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Energy Levels in Chromium-52†

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The excited states of Cr^{52} have been studied through the $Mn^{55}(p,\alpha)Cr^{52}$ reaction and by an investigation of inelastic proton scattering from chromium. A 6.51-Mev proton beam from an electrostatic generator and a high-resolution magnetic spectrograph were used. Excited states in Cr^{52} were found at 1.433, 2.368, 2.648, 2.767, 2.965, and 3.161 Mev. The Q-value for the ground-state transition in $Mn^{55}(p,\alpha)Cr^{52}$ is 2.568 ±0.008 Mev.

IN the course of a current study of inelastic proton scattering from manganese, a number of alpha-particle groups were observed. The $Mn^{55}(p,\alpha)Cr^{52}$ reaction, from which these groups presumably arose, provides an important mass link in this region of the periodic table, and since, in addition, there are some questions about the level scheme of Cr^{52} as determined from beta- and gamma-ray studies, we have investigated these alpha-particle groups. As an additional check on their origin, a separate study was made on the level scheme of chromium. This was carried out through measurements on inelastic proton scattering from natural chromium targets.

A 6.51-Mev proton beam from the MIT–ONR electrostatic accelerator was used, and the charged particles from the targets were analyzed with the broad-range spectrograph. This equipment and its use in studies of this sort have been described in some detail in earlier publications.[1,2]

For the studies of the (p,α) reaction, thin manganese targets were prepared by evaporation of high-purity manganese metal from a tungsten boat onto a Formvar film. A mass analysis of the target, carried out by elastic proton-scattering measurements, showed that only small amounts of tungsten, chlorine, and sodium were present as impurities in these targets in addition to the usual amounts of oxygen, nitrogen, carbon, and hydrogen expected in the Formvar backings. None of these impurities gave rise to measurable alpha-particle groups in the present experiment.

The alpha-particle spectrum was observed at angles of 90 and 130 degrees with respect to the incident 6.51-Mev proton beam. At each angle, six alpha-particle groups were observed, and for each the shift in energy with angle was that to be expected for a (p,α) reaction involving a target nucleus with mass close to 55. The Q-values, calculated on the assumption that the groups were from $Mn^{55}(p,\alpha)Cr^{52}$, are listed in Table I.

A large number of proton groups were also recorded during the exposures for the alpha-particle spectrum. These groups, which were associated with inelastic scattering from manganese, will be reported on in a separate publication.

While the mass analysis of the target, carried out from elastic scattering, together with the energy variation with angle, was sufficient to show definitely that the observed groups arise from manganese, it is not possible from these measurements alone to determine that the highest energy group is associated with the ground-state transition in the reaction leading to Cr^{52}. In order to investigate this aspect of the problem, a study of inelastic proton scattering from a chromium target was made. This enabled an independent determination of the level scheme in Cr^{52}. Since naturally occurring chromium is a mixture of several isotopes, it is not possible from proton-scattering experiments alone to determine which of the inelastically scattered groups from a natural chromium target correspond to the mass-52 isotope. However, there should be a correspondence between certain of the chromium levels as observed in proton scattering with those calculated from the (p,α) results. Actually, the selection of the appropriate groups for comparison is considerably simplified in the present case since natural chromium contains 83.9% Cr^{52}, the remainder being 4.4% Cr^{50}, 9.5% Cr^{53}, and 2.4% Cr^{54}.

Thin targets for the inelastic-scattering measurements were prepared by the evaporation of high-purity chromium metal onto Formvar films. The charged particles resulting from the bombardment of the targets with 6.51-Mev protons were analyzed at angles of observation of 50 and 90 degrees with respect to the beam. The spectrum observed at 90 degrees is shown

TABLE I. Energy levels in Cr^{52}.

