molecule, permits a rough calculation of several transitions in the above indicated region.

The $J=2$ to $J=3$ transitions for nitrosyl chloride have been observed in the region from 33,130 to 33,950 Mc/sec. as predicted from previous data.[2] This spectrum is complicated by the isotopic shift between $NOCl^{35}$ and $NOCl^{37}$, the slight asymmetry of these molecules, and the nuclear quadrupole effects of the chlorine and nitrogen nuclei. The theory, excluding the nitrogen quadrupole interaction, predicts five sets of lines for each isotopic molecule with hyperfine structure giving a total of thirty-three lines per molecule. More accurate frequency measurements are being made and a detailed analysis of both spectra is in progress.

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Transitions to the Ground States in Nuclei Excited by Slow Neutron Capture

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THE γ-radiations produced by the capture of slow neutrons in various elements have been studied with the aid of a pair spectrometer. A brief description of the method of energy measurement and the results for Be, C, N, and Pb and Bi have been given in a previous communication.[1] The present note concerns the intensities of the γ-radiations resulting from transitions from the capturing states to the ground states of the product nuclei. For brevity, these radiations will be called "ground-state" radiations. The intensities are determined by correcting the peak coincidence counting rate for the pair formation cross section and its angular distribution.

TABLE I. Ground-state radiations.

Capturing nucleus[a]	Spin of capturing nucleus	Spin of product nucleus: Excited state	Spin of product nucleus: Ground state[a]	Minimum spin radiated	Neutron binding energy in product nucleus (Mev)
		Class A: Predominant			
Be^{9}	3/2	1, 2	0	1, 2	6.797 ±0.008
C^{12}	0	1/2	1/2	1	4.947 ±0.010
Al^{27}	5/2	2, 3	2 ?	1	7.72 ±0.02
Mn^{55}	5/2	2, 3			7.25 ±0.03
Fe^{54} ?	0	1/2			9.28 ±0.03
Fe^{56}	0	1/2			7.63 ±0.01
Ni^{58}	0	1/2			9.01 ±0.03
Ni^{60}	0	1/2			8.55 ±0.03
Cu^{62}	3/2	1, 2	1 ?	1	7.91 ±0.01
Pb^{206}	0	1/2	1/2	1	6.67 ±0.02
Pb^{207}	1/2	1	0	1	7.37 ±0.02
		Class B: Weak			
N^{14}	1	1/2, 3/2	1/2	1, 2	10.823 ±0.012
F^{19}	1/2	0, 1	2 ?	1, 2	6.63 ±0.03
S^{32}[b]	0	1/2	3/2	1	8.66 ±0.02
Cl^{35}	3/2	1, 2	2	1	8.56 ±0.03
Cl^{37}	3/2	1, 2	2	1	6.11 ±0.03
K^{39}	3/2	1, 2	4	2, 3	7.76 ±0.03
K^{41}	3/2	1, 2	2	1	7.39 ±0.03
V^{51}	7/2	3, 4			7.30 ±0.03
Co^{59}	7/2	3, 4	6 ?	2, 3	7.73 ±0.04
		Class C: Very weak or not detected			
Si^{28}	0	1/2	1/2	1	8.38 ±0.10
Si^{29}	1/2	0, 1	0	1	11.00 ±0.30
Na^{23}	3/2	1, 2	4 ?	2, 3	(7.0)
Mg^{24}	0	1/2	5/2	2	(7.3)
Mg^{25}	5/2	2, 3	0	2, 3	(12.0)
P^{31}	1/2	0, 1	2 ?	1, 2	(8.2)

[a] A question mark in column 1 indicates an uncertain isotope assignment, in column 4, a doubtful spin value.
[b] Assignment doubtful.

The results are summarized in Table I. With Be and C and with Pb no radiations other than the ground-state radiations were observed. All other elements studied give some radiations producing excited states. From some elements (e.g., Fe and Ni), there are relatively few radiations; from others, there is a copious emission, for example, seventeen different γ-rays have been separately detected in the Al spectrum with a resolution of 2 percent. In most of the heavier elements, such as Cr, Zn, Sr, In, Cd, Sn, W, Ta, and Au, the complexity of the spectrum or lack of knowledge of the binding energies do not permit classification in the table. With the exception of Cr, these elements produce a few homogeneous γ-rays superposed on a continuous spectrum of unresolved radiations.

