Joint Scientific Session of the Division of General Physics and Astronomy and the Division of Nuclear Physics; USSR Academy of Sciences (24-25 October, 1973)

Usp. Fiz. Nauk 113, 351-363 (June, 1974)

A joint scientific session of the Division of General Physics and Astronomy with the Division of Nuclear Physics was held on October 24 and 25, 1973 at the conference hall of the P. N. Lebedev Physics Institute. The following papers were delivered:

1. I. P. Stakhanov, On the Nature of Ball Lightning.

2. M. S. Rabinovich and V. N. Tsytovich, New Collective Methods of Charged-Particle Acceleration.

3. G. M. Drabkin, G. P. Gordeev, E. I. Zabidarov, Ya. A. Kasman, A. I. Okorokov, and V. A. Trunov, Investigation of Magnetic Ordering and Phase Transitions in Magnets by a Polarized-Neutron Method.

4. O. I. Sumbaev, V. A. Shaburov, I. M. Band, A. E. Sovestnov, E. V. Petrovich, Yu. P. Smirnov, and M. B. Trzhaskovskaya, Investigation of the Electronic Mechanism of Isomorphic Phase Transitions Using the "Chemical" Shifts of X-Ray Lines.

5. G. M. Drabkin, V. A. Noskin, É. G. Tarovik, A. Z. Yugud, M. M. Agamalyan, and N. P. Zhuchenko, Investigation of Diffusive Mass Transport of the Isotope He^3 in Liquid He I with the Aid of Thermal Neutrons.

6. S. V. Maleev, Magnetic Dipole Forces and Dynamics of Critical Fluctuations Above the Curie Point in Ferromagnetics.

7. O. M. Sumbaev, E. V. Petrovich, Yu. P. Smirnov, I. M. Band, and A. I. Smirnov, Use of a Method of Small X-Ray Line Shifts to Investigate the Electronic Structure of Crystal Chemical Bonds.

8. Yu. S. Grushko, L. I. Molkanov, I. M. Band, and A. V. Oleĭnik, Combination of the X-Ray Chemical Shift Method and the Mossbauer Effect in Study of Electron Valence Structure.

9. G. M. Drabkin, A. I. Sibilev, V. V. Klyubin, T. G. Braginskaya, and G. E. Shmelev, Spatial Correlation Effects of Fluctuations in a Liquid Binary Mixture and its Electrical Conductivity Near a Phase-Transition Point.

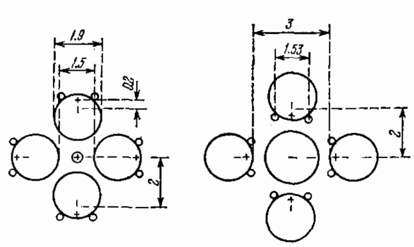
We publish below brief contents of the papers.

I. P. Stakhanov. On the Nature of Ball Lightning. 1. It is assumed that recombination in ball lightning is delayed by the formation of solvate shells consisting of water molecules (see figure). The bonding energy of the water molecule to the ion is found to be on the order of 1 eV and, consequently, destruction of the solvate envelope requires several electron volts. Thus, the solvate envelopes are stable at temperatures of $(1-2)\times 10^3$°K, and they can block recombination by preventing direct contact of the ions in collisions. Recombination can continue on merging of two ions to form a single "molecule" in inelastic collisions. However, because of the large size of this "molecule" and weakening of the interaction among ions surrounding the solvate envelopes (because of the high dielectric constant of the water), its stability would appear to be low in the temperature range that interests us. It is assumed that recombination proceeds slowly as a result of rapid decay of the "molecules."

It can be shown[1] that an explosive chain reaction of solvate-envelope breakdown begins if the temperature of the matter exceeds a certain limit. Otherwise, there will be slow recombination via the formation of "molecules." At $T \approx 10^3$°K and an ion concentration 10^{19} cm^{-3}, the energy density enclosed in the matter of the lightning is 7 J/cm^3 (about 10 eV to each pair of ions). With a radius R = 15 cm, this gives about 10^5 J, which is consistent with existing estimates[2]. The decrease in the density of the matter as a result of heating is offset by the increase in the molecular weight of the ions. At $T = 10^3$°K, the density of the matter in the lightning is approximately equal to the density of air if the solvate envelopes of the ions consist of four water molecules.

