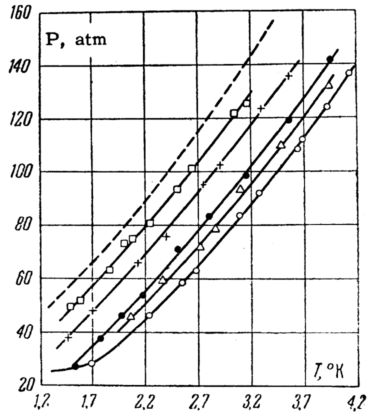

FIG. 1. Temperature dependence of the pressure at the commencement of solidification of helium isotope solutions containing various amounts of He^3. Molar concentrations of He^3 in the solutions were (in %): ○ – zero (continuous line plotted from the data of Swenson;[4] △ – 10.3; ● – 24.1; + – 53.0; □ – 76.4; dashed curve represents pure He^3.[3]

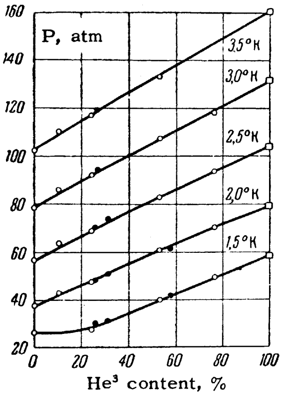

FIG. 2. Dependence of the solidification pressure of helium isotope solutions on the liquid phase composition: ○ – results of the present work; ● – results obtained by the blocked-capillary method; □ – data of Grilly and Mills for pure He^3.

The latter figure also includes the results obtained by the blocked-capillary method.[1]

The form of the isotherms and the good agreement with the results of measurements by the blocked-capillary method allow us to conclude that the equilibrium diagram of the liquid and solid phases probably has a narrow phase separation region.

It is worth noting that the results reported also agree satisfactorily with data obtained recently in the temperature range 1.0—2.1°K,[2] but the absence of a table in this work makes it difficult to carry out a detailed comparison.

Experiments to determine the completion of the solidification of solutions of He^3 in He^4 are being carried out.

The authors take this opportunity to thank Professor B. G. Lazarev for his interest in this work.

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STAR PRODUCTION IN AN EXPANDING UNIVERSE

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EXPANSION of strictly uniform matter, of infinite density at the initial instant of time, is at present the only reasonable explanation for the earlier stage of evolution of the universe. Is it possible for uniform matter to segregate into individual stars and nebulas as a result of gravitational instability in an expanding universe? As will be shown below, to get an affirmative answer it is essential to take account of the phase transition from the solid to the gas during the course of the expansion.

E. Lifshitz[1] has shown that small density perturbations increase with time in proportion to the radius of the world, so that $\delta\rho/\rho \sim R \sim \rho^{-1/3}$. This result holds for the period when the pressure is small compared with the energy density, $p \ll \rho c^2$, that is, starting with nuclear density, $\rho = 10^{14}$ g/cm³. Since the density now is not less than 10^{-30} g/cm³, the perturbations increase by not more than $(10^{-30}/10^{14})^{-1/3} = 5 \times 10^{14}$ times. The sun contains about 10^{57} nucleons, and the galaxy about 10^{68}. Regarding the nucleons at the start of the period as independent, we obtain for the density-fluctuation probabilities at the start of the period an estimate $\delta\rho/\rho = 1/\sqrt{N}$, that is, 3×10^{-29} for the sun and 10^{-34} for the galaxy. These fluctuations are so small, that if we increase them by 5×10^{14} we still do not obtain an appreciable quantity.1) It is therefore concluded[1] that "it can apparently be assumed that this mechanism cannot cause separation of the matter into individual nebulas."

