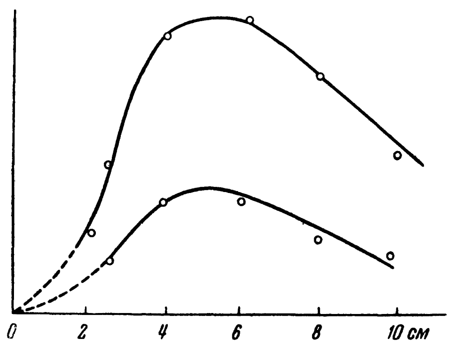
direction, we made use of a combination radiator, which was a quartz plate of 20 mm diameter. To one side of the plate was attached a foil membrane with air padding, and to the other side, foil electrodes in the form of two sectors, each covering half of the radiating face of the crystal. These sectors were separated by a distance of 1 mm. Variable voltages were applied from two independent generators. The foil membrane acted as the ground electrode. The generators developed variable voltages of 250-300 v. The thickness of the quartz plate was so chosen that the radiator was adjusted to resonance at one of the fundamental frequencies (either one). Frequencies of 1 mc and 1.5 mc were used as fundamental frequencies.



A barium titanate plate was used as the pressure receiver. The voltage developed across the receiver was amplified by a two-channel (for the sum and difference frequencies) tuned amplifier. An oscilloscope was used as the output meter. By displacing the receiver relative to the source (maintaining strict parallelism between the two surfaces), it was possible to observe (on the oscilloscope) the change in the intensity of the sum of difference frequency. As these observations showed, the intensity of these waves was spatially modulated by the base frequency . In the Figure the intensity of the modulated vibrations is plotted against distance; the distance from the source in cm is plotted along the abscissa, while the ordinate is a quantity proportional to the intensity of the modulated vibration. The results of the observation refer to the sum wave at 2.5 mc obtained in vaseline oil (at $t = 20^0$). Two curves are shown in the Figure, taken for different intensities of the source (the lower curve was taken for an intensity one-half the higher one). As the curves show, the intensity of the modulated combination waves increases with distance from the source, passes through a maximum and then decreases.

Thus we can draw the following conclusions:

1. The intensity of the modulated vibration has a maximum with respect to distance.
2. The location of the maximum does not depend on the intensity of the fundamental waves.
3. As the data show, the position of the maximum for a given frequency is determined principally by the vicosity of the medium.

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The Applicability of the Second Law of Thermodynamics for Large Volumes of a Gravitating Gas

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1. ACCORDING to Terletskii[1-3] the second law of thermodynamics is not applicable to large volumes of a gravitating gas. It is claimed[2] that processes begin to take place in large volumes of a gravitating gas which contradict the second law. Publication of a criticism by the present author[4] was followed by an assertion in discussion form[1] that the earlier conclusions[2,3] were still correct under conditions in which the gravitating gas is enclosed in a thermostatted vessel covered with a piston which works at a fixed force, the pressure being $P > NkT/4V$. We will show that even under these stated conditions, the conclusions[1-3] on the inapplicability of the second law of thermodynamics for large volumes of a gravitating gas cannot be considered correct.

Terletskii[1] assumes that all conditions of the gravitating gas for which $dP/dV < 0$, are entirely stable. Account is not taken of the fact, as we will show below, that the gravitating gas has a metastable region. It is for precisely these same conditions that a greater probability of fluctuations of a cosmic scale is assumed[1].

Let us call the mass of the gravitating ideal gas M, occupying a volume V, situated near the center of the cloud of diffused material, and in a quasistatistical equilibrium. Volume V is much smaller than the volume of the whole diffusion cloud, so that one can assume that the gas is distributed uniformly throughout the volume V. The identical case was considered by Jeans[5], and then in a more general way by Lebedinskii[6] with conclusions on the instability criterion for a gravitating gas. Let us say that the diffusion cloud outside the volume V can be considered as a weight applying a constant pressure P on the separated mass of gas. Then for the free enthalpy of the gas we can write

$$\Phi = -\alpha\varkappa M^2 V^{-1/3} - NkT \ln V + PV - C(T), \qquad (1)$$

where α has a numerical value of unity and $\varkappa$ is the gravitational constant.

