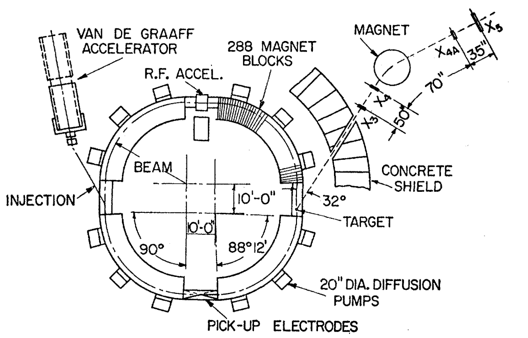

FIG. 1. The schematic arrangement of the scintillation counter telescope in the direct beam produced by the Brookhaven 2.3-Bev cosmotron. X_3 and X_4 are 2½-inch diameter diphenolacethylene crystal counters, X_{4A} is a 1½-inch crystal and X_5 is a 6-inch liquid scintillator. The beam intensity was approximately 10^{10} protons per pulse.

In order to determine the composition of the beams, copper range curves were taken, and it was found that both beams consisted of about 90 percent negative pions and 10 percent negative muons and electrons.

Transmission measurements on polyethylene, carbon, and copper yielded the cross sections,[5] shown in Table I. The results

TABLE I. Total interaction cross sections for 450-Mev negative pions.

Element	Cross section in millibarns	Percentage of geometrical cross section using $R=1.37A^{\frac{1}{3}}\times10^{-13}$ cm
Hydrogen	25 ± 3	46 ± 5.7
Carbon	186 ± 22	61 ± 7
Copper	730 ± 109	77 ± 11.5

obtained by using several lengths of absorbers came out to be the same within the errors for the two arrangements employed. In the case of hydrogen, a relatively good (6°–13° mean acceptance angle) geometry was used and varied sufficiently to show that the geometry was good enough so that the possible errors due to acceptance of secondaries were smaller than the other errors. In the case of carbon and copper the geometry was chosen to be just poor enough to avoid contributions from shadow scattering. A study of the effects of the variation of the geometry revealed an approximate plateau in the cross section as a function of geometry above the shadow and Coulomb scattering limits. Hence, these results should essentially represent the cross section for all interactions other than shadow scattering. All the listed cross sections have been corrected for the contamination of the beam.

The results show considerable transparency for carbon and copper for negative pions at 450 Mev, and one can deduce the approximate average cross section per nucleon using Serber's[6] model of the nucleus. The results thus deduced are shown in Table II, where the hydrogen result is also listed for comparison.

TABLE II. Average cross section per nucleon for 450-Mev negative pions computed from the observed transparency of carbon and copper.

Element	Computed average cross section per nucleon	Observed hydrogen cross section
Carbon	26 ± 4	25 ± 3
Copper	25 ± 5	

If we compare the hydrogen result with that of Anderson, Fermi, *et al.* ($\sigma_{\pi}=60\pm6$ mb at 217 Mev) we see that the negative pion cross section has decreased by a factor of about 2.5 from 217 Mev to 450 Mev, indicating a fairly sharp peak in the energy dependence curve of $\sigma_{\pi-\rightarrow p}$. Although Brueckner's resonance calculations[7] on the pion-nucleon interactions do not appear to agree with Fermi's latest data,[4] they give a calculated total cross section of about 20 mb when extended to 450 Mev, which is not in serious disagreement with our experimental result. Chew is also extending his calculations[8] to higher energies.

Also in Anderson's and Fermi's measurements[1] the hydrogen cross section for positive pions seems to be still increasing at the highest energy measured (135 Mev, $\sigma_{\pi+\rightarrow p}=125-150$ mb) and the magnitude of the cross section was about 2.5 times that for the negative pions. In order to ascertain whether there exists a peak in the energy dependence of the hydrogen cross sections for positive pions similar to that for negative pions, we have also measured the hydrogen cross section for 340-Mev positive pions.

The second experimental arrangement in the 32° direct beam described above was used to accept all positive particles of the proper momentum emanating from the target at 32° from the forward direction. The high resolution ($2-3\times10^{-9}$ sec) circuitry normally employed in all our measurements automatically eliminated the proton component in the beam because of its longer time of flight through the telescope. The beam composition was also determined by a copper range curve.

An analysis of the range curve confirmed the elimination of the proton component by time of flight and demonstrated that the beam contained about 92 percent positive pions and about 8 percent positive muons and electrons.

