and bremsstrahlung in the frequency interval $d\omega$ has an order of magnitude

$$(dW_c/dW_b) \sim (n_0/n)(n_0/\omega m^2 e^4)(M/mZ)^2,$$

where n is the total number of atoms per unit volume. It follows therefore that when $n_0 \sim n$, for low frequencies, heavy particles, and light elements, combination radiation is more intense than bremsstrahlung.

For hydrogen, the radial integral in the matrix element can be calculated exactly. For example, for the 2p—1s transition the probability of radiation turns out to be

$$dW = 0.29 \cdot \pi \, (e^2 n_0^2/m^4)\, \omega^{-2}\, d\omega.$$

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PRESTELLAR STATE OF MATTER

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In accordance with the presently observed expansion of the nebulas, it is deemed probable that in the earlier stages of the evolution of the universe there existed a homogeneous isotropic Friedmann nonstationary solution with the density of matter decreasing from an infinite value at the initial instant.

Let us consider the state of matter in the initial stage of evolution. We assume that the matter consists of a mixture of protons, electrons, and neutrinos in equal amounts, and that the entropy is low. Then at high density (on the order of nuclear density) and at zero temperature the neutrinos and the electrons form a degenerate relativistic Fermi gas, and owing to the helicity (two-component nature) of the neutrino their Fermi energy $E_{F\nu}$ exceeds the Fermi energy of the electrons; at a density 2.5×10^{38} particles/cm^3 we have $E_{F\nu} = 500$ MeV and $E_{Fe} = 400$ MeV. The process $e^- + p = n + \nu$, which leads to the formation of neutrons at high density of matter in the stars [1], turns out to be forbidden here, since the neutrino states that are energetically obtainable in this process are occupied. In the uniform model (closed or open) the neutrinos do not depart anywhere. Upon expansion such a substance turns into pure cold hydrogen.

According to modern views, it is deemed most probable that it is precisely pure hydrogen which is the initial substance from which the stars were originally formed, and that the heavier elements were the result of nuclear processes in stars.

Earlier, Gamow, Alpher, and Herman [2,3] suggested that in the initial state matter consists of neutrons or of approximately equal amount of neutrons and protons (see also [4]) and is at such a high temperature, that the radiation density is gigantically in excess of the nucleon density. This point of view, on the basis of which the authors attempted even to reconstitute the presently observed abundance of the elements, leads to unsurmountable contradictions. In the prestellar stage they obtain a large amount of helium (about 10—20%) and deuterium (about 0.5%). The radiation density (energy/c^2) remains approximately equal to the nucleon density after the matter has expanded to the modern average nucleon density 10^{-30} g/cm^3. These deductions are incompatible with the observations; the notion of matter consisting of protons, electrons, and neutrinos is the only one possible 1). At a density many times larger than nuclear, when the Fermi energy of the protons becomes comparable with their rest mass, various processes of neutron and hyperon productions become possible in principle (see [5]) ($p \to \Sigma^+$, $p \to n + \pi^+$, $p + e^- = n + \nu$). However, the expansion is slow (see [4]) compared with the relaxation time of these processes 2), and therefore only p, e^-, and ν remain by the time nuclear density is reached.

For the theory of the decay of homogeneous matter into individual clusters corresponding to the galaxies, an important factor may be the inhomogeneities of the density, arising during the course of expansion in the density interval 0.5—2 g/cm^3, where metallic hydrogen is transformed into molecular hydrogen [6], and where a phase transition from the solid body to the gas at density < 0.07 g/cm^3 is also possible. This question needs further investigation.

1) This deduction is motivated in detail in an article by the author, submitted to the collection "Voprosy kosmogonii" (Problems of Cosmogony).

2) We note that the process inverse to neutron formation proceeds not as the decay of a free neutron, but under the influence of a Fermi gas of neutrinos, and therefore is practically terminated within the expansion time.