If the volume of the gas has the value $V_1 = (\alpha\varkappa M^2/3NkT)^3$ (condition 1), then $P = 0$, $dP/dV > 0$. The condition of the gas is unstable. The requirement $V < V_1$ is the equivalent of the known criterion for a gravitating unstable gas (see, for example, Ref. 6). If the volume of gas is $V_2 = (64/27)V_1$ then $P = NkT/4V_1$; $dP/dV = 0$. When $V > V_2$, $dP/dV < 0$ and it appears that the condition of the gas is thermodynamically stable. But this is not so. It follows from Eq. (1) that $\Phi_1 - \Phi_2 = NkT\,[\ln(64/27) - 1]$, i.e., $\Phi_1 < \Phi_2$. Consequently, the condition of the gas, immediately adjoining condition 2, appears to be metastable. Simple calculations show that the region of metastable equilibrium extends toward a minimum value of $V \approx 1.5\, V_2$. In this region the condition of the gravitating gas is in a certain sense, in a condition similar as to that of a supercooled vapor. The formation of small incidental condensation in the metastable region of the gravitating gas leads to the gravitational condensation of the whole gas. As we know, the fluctuation theory in its strict form is not applicable to the condition of metastable equilibrium. The relationship $\overline{(\Delta V)^2} = -kT\,\partial V/\partial P$,[1-3] is correct only for small deviations from equilibrium and under conditions such that the system is in a fixed thermodynamic equilibrium (see, for example, Ref. 7, p. 98). This consideration holds good for all the conditions of the gravitating gas models used in Ref. 1, both those obeying Newton's law and those not obeying it.

Thus the reasoning in Refs. 1-3 is appropriate only for a gravitating gas whose V is significantly greater than V_2. Under these conditions the factor $(1 - 4\alpha\varkappa M^2/9NkTV^{1/3})$ used in Eq. (2) of Ref. 1 significantly differs from zero and consequently cannot have any essential effect on the quantity $\overline{(\Delta V)^2}/V^2$. Furthermore, Eq. (2) or the analogous Eq. (11) in Ref. 1 cannot serve as a proof of the statement concerning the applicability of the second law of thermodynamics for a greater volume of a gravitating gas.

2. Statistical thermodynamics in principle cannot lead to results contrary to the second law of thermodynamics since it itself originated in the statistical interpretations of this law; otherwise, statistical thermodynamics would be internally inconsistent. In a similar way, classical mechanics cannot lead to results contrary to Newton's law on which it is based. Since only statistical thermodynamic methods are used in Refs. 1-3 one can consider to be mistaken, *a priori*, the statement concerning the inapplicability of the second law of thermodynamics for large volumes of a gravitating gas.

3. The hypothesis of J. P. Terletskii on the inapplicability of the second principle of thermodynamics to large volumes of a gravitating gas was introduced with the aim of defending the fluctuation hypothesis of Boltzmann. This hypothesis of Boltzmann is not true because of errors in the hypothesis of Clausius concerning the thermal death of the universe. In both these hypotheses the problem of the development of the universe is approached by the introduction of the universe as if it were an insulated system. This approach is physically unfounded. From the point of view of philosophy it appears to be idealistic. It is precisely the assumption of a finite or insulated universe and not the second law of thermodynamics which leads to the conclusion of the expectation of the thermal death of the universe[8]. To prove the error in the Clausius hypothesis it is not necessary to leave the framework of thermodynamics and go to statistical physics and to theories of clusters.

4. The existence of regions of metastability in the gravitating ideal gas has not been given much attention. We believe that the calculation of the metastable condition of a gravitating ideal gas will be useful for research into gravitational condensation of interstellar material.

[1] J. P. Terletskii. J. Exptl. Theoret. Phys. (U.S.S.R.) **29**, 237 (1955); Soviet Phys. JETP **2**, 262 (1956).

[2] J. P. Terletskii, Proceedings of the Second Conference on Problems of Cosmogony, Acad. Sci., USSR, p. 507, 512 (1953).

[3] J. P. Terletskii, J. Exptl. Theoret. Phys. (U.S.S.R.) **22**, 506 (1952).

[4] M. I. Shakhparonov, J. Exptl. Theoret. Phys. (U.S.S.R.) **27**, 646 (1954).

[5] J. H. Jeans, *Astronomy and Cosmogony*, Cambridge, 1928.

[6] A. I. Lebedinskii, *Problems of Cosmogony*, Acad. Sci., USSR, pp. 113-117 (1954).

[7] M. A. Leontovich, *Statistical Physics*, Gostehezdat, 1944.

[8] M. I. Shakhaparonov, Vestn. Moscow State Univ. 6, 15 (1953).

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On the Nuclear Reaction Be^9 (pd) Be^8

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WE know that the nucleus of Be^9 can be regarded as consisting of Be^8 as a core, with an unpaired neutron moving in its field. This model proved to be quite satisfactory in connection with the photo- and electrodisintegration of this nucleus[1,2]. On the basis of this model, the Be^9 $(pd)Be^8$ reaction can be considered to be the result of the direct interaction of a proton and the unpaired neutron. The mechanism of this reaction then appears to be the following: an incident proton interacts with the unpaired neutron to form a deuteron, which escapes from the nucleus, leaving the Be^8 nucleus in its ground state. We here neglect particle spins, the Coulomb interaction and the recoil of the Be^8 nucleus.