Transmission measurements on the polyethylene-carbon difference were performed for a relatively good geometry (mean acceptance angle = 10°). The cross section of hydrogen for 340-Mev positive pions, after corrections for muon and electron contaminations in the beam, was determined to be 48 ± 9 mb. This value when compared to the result of Anderson, Fermi *et al.* ($\sigma_{\pi+\rightarrow p}=125-150$ mb at 135 Mev) shows that the positive-pion cross section has decreased by a factor of close to 3 from 135 to 340 Mev. The extension of Brueckner's resonance calculations yields value of 66 mb for the positive-pion hydrogen cross section at 340 Mev.

The sharp drop in the hydrogen cross section for both positive and negative pions evidenced in these results and other preliminary measurements (not yet published) enhances the possibility of a resonance or near-resonance interaction.

A detailed description and analysis of the experiment will be presented in the near future.

The authors are greatly indebted to the entire Cosmotron staff, for their assistance and cooperation in this work. We are especially grateful to Dr. G. K. Green and Dr. J. P. Blewett for their valuable advice and cooperation in setting up the proper Cosmotron conditions for this experiment. We also wish to thank Dr. E. O. Salant for his interest and valuable discussions during the course of this experiment.

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Internal Conversion Electrons from Coulomb Excited Ta and W

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INTERESTING information can be obtained about the lowest-lying levels in heavier nuclei when these are excited by means of the electrical field of impinging particles which have an energy too low for barrier penetration. In recent investigations[1,2] of such

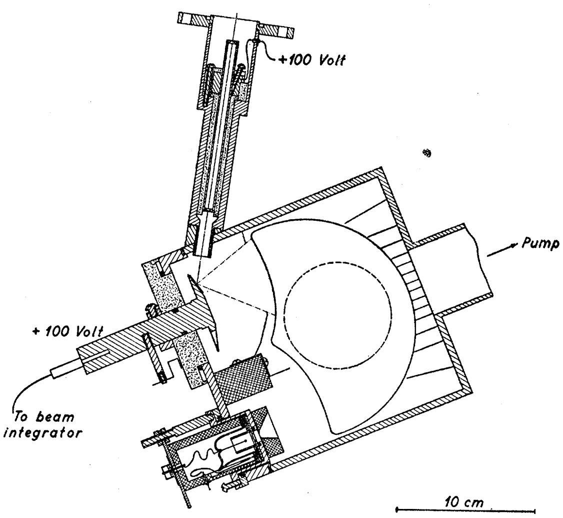

FIG. 1. Wedge-shaped magnetic beta-ray spectrometer with Geiger counter.

Coulomb-excitation processes, the gamma radiation emitted by the subsequent de-excitation was detected by means of scintillation spectrometers. However, this method gives only a relatively poor energy resolution at the low energies in question; and, therefore, the strong x-radiation from the K shell of the atoms, which are also excited by the protons, to some extent prevents measurements at the lowest energies.

In this region better results should be expected if one instead measures the spectra of the internal-conversion electrons, the yield of which is comparable to that of the gamma rays. Furthermore, the relative yields of the different conversion lines give additional information about the multipole order of the transitions.

As a test of the method we have investigated the electrons emitted by Ta and W under bombardment of protons. Our interpretation of the gamma-ray measurements[2] is confirmed by the new results.

The spectra were measured by means of the wedge-shaped magnetic spectrometer shown in Fig. 1. This spectrometer, which has been constructed by Kofoed-Hansen *et al.*,[3] proved particularly suited for the present purpose. The only change needed was the introduction of a proper set of stops at the wall opposite to the target and the Geiger counter, in order to trap the protons scattered from the target. The spectrometer was calibrated by means of the ThB lines. It was used with stops giving a solid angle of about 1.5 percent of 4π and a relative window-width $d(H\rho)/H\rho$ of about 0.7 percent.

A thin layer of Ta evaporated on a disk of graphite and a thin layer of W evaporated on a copper disk were used as targets.

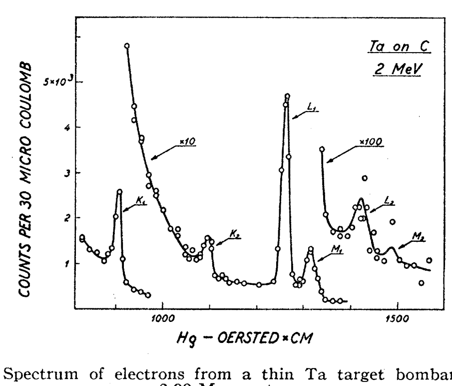

FIG. 2. Spectrum of electrons from a thin Ta target bombarded with 2.00-Mev protons.

