5 — RELATION BETWEEN MODERN COSMOLOGIES AND NUCLEAR ASTROPHYSICAL PROCESSES

BY

T. GOLD

Royal Greenwich Observatory, Herstmonceux Castle, Sussex, England

I wish to point out the ways in which new knowledge of nuclear processes in astrophysics influences cosmological theories. Firstly, there is the important point made by Hoyle that we know of processes that occur which convert hydrogen into helium, but we know of no processes that do the reverse. It is therefore impossible to ascribe an indefinite or a very great age to the bulk of the matter in the universe, except by supposing extremely different conditions to have prevailed in the past. This argument disposes of the simple oscillatory models of infinite age.

The next point that I shall discuss concerns the generation of the elements that one can postulate in each of the two main cosmological theories.

In the theory according to which the universe began with an explosion it is possible to consider that the conditions in this explosion were suitable for building up the elements out of whatever matter was originally created. It is also possible within that theory to suppose that the generation of heavy elements is still in progress in some stars. Indeed the amount of freedom for speculation that one has in such a theory is embarrassingly great.

In the other type of cosmological theory, according to which the universe is in a steady state, the generation of heavy elements must be currently in progress. If one leaves out of account the displeasing hypothesis that heavy atoms are created and considers only the creation of hydrogen, or such particles as will decay into hydrogen, then one is forced to conclude that stellar processes must occur which build up and distribute heavy elements. The super-nova theory of the generation of elements is then clearly the most satisfactory one. In the steady state theory the ratio of heavy elements to hydrogen is then just given by the rate of generation of such elements and the rate of creation of hydrogen. The known abundances can then be taken as an indication of the mean rates of production of heavy elements, and this can be compared with independent estimates for this rate.

Within that theory clusters of galaxies are likely to be older the bigger they are, and with a creation of hydrogen which is diffuse in space and generation of heavy elements which is concentrated in galaxies, one would expect local differences in abundances which would favour the massive nebular clusters. It may be that some evidence on this point will one day come to light.

In comparing these two cosmological theories one finds that the theory of the original explosion loses an important advantage if it can be shown that the generation of heavy elements is in fact a current process. The discovery of Technetium is an important step in that direction.

DISCUSSION
des communications 1 à 5

SCHATZMAN. — Je ne pense pas que l'on puisse considérer comme définitivement prouvé que l'Univers est effectivement en expansion. Mais cela n'a pas d'influence sur la théorie de la formation des éléments hors de l'équilibre. En effet, si l'on considère une sphère uniformément remplie de radiation, en expansion dans le champ de gravitation du rayonnement pesant, on trouve de façon tout à fait classique, une vitesse d'expansion presque égale à celle qui a été utilisée par Alpher et Hermann dans leurs calculs.

BESKOW. — In Beskow-Treffenberg, (part II), the general electrostatic field in the stellar models was accounted for, whereas the ion forces were neglected. Later investigations indicate a strong influence from ion forces on the thermal motions of heavy nuclei, which are likely to be oscillatory with amplitudes much smaller than the mutual distances, thus more like that in a fluid or a solid than in a gas. The corresponding revision of the statistics however, ought not to change qualitatively the total distribution of nuclei.

ÖPIK. — According to Öpik and Salpeter, $He^4 + He^4 \rightarrow (Be^8) + He^4 \rightarrow C^{12} + \gamma \rightrightarrows O^{16}Ne^{20}Mg^{24}$ will remove all helium at $T \sim 4 \times 10^8$, $\rho \sim 10^5 - 10^6$. Hoyle's helium at $T \sim 4 \times 10^9$, $\rho \sim 10^7$ will not exist except from dissociation of the heavier (Mg^{24}, Si^{28}... elements which are already there at this temperature.

(The energy of $3He^4 \rightarrow C^{12} \rightarrow \rightarrow$ is radiated away. Where does the energy of dissociation subsequently come from ? It will be an unstable collapsing star.) This is also the solution for the bottleneck at He^4 to be overcome.

TER HAAR. Should not the binding energy entering into the formulae for the grand canonical ensemble include terms connected with electrostatic effects and the higher Fermi energy due to neutron excess terms, such as introduced by van Albada.

