tational radiation is a small part of the whole. Wheeler (1958) has remarked that gravitational radiation could be important.

For the purpose of obtaining definite numerical results we take the present Hubble redshift age to be 10^{10} years.

Assuming the validity of Einstein's field equations, the above discussion and numerical values impose severe restrictions on the cosmological problem. The possible conclusions are conveniently discussed under two headings, the assumption of a universe with either an open or a closed space.

Open universe.—From the present observations we cannot exclude the possibility that the total density of matter in the universe is substantially below the minimum value 2×10^{-29} gm cm^3 required for a closed universe. Assuming general relativity is valid, we have concluded from the discussion of the connection between helium production and the present radiation temperature that the present density of material in the universe must be $\lesssim 3 \times 10^{-32}$ gm cm^3, a factor of 600 smaller than the limit for a closed universe. The thermal-radiation energy density is even smaller, and from the above arguments we expect the same to be true of neutrinos.

Apparently, with the assumption of general relativity and a primordial temperature consistent with the present 3.5° K, we are forced to adopt an open space, with very low density. This rules out the possibility of an oscillating universe. Furthermore, as Einstein (1950) remarked, this result is distinctly non-Machian, in the sense that, with such a low mass density, we cannot reasonably assume that the local inertial properties of space are determined by the presence of matter, rather than by some absolute property of space.

Closed universe.—This could be the type of oscillating universe visualized in the introductory remarks, or it could be a universe expanding from a singular state. In the framework of the present discussion the required mass density in excess of 2×10^{-29} gm cm^3 could not be due to thermal radiation, or to neutrinos, and it must be presumed that it is due to ordinary matter, perhaps intergalactic gas uniformly distributed or else in large clouds (small protogalaxies) that have not yet generated stars (see Fig. 1).

With this large matter content, the limit placed on the radiation temperature by the low helium content of the solar system is very severe. The present black-body temperature would be expected to exceed 30° K (Peebles 1965). One way that we have found reasonably capable of decreasing this lower bound to 3.5° K is to introduce a zero-mass scalar field into the cosmology. It is convenient to do this without invalidating the Einstein field equation, and the form of the theory for which the scalar interaction appears as an ordinary matter interaction (Dicke 1962) has been employed. The cosmological equation (Brans and Dicke 1961) was originally integrated for a cold universe only, but a recent investigation of the solutions for a hot universe indicates that with the scalar field the universe would have expanded through the temperature range $T \sim 10^9$ ° K so fast that essentially no helium would have been formed. The reason for this is that the static part of the scalar field contributes a pressure just equal to the scalar-field energy density. By contrast, the pressure due to incoherent electromagnetic radiation or to relativistic particles is one third of the energy density. Thus, if we traced back to a highly contracted universe, we would find that the scalar-field energy density exceeded all other contributions, and that this fast increasing scalar-field energy caused the universe to expand through the highly contracted phase much more rapidly than would be the case if the scalar field vanished. The essential element is that the pressure approaches the energy density, rather than one third of the energy density. Any other interaction which would cause this, such as the model given by Zel'dovich (1962), would also prevent appreciable helium production in the highly contracted universe.

Returning to the problem stated in the first paragraph, we conclude that it is possible to save baryon conservation in a reasonable way if the universe is closed and oscillating. To avoid a catastrophic helium production, either the present matter density should be $< 3 \times 10^{-32}$ gm/cm^3, or there should exist some form of energy content with very