

3. The  $\text{Sb}^{3+}$  absorption line in Rb and Cs salts is appreciably broadened, whereas the  $\text{Sb}^{3+}$  absorption line in  $\text{Rb}(\text{NH}_3)_6\text{SbCl}_6$  (spectrum C) has no broadening compared with the source line. The quadrupole broadening of the  $\text{Sb}^{3+}$  line indicates that the  $\text{SbCl}_6^{3-}$  octahedra are distorted (static Jahn-Teller pseudoeffect).

We note in conclusion that the role of the cations apparently reduces to an effective change of the width of the forbidden band of the crystal, and hence to a change of the electron-vibrational interaction, on which are dependent the static distortion of the  $\text{CbSl}_6^{11-}$  octahedra and the dynamic phenomena in the  $\text{M}_2\text{SbCl}_6$  crystal lattices.

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#### MOLECULES IN AN ULTRA STRONG MAGNETIC FIELD

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In a very strong magnetic field, greatly exceeding  $10^9$  Oe (such fields can exist in neutron stars), an atom with an atomic number  $Z$  becomes strongly stretched along the magnetic field  $B$  [1 - 3]. Such atoms have a large electric quadrupole moment and should become bound into stable molecules. This makes possible the formation of molecules of a highly extraordinary type, in which the electron cloud becomes common, and all the electrons form a negatively-charged "needle," with the nuclei lying on its axis. We shall determine approximately the binding energy of such a molecule, disregarding the interaction of the atoms at large distances.

Let us consider first a diatomic molecule with nuclei lying on a single magnetic force line at distances  $R$  from one another, and having a charge  $Z$  each. Neglecting the exchange correction, the energy can be approximately expressed in the form (cf. formula (2) of [3]):

$$E = N \int \left\{ \frac{1}{2} \left( \frac{\partial \tilde{\psi}}{\partial \mathbf{z}} \right)^2 - \left( \frac{Z}{r} + \frac{Z}{|\mathbf{r} - \mathbf{R}|} \right) \tilde{\psi}^2 + \frac{N-1}{2} \left\langle \frac{1}{r_{12}} \right\rangle \tilde{\psi}^2 \right\} d\mathbf{r} + \frac{Z^2}{R}. \quad (1)$$

Here  $\tilde{\psi}$  is the average wave function, so that  $N\tilde{\psi}^2$  equals the average electron density,  $N$  is the number of electrons,

$$\left\langle \frac{1}{r_{12}} \right\rangle = \int \frac{1}{|\mathbf{r} - \mathbf{r}_2|} \tilde{\psi}^2(\mathbf{r}_2) d\mathbf{r}_2,$$

atomic units are used throughout.

The ground-state energy is determined by the minimum of the functional

(1) subject to the additional condition  $\int \tilde{\psi}^2 dr = 1$ . When  $B \gg Z^3$  (the magnetic field is measured in units of  $m^2 e^3 c h^{-3} = 2.35 \times 10^9$  Oe), the lowest levels with respect to longitudinal motion become filled [1 - 3], and the electron cloud assumes a needle-like shape with a small radius  $\rho_N = \sqrt{2N/B}$ . To determine the minimum of the energy (1) under these conditions, we can use the approximation of a thin charged body with a running charge density  $\lambda(z) = \int \tilde{\psi}^2 2\pi r dr$ . We choose for  $\lambda$  a trial function in the form  $\lambda = \beta = \text{const}$  between the nuclei, i.e., at  $0 < z < R$ , and in the form of an exponential outside the nuclei:  $\lambda = \beta \exp(-2\alpha|z|)$  at  $z < 0$  and  $\lambda = \beta \exp[-2\alpha(z - R)]$  at  $z > R$ . From the normalization of  $\tilde{\psi}$  it follows that  $\beta = (\alpha^{-1} + R)^{-1}$ . The integrals in (1) can be easily calculated with logarithmic accuracy and in the approximation  $R \ll \alpha^{-1}$ , when the nuclei lie close to the center of the electron cloud, the approximate expression for E becomes

$$E \cong N \left\{ \frac{\beta^2}{2} - 4ZL\beta + \frac{N-1}{2} L(\beta + R\beta^2) \right\} + \frac{Z^2}{R}, \quad (2)$$

where  $L = \ln(1/\beta\rho_N) \gg 1$  when  $B \gg Z^3$ . From the condition that E be minimal with respect to R, i.e., from  $\partial E/\partial R = 0$ , we get

$$R^2 = \left( \frac{1}{\beta^2} \right) \left( \frac{2Z^2}{N(N-1)} \right) \left( \frac{1}{L} \right).$$

