the particles were carefully measured. For a small interval, the range-momentum relation is well represented by a power law: $R/m=c(p/m)^q$, where R is the range, m the particle mass, p the momentum, and c a constant of the emulsion. We have used the exponent $q=3.50$ derived from the range-energy relation[3]; the results, however, are insensitive to the value of q chosen. The utilization of protons with velocities distributed about the average meson velocity enabled us to evaluate c, and only momentum and range ratios entered into the determination of the mass ratios. Since all the particles are stopped in the same body of nuclear emulsion, the stopping power of the emulsion is eliminated. The momentum ratios are independent of the absolute value of the magnetic field intensity.

Other statistical errors are small in comparison to the range-straggling error of an individual observation. We have observed that for monoenergetic (π-μ-decay) particles the straggling of ranges has closely a normal distribution. The most probable mass is therefore obtained by averaging the individual observations of that function of the mass in which the range occurs linearly (i.e., $R/p^{3.5}$).

We find the following mass ratios:

$$(\pi^+/\text{proton})=0.1511\pm0.0006,$$
$$(\pi^-/\text{proton})=0.1504\pm0.0007.$$

If the proton to electron mass ratio is 1836.1, these figures correspond to 277.4 ± 1.1 and 276.1 ± 1.3, respectively, in units of the electron mass.

Particles[4] which were presumed to be μ^+ mesons originating from the decay of π^+ mesons stopping in the target were measured in the same experiment. The dispersion of apparent masses in this case, however, exceeds that to be expected if the particles were representatives of a single mass group, all of which comes from the target. μ^+ mesons which arise from decay of π^+ mesons in flight doubtlessly contribute to the distribution found, and we therefore must defer quoting a new μ^+ mass measurement until a better separation of the groups is obtained.

We wish to acknowledge the assistance we have received from numerous individuals of the Radiation Laboratory staff.

* This work was supported by the AEC.

† Dr. Gardner died on November 26, 1950, as a result of beryllium poisoning contracted while working on the Manhattan Project in 1942.

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Erratum: Energy Dependence of Proton-Proton Scattering, 18.8 to 31.8 Mev

[Phys. Rev. **80**, 321 (1950)]

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THE value given in row 8 of column 5 of Table I for the normalized triple should be 14.45 millibarns rather than 25.45 millibarns. The values given in Table IV are correct.

Recombination and the Helium Afterglow Spectrum

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JOHNSON, McClure, and Holt[1] have recently made some important observations on the spectrum of a helium afterglow. They find that it consists of He_2 bands and that it does not contain He lines; they find also that the intensity of the luminosity is high, and over a considerable period is proportional to $[n(e)]^2$, the square of the electron concentration. These results might seem to be contradictory to the view[2] that electrons in such an afterglow disappear by dissociative recombination,

$$He_2^+ + e \rightarrow 2He. \quad (1)$$

However, in fact this is not necessarily the case. The absence of lines is to be expected: For the energy available from (1) is only about 21.4 ev, so that the atoms formed are limited to the 1^1S, 2^1S, 2^1P, 2^3S, 2^3P levels and in consequence do not radiate in the λ2000–8000A region studied.[3] Collisions involving them might, however, give rise to excited helium molecules and hence to band emission. Their rate of formation through (1) is proportional to $[n(e)]^2$ during the period in which He_2^+ is the principal ion, and, therefore, the intensity also follows this law. It is only necessary that their removal should be mainly due to the process suggested in order that a high photon yield should ensue. Phelps[4] finds that the rate of destruction of helium metastable atoms is proportional to the square of the gas pressure. The natural inference is that three-body collisions are the predominant cause of the destruction. These are likely to result in the production of molecules; it is not known whether they lead to the required excitation.

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[2] D. R. Bates, Phys. Rev. **77**, 718 (1950); **78**, 492 (1950).
[3] Although all the levels listed can be reached energetically, this does not mean that all are necessarily populated since other factors besides energy considerations enter. It would be of value to determine whether λ10,830A (2^3P-2^3S) is emitted.
[4] A. V. Phelps, *Conference on Gaseous Electronics* (American Physical Society, Division of Electron Physics, New York, October, 1950). Unfortunately the abstract of the paper read at the conference does not give the pressure range covered.

The Disintegration Scheme of I^{131}

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COINCIDENT scintillation spectrometers have been applied to the study of 8-day I^{131}. Gamma-gamma and beta-gamma-coincidence spectra show that a consistent decay scheme can be made including the 720-kev gamma-ray recently found by Zeldes, Brosi, and Ketelle.[1]

The gamma-gamma-coincidence spectra were obtained using NaI-Tll phosphors and 5819 photo-multipliers. A thin sample was placed in a central hole in a 3-mm lead diaphragm between the two crystals, as shown, approximately to scale, in Fig. 1A. The lead absorber reduces the back scattering of photons by the Compton process from crystal to crystal. Curve A, Fig. 2 shows the gross gamma-ray spectrum. The positions of the six known gamma-rays[1,2] are indicated by arrows.