2. Because of the large effective radius of the Coulomb forces, the surface tension (σ) of plasma media should be anomalously high. In liquid metals, it is 500 – 1000 erg/cm^2 as compared to 20 – 30 erg/cm^2 for organic liquids. The surface tensions of strong electrolytes (except for HCl) increase linearly with increasing solution concentration.

If the ionic contribution is calculated on this basis, it is found to be 100 – 200 erg/cm^2 according to rather conservative estimates.



Schematic structure of hydrated ions (dimensionsiin Å).

Assuming that the molecular forces are of the same nature, $\sigma \sim n^{2/3}$ (where n is the particle concentration), we find that $\sigma = 1 - 10$ erg/cm^2 for the lightning. A number of facts (such as the ball shape of the lightning, its decay into several smaller lightnings, also of ball shape[3], and the penetration of the lightning into closed rooms through very small holes, even chinks[4], after which it resumes its shape) indicate that surface tension is a significant factor in this phenomenon. It alone can explain the strange stability of the lightning to the development of turbulent convection, which should disperse its matter in the surrounding air within a fraction of a second. An estimate of the stability of the shear discontinuity at the boundary of a lightning ball moving at 0.3 – 1 m/sec is consistent with the value of σ given above.

3. The stability of ball lightning with respect to buildup of capillary-gravity waves that appear as a result of the convective instability resulting from the fact that the lightning matter has a density different from that of the surrounding air was calculated in[5]. It was found that the lightning is stable at $\sigma = 2$ erg/cm^2 if

$$|\rho-\rho_0| \leqslant \frac{24\cdot 10^{-3}}{R^2}, \quad (1)$$

where ρ and ρ_0 are the densities of the lightning matter and the surrounding air. Hence it follows that at R = 15 cm, the ratio $|\rho - \rho_0|/\rho_0$ should be smaller than 10%. This explains why the lightnings often hover in the air. Formation of lightnings larger than 1 meter in diameter requires very specific initial conditions ($|\rho - \rho_0|/\rho_0$ smaller than 1%), and such lightnings are therefore practically never encountered. Lightnings with diameters smaller than 1 cm have not been observed because, according to estimates, they should burn out within a fraction of a second. The most commonly encountered lightning balls have diameters from 10 to 20 cm, and for them condition (1) is not too stringent.

Since the density of the matter must change on recombination, condition (1) is violated long before much of the matter of the lightning has had time to recombine. As a result, the lightning should disintegrate as a result of the development of instability. This explains the short lifetime of the lightning (averaging 2 – 10 sec[6]) and agrees with eyewitness accounts as to the manner in which it disappears 7.

4. The lightnings apparently begin to radiate on ion recombination, releasing energies of about 1 eV per particle (with consideration of the solvate envelopes).

We note that ions bound to several water molecules (so-called ion bunches or clusters) have recently been observed in considerable numbers in the lower ionosphere[8]. It is curious to note that since the water-vapor content is very low at these heights, the ion clusters must be stable.

It is known that many different reactions take a different course in plasma than in a neutral gas. However, the persistence of plasma is usually associated with high temperatures and high energy releases. In principle, delay of recombination in a system consisting of solvate ions would make it possible to produce a "quiet" and dense plasma with comparatively low temperatures. This would open the way to the conduct of new chemical reactions and preparation of a number of chemical compounds that are unstable under plasmotron conditions. It is not impossible that a totally new type of dischargelss plasma reactor might be designed on this basis. The contents of this study are set forth in greater detail in[1,5].

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[7]M. T. Dmitriev, Priroda No. 6, 98 (1967).
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M. S. Rabinovich and V. N. Tsytovich. New Collective Methods of Charged-Particle Acceleration. 1. Collective methods of accelerating charged particles were proposed some time ago by Veksler (see[1,2]). Attention was initially focused on theoretical developments (see[3,4]), and then on experiments with relativistic electron rings[5]. Papers on relativistic rings are well known, and note should be taken here of the progress that has been made in the acceleration of multiply charged ions. Considerable progress has been made in another direction in recent years (1968–1972): the study of linear collective acceleration of ions in powerful relativistic electron beams. More than six experimental groups (see[6]) have used relativistic electron beams with energies of 1 – 2 MeV, currents of $5 \cdot 10^4$ to 10^6 A, and powers of 10^{10} to $2 \cdot 10^{12}$ W, and they have obtained accelerated ions (accelerated in the direction of electron motion) with energies from 2 to 12 MeV/Z in numbers of 10^{12} to 10^{15} particles per pulse, which corresponds to accelerating fields from 40 to 400 mV/m and acceleration powers from 10^9 to 10^{11} W. These parameters are at the moment better than those recently obtained with relativistic electron rings, forcing, on the one hand, a review of some of the earlier theoretical developments[4] and, on the other, examination of new proposals being advanced for discussion of general physical principles that might increase the efficiency and power of the new collective accelerators using relativistic electron beams and dense plasmas. But until now neither the acceleration mechanism nor the cause of termination of the acceleration even before the end of the electron pulse has as yet been fully clarified. This is another cogent reason for developing the theory.