$Mn^{55}(p,\alpha)Cr^{52}$ reaction mean values		$Cr^{52}(p,p')Cr^{52}$ reaction mean values
Q (Mev)	E_x (Mev)	E_x (Mev)
2.568±0.008	0	0
1.134±0.008	1.434	1.433±0.005
0.200±0.010	2.368	2.368±0.005
−0.081±0.010	2.649	2.648±0.008
−0.201±0.010	2.769	2.767±0.008
−0.397±0.012	2.965	2.965±0.008
···	···	3.161±0.008

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[1] Buechner, Mazari, and Sperduto, Phys. Rev. **101**, 188 (1956).
[2] C. P. Browne and W. W. Buechner, Rev. Sci. Instr. **27**, 899 (1956).

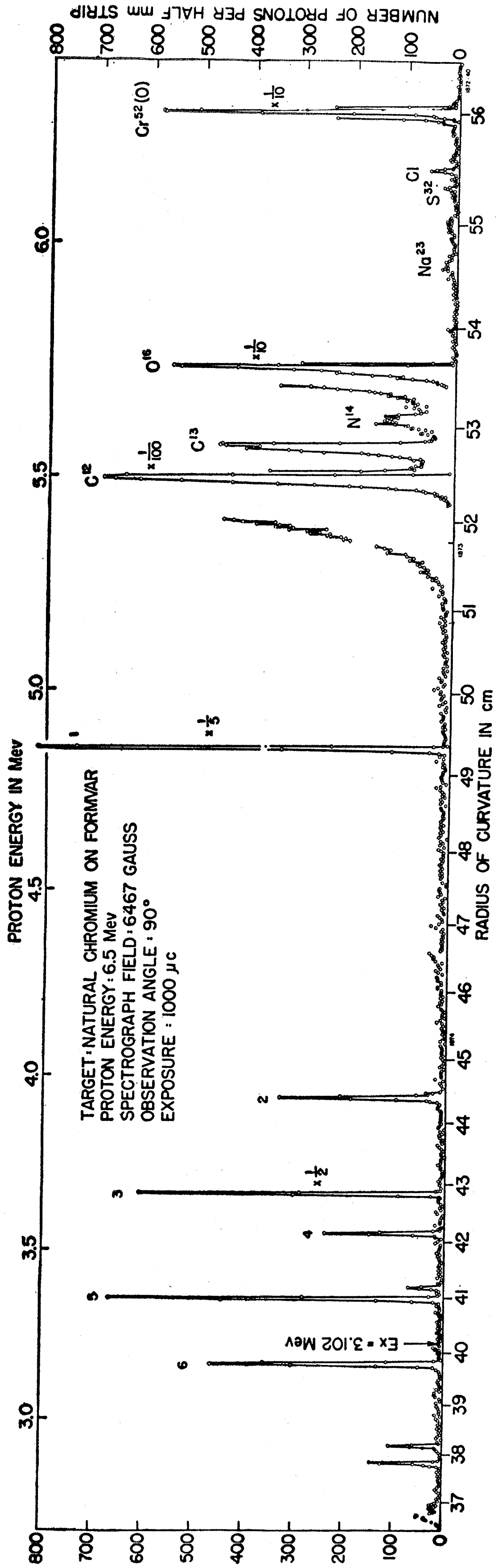

FIG. 1. Proton spectrum from a natural chromium target. The incident proton energy was 6.51 Mev, and the angle of observation was 90 degrees.

in Fig. 1. In addition to a number of low-intensity groups, six intense proton peaks were found which resulted from inelastic scattering in chromium. On the assumption that these six groups arose from Cr^{52}, the associated excited states in this nucleus have been calculated and are tabulated in Table I, where these numbers can be compared with the excited states in this nucleus obtained from the (p,α) results, assuming that the alpha-particle group with the Q-value 2.568 Mev represents the ground-state transition. The excellent correspondence of the two sets of excitation energies shows conclusively that the proton peaks chosen on the basis of their intensities were identified with the correct isotope and that the high-energy alpha-particle group does give the ground-state Q-value for the $Mn^{55}(p,\alpha)Cr^{52}$ reaction. The other low-intensity groups are presumably associated with the other chromium isotopes, but they cannot be definitely assigned until experiments with separated isotopes have been carried out.

