The Possible Role of Neutrinos in Stellar Evolution

It can be considered at present as definitely established that the energy production in stars is caused by various types of thermonuclear reactions taking place in their interior. Since these reaction chains usually contain the processes of β-disintegration accompanied by the emission of high speed neutrinos, and since the neutrinos can pass almost without difficulty through the body of the star, we must assume that a certain part of the total energy produced escapes into interstellar space without being noticed as the actual thermal radiation of the star. Thus, for example, in the case of the carbon-nitrogen cycle in the sun, about 7 percent of the energy produced is lost in the form of neutrino radiation. However, since, in such reaction chains, the energy taken away by neutrinos represents a definite fraction of the total energy liberation, these losses are of but secondary importance for the problem of stellar equilibrium and evolution.

We want to indicate here that the situation becomes entirely different in cases where, as the result of the progressive contraction of the star, the density and temperature in its interior become sufficiently high to permit the penetration of free electrons into different nuclei resulting in the formation of unstable isobars with smaller atomic number.

The two processes which will take place under such conditions can be written schematically as:

$$(\text{Nucleus})^{z}+e\rightarrow(\text{Nucleus})^{z-1}+\text{neutrino},$$
$$(\text{Nucleus})^{z-1}\rightarrow(\text{Nucleus})^{z}+e+\text{neutrino}.$$

Since the neutrinos produced in both reactions cannot be held back by gaseous walls surrounding the central region of the star, no actual thermodynamic equilibrium is evidently possible, and the matter under these conditions will rapidly lose its extra heat content through the neutrino emission. Such a star can be considered as possessing in its interior a "negative energy source," the efficiency of which increases very rapidly with the temperature.

It is thus clear that when, in the process of progressive contraction, the star reaches the above-described state, the gas pressure in the interior will no longer be able to increase in order to support the weight of the outer layers, and the slow contraction will give place to a rapid collapse. Although the energy is actually lost in the central regions of such a collapsing star, a very large amount of heat will necessarily be produced in the rapidly contracting outer shells, and the thermal radiation from the surface of the star must increase enormously. This seems to give the possibility of applying the above-described process to the explanation of the vast stellar explosions of the supernova type.

More detailed calculations on this collapse process are now in progress.

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The Ground States of Be^{10} and C^{10}

Many properties of nuclei have been adequately interpreted through a model constructed of neutrons and protons interacting with each other with forces that are approximately the same between all pairs of particles. The only known forces which remove this symmetry, the Coulomb force and the interaction of magnetic moments, are believed to have a small effect in light nuclei. The question of the validity of this model is raised by the anomalous behavior of Be^{10}, which decays with a half-life $\sim 10^6$ years into stable B^{10} emitting 550-Kev β-particles.[1] In contrast to this activity C^{10}, which differs from Be^{10} only by the substitution of two protons for two neutrons, decays in 9 seconds also into B^{10} emitting 3.36-Mev positrons.[2] This difference in half-lives cannot be accounted for just by the difference in energy of the emitted particles so that the Be^{10} transition is classed as "forbidden," requiring a change of several units of angular momentum. Both transitions are presumably between ground states. Since the ground state of B^{10} is known, through measurement of its spin (1) and its magnetic moment (0.6 nuclear magneton),[3] to be a mixture of ^3S and $^3D_1$, it is to be expected from the observed lifetimes of Be^{10} and C^{10} and the Gamow-Teller selection rules that their ground states are ^1G and ^1S or ^1D, respectively. However, using the single particle model with a symmetric Hamiltonian,[4] one finds in both nuclei the same states having the same order and spacing with ^1S lowest separated from ^1G by 12 mc^2. From the theory of holes, the symmetry of Be^{10} and C^{10} about B^{10}, the center of the p shell, requires that the Coulomb energy does not in first order alter this level structure. We have estimated, by using closure, the contribution of the Coulomb energy in the second order where it, by interaction through excited configurations, disturbs this symmetry. The net result of the first- and second-order perturbations is to depress the ^1G state relative to ^1S state by 0.10 mc^2 in Be^{10} and by 0.07 mc^2 in C^{10}. This shift is in the right direction, but is very small compared to the calculated $^1S-{}^1G$ difference, 12 mc^2. Thus the Coulomb energy, which, on this model,[4] gives correctly the observed $Be^{10}-C^{10}$ ground state energy difference, would not lead us to expect *a priori* an inversion of levels in Be^{10}, and no inversion in C^{10}. In addition, it would seem that the interaction of magnetic moments (on account of the low velocities of nuclear particles and small nuclear moments) should introduce no significant shift. We are then led to the conclusion either that the level spacing given by the Hartree approximation is in error by more than an order of magnitude or that some asymmetry other than the known electromagnetic forces must appear in nuclear interactions.

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