Letters to the Editor

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The Origin of Chemical Elements

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AS pointed out by one of us,[1] various nuclear species must have originated not as the result of an equilibrium corresponding to a certain temperature and density, but rather as a consequence of a continuous building-up process arrested by a rapid expansion and cooling of the primordial matter. According to this picture, we must imagine the early stage of matter as a highly compressed neutron gas (overheated neutral nuclear fluid) which started decaying into protons and electrons when the gas pressure fell down as the result of universal expansion. The radiative capture of the still remaining neutrons by the newly formed protons must have led first to the formation of deuterium nuclei, and the subsequent neutron captures resulted in the building up of heavier and heavier nuclei. It must be remembered that, due to the comparatively short time allowed for this process,[1] the building up of heavier nuclei must have proceeded just above the upper fringe of the stable elements (short-lived Fermi elements), and the present frequency distribution of various atomic species was attained only somewhat later as the result of adjustment of their electric charges by β-decay.

Thus the observed slope of the abundance curve must not be related to the temperature of the original neutron gas, but rather to the time period permitted by the expansion process. Also, the individual abundances of various nuclear species must depend not so much on their intrinsic stabilities (mass defects) as on the values of their neutron capture cross sections. The equations governing such a building-up process apparently can be written in the form:

$$\frac{dn_i}{dt}=f(t)(\sigma_{i-1}n_{i-1}-\sigma_i n_i) \quad i=1,2,\cdots 238, \tag{1}$$

where n_i and σ_i are the relative numbers and capture cross sections for the nuclei of atomic weight i, and where $f(t)$ is a factor characterizing the decrease of the density with time.

We may remark at first that the building-up process was apparently completed when the temperature of the neutron gas was still rather high, since otherwise the observed abundances would have been strongly affected by the resonances in the region of the slow neutrons. According to Hughes,[2] the neutron capture cross sections of various elements (for neutron energies of about 1 Mev) increase exponentially with atomic number halfway up the periodic system, remaining approximately constant for heavier elements.

Using these cross sections, one finds by integrating Eqs. (1) as shown in Fig. 1 that the relative abundances of various nuclear species decrease rapidly for the lighter elements and remain approximately constant for the elements heavier than silver. In order to fit the calculated curve with the observed abundances[3] it is necessary to assume the integral of $\rho_n dt$ during the building-up period is equal to 5×10^4 g sec./cm³.

On the other hand, according to the relativistic theory of the expanding universe[4] the density dependence on time is given by $\rho\cong10^6/t^2$. Since the integral of this expression diverges at $t=0$, it is necessary to assume that the building-up process began at a certain time t_0, satisfying the relation:

$$\int_{t_0}^{\infty}(10^6/t^2)dt\cong5\times10^4, \tag{2}$$

which gives us $t_0\cong20$ sec. and $\rho_0\cong2.5\times10^5$ g sec./cm³. This result may have two meanings: (a) for the higher densities existing prior to that time the temperature of the neutron gas was so high that no aggregation was taking place, (b) the density of the universe never exceeded the value 2.5×10^3 g sec./cm³ which can possibly be understood if we

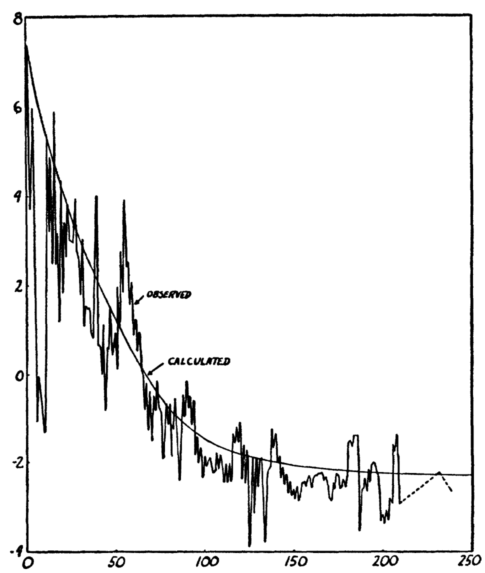

FIG. 1.
Log of relative abundance
Atomic weight

use the new type of cosmological solutions involving the angular momentum of the expanding universe (spinning universe).[5]

More detailed studies of Eqs. (1) leading to the observed abundance curve and discussion of further consequences will be published by one of us (R. A. Alpher) in due course.

* A portion of the work described in this paper has been supported by the Bureau of Ordnance U. S. Navy, under Contract NOrd-7386.

[1] G. Gamow, Phys. Rev. **70**, 572 (1946).
[2] D. J. Hughes, Phys. Rev. **70**, 106(A) (1946).
[3] V. M. Goldschmidt, *Geochemische Verteilungsgesetz der Elemente und der Atom-Arten*. IX. (Oslo, Norway, 1938).
[4] See, for example: R. C. Tolman, *Relativity, Thermodynamics and Cosmology* (Clarendon Press, Oxford, England, 1934).
[5] G. Gamow, Nature, October 19 (1946).

