Detailed calculations for the supracritical region are in progress. We are indebted to the Research Corporation for financial support.

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A Test for the Charge-Symmetry Hypothesis

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Yang has recently suggested[1] an experiment to test the charge-symmetry hypothesis in the coupling of mesons to nucleons. The proposed experiment is to study the following pair of reactions

$$p+p\rightarrow d+\pi^+ \tag{1a}$$
$$n+p\rightarrow d+\pi^0. \tag{1b}$$

These reactions have the advantage over those studied so far in that only one isotopic spin state of the nucleons in the initial state can contribute to the reactions if isotopic spin is conserved, i.e., if it is a good quantum number. The simple argument here is that since a nucleon in the theory of isotopic spin is defined by four variables (position, momentum, spin S, and isotopic spin I) and is a fermion, then the total wave function of a pair of nucleons must be antisymmetric. Now, since the deuteron has an even space wave function and a symmetric spin function, the isotopic spin function must be antisymmetric. The only odd isotopic spin function for two isotopic spins $\frac{1}{2}$ is that one with total $I=0$. Therefore, the final state of (1a) has $I=1$ (that of the pion, with $I_z=+1$ for π^+, 0 for π^0, and -1 for π^-) and $I_z=+1$. Thus the two protons in the initial state have total $I=1$ and $I_z=+1$. Likewise in (1b) the two nucleons have $I=1$, $I_z=0$. Since the statistical probabilities of these total spin orientations are equal, these two reactions (granting the charge-symmetry hypothesis) must have the same angular distributions, and cross sections differing exactly by a factor 2 (since only half of the state $n+p$ is the required isotopic triplet).[2]

It is the purpose of this note to point out two other reactions which give as good a test of charge-symmetry, are probably considerably easier experimentally, and in addition measure the interaction of pions and mesons in states of total isotopic spin $\frac{1}{2}$—a question in which there is considerable interest as the result of recent scattering measurements[3] which have been interpreted[4] as interactions through a resonance state of total isotopic spin $\frac{3}{2}$. The two reactions are really the two branches of the reaction

$$p+d\rightarrow d+n+\pi^+ \tag{2a}$$
$$p+d\rightarrow d+p+\pi^0. \tag{2b}$$

These reactions are the two possible breakups of a proton catalyzed by the presence of the deuteron which absorbs the extra momentum.

Here again the deuteron with $I=0$ forces the initial state to have $I=\frac{1}{2}$, $I_z=+\frac{1}{2}$, as must the final state. Therefore the odd nucleon and the pion must be in a state with $I=\frac{1}{2}$, $I_z=+\frac{1}{2}$, instead of the usual variety of states available to a nucleon and a pion. So we see that the branching ratio should be 2:1, with identical angular distributions, etc. The factor 2 comes again from the fact that the interaction leads only to a final state $I=\frac{1}{2}$, $I_z=+\frac{1}{2}$. Thus, the square of the matrix elements must be reduced to the fraction of $I=\frac{1}{2}$ contained in the ordinary $I_z=+\frac{1}{2}$ state. This is $\frac{2}{3}$ for $n+\pi^+$ and $\frac{1}{3}$ for $p+\pi^0$.

Since there are three particles in the final state one must investigate not only the angle of emission of the π^+ or p, but the energy also (or the angles of the light charged particle and the deuteron also). In a cloud chamber with magnetic field, one of the easiest things to do is to measure the energy spectrum of deuterons accompanied by positive pions in (2a) or by inelastically scattered protons as in (2b).

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A Proposed Test of the Nuclear Shell Model

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In this note we wish to suggest certain experiments which should give direct information concerning the accuracy of the independent particle model of nuclear structure[1] in ascribing definite orbital angular momentum states to nucleons in a nucleus.

Interpretation of the angular distributions from (d, p) and (d, n) nuclear reactions[2] has shown these reactions to proceed mainly by means of a stripping process, the angular distribution of the outgoing particle in any one case being characterized by the orbital angular momentum l with which the captured particle can be accepted into the appropriate final state. The angular distributions all show a pronounced peak at small angles, this maximum lying directly forward if $l=0$, but moving progressively towards larger angles as l is increased. Also, if more than one value of l is allowed by the selection rules in a particular case, and if the initial nucleus should be indifferent as to which of these values it accepts, then it is found that the maximum in the angular distribution which is nearest the forward direction, i.e., which results from the smallest allowed l, is of much larger magnitude than the others; there is, in fact, an order of magnitude decrease in the heights of the maxima as l is increased by 2 (the allowed values of l in any one case being either all even or all odd).