In Table I, an excited state in Cr^{52} is listed at 3.161 Mev. This figure was arrived at solely by the observation at both angles of an intense proton group. The corresponding group was not observed in the (p,α) reaction. However, all the alpha-particle groups were of relatively low intensity, and it is not surprising that, in these experiments, the peak which would be associated with a level in Cr^{52} at this energy was not observed. As will be mentioned in subsequent paragraphs, there are additional reasons beyond the high intensity of the observed proton group for believing that there is a Cr^{52} level at this energy.

The Q-value measured in the present experiments for the $Mn^{55}(p,\alpha)Cr^{52}$ reaction is 0.23 Mev lower than the value calculated from the atomic masses of Mn^{55} and Cr^{52} as determined by mass-spectroscopic measurements.[3] However, more recent measurements on these masses at the University of Minnesota by C. Giese lead to a Q-value of 2.559 ± 0.004 Mev.[4] This excellent agreement between the mass differences as determined from nuclear reactions and from mass-spectroscopic studies is gratifying, particularly in view of the rather wide discrepancies which have existed between the results of these different methods in the past.

The excited states of Cr^{52} have also been investigated by using inelastic proton scattering by Hausman *et al.*[5] Working with natural chromium targets, these investigators found a number of inelastically scattered proton groups of which three, corresponding to excitation energies of 1.45, 2.43, and 2.99 Mev, were assigned to Cr^{52} on the basis of a comparison with the level scheme of Cr^{52} as inferred from beta- and gamma-decay measurements on Mn^{52}. Other groups corresponding to

[3] Collins, Nier, and Johnson, Phys. Rev. **86**, 408 (1952).
[4] A. O. Nier (private communication). We wish to thank Professor Nier for sending us these results.
[5] Hausman, Allen, Arthur, Bender, and McDole, Phys. Rev. **88**, 1296 (1952).

excited states at 2.69, 2.79, and 3.20 were also reported in these studies. On the basis of the present results, it appears that all these levels are in Cr^{52}. It will be noted that the excitation energies, as determined by Hausman *et al.*, are uniformly higher by from 20 to 40 kev than the present results. Similar discrepancies between the early work at the University of Pittsburgh and the results from this laboratory have been remarked on in previous publications.[6]

There is an extensive literature on the beta and gamma radiations associated with the decay of V^{52} and Mn^{52}. This in large part has been summarized by Way *et al.*[7] These various results have generally been interpreted in terms of excited states in Cr^{52} at 1.45, 2.43, and 3.13 Mev and an isomeric state in Mn^{52} at 0.39 Mev.[7–9] States in Cr^{52} at approximately the same energies are also indicated in various studies[7] which show that gamma radiations of 0.75, 0.97, and 1.44 Mev result from the interactions of neutrons with chromium.

Figure 2 shows an energy-level diagram of Cr^{52}, in which the level positions are those determined in the present work. Aside from the fact that there is no indication in the beta- and gamma-ray studies of the states at 2.648, 2.767, and 2.965 Mev, the present and the earlier results are in reasonable agreement if one identifies the states previously regarded as being at 1.45, 2.43, and 3.13 Mev with those measured here at 1.433, 2.368, and 3.161 Mev. The observed beta and gamma rays have been assigned, as shown in Fig. 2, on this assumption.