We note in this communication that if the expanding matter is cold (hydrogen), the matter will elongate upon reaching the normal density of the condensed phase (0.07 g/cm^3) and then break up into individual lumps or drops, separated by space filled with gas of low density. Under these conditions the deviations of the density from the average become gigantic compared with the estimate ($1/\sqrt{N}$) for the independent nucleons; the prime cause of this is the Van der Waals attraction of the molecules, which leads to a separation of the matter into two phases. Taking into account the phase transition, the gravitational increase in the perturbations, calculated by E. Lifshitz, may turn out to be sufficient for the segregation of stars.

In the super-high-temperature ideas advanced by Gamow[3] and by Alpher and Herman[4] (radiation density on the order of 1 g/cm^3, temperature on the order of 100 keV, nucleon density 10^{-6}—10^{-8} g/cm^3) there can be no phase transitions during the course of expansion. Gamow[5] finds the instant when, in accordance with the Jeans criterion, the matter becomes unstable against perturbations of wavelength corresponding to the dimensions of the galaxy; he does not notice, however, that in the presence of instability the development of perturbations calls for a time that depends on the initial amplitude. The phase transition can cause large amplitudes of the initial perturbations only under the assumption, developed in an earlier communication[6], concerning the composition of matter in the prestellar stage (protons, electrons, neutrinos). Let us present a brief estimate of this phenomenon.

The dependence of the density on the time is given by the expression

$$\rho = 1/6\pi\varkappa t^2 = 0.8 \cdot 10^6 t^{-2}$$

(ρ in g/cm^3 and t in seconds). The density 0.07 g/cm^3 of solid hydrogen at normal pressure is attained at $t = 3200$ sec. Let us assume that total breakup occurs at an elongation $\Delta l/l = 1.5\%$, $\Delta\rho/\varphi = -4\%$, that is, 60 seconds after attainment of normal density. These values of the rupture stress are taken in analogy with ordinary substances (the strength of steel, condition for cavitation of water). Thus, the tensile stress in the layer of matter increases gradually during the course of the expansion, which terminates in rupture everywhere at $t = 3260$ seconds.

Let us imagine that accidentally the rupture occurs at some point earlier, at a sufficiently smaller stress, at an instant close to $t = 3200$ sec. On the surface of the crack the stress is equal to zero; during the course of the overall elongation, the crack expands, and a sound wave propagates from it in the matter, relieving the stress in layers of matter adjacent to the crack. In the case of local rupture starting at an instant of normal density, the sound wave will relieve the stress at a velocity of 1.5 km/sec over a distance of 100 km after 60 sec. Consequently, solid hydrogen will break up into lumps measuring, in order of magnitude, 100 km, with a mass $0.07 \times (10^7)^3 \sim 10^{20}$ g. The mass of the sun is 2×10^{13} the mass of the lumps, hence $\Delta\rho/\rho \approx (2 \times 10^{13})^{-1/2} = 2 \times 10^{-7}$. We assume that this fluctuation has taken place at $\rho_0 = 0.01$. The fluctuation reaches a magnitude on the order of unity when the density drops to a value ρ_1 such that $2 \times 10^{-7}(\rho_1/\rho_0)^{-1/3} = 1$, hence $\rho_1 = 0.01(2 \times 10^{-7})^3 = 10^{-22}$. This density will be attained at the instant t_1, $\rho_1 = 0.8 \times 10^6/t_1^2$, $t_1 = 10^{14}$ sec $= 3 \times 10^6$ years.

Such a mechanism is not sufficient for the formation of galaxies, but it can be assumed that star production and the start of nuclear reactions in stars give rise to strong perturbations, which contribute to the gravitational instability. The present note does not claim to present a complete description of the creation of stars or galaxies from the homogeneous expanding matter of the universe. The gist of the note is that in this question one cannot be confined to molecular fluctuations. An account of the phase transitions offers a real possibility of approaching the question of the causes of the breakup of homogeneous matter into stars under the influence of gravitational instability. The question of the gravitational instability of the expanding world, and particularly the relation between general relativity theory and classical theory in this case, is considered in an article by the author in [7].

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1) An analogous estimate was made by Bonnor.[2]

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