reported determinations by very similar methods and the values obtained are in close agreement, 5720 ± 47 and 5589 ± 75 years, respectively. Both of the latter procedures involve expansion and dilution of active CO_2 gas to obtain samples which were counted as small partial pressures of CO_2 in argon-alcohol G-M counters.

Over the last two years we have carried out a series of experiments that sum up to two completely separate and independent determinations of this half-life with different source materials, isotope abundance determinations on different mass spectrometers, different counting methods, and many of the steps of the experimental procedures by different operators. The work does not clear up the discrepancy between the two values previously reported but does indicate a basis on which to make a choice of values, and a possible source of discrepancy.

Determination I.—This determination was carried out on a lot of Oak Ridge C^{14} as $BaCO_3$ identified as MIT-1. The isotopic abundance of C^{14} in the total CO_2 obtained from a portion of this material by vacuum fusion with $PbCl_2$ was determined on a mass spectrometer previously described by one of us.[5] Applying the usual corrections and accounting for the presence of natural C^{13} and O^{18} gave the abundance of C^{14} as 3.80 mole percent.

The CO_2 content of MIT-1 was determined gas volumetrically by a method known to be better than 1 percent from determinations on $BaCO_3$ of known purity. It assayed 98.3 percent of theoretical.

Direct stepwise dilution and homogenization of solid $BaCO_3$, by evolution of the CO_2 from the active and diluent $BaCO_3$ and reabsorption in $Ba(OH)_2$ solution, was employed as a reliable method of dilution to a specific activity suitable for counting. By two different procedures, samples F and K were obtained from MIT-1 diluted by the factors 5.247×10^5 and 3.343×10^5 respectively. The procedures were checked in blank runs and the factors are good to better than 1 percent.

The activity of the CO_2 obtained from portions of materials F and K above was measured in CO_2 filled G-M counters. The counters, associated circuits, and the operating characteristics of the system have been previously described,[6,7] as has also the factor V_T/V_C, the ratio of the total volume to the cathode volume, that has been shown to normalize large variations of counter geometries to the same response. It is this point, together with the independence of the system to other parameters that has been taken to justify the assumption that the adjusted counter response very nearly represents an absolute count. From four determinations on the two dilutions in two different counter tubes the average value of the disintegration rate of MIT-1 is 2.36×10^7 d.p.m./mg with a spread of less than 1 percent.

Combining the specific activity, the chemical assay, and the isotopic abundance, the half-life is calculated to be 6360 years. The limiting error is in the isotopic abundance and is not more than 3 percent.

Determination II.—A different lot of Oak Ridge C^{14} as $BaCO_3$ identified as AUI-30 was assayed gas volumetrically for CO_2 and found to yield 92.4 percent of theoretical.

One of the samples of active gas obtained in the chemical assay was run on a Consolidated-Nier isotope-ratio mass spectrometer using standard techniques for this commercial instrument. The value found, after accounting for the natural C^{13} and O^{18} abundances, was 4.18 mole percent C^{14} in the active CO_2.

The CO_2 obtained from a weighed sample of AUI-30 and diluent $BaCO_3$ was absorbed in NaOH and aliquots of this solution or dilutions made from it with inert carbonate solution were taken for counting.

The gas sample filled proportional counter method used for the measurement of the activity of these diluted solutions has been recently described.[8] In substance it is a cylindrical counter tube of conventional design filled with methane and CO_2, high voltage supply, amplifier, discriminator, and scaler circuit. It is sensitive to 1-kev electrons, does not produce multiple pulses, and its response in the region of the characteristic curve in which the measurement is made is flat within 1 percent. The V_T/V_C factor

used with the G-M counters has been shown to apply in the same manner and its use has been justified for the same reason.

Two separate determinations of the specific activity of AUI-30 made on the above solution, each consisting of a series of values obtained on different counter tubes and circuit components combined with their appropriate dilution factors, give an average value of 2.81×10^7 d.p.m./mg with an error of less than 2 percent.

In the same manner as before, the half-life is calculated to be 5513 years, with an over-all error limited by the isotopic abundance determination to about 3 percent.

Activity K, used in determination I, was assayed by the proportional counter method and the ratio of specific activities shown by the two methods, 1.15, is the same as the ratio of the half-lives by the two methods, and indicates that the sole source of the discrepancy between the two determinations must lie with the counter methods. Including the work presented here, the five determinations fall into two groups, two values at 6400 years, and three at 5600 years. The unique difference between the two groups is the type of counter system used. The latter three values have been done with two radically different counter methods, while both of the former values were determined with the CO_2-CS_2 G-M counter system. It seems unlikely that the two different methods used for the second value would be erroneous by the same amount and we are inclined to the tentative view that the CO_2-CS_2 G-M counters may have an efficiency of only about 85 percent, in spite of the recent careful work of Hawkings.[9] Further work on the absolute efficiency of the CO_2-CS_2 G-M counter is being undertaken.

