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POSSIBILITY OF PRODUCING HIGH PRESSURE IN A SOLID BY MEANS OF A STRONG-CURRENT ELECTRON BEAM

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The problem of obtaining new materials in phase transitions frequently encounters the need for producing a static or dynamic pressure of the order of $10^5 - 10^6$ bar. To produce such high dynamic pressures in a solid one can use a strong-current relativistic electron beam. By focusing such a beam in a small volume at a certain depth from the surface of the solid, and by choosing the beam parameters and the target material in such a way that multiple ionization gives rise to a large number of free electrons, it is possible to obtain a state wherein the electron density is lower by one order of magnitude than in metals, i.e., $N_e \sim (1 - 3) \times 10^{23}$ cm^{-3}. In this case the Fermi energy will be on the order of $\varepsilon_F \simeq 0.5 \times 10^{-26}$ and $N_e^{2/3} \simeq 10 - 30$ eV. If we choose as the target a substance with readily-ionized atoms and closely-lying ionization levels (e.g., rare-earth elements or actinides, in which the first ionization potential is $\sim$5 eV and the next five - six levels are spaced 5 - 10 eV apart), then the temperature of the electron gas may turn out to be lower than the Fermi energy, and the gas is degenerate. To this end, obviously, it is necessary to satisfy the condition $T_e \lesssim (\bar{I} - \varepsilon_F) < \varepsilon_F$, where I is the average ionization potential of the substance per electron. The pressure in such a degenerate electron gas is of the order of $p \simeq 2 \times 10^{-27} N_e^{5/3} \simeq (0.5 - 3)$ Mbar.

Let us estimate the beam parameters necessary to attain a pressure of 1 Mbar. Such a pressure is ensured by an electron concentration $N_e \simeq 1.5 \times 10^{23}$ cm^{-3}, corresponding approximately to fivefold ionization of the target atoms. The average ionization potential per electron in easily-ionized substances is in this case of the order of 25 - 30 eV, and the Fermi energy is $\varepsilon_F \simeq 15$ eV, i.e., $T_e \leq 10 - 15$ eV, and consequently the electron gas will be degenerate.

For complete fivefold ionization of a volume with linear dimension a the required energy is $\sim 4 \times 10^5 a^3$ J. Obviously, the dimension a should be, on the one hand, of the order of the beam electron mean free path, which amounts to several millimeters at an electron energy $\sim$3 - 5 MeV, and on the other hand, $a \ll V_F \tau_0$, where τ_0 is the duration of the beam pulse. The latter inequality ensures the absence of accumulation of space-charge-producing excess electrons in the volume. We shall use in the estimates $\varepsilon \sim 5$ MeV and a linear dimension $a \simeq 0.5$ cm. The necessary total beam energy is then 50 kJ. Each beam electron produces in this case 1.5×10^5 ionization electrons and, if it is recognized that the total number of beam electrons per pulse is $n \sim 10^{17}$, then the ionization results in 1.5×10^{22} electrons in a volume a^3, corresponding to the concentration $N_e \simeq 1.5 \times 10^{23}$ cm^{-3} needed to produce a pressure $p \simeq 1$ Mbar.

The pulse time τ_0 is, in turn, bounded from above. It can be easily understood that τ_0 must satisfy the condition $\tau_0 < a/v_0$, where v_0 is the velocity of the ions dragged by the electron-gas pressure, $v_0 \simeq 3 \times 10^5$ cm/sec. For the target and beam parameters assumed above, we have 3×10^{-9} sec $\ll \tau_0 < 2 \times 10^{-6}$ sec, then we obtain for the beam power $W \simeq 5 \times 10^{10}$ W, and for the current in the electron beam $I \simeq 10$ kA.

The electron pressure under such conditions will act on a layer of thickness $\simeq 0.3$ cm surrounding the target.

We note finally that the Rosseland free path of the equilibrium quanta in the volume considered by us corresponds to $\ell = 10^{-6}$ cm even at $T \sim 15$ eV; the free path of electrons of energy 30 - 50 eV is of the order of 10^{-5} cm. Therefore the effective process of radiative recombination is possible on the surface of the volume and does not play an important role in the balance of the ionization of the target atoms by the electron beam. The radiation power from the surface of the target is negligibly small compared with the power of the electron beam. For the same reason, a negligible role is played by triple recombinations resulting in the formation of high-energy electrons capable of again ionizing the atoms of the substance.

One of the possibilities of using the high pressure produced in a solid by an electron beam, from our point of view, is that of obtaining metallic hydrogen. According to contemporary theoretical notions [1], molecular hydrogen goes over at pressures on the order of $\sim 10^6$ bar into a new phase state, which may turn out to be metastable and have superconducting properties. The Debye temperature of superconducting hydrogen amounts, according to theoretical estimates, to $\Theta \gtrsim 0.3 - 1$, and the critical temperature is $T_c \gtrsim 90°K$. Owing to these parameters, the production of superconducting hydrogen is an enticing problem. Obviously, in order to obtain it, the working medium for producing the high pressure must be a readily-ionized material, placed in the form of a small granule in liquid hydrogen near its surface, and on which an electron beam is focused. If the temperature of the electron gas in multiple ionization of the target atom by the electron beam constitutes a small fraction of the average ionization energy, then the proposed method of obtaining metallic hydrogen may turn out to be promising. Under conditions when the ionization of the atoms occurs in a medium of a degenerate electron gas with a Fermi energy on the order of 15 - 20 eV, the formation of such a low-temperature electronic plasma seems to us quite probable. To verify this assumption, we are attempting to solve numerically the problem of determining the average thermal energy of electrons produced as a result of cascade ionization of atoms by an electron beam.

In conclusion, the authors are grateful to S. Darznik for a discussion.

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ELECTROMAGNETIC CONTRIBUTIONS TO THE TOTAL CROSS SECTION OF HADRON SCATTERING

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If we extrapolate the old data on the total cross section for the scattering of hadrons in the Regge-pole model [1], then the cross section should still decrease at $E \gtrsim 30$ GeV. At the same time, the experimental [2] cross section σ^{exp} is practically constant starting with 25 - 30 GeV. With increasing energy, it deviates more and more from the extrapolation of [1], and exceeds it at 60 GeV (for π^-p and K^-p scattering) by approximately 1 mb. In addition, the data of [2] point to violation of the Pomeranchuk and Okun'-Pomeranchuk theorems, if the observed constant value is indeed the asymptotic value of the cross section.