[1] L. D. Landau, DAN SSSR **17**, 301 (1937).
[2] G. Gamow, Revs. Modern Phys. **21**, 367 (1949).
[3] R. Alpher and R. Herman, Revs. Modern Phys. **22**, 153 (1950); Annual Rev. of Nuc. Science **2**, 1 (1953).
[4] C. Hayashi, Prog. Theoret. Phys. **5**, 224 (1950).
[5] V. A. Ambartsumyan and G. S. Saakyan, Astronom. zh. **37**, 193 (1960), Soviet Astronomy **4**, 187 (1960).
[6] A. A. Abrikosov, Astronom. zh. **31**, 112 (1954).

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AN INVESTIGATION OF ROTATING He II NEAR THE λ -POINT USING SECOND SOUND

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EXPERIMENTAL studies recently carried out at Tbilisi have shown, on the one hand, that the central macroscopic vortex formed when He I is rotated and subjected to vigorous pumping persists for a certain time, even when a transition to He II takes place.[1] On the other hand, the Onsager-Feynman vortices generated by the rotation of He II survive in He I.[2] These facts clearly demonstrate the possibility of supercooling a form of motion subject to the laws of classical hydrodynamics, and of superheating a type of motion governed by quantum hydrodynamics.

The delay in the establishment of steady-state motion in He II following a transition from He I in rotation to rotating He II—i.e., the delay in the formation of Onsager-Feynman vortices—can be investigated using the scattering of second sound waves by the vortices.[3] In order to carry out a measurement of this sort, we conducted the following experiment. Liquid helium was introduced into an annular resonant cavity provided by the space between two coaxial cylinders. The resonator was capable of rotation about its axis of symmetry. The second sound source and detector were wound in bifilar fashion into a quadruple thread cut onto the inner cylinder. The source was of constantan wire 50 μ in diameter, and the detector, of 40 μ phosphor bronze. Uniform rotation of the resonator was achieved by means of a mechanical system using electromagnetic coupling which we had developed previously.[4] Electrical connections to the rotating resonator were made through mercury contacts situated within the cover of the cryostat. The second sound source was driven by an audio-frequency oscillator of high stability. The second-sound signals taken from the potential terminals of the detector were amplified by a tuned amplifier having a gain of 10^7, rectified, and fed into an ÉPP-09 recorder. An ÉO-7 oscilloscope provided a visual check on the tuning accuracy of the second sound resonances.

The initial experiments, in which the propagation of second sound in a radial direction was studied, provide a basis for the present preliminary communication.

The procedure which we used was as follows. The second-sound resonant frequency was determined with the helium at rest at temperatures near the λ-point (2.09 and 2.15°K). The pump was then shut off, and the temperature of the helium raised to 2.25°K. The resonator was set into rotation (with an angular frequency $\omega_0 = 0.98$ sec^{-1}), and, after 3—4 minutes, pumping was resumed on the helium vapor at a rate of 2 mm Hg per minute. As the previously-selected temperature was passed a measurement was made of the second sound amplitude. Similar measurements were also made with the resonator stationary.

The measurements made at 2.15°K showed that the peak amplitude of the second sound is virtually unchanged, which indicates the presence of a delay in the formation of the vortices. If, without stopping the rotation, the temperature is raised again (but not above the λ-point) and then lowered once more to 2.15°K, the second sound amplitude is then found to be reduced. A different situation is found in the measurements at 2.09°K. In this case, a clearly-marked decrease in the amplitude of the second sound, by approximately 20% relative to the initial value, is observed when the temperature is lowered the first time. Control measurements showed that the same reduction in the second sound amplitude is reached in 1.5—2 min, when the resonator is rotated at the same rate with the temperature held in the vicinity of 2.09°K. The difference in the times required to reduce the temperature from the λ-point to 2.15°K, in the one case, and to 2.09°K, in the other, makes it possible to estimate the time delay in the formation of the