Korff, and Placzek.[2] These values, as well as those calculated from recent results of Korff and Cobas,[3] Agnew, Bright, and Froman,[4] are shown in Fig. 2. (The upper limit of q cannot exceed twice the calculated value.)

The cadmium ratio, i.e., the ratio between the unshielded and cadmium-shielded counters, is of the order of 2.2 over the depth from 22.8 cm of Hg to 4 cm of Hg. This is in agreement with Agnew, Bright, and Froman's[4] results.

The author wishes to express his gratitude to Professor R. Ladenburg for many helpful discussions, to Mr. D. B. Davis, who is responsible for the designing and building of the balloon equipment and to members of the Ordnance Research Laboratory who helped to make the flight a successful one.

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Neutron Absorption in Samarium

A. J. Dempster
Argonne National Laboratory, Chicago, Illinois
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In a recent paper[1] it was shown that the large neutron absorption in samarium is due to the isotope at mass 149. Since the alteration produced by the neutrons was not very large, the experiment was repeated with a 4-mg sample exposed in a thin layer of approximately 1 mg per sq. cm to a much stronger neutron flux. The isotope at mass 149 was so reduced that it could not be detected. One of ten mass spectra made with one milligram of the sample is shown in Fig. 1, together with a mass spectrum of normal samarium. The intensity of the isotope at mass 150 was greatly increased so that it appears approximately equal to the one at 154. A faint gadolinium impurity showed on the long exposures, with the two absorbing isotopes at 155 and 157 missing.

Photometric measurements of the plates showed that the densities at the masses 147, 148, 152, and 154 fell on a normal photographic density curve indicating no changes as a result of neutron absorption in any of these isotopes. The new abundance at mass 150 was found from four spectra to have increased to 21.2±0.4 percent. The normal abundance at 150 is 7.47, and at 149, 13.84 percent, the sum being 21.3 percent. This shows that within the experimental error the isotopes that disappear at mass 149 reappear at mass 150. The absorbing cross sections of the other isotopes were estimated to be less than one percent of that of the isotope at mass 149.

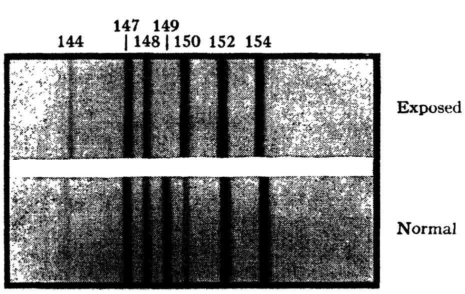

Fig. 1. Samarium isotopes altered by neutron absorption.

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The Origin of Elements and the Separation of Galaxies

G. Gamow
George Washington University, Washington, D. C.
June 21, 1948

The successful explanation of the main features of the abundance curve of chemical elements by the hypothesis of the "unfinished building-up process,"[1,2] permits us to get certain information concerning the densities and temperatures which must have existed in the universe during the early stages of its expansion. We want to discuss here some interesting cosmogonical conclusions which can be based on these informations.

Since the building-up process must have started with the formation of deuterons from the primordial neutrons and the protons into which some of these neutrons have decayed, we conclude that the temperature at that time must have been of the order $T_0 \cong 10^9$ °K (which corresponds to the dissociation energy of deuterium nuclei), so that the density of radiation $\sigma T^4/c^2$ was of the order of magnitude of water density. If, as we shall show later, this radiation density exceeded the density of matter, the relativistic expression for the expansion of the universe must be written in the form:

$$\frac{d}{dt}\lg l = \left(\frac{8\pi G}{3}\frac{\sigma T^4}{c^2}\right)^{\frac{1}{2}} \quad (1)$$

where l is an arbitrary distance in the expanding space, and the term containing the curvature is neglected because of the high density value. Since for the adiabatic expansion T is inversely proportional to l, we can rewrite (1) in the form:

$$-\frac{d}{dt}\lg T = \frac{T^2}{c}\left(\frac{8\pi G\sigma}{3}\right)^{\frac{1}{2}} \quad (2)$$

or, integrating:

$$T^2 = \left(\frac{3}{32\pi G\sigma}\right)^{\frac{1}{2}}\cdot\frac{c}{t}. \quad (3)$$

For the radiation density we have:

$$\rho_{\text{rad.}} = \frac{3}{32\pi G}\cdot\frac{1}{t^2}. \quad (4)$$

These formulas show that the time t_0, when the temperature dropped low enough to permit the formation of deuterium, was several minutes. Let us assume that at that time the density of matter (protons plus neutrons) was $\rho_{\text{mat.}}{}^{\circ}$. Since, in contrast to radiation, the matter is conserved in the process of expansion, $\rho_{\text{mat.}}$ was decreasing as $l^{-3} \sim T^3 \sim t^{-\frac{3}{2}}$. The value of $\rho_{\text{mat.}}{}^{\circ}$ can be estimated from the fact that during the time period Δt of about 10^2 sec. (which is set by the rate of expansion), about one-half of original particles were combined into deuterons and heavier nuclei. Thus we write:

$$v\Delta t n\sigma \cong 1 \tag{5}$$

where $v=5\cdot 10^8$ cm/sec. is the thermal velocity of neutrons at 10^9 °K, n is the particle density, and $\sigma\cong 10^{-29}$ cm^2 the capture cross section of fast neutrons in hydrogen. This gives us $n\cong 10^{18}$ cm^{-3} and $\rho_{\text{mat.}}{}^{\circ}\cong 10^{-6}$ g/cm^3 substantiating our previous assumption that matter density was negligibly small compared with the radiation density. (Thus we have $\rho_{\text{mat.}}{}^{\circ}\cdot\Delta t\cong 10^{-4}$ g$\cdot$cm$^{-3}\cdot$sec. and not 10^{+4} g$\cdot$cm^{-3} sec. as was given incorrectly in the previous paper[2] because of a numerical error in the calculations.)