The spectrum obtained when the Ta target was bombarded with 2-Mev protons is shown in Fig. 2. It clearly exhibits not only the lines K_1, L_1, and M_1 resulting from the internal conversion in the K, L, and M shells, of the radiation from the first excited state of Ta^{181}, but also, as expected from the gamma-ray measurements, the lines K_2 and L_2, corresponding to the first step in the cascade transition from the second excited state. The quantum energies in the two cases are found to be 137 kev and 166 kev, respectively, to an accuracy of better than 1 percent. The excitation energy for the second excited state is therefore 303 kev, which is 2.21 ± 0.02 times larger than for the first state. This is in complete agreement with the ratio 20/9 predicted for the rotational states[4] of a nucleus with ground-state spin 7/2.

One should therefore expect the first and second excited state to have the same parity as the ground state and spins 9/2 and 11/2, respectively. This means that the 137-kev and 166-kev transitions should both be mixtures mainly of the $M1$ and $E2$ types. From Fig. 2 one derives K/L ratios of about 5, showing that the two transitions are nearly pure $M1$ [about 85 percent pure, (see reference 5)].

The figure also shows that the ratio of the total number of 166-kev transitions to that of 137-kev transitions is about 1:20, when a correction is made for the difference in the conversion coefficients.[5,6] At a bombarding energy of 2 Mev it was not possible to

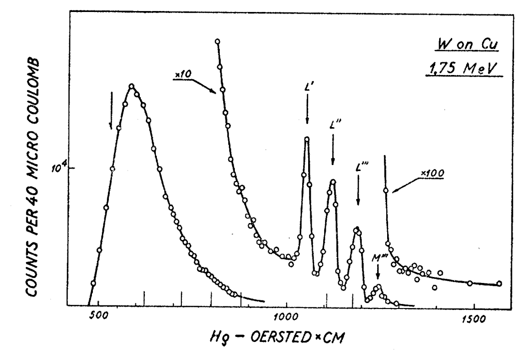

FIG. 3. Spectrum of electrons from a thin W target bombarded with 1.75-Mev protons. The marks on the $H\rho$ axis indicate where K and M conversion lines could be expected.

see any conversion lines from the weak 303-kev cross-over transitions, for which the conversion coefficients are small. However, from the gamma-ray measurements,[2] it is known that the relative number of 303-kev and 137-kev transitions is 1:80 at this energy. It therefore follows that the relative number of 303-kev and 166-kev transitions is 1:4, as also had to be assumed in the gamma-ray work in order to obtain the correct relative excitation cross sections for the two levels. This branching ratio again implies that the 166-kev radiation should correspond to about 85 percent pure $M1$ transitions. It is therefore possible by means of the conversion coefficients to determine the transition probability for the 166-kev $M1$ gamma rays relative to the transition probability for the 303-kev $E2$ gamma rays, which is known from the measurements of the absolute gamma yield. For the rotational states of a uniformly charged nucleus, one can estimate the transition probability for $M1$ gamma radiation in terms of the magnetic moment of the nucleus in the ground state.[4] On the basis of this model one finds that the experimental yield should correspond to a magnetic moment of 2.8 nuclear magnetons. The spectroscopically measured moment of Ta^{181} is 2.1 nuclear magnetons.[7]

A conversion spectrum for Ta was also measured at 1.75 Mev. Here the 166-kev transitions could barely be observed, and the yields of the 137-kev transitions decreased by a factor of 1.4, in agreement with the theoretical energy dependence.[8]

The spectrum obtained for the thin W target at a bombarding energy of 1.75 Mev is shown in Fig. 3. The curve exhibits four sharp peaks, and from the fact that no corresponding K lines can be seen it can be concluded that the peaks are the result of $E2$ transitions in the three abundant even-A isotopes. This is also the type of transitions expected for rotational states of even-A nuclei. The M' and M'' lines cannot be resolved from the L'' and L''' lines, respectively, although they do make these peaks somewhat broader than the L' line. The three excitation energies in question are found to be 102 kev, 113 kev, and 124 kev. As the three isotopes are about equally abundant, this is in good agreement with the average energy of 115 kev found for the gamma radiation. The 124-kev line can be assigned to the isotope W^{186}, which is known to have approximately this excitation energy for the first level. It is to be expected that the 102-kev line is the result of W^{182} and the 113-kev line to W^{184}.

We are going to check these assignments on separated targets, and we also hope thereby to find the lines for the odd isotope W^{183}, which in the present case may be covered by those of the even isotopes.

The absolute cross sections have not been determined very accurately in the present measurements, but the estimates are in agreement with our previous work.[2] We intend to make more careful measurements of the total Coulomb-excitation cross sections in order to get more reliable values for the quadrupole moments as well as for the magnetic moment, which can be derived from the corresponding transition probabilities.