In Table I, the capturing nuclei are classified according to the intensities of the ground-state radiations relative to those leading to excited states. In Class A, the intensity of the ground-state radiation predominates over that of all other radiations; in Class B, it has an intensity comparable to, or weaker than those of transitions to excited states; in Class C, it is less than 5 percent of the intensity of the strongest γ-ray emitted by the excited nucleus, or it is not detected. The first column of Table I indicates the capturing nucleus; the second, its spin; the third, the spin of the capturing state of the product nucleus and the fourth, the spin of its ground state. The minimum angular momentum ra liated in the ground-state transition is given in the fifth column and the energy of this radiation, as measured in the present experiments, in the sixth. In Class C the energies in parentheses have not been measured directly because the ground state transitions have not been observed and they refer to the energies calculated from the energy balance of (d,p) reactions and the binding energy of the deuteron, or from other sources.

The interpretation of the spectra obtained is difficult because little is known about the parities of the ground states of the nuclei of the target material or their products. Even in circumstances where the parity can be inferred from other evidence, it is not possible to account unambiguously for the intensities of the ground-state transitions. Nuclei such as N^{15} and K^{39}, which contain a closed shell of neutrons, possess magnetic moments in good agreement with those deduced from the Schmidt formula on the basis of a single unmixed state. For these nuclei the parity is determined by the proton which must be added to complete the proton shell. From this and from the shell structure theory of Feenberg and Hammack,[2] it follows that the parity of N^{15} in its ground state should be odd and the parities of K^{39} and K^{41} should be even. Similarly, the parity of N^{14} should be even and the parities of K^{40} and K^{42} should be odd, a conclusion which is supported by the β-decay[3] of K^{42}.

If these parity assignments are correct the ground-state radiation of N^{15} is of the electric dipole type since the spin of the capturing state must be $\frac{1}{2}$ or $\frac{3}{2}$. Our measurements show that it is weak compared to the radiation emitted to the excited state at 5.3 Mev. Further, the ground-state radiation from K^{40} should be electric octupole or magnetic quadrupole because the minimum angular momentum radiated in this transition is two units. It is surprising that a radiation of this type should compete successfully with the numerous radiations emitted by the capturing state (its intensity is about one-fifth of that producing an excited state at 2 Mev).

The low intensity or absence of the ground-state transitions of the Mg, P, and Si isotopes presents further difficulties. Since Mg^{24} and Mg^{26} are even-even nuclei the ground-state transitions in Mg^{25} and Mg^{26} are of the same type where parities are concerned: if there is a parity change in the one nucleus there is a parity change in the other. If there is no change, as the shell model would seem to indicate, the ground-state transition in Mg^{25} is electric quadrupole and it is difficult to understand why it is not detected, although that of Mg^{26} may be forbidden if capture in Mg^{25} takes place in a state with a spin of three units. If there is change in parity, the radiation is magnetic quadrupole and capture in Mg^{24} should fall into the same intensity class as K^{39}. A similar difficulty

occurs in the understanding of the low intensity of the ground-state transition in P^{32}. Furthermore, the very weak intensities for the ground-state radiations in Si^{29} and Si^{30} are hard to reconcile with the single unit of angular momentum which must be radiated in these transitions if the spin of $\frac{1}{2}$ recently suggested for Si^{29} is correct.[4]

It is clear that the familiar selection rules concerning differences in parity and spin are not sufficient to account for the relative intensities of ground-state transitions. The experimental data, therefore, indicate the existence of additional parameters which determine the relative intensities of nuclear radiations. We wish to thank Dr. L. G. Elliott for helpful discussions.

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The Viscosity of Liquid He^3

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SOME recently announced results by Weinstock *et al.*[1] show that the vuscosity of liquid He^3 increases smoothly from a value of 22 micropoise at 2.8°K to 30 micropoise at 1.05°K. The curve is everywhere convex to the temperature axis and shows no sign of a discontinuity anywhere in this range. Such a variation of viscosity is similar to that of an ordinary liquid, but it does not seem possible to explain it in the conventional way by assuming that the atoms moving through the liquid have potential barriers to surmount. Liquid He^4 (above the λ-point) already shows a viscosity increasing with temperature in much the same way as does that of a gas. The density of liquid He^3 is only just over half that of liquid He^4, and the effective height of any potential barrier is therefore correspondingly smaller. The fact that an opposite trend of viscosity is observed in liquid He^3 therefore points to an increase in mean free path as the temperature falls, which may be explained in one of two ways: (a) by a decrease in the effective cross-section at low velocities of impact of helium atoms (Ramsauer effect); (b) by a decrease in the effective cross section at low temperatures due to the scattered states being already occupied. The existence of such an effect in a Fermi gas was first pointed out by Tomonaga,[2] and a similar point has recently been made by Singwi and Kothari.[3]