For a neutral diatomic molecule,  $N = 2Z$  and  $R\beta = (1/\sqrt{2L}) \ll 1$ , i.e., when  $L \gg 1$  the distance between the nuclei is actually small compared with the characteristic length of the electron cloud  $\beta^{-1} \approx \alpha^{-1}$ , but is large compared with its radius  $\rho_N$ . It is seen from (2) that when  $R\beta \ll 1$  the term with R in the curly brackets is small, and consequently the minimum of E with respect to  $\beta$  is determined in the same manner as for an isolated atom with a nuclear charge  $2Z$  [3], so that we obtain

$$\beta = \frac{1}{2}(8Z - N + 1); \quad E = -\frac{N}{8}(8Z - N + 1)^2 + \sqrt{\frac{N(N-1)}{2}}(8Z - N + 1)L^{3/2}, \quad (3)$$

$$L_n = \ln(1/\beta\rho_{nz}) \approx 1/2 \ln[B/(nZ)^3]$$

(n is an integer). The second term in the expression for E in (3) corresponds to allowance for the Coulomb repulsion of the nuclei. For a neutral molecule ( $n = 2Z$ ), expression (3) is approximately equal to

$$E = -9Z^3 L_2^2 + 6\sqrt{2}Z^3 L_2^{3/2}. \quad (4)$$

We recall that the energy of an isolated atom in a superstrong magnetic field  $B \gg Z^2$  is equal to  $E_a = -(9/8)Z^3 L_1^2$  [3]. It thus follows from (4) that the binding energy of a diatomic molecule in a field  $B \gg Z^3$  is tremendously large, six times larger than  $E_a$ .

For a triatomic molecule with nuclei lying along a single force line with a distance between them, we can again use the same approximation as before:  $\lambda = \beta = \text{const}$  between the nuclei, and exponential outside the nuclei. When  $R \ll \beta$  and  $N \approx 3Z \gg 1$  the expression for the energy E takes the form

$$E = 3Z \left\{ \frac{\beta^2}{2} - 6ZL\beta + \frac{3Z}{2} L(\beta + 2R\beta^2) \right\} + \frac{5Z^2}{2R}. \quad (5)$$

Repeating the arguments that led to (3) and (4), we get

$$E = -\frac{9}{8}L^2(3Z)^3 + \sqrt{\frac{5}{2}}L^{3/2}(3Z)^3. \quad (6)$$

For a triatomic molecule the binding energy, i.e., the difference between the energy in (6) and the energy of a system consisting of a diatomic molecule and an isolated atom is positive only if  $L > 6$ , i.e., at very large  $B$ . This means that homogeneous atoms in a superstrong magnetic field should form diatomic molecules with large binding energies. Of course, one cannot exclude the possibility of the coalescence of such molecules with one another to form more complicated complexes but with smaller binding energies.

Let us consider now a molecule made up of one heavy atom  $Z$  and two light atoms  $Z'$  lying on the same force line on both sides of the heavy atoms and at equal distances  $R$  from it. It is natural to use for the running electron density the approximation  $\lambda = \alpha \exp(-2\alpha|z|)$ . Then we obtain for  $E$ , if  $\alpha R \ll 1$ ,

$$E = N \left[ \frac{a^2}{2} - 2ZLa - 4Z'La(1-2\alpha R) + \frac{N-1}{2}La \right] + \frac{2ZZ'}{R}. \quad (7)$$

In analogy with the foregoing, we obtain the minimum value of  $E$  when  $Z' \ll Z$  and  $N = Z + 2Z'$ :

$$E = E_0 - \frac{27}{4}Z^2Z'(L^2 - 16L^{3/2}) - E_0 - \frac{27}{4}Z^2L^2Z'. \quad (8)$$

It is seen from (8) that when  $L > 1$  the binding energy is positive and is much larger than the energy of adhesion of  $2Z'$  electrons to the atom; the latter is equal to  $2Z'E_I = (3/4)L^2Z^2Z'$ , where  $E_I$  is the ionization energy [3]. Thus, if light atoms (say with  $Z' < 10$ ) are present in addition to the heavy ones, the formation of molecules of different types is favored energywise. It is easy to verify that the light nuclei are located in this case at the points of the minimum potential  $\phi(z)$  along the axis of the heavy atom. With further addition of new light atoms, their nuclei will again lie close to the same points, since the electrostatic repulsion of the added nuclei is smaller than the interaction with the main field.  $Z'$  can then be taken to mean the average charge of the light nuclei in a molecule of the type  $HL_n$ , where  $H$  and  $L$  are the heavy and light atoms, and  $n$  is an integer. When  $Z'$  is added to  $Z$ , such a molecule should apparently become realigned.