The large broad peak at the low energies, which can be seen in Fig. 3, was also found in the case of Ta and other elements. It is believed to be the result of stopping electrons[9] which, by means of momentum exchange with their nuclei, have acquired more energy than the maximum of about 4 kev obtainable in a free collision with a 1.75-Mev proton. The cut-off at the low-energy side is the result of the 0.9-mg/cm^2 mica window of the counter. Such peaks were found to have a shape practically independent of the proton energy and the target material, but to have thick target yields which were approximately proportional to $Z^{5/2}\cdot E^4$. Unfortunately, this process implies that the present method also is less applicable at very low excitation energies.

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Zeeman Splitting of Nuclear Quadrupole Resonance Lines*

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THE nuclear quadrupole resonance line in sodium chlorate is a narrow intense absorption line at room temperature[1] and is, therefore, well suited for studies of the Zeeman effect.[2] The crystal lattice is a simple cube in which there are four unique directions of the gradient of the electric field at the chlorine nucleus; these four directions are along the diagonals of the unit cell.

When a single crystal of sodium chlorate is placed in an external magnetic field, the zero-field nuclear quadrupole resonance line generally splits into four components. This Zeeman pattern depends upon the external magnetic-field strength and upon the orientation of the crystal with respect to the external field. At certain orientations only two or three Zeeman components are observed. These observations are readily interpreted in terms of perturbation theory.

The theory predicts that at one orientation, in which the 111 plane is normal to the magnetic field, there should be two symmetrical Zeeman components whose frequency separation from the parent line is *strictly* proportional to the strength of the applied field. In order to verify this prediction we have studied the splitting of the Cl^{35} line in external fields in the range 0 to 8000 gauss. At the highest fields employed the separation between the Zeeman components is approximately 20 percent of the frequency of the zero-field line. The experimental results show that the splitting is indeed directly proportional to the applied field.

From the observed Zeeman pattern the nuclear magnetic moment of Cl^{35} can be calculated. The value obtained is 0.8215 $\pm$0.0010 nuclear magnetons. This result is in excellent agreement with the value 0.82180$\pm$0.00005 nuclear magnetons obtained in earlier work on magnetic resonance, in which aqueous solutions of LiCl were employed.[3] Diamagnetic corrections have not been applied in either quoted value.

Our work on sodium chlorate is being continued. Zeeman patterns for various orientations and field strengths are being investigated. Studies of line widths are also in progress. Further results will be reported in the near future.

The writers wish to express their appreciation to Mr. John Hockenberry and Mr. Carlton Brown for their assistance in parts of the experimental work.

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Hyperfine Structure and Nuclear Electric Quadrupole Moment of Boron 11

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THE hyperfine structures of the $^2P_{\frac{1}{2}}$ ground state and the $^2P_{\frac{3}{2}}$ metastable state of boron 11 have been measured by the atomic beam magnetic resonance method. The nuclear spin of B^{11} being $\frac{3}{2}$, the hyperfine structure of the $^2P_{\frac{1}{2}}$ state consists of two levels characterized by the total quantum numbers $F=2$ and 1, whereas that of the $^2P_{\frac{3}{2}}$ state consists of four levels characterized by $F=3$, 2, 1, and 0. Transitions between Zeeman components of the various levels have been observed at low magnetic fields and the field-free intervals obtained by extrapolation. We find:

$$^2P_{\frac{3}{2}}$$
$$\Delta\nu(F=3-F=2)=3a'+b=222.737\pm0.010 \text{ Mc/sec},$$
$$\Delta\nu(F=2-F=1)=2a'-b=144.00\pm0.02 \text{ Mc/sec},$$
$$\Delta\nu(F=1-F=0)=a'-b=70.66\pm0.20 \text{ Mc/sec},$$

$$^2P_{\frac{1}{2}}$$
$$\Delta\nu(F=2-F=1)=2a''=732.4\pm0.1 \text{ Mc/sec},$$

where we have expressed the intervals in terms of the theory of Casimir,[1,2] a', a'' being magnetic dipole interaction constants and b an electric quadrupole interaction constant. Of the three intervals of $^2P_{\frac{3}{2}}$, the smallest one has been measured less accurately than the other two. The reason for this is that it was necessary to use a two-frequency transition, in the manner described by Davis, Feld, Zabel, and Zacharias,[2] in order to observe this interval and the resulting intensity was consequently lower than that in the other cases. If we solve for a' and b from the first two relations above, we obtain

$$a'=+73.347\pm0.006 \text{ Mc/sec}, \quad b=+2.695\pm0.016 \text{ Mc/sec},$$

where the positive sign of a' is taken from the known positive magnetic moment of B^{11}. These two values are consistent with the third relation above, for we have $a'-b=70.652\pm0.022$ Mc/sec. The possibility of describing the three observed intervals of $^2P_{\frac{3}{2}}$ by the two constants a' and b indicates that, to within the accuracy of