Therefore we think there still exists no conclusive direct evidence about the nuclear interaction properties of fast pi-mesons, and that indirect evidence favors a large cross section.

[1] O Piccioni, Phys. Rev. **77**, 6 (1950).
[2] Lovati, Mura, Salvini, and Tagliaferri, Phys. Rev. **77**, 284 (1950).
* Dr. Piccioni has kindly pointed out that the tray D has an apparent inefficiency of six percent, as judged by the difference between the rates A_2BC and A_2BCD; and that the HS defined only by A_2B contain on the average only one ionizing particle striking tray C in experiment III, when it contains only four counters. These facts modify the above statements only slightly. Still it appears that 2×12 or 24 percent of the stopped mesons are locally produced by neutrons, and likely an equal number are produced in secondary reactions by charged particles. The large statistical errors in experiment III make the precise magnitude of this effect very uncertain, but many cloud-chamber photographs (as well as recent, unpublished counter experiments) support the contention that the cascade multiplication of penetrating particles in hard showers is a process of major importance.
[3] H. S. Bridge and B. Rossi, Phys. Rev. **75**, 810 (1949).
[4] D. E. Hudson, Echo Lake Conference (June 1949).
[5] J. Tinlot and B. Gregory, Phys. Rev. **75**, 519 (1949). Their experimental arrangement was such as to measure a length intermediate between λ_a and λ_i.
[6] Bernardini, Cortini, and Manfredini, Phys. Rev. **74**, 845 and 1878 (1948); E. P. George and A. C. Jason, Proc. Phys. Soc. London **A62**, 243 (1949) and *Research* (Special Supplementary Volume, Colston Papers) (1949); Harding, Lattimore, Li, and Perkins, Nature **163**, 319 (1949).
[7] G. Cocconi, Phys. Rev. **75**, 1074 (1949) and **76**, 984 (1949); E. P. George and A. C. Jason (unpublished communication).
[8] λ_a(air) = 118, J. Tinlot, Phys. Rev. **74**, 1197 (1948); λ_i(carbon) = 90–100, G. Cocconi (reference 7); λ_i(carbon) = 85, W. D. Walker and K. Greisen (unpublished); λ_i(carbon) = 70, E. P. George and A. C. Jason, reference 7.

Cross Sections for the Photo-Disintegration of Nitrogen and Oxygen Nuclei by 100-Mev Betatron X-Rays*

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NUCLEAR disintegrations caused by x-rays from the 100-Mev betatron have been investigated with a cloud chamber.[1] The disintegrations studied are those occuring in the filling gas of the cloud chamber; they are observed as single, double (flag), and multiple (star) tracks. The singles are nuclear recoils mostly from (γ,n) processes; according to our preliminary analysis most of the flags in nitrogen result from (γ,pn) reactions; the stars represent various modes of disintegration involving the emission of several charged particles and probably neutrons. Approximate values of the integrated cross sections have been obtained for the flags in air, and for singles, flags, and stars in nitrogen and oxygen, for a peak betatron energy of 100 Mev. The latter measurements give the total integrated photo-disintegration cross sections for nitrogen and oxygen.

The experimental procedure is as follows. X-rays from the General Electric 100-Mev betatron pass through an aperture in a lead shield, which defines a beam $\frac{1}{8}$ in.$\times\frac{3}{4}$ in. in cross section, and enter the cloud chamber through a thin window. The data for air are taken with the x-ray intensity adjusted so that an average of one positron-electron pair in ten expansions is formed in the gas. The data for nitrogen[1] and oxygen are taken at a higher intensity, yielding an average of one nuclear disintegration in five expansions; the growth time of the tracks is shortened in this case to reduce the background caused by electron tracks.

The measurements with the air-filled chamber involve a simultaneous observation of flags and positron-electron pairs. This gives a ratio of the flag cross section to the pair cross section, when account is taken of the x-ray energy interval in which flags are produced. The mean x-ray energy for producing flags in nitrogen is about 30 Mev, according to our previous measurements.[2] The ratio of the flag cross section to the pair cross section is given by a total count of 27 flags and a count of 344 pairs with energy in the range 30 ± 10 Mev.[3] Using the pair cross section suitably averaged over this energy interval, we find the integrated flag cross section to be 0.3 Mev-barn. The estimated error is ±20 percent, determined mostly by the number of events counted.

The flag cross sections for nitrogen and oxygen can be derived from the value for air if their relative cross sections are known.[4] A comparison of these cross sections has been made by counting the flags produced in oxygen and in nitrogen by strong x-ray beams monitored with a Victoreen r-meter. The oxygen cross section is 90 percent of the nitrogen cross section, according to a count of 185 flags in nitrogen and 166 in oxygen for equal r-meter readings. The integrated flag cross section for each is, therefore, approximately equal to the measured value for air.