The spectrum of pulses that have a coincident pulse of any energy in the other spectrometer is shown in Fig. 2, curve B. This curve has been corrected for random coincidences which are shown in curve C. The random coincidences were measured by delaying one spectrometer pulse with respect to the other until immediate coincidences were impossible. The peak due to the 364-kev gamma-ray, as well as the bulge due to the 720-kev transition, is absent from the coincidence spectrum. The x-rays, the 80-kev, 284-kev, and 638-kev gamma-rays remain, showing that each is in coincidence with at least one other.

When the second spectrometer is set to count only pulses representing 525-kev energy or greater, the coincidence spectrum is that shown in Fig. 2D. The peak due to the 284-kev gamma-ray and, of course, the 638-kev peak are now absent. This result shows that the 284-kev transition is not in cascade with the 638-kev transition, and since it does appear in the total coincidence curve, it must be in cascade with that of 80 kev. The presence of the 80-kev peak (and the x-rays) in Fig. 2D shows that the 638-kev transition is in cascade with the 80-kev transition. The coincidence count at two points, with the second spectrometer set to count 675 kev and over, are shown at the bottom of Fig. 2 without subtracting the accidentals, together with the accidentals corresponding, showing that only a few x-ray coincidences remain.

These coincidence results lead to the decay scheme shown in Fig. 3. This is essentially that of Kern, Mitchell, and Zaffarano,[3] except for the 720-kev transition, which they did not see.

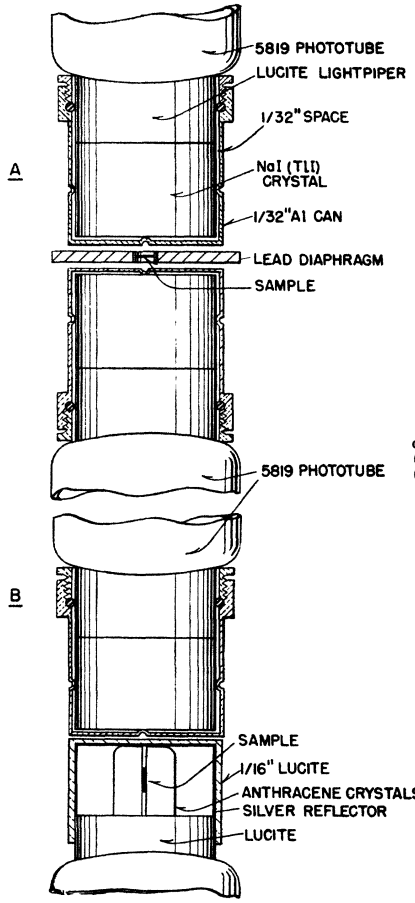

FIG. 1. Arrangement of source and detectors. (A) $\gamma-\gamma$ coincidence. (B) $\beta-\gamma$ coincidence.

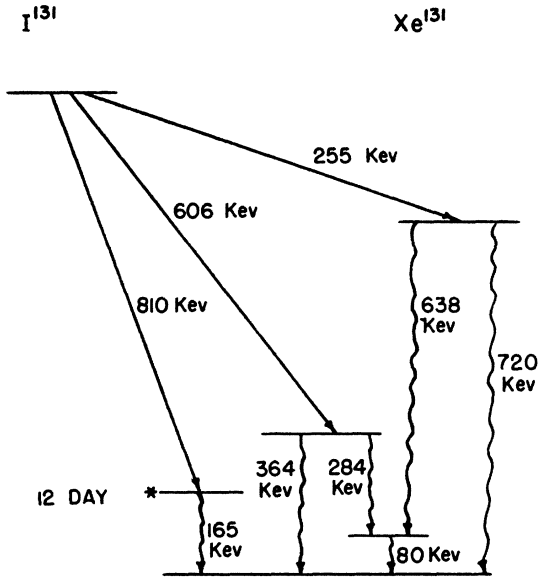

FIG. 3. Decay scheme of I^{131}.

Since the energy generally reported for the lower beta-ray[2] would not fit this decay scheme, a redetermination of this beta-ray was made. A split crystal spectrometer[4] using anthracene was placed in coincidence with a NaI-TlI gamma-spectrometer (Fig. 1B to scale). A thin source on 0.1 mg/cm² formvar was used inside the split crystal. The beta-spectrum in coincidence with all pulses in the gamma-spectrometer representing 525 kev or greater gives the Fermi-Kurie plot of Fig. 4A. This plot is quite distorted and gives an end point which is 80 kev higher than the expected beta-ray, since all electrons emitted by the source are absorbed by the anthracene.

