TABLE I.

Altitude (feet)	Pressure (g cm^{-2})	Time (hour)	$A_1B_2C_2$ (counts)	$A_1B_2C_2F_1$ (counts)	$A_2B_2C_2$ (counts)	$A_2B_2C_2F_1$ (counts)	$A_2B_2C_2F_2$ (counts)	$A_2B_2C_2F_3$ (counts)	$A_2B_2C_2F_4$ (counts)
250	1030	308 113.5	309	16	25	3			
9500	725	58			174	17	12	10	6
14,000	625	41.5			.293	15	10	9	8

density. The area of each counter is 67.5 cm^2. If one assumed that all of the showers striking tray F had the same average density, one would calculate this density as being about 220 particles per square meter.

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Development of Thick Emulsions by a Two-Bath Method*

M. BLAU
Columbia University, New York, New York
AND
J. A. DE FELICE
Brookhaven National Laboratory, Upton, Long Island, New York
September 13, 1948

THE increased use of thick emulsions in nuclear physics has made it desirable to find a satisfactory technique of uniformly developing them. Dilworth, Occhialini, and Payne[1] have described the so-called temperature development method. We are using an alternate method of development on Ilford, C2, 200 u plates, which is probably applicable to even thicker emulsions. The results we have obtained to date might be helpful to others who are using these emulsions.

The method we adapted for our purpose is essentially that described by Crabtree *et al.*[2] which was used for the uniform development of large quantities of motion picture film. In this method the developer is divided into two baths. The first bath contains the developing agent, part of the sodium sulfite and the potassium bromide, but no alkali. The second bath contains all the necessary constituents of an ordinary developer plus an additional amount of alkali. In the first bath the developer diffuses into the emulsion. However, the rate of development is very low because of the lack of alkali. In the second bath the actual development takes place because of the presence of the alkali. It was necessary to add developing agent to the second bath, because not enough can be absorbed from the first bath.

After trying various combinations of the constituents and different times of development we find the following procedure to give the best results.

Step 1: Soak in water for 10 min.
Step 2: Solution A for 30 min. (slight agitation).
Step 3: Solution B for 30 min. (no agitation).
Step 4: 2 percent acetic acid 15 min. (agitation).
Step 5: Fix in F-5 at 74°F with constant agitations 6–8 hours.
Step 6: Wash in running water 2 hours.

Solution A:

Elon	1.1 g.
Na_2SO_3	24.0 g.
Hydroquinone	4.4 g.
KBr	2.0 g.
H_2O to make	2000 cc

Solution B:

Stock D-19	400 cc
H_2O	1600 cc
Additional Na_2CO_3	16 g.

For different batches of the same emulsion, slight adjustments of the developing times and the composition of the solutions may be necessary. The temperatures of the solutions in the Steps 1–4 were all kept constant at 68°F. The temperature of the fixer could also be kept at 68°F. However, it was increased to 74°F to shorten the fixing time.

Because the temperature is kept constant the danger of reticulation is avoided. None of our plates showed any sign of reticulation. Proton tracks in the emulsion had their normal grain density while the background fog was very low. The plates appeared to be uniformly developed throughout the emulsion.

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Thermonuclear Reactions in the Expanding Universe

R. A. ALPHER AND R. HERMAN
Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland*
AND
G. A. GAMOW
The George Washington University, Washington, D. C.
September 15, 1948

IT has been shown in previous work[1–3] that the observed relative abundances of the elements can be explained satisfactorily by consideration of the building up of nuclei by successive neutron captures during the early stages of the expanding universe. Because of the radioactivity of the neutron, and also because neutrons are used in forming the elements, the building up process must have been completed essentially in a time of the order of several neutron decay periods, i.e., about 10^3–10^4 sec. It should be noted that following the essential completion of the main element forming process, the temperature prevailing

in the expanding universe was still high. Consequently, one should expect changes in the relative abundances of the lighter elements as a result of thermonuclear reactions of these nuclei with protons. While these thermonuclear reactions must have proceeded during the element forming stage, their rates were negligible by comparison with those of neutron capture reactions. Examination of the relative abundance data suggests that the abnormally low abundances of certain of the light elements, such as lithium, beryllium, and boron, resulted from thermonuclear destruction of these nuclei with the concomitant formation of additional helium. In contradistinction to the other light elements, these are found to have large cross sections for proton reactions.[4]