The flag cross section for nitrogen has been measured in an independent way by comparing the number of flags observed in nitrogen with the number of x-ray quanta in the appropriate energy interval at 30 Mev. The latter number is obtained from the reading of a Victoreen r-meter by the use of a previous absolute calibration[5] of the number of quanta per Mev at 30 Mev per unit r-reading. In this way we obtain an integrated flag cross section of 0.36 Mev-barn, in satisfactory agreement with the value measured by our first method. This result is based on a count of 212 flags. The estimated error is ±40 percent, determined primarily by the probable error of the intensity calibration.

The (γ,n) cross sections for nitrogen and oxygen have been derived from the ratio of singles to flags, on the assumption that these reactions are produced by x-rays in the same energy interval. For nitrogen the (γ,n) cross section is 25 percent[1] of the flag cross section, or 0.08 Mev-barn. For oxygen the (γ,n) cross section is 52 percent of the flag cross section, or 0.15 Mev-barn, based on a count of 315 flags and 164 singles.

The total photo-disintegration cross sections can be derived from the single and flag cross sections and our data relating to multiple disintegrations. The ratio of flags to stars is 3.0 for nitrogen;[1] for oxygen it is 4.4, as given by a count of 636 flags and 144 stars. Assuming the x-ray spectrum to be of the form dE/E and taking the energy range for star production to be about 30–60 Mev, we find the star cross section to be 0.16 Mev-barn for nitrogen and 0.11 Mev-barn for oxygen. The total integrated photo-disintegration cross section, up to 100 Mev, is therefore about 0.6 Mev-barn for both nitrogen and oxygen.

Our results for the (γ,n) cross sections are in good agreement with other measurements made in this Laboratory. Perlman and Friedlander[6] give values of 2.2 and 2.3, respectively, for the (γ,n) cross sections in oxygen and in carbon relative to nitrogen. Using the value of 0.15 Mev-barn for carbon measured by Lawson and Perlman,[7] one obtains a (γ,n) cross section of 0.14 Mev-barn for oxygen and 0.07 Mev-barn for nitrogen.

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* The cloud-chamber equipment used in this investigation was developed under Contract N7onr 332 with the ONR.
[1] For additional information about the photo-disintegration of nitrogen see E. R. Gaerttner and M. L. Yeater, Phys. Rev. **77**, 570 (1950). The apparatus is described in Rev. Sci. Inst. **20**, 588 (1949).
[2] The energy dependence of flags and stars in nitrogen is discussed in reference 1. The same energy dependence is assumed for oxygen.
[3] The numerical value of the flag cross section is not sensitive to the choice of interval up to about ±20 Mev.
[4] About 1 percent argon is present in the air. A preliminary study of the flags produced in an argon-filled cloud chamber indicates that the effect of this contaminant is negligible.
[5] E. R. Gaerttner and M. L. Yeater, Phys. Rev. **76**, 363 (1949).
[6] M. L. Perlman and G. Friedlander, Phys. Rev. **74**, 442 (1948).
[7] J. L. Lawson and M. L. Perlman, Phys. Rev. **74**, 1190 (1948).

The Half-Life of Carbon Fourteen and a Comparison of Gas Phase Counter Methods*

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OF the published determinations of the half-life of C^{14}, three have been done by methods that would allow accuracy of 5 percent or better. All are by mass spectrometry of a rich sample of active material and absolute gas counting of a diluted aliquot of the same material. The first[1,2] was done by diluting as carbonate ion in solution, and counting in a differential CO_2-CS_2 G-M counter which eliminates end effects. The value found for the half-life was 6360 ± 200 years. Two more recent papers[3,4] have

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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[1] Hawkings, Hunter, Mann, and Stevens, Phys. Rev. **74**, 696 (1948).
[2] Hawkings, Hunter, Mann, and Stevens, Can. J. Research **27**, 545 (1949).
[3] Engelkemeir, Hamill, Inghram, and Libby, Phys. Rev. **75**, 1825 (1949).
[4] W. M. Jones, Phys. Rev. **76**, 885 (1949).
[5] A. O. Nier, Rev. Sci. Inst. **18**, 398 (1947).
[6] W. W. Miller, Science **105**, 123 (1947).
[7] S. C. Brown and W. W. Miller, Rev. Sci. Inst. **18**, 496 (1947).
[8] W. Bernstein and R. Ballentine, Rev. Sci. Inst. (in press).
[9] Hawkings, Hunter, and Mann, Can. J. Research **27**, 555 (1949).

The Lateral Distribution of Photons in Extensive Air Showers

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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:

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