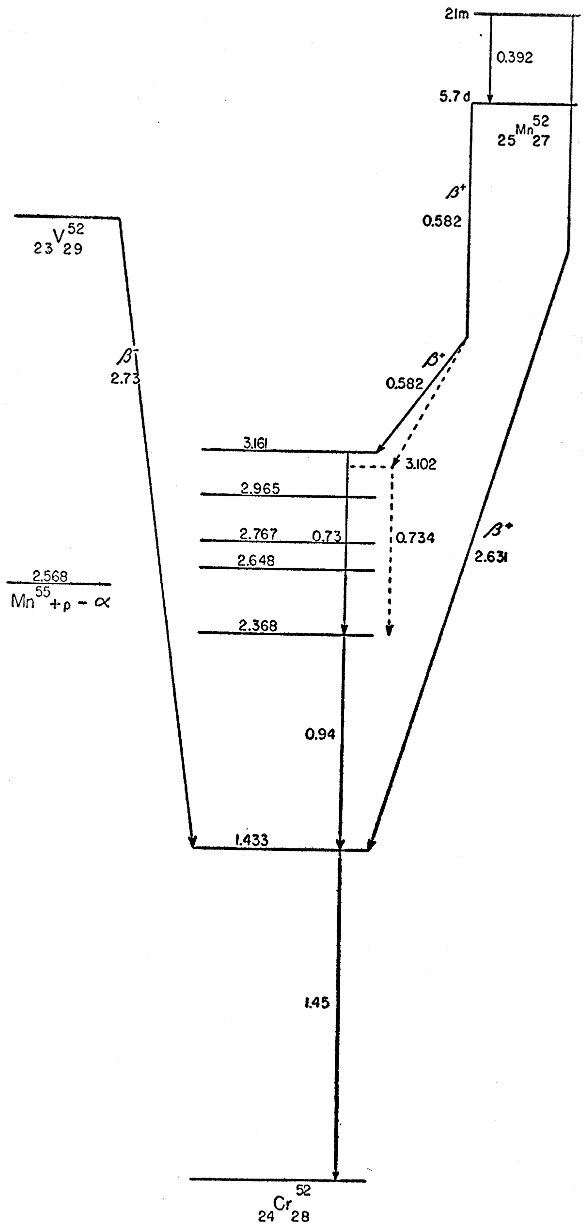

FIG. 2. Energy-level diagram of Cr^{52}, incorporating the results of the (p,p') and (p,α) studies and the beta- and gamma-ray results. The alternate mode of decay of the ground state of Mn^{52} (indicated by the dashed lines) is discussed in the text.

There are, however, some difficulties with this decay scheme. If the ground state of Mn^{52} decays by positron emission to the 3.161-Mev state and if this is followed by a gamma-ray transition to the 2.368-Mev state, as shown in Fig. 2, the expected energy for this gamma ray is 0.793 ± 0.007 Mev. While a gamma ray of approximately this energy has been observed from the Mn^{52} decay, the various measurements have clustered closely about the value of 0.734 ± 0.015 Mev, measured by Peacock and Deutsch.[10] A similar discrepancy between the present results and of those from beta decay involves the energy of the isomeric state in Mn^{52}. Peacock and Deutsch[10] have measured the maximum positron energy from the ground state of Mn^{52} as 0.582 ± 0.015 Mev, while the maximum positron energy from the decay of the isomeric state in Mn^{52} has been measured as 2.631 ± 0.015 Mev.[11] Assuming, as indicated in Fig. 2, that these decays proceed to the 3.16- and 1.43-Mev levels of Cr^{52}, one obtains 0.32 Mev for the energy of the isomeric state in Mn^{52}. This would imply that the 0.392 ± 0.008 Mev gamma ray observed[12] from Mn^{52} does not originate from the decay of the isomeric state associated with the beta transition.

These various results can be brought into agreement if one assumes the existence in Cr^{52} of an excited state at 3.10 Mev which is formed in the Mn^{52} beta decay

[6] Browne, Zimmerman, and Buechner, Phys. Rev. **96**, 725 (1954); and Buechner, Braams, and Sperduto, Phys. Rev. **100**, 1387 (1955).