On the basis of the foregoing discussion it may be shown that for certain of the light elements the difference between the present relative abundance and the abundance computed according to the neutron capture process is consistent with known thermonuclear reaction rates and cosmological information afforded by the neutron capture process. The well-known formula for the rate of thermonuclear reactions gives the number of processes per gram per second as[4,5]

$$p=5.3\times10^{25}\rho x_1x_2\Gamma\phi\tau^2e^{-\tau}\ \text{g}^{-1}\ \text{sec.}^{-1}, \tag{1}$$

where ρ is the total density of matter, x_1 and x_2 the concentrations by weight of the nuclei involved in the reaction, $\Gamma/\hbar$ the probability of the reaction in sec.$^{-1}$ after penetration, ϕ a function of the nuclear parameters, and

$$\tau=\alpha T^{-1/3}, \tag{1a}$$

where T is given in units of 10^6°K. The time dependence of temperature and density[6] of matter in the expanding universe, consistent with the conditions required by the neutron capture process, has been shown to be [7,8]

$$T=2.14\times10^{10}t^{-1/2}\text{°K}, \tag{2a}$$

and

$$\rho=7.2\times10^{-3}t^{-3/2}\ \text{g cm}^{-3}. \tag{2b}$$

Using Eqs. (1) and (2) in

$$\frac{d[\ln x_2]}{dt}=-pm_2, \tag{3}$$

where m_2 is the mass of the nuclear species 2, with the concentration by weight of protons assumed constant, $x_1=0.5$, we obtain

$$\ln R=A[I(t_0)-I(t)], \tag{4}$$

where R is the ratio of the observed relative abundance to that computed by the neutron capture theory,[1-3]

$$A=-2.96\times10^{21}m_2x_1\Gamma\phi\alpha^2, \tag{5a}$$

$$I(t)=t^{-1/6}\exp(-Bt^{1/6})+BEi(-Bt^{1/6}), \tag{5b}$$

and $B=3.60\times10^{-2}\alpha$. In Eqs. (5), t_0 represents the time at which the proton reactions became important, and t represents the current epoch. The quantities Γ, ϕ, and α are given by Bethe[4] for a number of reactions. The quantity α is $(20)^{1/3}$ times the value of τ tabulated by Bethe for $T=20\times10^6$°K.

Applying Eqs. (5) to the reactions of Li, Be, and B with protons, we find that in order to explain the present extremely low relative abundances of these elements by thermonuclear destruction one must assume that the process became important at about $t_0\sim10^3$ sec. This value of t_0 is of the correct order of magnitude for the time at which the neutron capture process became unimportant.

The same analysis applied to other light elements, such as F^{19}, which also have rather low abundances compared to their computed values, yields a similar result. On the other hand, the elements involved in the carbon-nitrogen cycle reactions do not show any appreciable depletion because of thermonuclear reactions in the expanding universe. For example, in the case of N^{14} the assumption that $t_0\sim10^3$ sec. leads to the result that up to the present epoch the abundance of this nuclear species would have been reduced by only one part per million.

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On the Total Half-Life Period of K^{40}

T. GRÅF
L. Meitner Laboratory of Nuclear Physics, Stockholm, Sweden
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IN connection with the recent determination[1] of the β-decay constant of K^{40}, which yielded $\lambda_\beta=(0.505\pm0.055)\times10^{-9}$ year^{-1}, with a corresponding β-decay period $T_\beta=(13.7\pm1.5)\times10^8$ years, an attempt was made to revise the branching ratio λ_e/λ_β, where λ_e is the decay constant for electron capture, as obtained by Bleuler and Gabriel,[2] in order to allow for the effect of back-scattering. With the corrected branching ratio (1.8 ± 0.5) an approximate value of $(5\pm1.5)\times10^8$ years was computed for the total half-life T.

At present a more accurate value of T may be calculated by combining the above value of λ_β with Ahrens and Evans'[3] recent Ca^{40}/K^{40} ratio in lepidolites, which became available after the mailing date of the author's notes.[1,4] Since in these minerals, of age $t=2.1\times10^9$ years, an excess

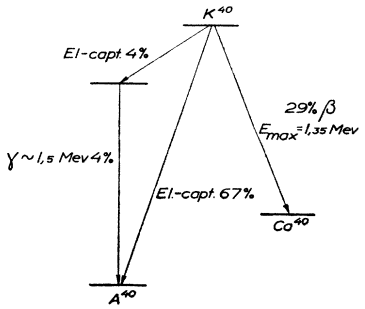

FIG. 1. Decay scheme of K^{40} with relative branching intensities.