved on the way to microexplosions? The initiation of a microexplosion requires laser or electron beams of total energy ranging, according to various estimates, from 10^6 to 10^7 J for a pulse width of the order of 10^{-8} sec, which corresponds to a beam power of 10^{14}–10^{15} W. As is well known, this will require the construction of lasers with active media of volume from 1 to 10 m^3 and with a pumping energy of the order of 10^8–10^9 J. The beam should be focused on an area of about 10^{-1}–10^{-2} cm^2 or even smaller. These lasers can apparently be constructed in this decade.

The mechanism of the interaction between a high-power laser beam and a target is not as yet clear, but it is quite probable that at energies of the order of a megajoule and higher, the nonlinear effects of the target-light interaction will result in the heating of the condensed matter to the requisite depth.

In the case of the relativistic electron beam, the feasibility of focusing and slowing it down over a distance less than the Coulomb mean free path is still not apparent. There is, however, a wide range of possibilities here for controlling the beam: diverse plasma and magnetic beam focusing, the effects of the reverse current-plasma interaction, the formation of the magnetic channel, the collective effects of the beam-target and reverse current-target interactions, etc. Out of the set of problems pertaining to the properties of relativistic electron beams, let us dwell here on only the following: 1) the focusing of the electrons by the magnetic channel, 2) the probability of the collective effects of the beam deceleration, and 3) the prospects of the production of superpower electron beams.

It is known that the maximum value of an electron current in a vacuum is $I = (mc^3/e)\beta\gamma = 1.7 \times 10^4 \beta\gamma a$. But to heat, say, 0.1 cm^3 of a solid D-T target to thermonuclear temperatures, we require currents of up to 10^8–10^7 A for electron energies of 1–10 MeV. Therefore, the required current can be produced only in a plasma whose density exceeds that of the electron beam. In this case the current strength can be arbitrarily large, owing to the appearance in the plasma of a reverse current of cold electrons. This current appears only when the characteristic rise time for the current pulse is smaller than the skin time $4\pi\sigma r^2/c^2$, where σ is the plasma conductivity and r is the beam radius. In a dense plasma there are, naturally, no radial electric fields to repel the beam electrons, but owing to the reverse current, the current's beam-confining magnetic field also vanishes. Therefore, in a plasma of infinite conductivity the beam should scatter with thermal radial velocities. But because of the finite conductivity of a plasma, the reverse current partially dissipates and a weak magnetic field appears.

Since by heating it up, the reverse current increases the conductivity of the plasma, this magnetic field of the beam becomes "frozen" in the plasma and, consequently, the beam electrons which pass through the plasma earlier produce a magnetic channel for the subsequent electrons. In this way self-focusing of the beam occurs. Estimates show that a high-power relativistic electron beam can be well focused over a distance of a few meters through this mechanism. The focusing will, however, be even stronger if, by the proper choice of the plasma density, the reverse current is made to dissipate strongly, owing to the ion-sound instability.

Hence, it follows that it is possible to form along the beam a system of plasma "lenses" of different densities and electron temperatures, and to select the conditions for the requisite degree of focusing.

Let us consider the conditions for the slowing down of relativistic electrons, owing to the excitation of collective effects in the target. Collective interactions can arise in a plasma of such density only when the temperature of the plasma is not less than 1 keV. At this temperature the plasma becomes an "ideal" plasma. Estimates show that owing to Coulomb collisions in the target, the reverse current is capable of heating the fuel to 1 keV. Collective effects have been well studied in the case of weak electron beams, but the theory on which they are based can be carried over with sufficient accuracy to the case of very powerful beams. This work was done by Faĭnberg, Shapiro, Tsytovich, Rudakov, Ivanov, Ryutov, and others.

Without going into details, which may be found in the works of the indicated investigators, we should say that the slowing-down length of the beam in a plasma of temperature higher that 1 keV is shorter by several orders of magnitude than the Coulomb slowing-down length, and the mean free path of the beam in the solid target is a fraction of a millimeter or a few millimeters. This result can be considered to be quite satisfactory from the point of view of the problem of target heating. It is worth noting that if the D-T mixture is surrounded by a heavy shell, then the electron beam passes easily through the shell and undergoes collective deceleration only in the mixture.