[7] *Nuclear Level Schemes*, $A=40$—$A=92$, compiled by Way, King, McGinnis, and van Lieshout, Atomic Energy Commission Report TID-5300 (U. S. Government Printing Office, Washington, D. C., 1955).

[8] E. Segrè and A. C. Helmholtz, Revs. Modern Phys. **21**, 272 (1949).

[9] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).

[10] W. Peacock and M. Deutsch, Phys. Rev. **69**, 306 (1946).

[11] E. Arpman and N. Svartholm, Arkiv Fysik **10**, 1 (1956).

[12] L. Osborne and M. Deutsch, Phys. Rev. **72**, 467(A) (1947).

but which is not observed in the charged-particle reactions. A state at this energy and the alternative decay scheme are shown by the dashed lines in Fig. 2. All the alpha groups studied in the present experiment were of low intensity, and a weak group associated with a level at 3.10 Mev might not have been observed. It will be recalled that no group was found corresponding to the 3.16-Mev state. In the case of the inelastic proton scattering, if a peak associated with such a state at 3.10 Mev had an intensity greater than 3% of the one corresponding to the 3.16-Mev level, it would have been detected in the exposures at 50 and 90 degrees. In Fig. 1, an arrow marks the position a proton group would have if a state at 3.102 Mev were excited. The nonappearance of a group at this position might be explained on the basis of the high angular momentum required to excite Cr^{52} from its ground state, which has zero angular momentum, to the state formed in the beta decay which has been reported to have angular momentum of 6 units.[13] It should be pointed out that, while the assumption that a state exists at 3.10 Mev suffices to explain the discrepancy between the energy differences calculated from the charged-particle results and those observed in the beta-decay measurements, it does not explain why some evidence for the states established at 3.16, 2.97, 2.77, and 2.65 Mev was not found in the various decay studies.

The authors are indebted to Mrs. Mary Fotis for her very careful work in counting the tracks in the nuclear emulsions exposed during the present work.

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Study of Geomagnetic Cutoff Energies and Temporal Variation of the Primary Cosmic Radiation*

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The results of a series of 6 Skyhook balloon flights with combination Čerenkov-scintillation detectors, similar to ones previously described, are used to study spectral cutoffs as a function of latitude and to observe some aspects of temporal variations at high altitude of the alpha particles of the primary cosmic radiation. Observed cutoff energies are found to be in strong disagreement with geomagnetic theory. In one large cosmic-ray decrease the very low-energy portion of the cosmic-ray energy spectrum (300–600 Mev/nucleon) does not seem to be strongly affected.

I. INTRODUCTION

THE application of emulsion,[1–5] Čerenkov,[6–8] and Čerenkov-scintillation[9] techniques to the study of the flux and energy spectrum of primary cosmic-ray alpha particles has made helium the best known component of the primary radiation. Because of its abundance and because of its relative freedom from secondary effects, the helium component is an excellent one for the direct study of cosmic-ray temporal variations and geomagnetic effects at the top of the atmosphere. The Čerenkov-scintillation technique, which has been described in a previous article,[9] gives an absolute measurement of the primary alpha-particle intensity and energy spectrum. By carrying out measurements at a series of latitudes, the dependence of the energy spectrum on geomagnetic latitude can be studied. This technique is also well suited to the study of long-term temporal variations since it measures absolutely the intensity and energy spectrum. In addition, an electronic device of this type is uniquely suited to study short term temporal variations which occur during the course of a balloon flight or variations associated with changes in geomagnetic latitude along the balloon trajectory. At this time six successful Skyhook flights have been conducted by using the Čerenkov-scintillation method. This paper treats aspects of these flights dealing with temporal variations and changes due to varying geomagnetic latitudes of the energy spectrum and intensity of helium nuclei of the primary cosmic radiation.

II. EXPERIMENTAL APPARATUS

The experimental flight apparatus is identical to that previously described.[9] Briefly, the detector is a

* Assisted by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

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