The effect of joining of light atoms into a molecule should take place also for the type  $H_2$  molecule considered above. For the binding energy of such a molecule, in the form  $H_2L_n$ , we can use approximately formula (8), replacing  $E_0$  by the expression for the molecule energy (3), and replacing  $Z$  by  $2Z$ . The energy of such a molecule is minimal.

We have thus shown that in a superstrong magnetic field  $B \gg Z^3$  formation of molecules is energetically favored. In a pure substance there should be produced diatomic molecules, whereas in a mixture of heavy and light substances there should be produced molecules of the type  $H_2L_2$ , where  $n \sim Z_H/Z_L$ . Such molecules have a very large binding energy, much larger than the ionization energy. Therefore a plasma with molecular ions should be produced when this substance is heated.

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OBSERVATION OF ASYMMETRY OF THE DISTRIBUTION OF TURBULENT ELECTRIC FIELDS IN A DIRECT DISCHARGE PLASMA BY MEANS OF THE POLARIZATION IN THE STARK PROFILE OF THE H $\alpha$  LINE

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As shown in earlier experiments [1, 2], the Stark broadening of hydrogen spectral lines makes it possible to measure the degree of turbulence of a plasma. However, the amplitude of the intensity of the electric microfields is not the only characteristic of the mechanism of turbulent heating. According to the theory of Rudakov and Korablev [3], the distribution of the ion-acoustic oscillations should have a rather sharp maximum in the direction of the current. Such an asymmetry in the distribution of the electric fields has not been observed experimentally so far. We have established the existence of anisotropy of the spectrum of ion-acoustic oscillations in a direct discharge, and measured its magnitude.

To measure the degree of asymmetry, we used a new method based on the polarization in the Stark profile of the H $\alpha$  line, which experiences quasistatic broadening in the electric fields of ion-acoustic oscillations [4].

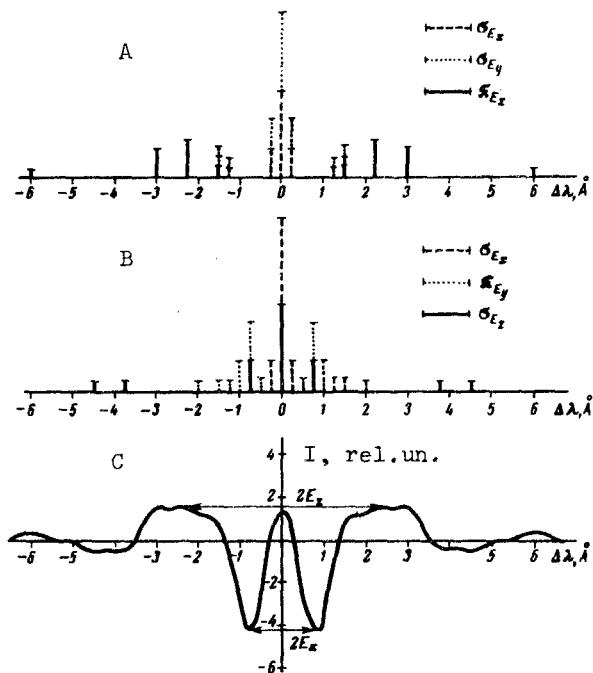


Fig. 1. Splitting of the H $\alpha$  line in z-polarization (a) and in y-polarization (b); C - difference of the line contours of the z- and y-polarizations; each individual component is assumed to have a Gaussian shape with  $\Delta\lambda_{1/2} = 0.8 \text{ \AA}$ .

1. Under straight-discharge conditions, the distribution function of the electric microfields has only axial symmetry. The presence of a maximum of the electric fields along the system axis will affect the profiles of the hydrogen spectral lines, depending on whether the polarization vector of the observed light is parallel or perpendicular to the system axis. Indeed, in a static electric field the splitting of the hydrogen spectral lines and the character of the polarization of the components depend strongly on the observation direction [5]. The  $\sigma$  components always lie near the center of the line, while the  $\pi$  components are farthest away from it. The expected character of the anisotropy effect can be visualized by considering the intensity distribution of light having different polarizations, radiated in the direction of the OX axis by hydrogen atoms, one-third of which are in the electric field