It remains to be considered the complex technical problem of producing high-power relativistic electron beams. The method used in forming the beams usually consists in a discharge of a high-voltage line unto a plasma cathode near which a thin, grounded foil—the anode—is located. The plasma that then forms in the gap between the cathode and the anode emits electrons, which penetrate the anode (foil) and move on the other side of the foil in a relatively tenuous plasma, which compensates the repulsion of the beam. To produce beams with a current strength of up to 10^7—10^8 A, the wave impedance of the line should be very low. But this can be achieved only by decreasing the thickness of the insulation of the line, i.e., by increasing the electric field strength in the dielectric. The power flux through 1 cm^2 of the line is equal to*

$$w = c\varepsilon^{1/2}\,[\mathbf{EH}/4\pi].$$

In a running wave $\mathbf{E} = \mathbf{H}$, and

$$w = c\varepsilon^{1/2}E^2/4\pi.$$

If E_m is the maximum strength of the electric field in the dielectric, then w_m is the maximum power attainable in the line. It is known that E_m increases sharply when the time the voltage potential acts on the dielectric is reduced; therefore to achieve the maximum power, the line must be charged impulsively and discharged rapidly unto the load. It is as yet not clear which dielectrics are most suitable for high-power lines. Water, however, seems to be one of the prospective insulating materials for which E_m possibly attains the value of 10^7 V/cm, which corresponds to $w_m = 2 \times 10^{12}$ W/cm^2. Therefore such a line with a cross section $s \approx 10^3$ cm^2 can produce in the load the power $w_m \sim 2 \times 10^{15}$ W. One should probably connect lines of such dimension to tabular cathodes of large cross section, and then focus the beams as discussed above.

What are the prospects of producing high-power electron beams? Unfortunately, in our country we have little experience in working with relativistic beams, and it is difficult to determine when this experience will be gained. Very roughly, we can expect that the fundamental problems of beam focusing will be solved in the seventies and that 10^{13}—10^{14}-W plants will be constructed during the same period. At such powers experiments on the collective interactions in solid targets will be possible.

If by the end of this period electron beams prove, for some reason, to be more promising than lasers, then one can imagine that an economically advantageous thermonuclear reaction in the form of microexplosions and, possibly, a chain reaction will be realized by the middle of the eighties.

It should be noted that the situation may turn out to favor the laser, or that each of the techniques will find its own areas of application. The last possibility is very probable, since high-power lasers and electron beams can, undoubtedly, be used in other areas of technology, and the extensive development of them within the next few years is inevitable.

Thus, on the basis of the very rough estimates one can expect that the main problems of thermonuclear microexplosions can be solved within the next 10—15 years.

In the wake of this, we shall probably see a very rapid utilization of microexplosions for power, space flight, etc., so that thermonuclear energetics may usher in a new era of technological progress by the year 2000.

G. A. Smolenskiĭ. A Magnetic Memory for Future Generations of Electronic Computers. The current methods of recording and readout of information in electronic computers with the aid of, as a rule, ferrite cores do not allow the solution of problems of the future. An urgent necessity arises for the capacity and speed of response of the memories of future generations of the electronic computer to be increased. In this connection intensive work is being done at present on the application of a number of new principles for the construction of memories, using integrated solid-state circuits, cylindrical magnetic domains, devices with charge coupling, optical phenomena (thermomagnetic, electro-optical, and other modes of recording, including the holographic method), and superconductors.

The fundamental investigations of domain structure and magneto-optical phenomena, as well as the discovery of new types of magnetically ordered media[1-7] formed the basis upon which the new types of magnetic memory were constructed.

1. Cylindrical Domains. It turned out that isolated cylindrical domains of small dimensions (a few microns) can be produced in certain magnetic crystals[8,9]. Such a domain structure is realized when weak external magnetic fields are applied in thin films with the direction of easy magnetization perpendicular to the surface of the film, when the field of the magnetic crystallographic anisotropy is stronger than the saturation magnetization. In the presence of a magnetic field gradient, the cylindrical domains can move through the crystal. A. Bobeck suggested that these mobile domains (they are called magnetic bubbles abroad) could be used as information carriers in large-capacity logical and mem-

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*[EH] ≡ E × H.