This effect is caused by the 80-kev transition, which is coincident with the beta-ray and the 638-kev gamma-ray. The 80-kev

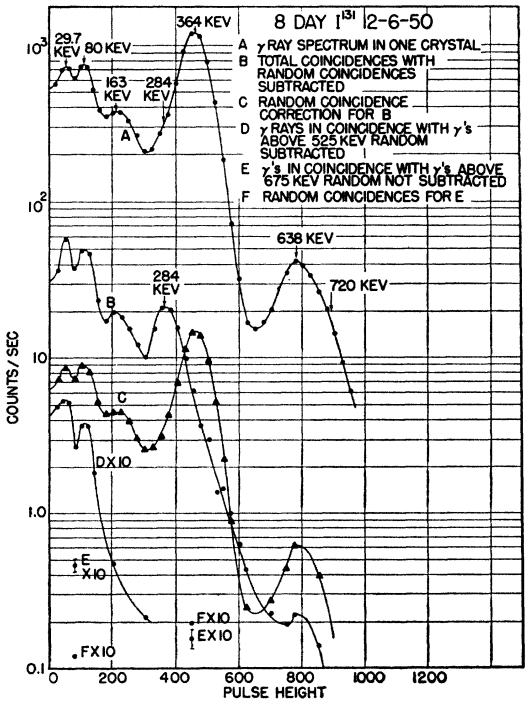

FIG. 2. γ-ray gross spectrum and coincidence spectra.

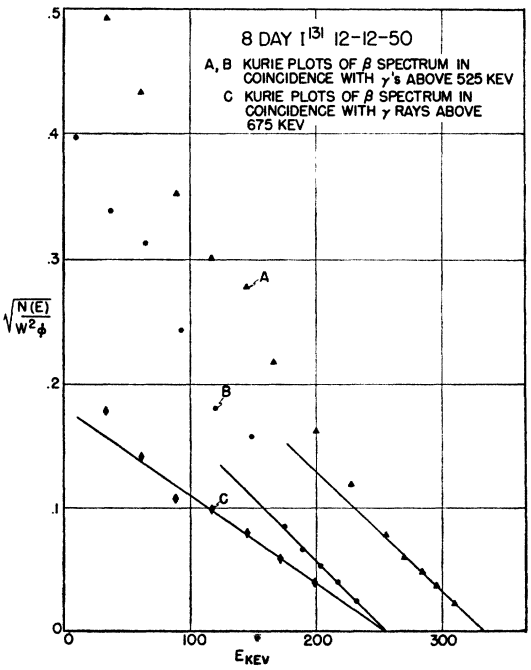

FIG. 4. Kurie plots of β-spectra in coincidence with higher energy γ-rays.

gamma-ray is strongly internally converted, and the conversion electron and following x-ray or Auger electrons are detected, simultaneously, with the beta-ray, and produce a pulse 80 kev larger than the beta-ray. If 80 kev is subtracted from the apparent energy of the spectrum points, and a new Kurie plot is made, curve B results with an end point at 255±10 kev. For confirmation, the gamma-spectrometer was set to 675 kev and the beta-coincidence spectrum run. The remaining number of counts was small, but the Fermi-Kurie plot of the results is shown in curve C. The endpoint is 255±15 kev. This seems to confirm the lower beta-ray energy and establishes the position of the 720-kev transition in the decay scheme.

* Work performed for the Atomic Energy Project at Oak Ridge National Laboratory.
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On the Magnetic Moments of Mg^{25}, Re^{185}, Re^{187}, and Be^{9}

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USING the nuclear induction spectrometer,[1] the magnetic moments of Mg^{25}, Re^{185}, and Re^{187} have been determined. The values of the magnetic moments listed in Table I were computed directly from the measured frequency ratios, and the values of the magnetic moments of N^{14} and Na^{23} were used for the comparison without corrections of any kind.

TABLE I. Magnetic moments.