According to the shell model, however, the initial nucleus will accept a particle only in a certain definite orbital angular momentum state. Although the lowest allowed l usually coincides with the value required by the shell model, there are some instances where the reverse is true, i.e., where the shell model l value is 2 units higher than the lowest value allowed by the selection rules. It is in these latter cases that we are interested. If the shell model were precise, the experimental angular distributions for such cases should show no evidence of the maximum nearest the forward direction which would be expected to be present on the grounds of selection rules alone; on the other hand, there has to be only a very small deviation from the shell model before this peak in the angular distribution is as large as the following one. The angular distributions will therefore effectively amplify by a factor ~10 any admixture of the lower orbital angular momentum state in the wave function of the final nucleus, as well as any admixture of states in the initial nucleus which allow the low orbital angular momentum transfer. Such angular distributions should, therefore, provide a sensitive measure of the accuracy with which a nucleon in a nucleus can be ascribed a definite orbital angular momentum.

Some examples of reactions which satisfy the above requirements, and for which therefore it would be very desirable to have experimental angular distributions, are given in Table I. These refer to formation of the final nuclei in ground states only, since the shell model cannot be expected to give the precise ordering of excited states. In choosing such examples it is, of course, important that the lowest allowed angular momentum does not correspond to an independent particle level which is so very little separated from the predicted ground level that the two could very easily cross. Such a state of affairs occurs, for example, in the shell with neutron or proton numbers between 8 and 20 where the ordering of levels is in general $d_{5/2}$, $s_{1/2}$, $d_{3/2}$, but where the $d_{5/2}$ and $s_{1/2}$ levels are very little separated and are known in fact to

Table I. Some examples of stripping reactions whose angular distributions should give direct information concerning the accuracy of the independent particle model of nuclear structure.

Reaction	Spin and parity		l	
	Initial	Final	Required by shell model	Allowed values
(1) $P^{31}(d, p)P^{32}$	1/2+	1+	2	0 and 2
(2) $Cl^{35}(d, p)Cl^{36}$	3/2+	2+	2	0, 2, and 4
(3) $Cl^{37}(d, p)Cl^{38}$	3/2+	2−	3	1 and 3
(4) $K^{41}(d, p)K^{42}$	3/2+	2−	3	1 and 3
(5) $Sc^{45}(d, p)Sc^{46}$	7/2−	4+	3	1, 3, 5, and 7
(6) $V^{51}(d, p)V^{52}$	7/2−	2 or 3+	3	1, 3, 5 (and 7)

cross on a number of occasions. In the region where the $d_{5/2}$ levels are being filled, therefore, if a reaction which is expected on the shell model to require an orbital momentum transfer of $l=2$ in fact shows strong evidence of an $l=0$ change, the reason might well be merely that for the case considered the $d_{5/2}$ and $s_{1/2}$ levels have crossed.

Near the end of the shell just discussed, however, when the $d_{5/2}$ and $s_{1/2}$ levels have all been filled, there should be no such difficulty, and it is in this region that our first two examples lie. These should be particularly good cases for our purpose since the next $s_{1/2}$ orbits on the independent particle model lie very much higher in energy than the ground state $d_{3/2}$ levels. Examples (3), (4), and (5) correspond to filling the $f_{7/2}$ shell in the region $20<N\leqslant 28$, and the aim of the experiments would be to detect any p admixture in the predicted $f_{7/2}$ orbital states. These again should be clear-cut cases, since the next p levels occur in a higher shell. The last example, however, lies in the region $28<N<38$ where the $f_{5/2}$ and $p_{3/2}$ levels have about the same energy, and this case must therefore be considered as doubtful. On Nordheim's rule[3] it is perhaps more likely that a spin of 2 or 3 for V^{52} be produced by a combination of the $f_{7/2}$ state for the odd proton with an $f_{5/2}$ rather than a $p_{3/2}$ state for the odd neutron, but this is of course not certain.