We have examined the consequences of effect (a) alone, by extending to He^3 the calculations of the viscosity of He^4 gas made by Massey and Mohr,[4] and by Buckingham, Hamilton, and Massey.[5] Two models have been used, the rigid sphere model (with a diameter of 2.1A for a helium atom[4]), and another using an interaction potential formed from repulsive exponential and van der Waals attractive terms. This second potential is one called "potential C" by the second group of authors. Although the attractive part of potential C is too weak to represent the interaction of He atoms correctly, it happens that the adjustment to the correct magnitude is very nearly compensated by the smaller mass of He^3. Consequently the results of previous calculations are readily adapted to give values of viscosity which are probably a good approximation for He^3.

TABLE I. Theoretical values of η (in micropoise) as a function of T.

	Rigid sphere			Potential C					
T (°K)	↑↓ (1)	↑↑ (2)	Mixture (3)	↓↑ (4)	↑↑ (5)	Mixture (6)	Classical (7)	Complete degeneracy (8)	Observed (9)
0.25				3.6	5.3	4.7	3.6	—	
0.5	1.1	32	3.6	8.0	5.2	5.5	6.3	—	
0.75	1.6	19.5	4.7	6.0	4.8	5.0	8.7	41	
1.0	1.8	14.7	5.3	4.8	6.3	5.8	10.8	23	30.5
1.25	2.3	13.2	5.9	4.4	8.5	6.8	12.3	14.5	
1.5	2.7	12.2	6.4	4.4	11.0	8.0	13.5	10.2	
2.0	3.7	11.1	7.4	4.9	14.8	9.8	15.4	5.8	
2.5	4.7	10.8	8.2	5.7	15.9	11.0	17.0	3.8	22 at
3.0	5.8	11.0	9.0	6.7	15.4	11.6	18.5	2.5	2.80°K

In Table I, columns 1 and 2 refer to the rigid sphere model, and assume that the nuclear spins of each colliding pair of atoms are respectively antiparallel and parallel, whereas column 3 represents the consequences of assuming a 3:1 mixture of these two types of collision. Columns 4, 5, and 6 give corresponding results for the interaction potential C. Column 7 gives the viscosity of a classical gas of atoms of diameter 2.1A, while column 8 refers to the formula

$$\eta=(1/15\pi^3)\cdot(2mE_0^5)^{\frac{1}{2}}/(kT)^2\cdot(1/Q),$$

obtained by Tomonaga for an almost completely degenerate gas. (His actual expression refers to a mixture of two types of Fermi particle, so we have divided it by 2. The scattering cross section, Q, has been taken to be πr^2, r being taken as 1.05A, the gas-kinetic radius.) Since E_0, for the observed density (~0.07 g/cm³) of liquid He^3, corresponds to a Fermi degeneracy temperature of the order of 5°K, the Tomonaga formula is only the limiting form at very low temperatures.

Though it might seem that model 2 (rigid spheres with parallel spins) has at least the correct trend to interpret the observed results, it appears nervertheless that the Ramsauer effect is insufficient by itself to explain them: first, because model 5 shows that alteration of the interaction to a more correct form lowers the predicted viscosity at temperatures below 1.5°K considerably; secondly, because the effect of many-body collisions, neglected in models 1 to 7, can only shorten the mean free path; and thirdly, because models 2 and 5 seem to be practically ruled out by the observation of Sydoriak and Hammel[6] that liquid He^3 is not ferromagnetic within the range of temperatures considered.

We thus seem forced to conclude that the observed rise in viscosity as the temperature falls is due, at least in part, to the effect of the exclusion principle in reducing the probability of scattering.

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The Nuclear Magnetic Moment of Praseodymium[141]

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BY means of super-regenerative oscillator techniques similar to those previously described,[1,2] a nuclear magnetic resonance absorption peak for Pr^{141} has been located. By comparison of the resonance peak with the sodium resonance peak observed simultaneously in the same magnetic field, the following tentative value for the ratio of the resonance frequency of Pr^{141} to the resonance frequency of Na^{23} in sodium borate in the same applied field was obtained:

$$\nu(Pr^{141})/\nu(Na^{23})=1.2362\pm0.0006.$$

Using Pound's value for the ratio of the resonance frequency of Na^{23} to the resonance frequency of the proton in the same field,[3] one obtains the following value for the ratio of the resonance frequency of Pr^{141} to that of the proton:

$$\nu(Pr^{141})/\nu(H^1)=0.32698\pm0.00016.$$