2. One of the basic problems of collective accelerators is that of producing strong collective electric fields. Progress in this direction is possible basically by increasing the plasma density in the relativistic beams. From the simple relation $E_{max} = 4\pi n_0 ea$, putting $a = c/\omega_{pe}$, and $\omega_{pe} = \sqrt{4\pi n_0 e^2/m_e}$, we obtain $E_{max}[mV/m] = (1/10\,000)\sqrt{n_0(cm^{-3})}$. For existing electron beams with $n_0 \approx 10^{13} - 10^{15}$ cm^{-3}, the fields E_{max} reach 300 – 3000 mV/m. But in a denser plasma, for example a laser plasma, they may reach 10^6 mV/m and higher.

3. Excitation of such fields requires the use of the maser-buildup principle, i.e., avalanche-like buildup of strong fields from initial weak fields. These instabilities may be of two-stream, parametric, or specific nature due in part to the charge neutralization that is necessary for equilibrium of a relativistic electron beam. It is necessary that nonlinear saturation processes not interfere with attainment of fields near E_{max}.

4. The fields excited must be quite regular in nature; this can be attained, for example, by reducing the energy scatter of the beam particles or the electromagnetic hf field exciting the instability. Such regularization has been brought about experimentally in several American laboratories. The possibility of exciting a regular strong wave of the nonlinear soliton type has been demonstrated. Ya. B. Faĭnberg[7] regularized a plasma-beam instability in an experiment by modulating the beam. The maximum fields estimated above have not yet been achieved in any of these experiments. The authors of the present paper point to new opportunities for regularization by using the nonlinear frequency decrease in systems having minima on the $\omega = \omega(k)$ dispersion curves.

5. Use of the properties of extreme-relativistic electrons to create deeper potential wells is of special importance. It is shown in[8] that in a relativistic electron beam with $\gamma = 1/\sqrt{1-\beta^2} \gg 1$, where $\beta = v/c$ (v is the velocity of the beam), i.e., a beam moving at a velocity near that of light, self-consistent stable potential wells formed by nonlinear waves that reach $2m_e c^2\gamma^2$ can exist in the laboratory system. Moving at nonrelativistic velocities in the laboratory system, such potential wells can trap and accelerate ions; their maximum electric fields are larger than that estimated above by $\sqrt{\gamma}$.

6. Control of the velocities of the potential collective wells is also of particular importance. The following methods may be used for this purpose: a) a decrease of beam density in space or an increase in the plasma density, which would result in an increase in the phase velocities of the waves in the plasma or a decrease in the beam, i.e., in an acceleration of the waves in the laboratory system in either case; b) use of an inhomogeneous decreasing magnetic field with buildup of cyclotron waves in the relativistic beam. Then $\omega_0/k = v - (\omega_H/k) \to v$, i.e., the waves are accelerated to the velocity of the beam[9]; c) use of external electric fields $E \ll E_{max}$, which accelerate the nonlinear relativistic waves to velocities near but not exceeding that of light, i.e., accelerate the nonlinear wave as a bunch[10].

7. An important possibility is that of using collective processes for autosynchronization of the collective acceleration[11]. This possibility arises out of the partial charge neutralization of the relativistic electrons. As a result, according to[11], the ions to be accelerated could create, with their charges, potential wells that are synchronous with their motion.

8. Another important possibility is that of a self-consistent increase in the potential wells as a result of dissipative loading of these wells by the ions being accelerated. This situation arises under conditions such that the potential wells are excited on negative-energy modes[9]. We proposed a similar principle in[12] for compression of a light electron beam by having a relativistic beam flow around it. Realization of these principles would permit an approach to solution of impact-acceleration problems[3].

All of these principles have been discussed or im-