In order that, in the angular distributions, there be appreciable separation between the peaks of interest, the most favorable incident deuteron energy is probably about 10–15 Mev. For these energies, the transition $l=2$ in our first two examples will produce a maximum at about 20–30 degrees from the forward direction, whereas that for the $l=0$ transition will lie directly forward; in the other cases the $l=3$ transition will produce a peak at about 35–45 degrees, while the maximum resulting from $l=1$ will be at angles of about 5–15 degrees. Moreover, if the probability of the smaller angular momentum transfer be only 1/10th the probability of the transfer required by the shell model, the two resulting maxima will be of approximately the same height.

We are indebted to Dr. Maurice Goldhaber for supplying us with information concerning the spins of the odd-odd nuclei employed in our examples.

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Radiations of Rh^{99}, Rh^{101}, Rh^{105}, and Ru^{105}

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Ruthenium metal of high purity was bombarded with 6.3-Mev protons and 10-Mev deuterons and the spectra of the activities obtained were examined in a 180° beta-ray spectrometer. The spectrometer sources consisted of the activated metal spread out evenly on thin Zapon foil ribbons. The source and backing had a thickness of about 15 mg/cm². The spectra were scanned in the spectrometer at suitable intervals of time. By correcting for decay the component spectra were separated.

Both the positron and negatron spectra were examined when the ruthenium metal was bombarded with protons. The positron spectra of 4.5-hour Rh^{99} and 19-hour Rh^{100} were observed. A Kurie plot of the corrected positron spectrum of Rh^{99} indicated that the spectrum is allowed and probably simple, having an end-point energy of 0.74±0.01 Mev, for which the log(ft) value is 4.95. No gamma-rays of 4.5-hour half-life were observed. The intensity of the Rh^{100} positrons was not sufficiently high to give a reliable Kurie plot. Examination of the negatron spectrum showed the presence of several well-defined internal conversion peaks, decaying with a half-life of 4.5 days. These peaks were attributed to K and L conversion electrons from gamma-rays of Rh^{101}. The energies of the corresponding gamma-rays are 0.148±0.005 and 0.300±0.005 Mev. The former value is in fair agreement with 0.13 Mev previously reported[1] from beta-ray spectrograph measurements, and the latter roughly agrees with the value 0.35 Mev reported from lead-absorption measurements.[2]

With deuteron bombardment of ruthenium two negatron spectra with half-lives of 4.5 hours and 36 hours were observed. The 4.5-hour activity is attributed to Ru^{105} which is obtained by a (d, p) reaction on Ru^{104}. A Kurie plot of the corrected Ru^{105} negatron spectrum indicated a simple spectrum of allowed shape. The end-point energy is 1.15±0.02 Mev. The 36-hour activity was attributed to Rh^{105} obtained by the reaction $Ru^{104}(d, n)Rh^{105}$ and by negatron decay of Ru^{105}. A Kurie plot of the corrected Rh^{105} spectrum indicated a simple spectrum also of allowed shape. The end-point energy is 0.57±0.01 Mev. The above results for Ru^{105} and Rh^{105} spectra are in agreement with those obtained by Duffield and Langer.[3] High internal conversion peaks at 1140 and 1250 gauss-cm with half-life of less than 6 hours were found superposed on the negatron spectra. These peaks are believed to be K and L conversion lines from a gamma-ray of Rh^{105}.[3] The corresponding energy of the gamma-ray is 0.127±0.005 Mev.

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Energy Absorption During Twin Formation in Zinc Single Crystals*

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The energy absorbed during the formation of twins in single crystals of 99.999 percent pure zinc was measured by means of ballistic pendulums in a manner first used by Chalmers[1] to measure the twinning energy in tin. The method was also used by the present author in measuring the energy absorbed during kink formation in zinc and cadmium.[2] It should be noted that in the very early stages of the latter work the kinks were thought to be twins and were erroneously reported as such.[3]

The single crystals were grown in a vacuum using a Bridgeman-type furnace. In order to study twin formation by impact it is necessary to have the (0001) plane nearly normal to the specimen axis. Using the Bridgeman technique the author had previously found that most of the crystals grew with the (0001) plane nearly parallel to the specimen axis.[2] In the current work, however, it has been possible to produce crystals with the (0001) plane nearly normal to the specimen axis by making short right angle bends in the Pyrex crucibles just beyond the seed point of the crucible. The crystals grown in this manner were rods 15 to 30 cm long and about 6 mm in diameter with the basal plane (0001) within 16° of the normal to the specimen axis. These rods were sectioned into lengths of about 2.5 cm for the twinning experiments.

As indicated in metallurgical literature, twins when produced in compression in pure zinc are rather narrow and frequently do not