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The Lateral Distribution of Photons in Extensive Air Showers

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January 16, 1950

THE lateral structure of single cosmic-ray extensive air showers has recently been investigated, using "core selectors" (CS), by Cocconi, Cocconi-Tongiorgi, and Greisen[1] and independently by Amaldi and co-workers.[2] As far as the electron density, measured by unshielded G-M counters with varied distances from the CS, is concerned, both groups of experimenters found fairly good agreement with the theoretical results obtained by the author on the basis of cascade theory and Coulomb scattering.[3] Amaldi in his experiments apart from unshielded counters also used lead shielded ones. His results in the latter case, where multiplication due to photons plays an important role, seemed strongly to contradict the author's theory. This conclusion had been drawn under the implicit assumption that the photon density (which had actually not yet been calculated by us) will be roughly proportional to that of the electrons.

To check this assumption we recently extended our theory to the photons in a single extensive shower. As a result, the number of photons of energy E within dE striking an element of area dS at a distance r (radiation units) from the core may be described with good approximation by the formula:

$$g(E,r)dEdS = \frac{2dEdS}{\pi K^2}\left\{\frac{1.03}{0.1}\frac{\exp[-2Er/(0.1)^{\frac{1}{2}}K]}{2Er/(0.1)^{\frac{1}{2}}K}\right.$$
$$\left.+\frac{0.26}{3.25}\exp[-2Er/(3.25)^{\frac{1}{2}}K]\right\}. \quad (1)$$

For easy comparison our corresponding result for electrons may be reproduced here:

$$f(E, r)dFdS = \frac{2dEdS}{\pi K^2}\left\{\frac{2.8}{1.36}L_{-1/6}\left(\frac{2Er}{(1.36)^{\frac{1}{2}}K}\right)\right.$$
$$\left.-\frac{1.8}{0.71}L_{5/6}\left(\frac{2Er}{(0.71)^{\frac{1}{2}}K}\right)\right\}, \quad (2)$$

with the abbreviation

$$L_p(x) = (\pi/2)(x/2)^{p}i^{p+1}H_p^{(1)}(ix)/p!.$$

$[K \approx 2 \times 10^7$ ev in (1) and (2).] Both formulas are valid for particle energies above the critical one and for big air showers at their maximum development, the normalization being chosen so that the energy spectrum is given by $E^{-2}dE$ for electrons and by $1.29E^{-2}dE$ for photons [as approximately valid for big showers at maximum, apart from a common constant factor in (1) and (2)].

The photon density (1) differs greatly from that of electrons by its more rapid singularity at $r=0$; varying as r^{-1} for photons as compared with $r^{-\frac{1}{2}}$ for electrons. This means a much stronger concentration of photons within the core and a more rapid variation of photon density in its vicinity than expected from the corresponding behavior of electrons. (The somewhat larger r.m.s.-spread of photons is almost entirely due to the tail of (1) and does not, therefore, contradict the above result.) This seems, at least qualitatively, to agree with the above-mentioned results of Amaldi and also with those recently obtained by Clay[4] with six- and eightfold coincidences of shielded counters. Our result further suggests that the stars which, according to observations of Blackett,[5] occur with an abnormally high frequency in the cores of cascade showers and which are evidently produced by some neutral radiation, are eventually due to energetic photons. Processes of this kind could be the source of fast nucleons and of the weak meson component accompanying the extensive air showers according to results of Cocconi and Greisen,[1] Brown and McKay,[6] and others.

The details of our theory will be published elsewhere.

Note added in proof: The first direct experimental determination of the lateral structure of single extensive air showers has been carried through by R. W. Williams.[7] His results are consistent with those of the other experimenters quoted (references 1 and 2, below) and with the authors calculations.

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On the Magnetic Moments of Mn^{55}, Co^{59}, Cl^{37}, N^{15}, and N^{14} *

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January 18, 1950

USING the nuclear induction radiofrequency spectrometer described earlier,[1] the nuclear magnetic resonances of Mn^{55}, Co^{59}, Cl^{37}, N^{15}, and N^{14} have been observed. The magnetic

TABLE I. Magnetic moments and diamagnetic corrections.