The interaction between the proton and the nuclear neutron, whose radius vectors are designated by $\mathbf{r}_2$ and $\mathbf{r}_1$, respectively, is taken in the form of a Yukawa potential

$$V(r) = -g^2 r^{-1} e^{-\varkappa r}, \qquad (1)$$

where $r = |\mathbf{r}_1 - \mathbf{r}_2|$. For the wave function $\psi(\mathbf{r}_1)$ of the unpaired neutron in the Be^9 nucleus we take an expression given in Ref. 1. The wave function $\psi(\mathbf{r}_2)$ of the incident proton is taken in the form of a plane wave with the wave vector $\mathbf{k}$ normalized to unit flux. The wave function of the deuteron with wave vector $\mathbf{k}'$ is

$$\psi_d(\mathbf{r}_1, \mathbf{r}_2) = (2\pi\hbar)^{-3/2} e^{-ik'(\mathbf{r}_1+\mathbf{r}_2)/2}\,\Phi(r), \qquad (2)$$
$$\Phi(r) = \sqrt{\alpha_1/2\pi}\, r^{-1} e^{-\alpha_1 r},$$

where $\Phi(r)$ is the wave function of the internal state of the deuteron.

The differential cross section of the process that we are considering, as calculated by the usual equation of perturbation theory, is given by

$$\frac{d\sigma}{d\omega} = \sqrt{2\left(1+\frac{Q}{E_p}\right)}\, 48 a^2 \frac{\mu^2 g^4 r_0^2 \alpha_1 r_0}{\beta r_0 \hbar^4} \qquad (3)$$
$$\times r_0^2 (|\mathbf{k}'/2 - \mathbf{k}|\, r_0)^{-2} \operatorname{arctg}^2 \frac{\left|\frac{\mathbf{k}'}{2} - \mathbf{k}\right| r_0}{\gamma r_0}$$
$$\times [\varphi(E_p, \vartheta) + (\beta/\alpha)^2 \sin\beta r_0\, e^{\alpha r_0} J(E_p, \vartheta)]^2;$$

$$\varphi(E_p, \vartheta) = \frac{\beta r_0 \sin(\beta + q) r_0}{2(\beta + q) r_0} + \frac{\beta r_0 \sin(\beta - q) r_0}{2(\beta - q) r_0}$$
$$+ \frac{\cos(\beta + q) r_0 - \cos(\beta - q) r_0}{2 q r_0},$$

$$J(E_p, \vartheta) = \int_{r_0}^{\infty} \frac{(1 + \alpha r)}{r} e^{-\alpha r} \cos qr\,dr$$
$$- \frac{1}{q} \int_{r_0}^{\infty} \frac{(1 + \alpha r)}{r^2} e^{-\alpha r} \sin qr\,dr,$$

where $\mathbf{q} = \mathbf{k}' - \mathbf{k}$. The integrals in the expression for $J(E_p, \vartheta)$ are not in explicit form. They must be calculated for given values of the energy of the incident proton E_p and for the scattering angle ϑ. In Eq. (3) we have used the notation

$$\alpha = \hbar^{-1}\sqrt{2\mu\varepsilon}, \quad \beta = \hbar^{-1}\sqrt{2\mu(V_0 - \varepsilon)}, \quad \gamma = \varkappa + \alpha_1,$$

where μ is the effective neutron mass with relation to the Be^8 core in the Be^9 nucleus, $\epsilon = 1.66$ mev is the binding energy of the neutron in the Be^9 nucleus, V_0 is the depth of the square potential well in the interaction between the unpaired neutron and the nuclear core, and r_0 is the width of this well. As has been shown in Refs. 1 and 2, $r_0 = 5 \times 10^{-13}$ cm and $V_0 = 12$ mev. Q is the energy liberated in the reaction and a is obtained from

$$\frac{a^2}{2}\left\{\beta r_0 + \left[(2 + \alpha r_0)\frac{\beta^4}{\alpha^4} + (1 + \alpha r_0)\frac{\beta^2}{\alpha^2} - 1\right]\frac{\sin^2\beta r_0}{\beta r_0}\right\} = 1. \qquad (4)$$

Experimental curves are given in Ref. 3 for the angular distribution of deuterons from the $Be^9(pd)$ Be^8 reaction at proton energies of 5, 6, 7, 8 and 22 mev.

We have calculated the angular distribution from Eq. (3) at 5-8 mev. In the Figure, Curve *1* is the angular distribution at $E_p = 8$ mev. The angular