A Beta-Ray Spectrometer Design of Quadratic Resolution-Solid Angle Relationship

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In a β-spectrometer for use with low intensity sources it is advantageous to collect electrons emitted by the source in as large as possible a solid angle consistent with the required resolution. In conventional spectrometers the usable solid angle, Ω, is proportional to the momentum spread, $\delta p/p$, for small δp. (δp is the half-intensity width observed for a point source of monoenergetic electrons.) The double focusing spectrometer[1] has a more favorable proportionality constant than the constant field magnetic lens ("solenoid") spectrometer. The thin-lens spectrometer has a still less favorable constant.[2] Figure 1 shows approximate Ω *vs.* $\delta p/p$ curves for these designs.

Witcher[3] has shown that the solenoid spectrometer brings monoenergetic rays having nearly the same initial angles with the axis, γ, to a "ring-focus" between the source and counter, nearer the latter (Fig. 2). By placing baffles inside and outside this ring-focus the resolution may be improved without decreasing Ω. The resolution attainable is approximately that shown in Fig. 1 for rays with $30° < \gamma < 60°$, somewhat poorer outside this range. For small Ω, $\delta p = 0(\Omega^2)$. Since the improvement in resolution attainable in this way seems not to be widely appreciated, it may be useful to direct attention to it.

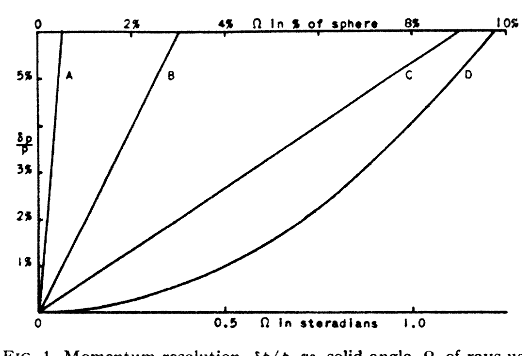

FIG. 1. Momentum resolution, $\delta p/p$, *vs.* solid angle, Ω, of rays used: (A) A typical thin-lens spectrometer.[2] (B) Solenoid spectrometer for small γ. (C) The Siegbahn-Svartholm double focusing spectrometer. (D) The ring-focus baffled solenoid spectrometer. All curves are approximate and refer only to a point source.

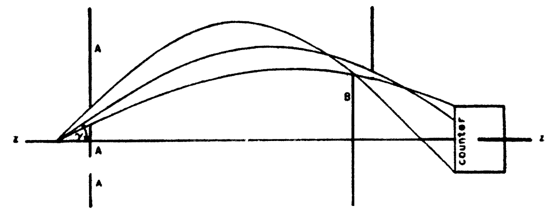

FIG. 2. Paths of electrons in a homogeneous magnetic field. $z-z$, axis of symmetry. Azimuthal motion of electrons not indicated. (A) Baffles defining range of γ. (B) Ring-focus baffles.

Changing the energy of the electrons (or the field strength) without change in the range of γ uniformly expands or contracts the paths shown in Fig. 2 about the source as the fixed point. The best resolution is therefore obtained by placing the ring-focus baffles so that their defining edges lie on a cone with vertex at the source and axis parallel to the magnetic field.

It seems likely that a similar ring-focus exists in a thin-lens spectrometer and has similar favorable properties. Thus it is probably possible to combine the copper and power efficiency of the thin-lens design with a favorable resolution *vs.* solid angle curve. The position and properties of this ring-focus could be found experimentally (e.g., by the use of moveable baffles) or by numerical integration of the electron path equations.

The source diameter just sufficient to impair the momentum resolution is of the order of $(\delta p/p)\cdot\tan\gamma\cdot$(radius of curvature) for the solenoid spectrometer either with or without the ring-focus baffles. Thus when an extended source is desirable (e.g., with a source of low specific activity) the improvement in counting rate at fixed resolution shown in Fig. 2 is genuine, while the improvement in resolution at fixed counting rate is in part specious.

[1] Siegbahn and Svartholm, Nature **157**, 872 (1946).
[2] T. Lauritsen, private communication.
[3] Clifford M. Witcher, Phys. Rev. **60**, 32 (1941).

The Hard Component of Cosmic Radiation as Affected by the Variation in Air Mass Distribution with Latitude

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It is the purpose of this note to call attention to a phenomenon which will complicate the interpretation of the latitude effect. The variation in height of the main mesotron production region with geographic latitude introduces variations in the intensity of the hard component comparable to the variations presently attributed to the geomagnetic latitude effect.