Nucleus	Nuclear moment in nuclear magnetons	Diamagnetic correction in percent
Mn^{55}	$+3.4624 \pm 0.0004$	0.191
Co^{59}	$+4.6399 \pm 0.0006$	0.214
Cl^{37}	$+0.6835 \pm 0.0001$	0.113
N^{15}	-0.28302 ± 0.00003	0.034
N^{14}	$+0.40369 \pm 0.00004$	0.034

moments listed in column 2 of Table I have been computed directly from our measured frequency ratios and the value of the magnetic moment of the nucleus used as a standard. Diamagnetic corrections were not applied; they are listed separately in column 3, and have been determined by linear interpolation from the values for specific atoms given by Lamb, using Hartree fields.[2] These corrections are to be applied so as to increase the magnitudes of the magnetic moments.

The resonance of Mn^{55} was located near 8.3 Mc, using a field of 7900 gauss and a 2.0-molar solution of $LiMnO_4$ in water as the sample. Comparing the resonance frequency three times with that of Na^{23}, from a sample containing 0.25-molar NaCl in 1.0-molar $MnSO_4$, we found

$$\nu(Mn^{55})/\nu(Na^{23}) = 0.9372 \pm 0.0001.$$

The sign of the magnetic moment, and spin, agreed with the h.f.s. data,[3] which indicated a spin of 5/2 and a magnetic moment of $3.0\mu_N$.

The frequency of the Co^{59} resonance was measured, by use of a 1.0-molar aqueous solution of the diamagnetic compound $K_3Co(CN)_6$ at a field of 6600 gauss and a radiofrequency near 6.6 Mc. Comparing this frequency to that of Na^{23} five times, we found

$$\nu(Co^{59})/\nu(Na^{23}) = 0.89709 \pm 0.00009.$$

Verifying that the spin is 7/2 and that the magnetic moment is positive,[4] we find this frequency ratio leads directly to a magnetic moment of $(4.6399 \pm 0.0006)\mu_N$, which is much larger than the value 2.0 to 3.0 nuclear magnetons obtained by More.[4] The new value indicates that the odd-proton is in an $f_{7/2}$ orbit, as proposed by Mayer;[5] this nucleus has hitherto been regarded as an exception to her single-particle model of the nucleus.

The frequencies of resonance of the chlorine isotopes were compared four times, using concentrated HCl and a field of 9400 gauss, with the result that

$$\nu(Cl^{35})/\nu(Cl^{37}) = 1.2014 \pm 0.0001.$$

Omitting the negligible correction from the reduced electron mass ratios, this differs by about 0.1 percent from the ratio $a_{35}/a_{37} = 1.20272 \pm 0.00008$ of the magnetic dipole interaction constants as determined by Davis, Feld, Zabel, and Zacharias[6] by the atomic beam method. In computing $\mu(Cl^{37})$ we have made use of the frequency ratio $\nu(Cl^{35})/\nu(H^1) = 0.09799 \pm 0.00007$ as determined by Chambers and Williams.[7]

The resonance frequency of N^{15} at a field of 11,000 gauss was compared with that of deuterium, the sample being 5 ml of liquid ammonia together with 1.18 grams of NH_4NO_3 and 1.25 grams of $Cr(NO_3)_3 \cdot 9H_2O$ in a sealed tube. The N^{15} in the ammonia was enriched to about 7.5 percent; the deuterium was from a 1.8-molar aqueous solution of $MnSO_4$ containing 25 percent D_2O. We found

$$\nu(N^{15})/\nu(D^2) = 0.66004 \pm 0.00006.$$

The sign of the magnetic moment, which was previously unknown, has been determined to be negative; its value is in good agreement with the molecular beam value.[8]

The frequencies of the resonance of N^{14} and D^2, from samples of concentrated HNO_3 and 0.6-molar $MnSO_4$ in 85 percent D_2O, respectively, were compared at 11,000 gauss with a General Radio Model 271 frequency meter, with the result that

$$\nu(N^{14})/\nu(D^2) = 0.47070 \pm 0.00005.$$

The magnetic moment is in good agreement with the molecular beam value.[9] Since we have observed that the frequency of resonance of N^{14} in liquid samples depends strongly upon the compound in which it is contained (see the following letter), we have felt that it is important to state carefully what compounds have been used as our samples.

The magnetic moment of Na^{23} has been computed by taking $\mu(H^1) = 2.79348 \pm 0.00014$ nuclear magnetons,[10] and $\nu(Na^{23})/\nu(H^1) = 0.26450 \pm 0.00003$;[11] the magnetic moment of D^2 was similarly computed using $\mu(D^2)/\mu(H^1) = 0.307013$.[12]