Nucleus	Magnetic moment in nuclear magnetons
Mg^{25}	-0.85466 ± 0.00015
Re^{185}	$3.1433\ \pm0.0006$
Re^{187}	$3.1755\ \pm0.0006$

$\mu(Re^{187})/\mu(Re^{185}) = 1.01026\pm0.00008$

From the optical hfs method the nucleus Mg^{25} was known to have a spin value 5/2 and its magnetic moment was determined to be[2] -0.96 ± 0.07 nm. Using a magnetic field of 11,000 gauss and a sample of 4.6-molar solution of $MgCl_2$ in water, the resonance of Mg^{25} was located near a frequency of 3.9 Mc. Comparing the resonance frequency of Mg^{25} with that of N^{14} from a sample of concentrated HNO_3, we found

$$\nu(Mg^{25})/\nu(N^{14}) = 0.84714\pm0.00008. \quad (1)$$

The sign was verified to be negative. Taking the value 5/2 for the spin of Mg^{25}, the frequency ratio (1) leads to

$$\mu(Mg^{25}) = -0.85446\pm0.00015 \text{ nm} \quad (2)$$

for the magnetic moment of Mg^{25} which is in good agreement with the spectroscopically determined value. In computing the value (2), we have made use of the value 0.40355 ± 0.00005 nm for the magnetic moment of N^{14}, which is different from the value 0.40369 ± 0.00006 nm reported by Proctor and Yu.[3] This is due to the fact that the newly determined value[4]

$$\mu(P) = 2.79245\pm0.00020 \text{ nm} \quad (3)$$

for the proton moment was used instead of the value 2.79348 ±0.00034 nm obtained by Taub and Kusch.[5]

The two isotopes Re^{185} and Re^{187} of rhenium were investigated by Schüler and Korsching.[6] From the hfs of the line λ4889 in the ReI spectrum, they obtained the ratio

$$\mu(Re^{187})/\mu(Re^{185}) = 1.02069\pm0.00043 \quad (4)$$

for the magnetic moments of Re^{185} and Re^{187}. In the present investigation, we have used a sample of an aqueous solution of the compound $NaReO_4$. As in the case of MnO_4^-, the ReO_4^- ion was presumed to be only feebly paramagnetic. The perturbation caused by a strong magnetic field at the position of the rhenium nucleus due to strong paramagnetism could thus be avoided. On the other hand, no resonance could be found with a water solution of the paramagnetic compound K_2ReCl_6. The two resonances of Re^{185} and Re^{187} were located near a frequency of 6.4 Mc in an external field of 6700 gauss. Their resonance frequencies were compared with that of Na^{23} from a 0.25-molar aqueous solution of NaCl with 1 molar of $MnSO_4$. We obtained

$$\nu(Re^{187})/\nu(Na^{23}) = 0.85987\pm0.00009, \quad (5a)$$
$$\nu(Re^{185})/\nu(Na^{23}) = 0.85114\pm0.00009, \quad (5b)$$
$$\nu(Re^{187})/\nu(Re^{185}) = 1.01026\pm0.00008. \quad (5c)$$

The sign of the magnetic moment was verified to be positive for both isotopes. Since both Re^{185} and Re^{187} are known[7] to have a spin 5/2, the ratio (5c) is equal to the ratio of their magnetic moments, which agrees very well with the hfs value (4). Taking the spin value 5/2 and the value 2.2158 ± 0.0003 nm for the magnetic moment of Na^{23}, we obtained the values of the two magnetic moments of rhenium listed in Table I. The value of the magnetic moment of Na^{23} was computed from the proton moment (3) and the frequency ratio $\nu(Na^{23})/\nu(P)$ given by Bitter.[8] Both rhenium isotopes possess a large quadrupole moment. The interaction of this quadrupole moment with the molecular electric fields gave a line width of about 10 gauss for both rhenium signals. The magnitude of these signals was very much enhanced by using an rf field of about 3 gauss.

In the course of these measurements, we have also investigated the sign of the magnetic moment of Be^{9} with the use of an aqueous solution of $Be(NO_3)_2$. An earlier and, as it seems to us, unambiguous determination by Rabi and his co-workers[9] gave the sign to be negative; nevertheless, it is listed in the table compiled by Mack[10] with a question mark. Our result fully confirms the correctness of the above-mentioned earlier assignment.

We would like to thank Professor F. Bloch for his constant interest in this work.

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† Assisted by the joint program of the AEC and ONR.
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On the Nuclear Interaction of π^- Mesons in Nuclear Emulsions*

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THE preliminary analysis of the nuclear interactions produced by π^- mesons in nuclear emulsions has been extended to the kinetic energy range of 70–90 Mev. Results are here presented on the nuclear stars, scatterings, and stoppings in flight observed in this energy range.

The experimental arrangement was similar to that already used for mesons of kinetic energy of 30–50 Mev.[1] The G-5 plates were exposed directly to the external meson beam (KE=95±5 Mev) of the Nevis cyclotron. Because of ionization losses suffered in traversing the glass and emulsion, the corresponding energies of mesons studied ranged between 70 and 90 Mev. Only those tracks entering the emulsion from the proper direction and longer than 500 microns were accepted in the analysis. The average grain density of the allowed tracks as compared to the minimum was found to be 1.18±0.07, in agreement with that expected for