Since $\rho_{\text{rad.}}\sim t^{-2}$ whereas $\rho_{\text{mat.}}\sim t^{-3/2}$ the difference by a factor of 10^6 which existed at the time 10^9 sec. must have vanished when the age of the universe was $10^2\cdot(10^6)^2 = 10^{14}$ sec.$\cong 10^7$ years. At that time the density of matter and the density of radiation were both equal to $[(10^6)^2]^{-2} = 10^{-24}$ g/cm^3. The temperature at that epoch must have been of the order $10^9/10^6\cong 10^3$ °K.

The epoch when the radiation density fell below the density of matter has an important cosmogonical significance since it is only at that time that the Jeans principle of "gravitational instability"[3] could begin to work. In fact, we would expect that as soon as the matter took over the principal role, the previously homogeneous gaseous substance began to show the tendency of breaking up into separate clouds which were later pulled apart by the progressive expansion of the space. The density of these individual gas clouds must have been approximately the same as the density of the universe at the moment of separation, i.e., 10^{-24} g/cm^3. The size of the clouds was determined by the condition that the gravitational potential on their surface was equal to the kinetic energy of the gas particles. Thus we have:

$$\frac{3}{2}kT=\frac{4}{3}\pi R^3\rho\frac{Gm_H}{R}=\frac{4\pi Gm_H\rho}{3}R^2. \tag{6}$$

With $T\cong 10^3$ and $\rho\cong 10^{-24}$ this gives $R\cong 10^{21}$cm$\cong 10^3$ light years.

The fact that the above-calculated density and radii correspond closely to the observed values for the stellar galaxies strongly suggests that we have here a correct picture of galactic formation. According to this picture the galaxies were formed when the universe was 10^7 years old, and were originally entirely gaseous. This may explain their regular shapes, resembling those of the rotating gaseous bodies, which must have been retained even after all their diffused material was used up in the process of star formation (as, for example, in the elliptic galaxies which consist entirely of stars belonging to the population II).[4]

It may also be remarked that the calculated temperature corresponding to the formation of individual galaxies from the previously uniform mixture of matter and radiation, is close to the condensation points of many chemical elements. Thus we must conclude that some time before or soon after the formation of gaseous galaxies their material separated into the gaseous and the condensed (dusty) phase. The dust particles, being originally uniformly distributed through the entire cloud, were later collected into smaller condensations by the radiation pressure in the sense of the Spitzer-Whipple theory of star formation.[5] In fact, although there were no stars yet, there was still plenty of high intensity radiation which remained from the original stage of expanding universe when the radiation, and not the matter, ruled the things.

In conclusion I must express my gratitude to my astronomical friends, Dr. W. Baade, Dr. E. Hubble, Dr. R. Minkowski, and Dr. M. Schwartzschield for the stimulating discussion of the above topics.

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Pressure Broadening in Ammonia at Centimeter Wave-Lengths*

DeForest F. Smith
Sloane Physics Laboratory, Yale University, New Haven, Connecticut
June 28, 1948

THE intensities and shapes of microwave absorption lines in gases have been successfully correlated with the Van Vleck-Weisskopf[1] modification of the Lorentz impact-broadening theory. The absorption in the long wave-length tails of the ammonia inversion lines offers a severe test of this theory. Precise measurements of this absorption have been completed at wave-lengths 4.43 cm and 3.20 cm in the pressure range 0.1 to 7 atmospheres. These results are plotted in Fig. 1, together with the absorption coefficients computed by numerically summing the Van Vleck-Weisskopf expression over the rotational states, using the measured Bohr frequencies,[2] and a linear pressure variation of the measured half-widths.[2]

The discrepancy between theory and experiment is most severe at the higher pressures, but exceeds the measurement errors at pressures as low as 10 cm of mercury. The discrepancies are apparently inherent in the impact theory

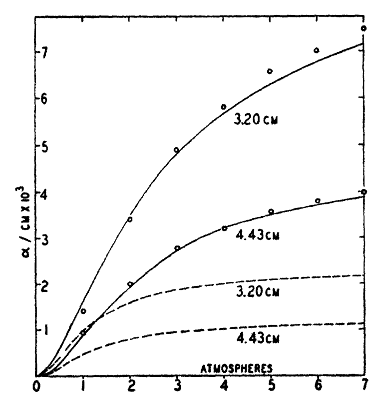

FIG. 1. Free-space absorption coefficient of ammonia at 20°C *vs.* pressure. Solid lines are experimental. Dashed lines are computed with impact theory. Circles are computed as discussed in text.