experiment should tend to lower the measured value of the para cross section slightly and should increase the measured value of the ortho cross section considerably.

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On the Abundance of Nuclei in the Universe

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THE correlation between the abundance of various nuclei in the universe and their mass defects, pointed out by several authors, gives us the first indication on the thermodynamical character of processes which determined the actual distribution of the isotopes. C. F. v. Weizsaecker,[1] S. Chandrasekhar and L. Heinrich[2] studied the problem and found by different methods the required temperature (with results of the expected order of magnitude: $kT\sim 10^6$ ev), but some disagreements between theoretical and observed abundances remained unexplained. The purpose of the present remark is to point out the advantages and the limitations of a statistical method, suggested some years ago by one of us,[3] and to give results of some preliminary calculations which may help to decide whether the nuclei were formed in a nearly thermal equilibrium state of matter of high temperature and density.

Obviously, if $kT\sim 10^6$ ev, many nuclear processes: as excitation of higher energy-states and higher spins, photo-effect, neutron evaporation and capture, β-processes and fission, become essential. Thus a non-negligible fraction of nuclei will not react in their normal states, and that is the chief reason of the difficulties of the Weizsaecker's method. Mesons production at this temperature can be neglected.

In view of the importance of β-processes under the conditions of our problem, it will be necessary to introduce explicitly the neutrinos into the statistics. Let N_s, n_{es}, n_{ps}, n_{ns}, n_{as}, n_{ZAs} be the numbers (per cm^3) of photons, electrons, positrons, neutrinos and antineutrinos and nuclei of charge Z and mass-number A, which belong to the momentum interval p_s, p_s+dp_s. We assume the validity of the laws of conservation of charge

$$(\Sigma_s[n_{ps}-n_{es}+Zn_{ZAs}]=\text{const.}),$$

of energy, of the total number of nucleons

$$(\Sigma A n_{ZAs}=\text{const.})$$

and of

$$\Sigma_s[n_{ps}-n_{as}-n_{es}+n_{ns}]=\text{const.}$$

or

$$\Sigma_s[n_{ps}-n_{es}+n_{as}-n_{ns}+Zn_{ZAs}-(A-Z)n_{ZAs}]=\text{const.} \quad (1)$$

We obtain in the usual way the formula for n_{ZAs} already published[3] with a somewhat different meaning of the parameter α, because of (1). Integrating n_{ZAs} in the momentum space (summing with respect to s), one can show that the term ± 1 can be neglected and one obtains, with a good approximation the following value for the abundance

$$n_{ZAs}=1.735\times 10^{35}\times(2\zeta+1)\times\left[\frac{kT}{mc^2}\times\frac{E_{ZA}}{M_Hc^2}\right]^{\frac{3}{2}}\times\exp\left[-\alpha Z+\gamma A-\frac{E_{ZA}}{kT}\right]. \quad (2)$$

Here E_{ZA} is the total energy of a nucleus at rest in the reference system of the centrum of gravity of the assembly (including the excitation-energy acquired in an inelastic collision). In the present preliminary survey, we shall substitute E_{ZA} with $M_{ZA}c^2$ where M_{ZA} is the rest mass of the nucleus in the fundamental state. In this way we obtain:

$$\log\frac{n_{ZA}}{n_{Z'A'}}\cong\log\frac{2\zeta+1}{2\zeta'+1}+\frac{3}{2}\log\frac{M_{ZA}}{M_{Z'A'}}+D\times(A-A')-B(M_{ZA}-M_{Z'A'})-\alpha(Z-Z'). \quad (3)$$

Here the parameter values

$$\alpha=\alpha\log e;\quad B=(c^2/kT)\log e;\quad D=\gamma\log e$$

can be determined from 3 values of log $(n_{ZA}/n_{Z'A'})$ known experimentally. Because of the uncertainty of the experimental data and of the limitations of the suggested method, we have chosen by trial approximated values of these parameters and we obtained as a preliminary result the theoretical abundances (for between 8 and 20) indicated in Fig. 1, with: $\alpha=0.1$, $D=525$, $D-B=-0.85$.

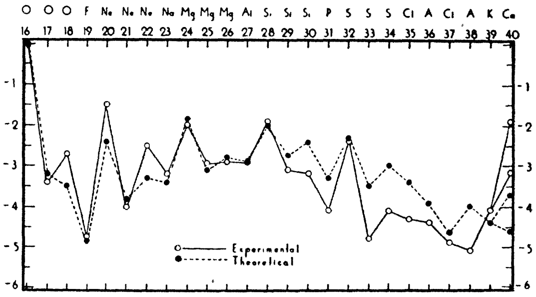

FIG. 1. Comparison of present theory with measured abundances.

We have not considered the excited states and the higher spin states. We have not taken into account the changes in the relative abundance subsequent to the equilibrium and due to the radioactivity, photo-effect, evaporation, and fission processes at temperatures below the equilibrium when the main nuclear reactions are already slowed or stopped. The general satisfactory accord between the theoretical and observed abundances, shown in Fig. 1, leads us to the conclusion that nuclei were formed under conditions not far from the conditions of a thermal equilibrium. Further results and a detailed account of the calculations will be published elsewhere.

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