BESKOW. — The use of semi-empirical binding energy formulae in the statistics of the equilibrium distribution indeed involves a considerable uncertainty factor due to the extrapolation to abnormally heavy or neutron rich nuclei. Other formulae than the current ones, better accounting for the effect of neutron surplus, could probably be found. The observation by van Albada on this point seems to be important and reasonable, even if other methods may be needed. This is also the case with van Albada's account for the electrostatic interaction by an additional term to the binding energy. This is reasonable when merely seeking the values of Z and A for nuclei of maximum stability at given high densities and low temperature, as is done by van Albada, although not satisfactory when calculating the equilibrium distribution.

DE JAGER. — Actually, one of the problems is whether all heavy elements have a common origin (« prestellar state of the universe »,) or whether they may have a different origin (e.g. in various superdense stars). In the first case the abundances of the heavy elements would be the same in the whole universe. It is often supposed that this is true but I should like to remark that this statement is still far from being proved. H. Brown's curve of the « cosmic abundances » of the elements is practically only based on the solar system (earth and meteorites) and the absolute abundances of the stars are in general very poorly determined, especially for the heavy elements.

GOLD. — The mean density of the universe is a very difficult quantity to establish observationally. If it is one day established to be about 10^{-28} gr/cm^3, then this cannot be taken as singling out a particular theory versus most others, for the great majority of cosmological considerations that lead to any value for the mean density of the universe lead indeed to that one.

LEDOUX. — As far as the generation of heavy elements in actual stars is concerned it could certainly increase their abundances but does it really answer the question of their origin, since as far as I know, all the models for actual stars already require the presence of heavy elements ? In particular the recent model computed by Rudkjøbing for a hot star (O9) leads to a fairly large abundance of heavy elements although in such a model, conditions for the formation of heavy elements have not yet been reached.

SCHATZMAN. — Il ne faut pas introduire l'idée de création dans l'élaboration de théories de la formation des éléments. Le problème est de rechercher dans quelles conditions l'abondance actuellement observée des éléments a été produite et non pas d'inventer un état entièrement différent de l'univers conduisant à l'état actuel.

TER HAAR. — Freundlich has recently pointed out that the red shift of extra-galactic nebulae may be due to the same effect which produce the at present unexplained large red shifts in O, B and A-stars. He proposes a red shift proportional to T^4 and proportional to the path traversed by the light.

GRATTON. — Speaking as an observer, I wonder whether the present theories may explain the remarkable constancy of composition of the stars. I will show in my communication to this symposium that the relative abundances of the heavy elements (from Mg to Eu) are the same in all stars to a very small per cent. It seems to me that we should expect bigger differences simply for statistical fluctuations.

PODOLANSKI. — In fact, especially in the case of Hoyle's theory, one would expect local deviation in the chemical composition of the stars.

GOLD. — Dr. Lyttleton once remarked that « If one believes that one can find out the abundance of elements in stars from their surface composition, one might as well believe that a chimney sweep is made of solid carbon. »

It is indeed necessary to have a theory that shows what degree of mixing must be expected in a star before the spectroscopic data are used for a description of the composition of the star.

ÖPIK. — I wanted to say what Dr. Gold said. There is little mixing in the stars; on their surface, light elements acquired by accretion are floating. About the inside nothing is known.

BIERMANN. — The O and B stars are usually surrounded by HII regions, and recent studies have shown, that these regions (at least if they are dense enough to be visible) must expand rapidly owing to the high pressure prevailing in them. Because of its large interaction interstellar matter will only under special circumstances be able to fall down under the gravitational action of these stars to their surface. Hence it seems difficult now to believe, that such stars may still acquire material by accretion (for a detailed discussion see the forthcoming Proceedings of the recent Symposium on Cosmical Hydrodynamics held in Cambridge in last July).

COWLING. — (Conclusion of part I). The study of the origin of the elements is still in its infancy. We are not yet even sure that we are asking the right questions. One British theoretical physicist told me that he did not find difficulty in explaining the generation of heavy elements, but in explaining the presence of so much hydrogen. Nevertheless the study of the origin of the elements has begun, and now at least we have enough data to begin to decide between rival theories.

PARTIE II

STRUCTURE INTERNE ET ÉVOLUTION DES ÉTOILES

RÉACTIONS THERMONUCLÉAIRES