our field of view is 2° in the vertical direction and hence will include more than the lower red border, and also since we may have been looking up through the red aurora to green aurora behind it, this is not surprising.

The night of July 1, 1951, there was considerable aurora at Saskatoon. A very steady homogeneous arc appeared about 15° above the southern horizon from 10.15 to 1.00 Mountain Standard Time. A line at 4860A was prominent in its spectrum the whole time. This is presumably $H\beta$ (4861). Many spectra were taken during this same period of very bright active forms with ray structure in the rest of the sky, none of which showed any sign of this line. The results of Meinel are similar; he reports[2] that hydrogen emissions are seen only in homogeneous arcs, though his conclusions are less definite because of the longer exposure times of around 15 minutes required with his conventional spectrograph.

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Interatomic Distances and Ferromagnetism in Spinels

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EXCELLENT agreement exists between the experimental saturation moments of ferromagnetic spinels determined by Gorter[1] and the values predicted by Néel.[2] The essence of Néel's theory was to assume that strong negative (antiferromagnetic) interactions exist between the unpaired spins of cations occupying the tetrahedral voids amidst close-packed oxygens in the spinel lattice and the unpaired spins of cations occupying octahedral voids. Thus, in the series of inverse spinels[3] $Fe^{+++}MeFe^{+++}O_4$ (where the metal Me = Mn, Fe^{++}, Co, $Li_{\frac{1}{2}}Fe_{\frac{1}{2}}^{+++}$, Ni, Cu[4], or Mg[4]), since one Fe^{+++} occupies tetrahedral interstices and (Me plus the other Fe^{+++}) share octahedral interstices, the saturation moment is simply that corresponding to the unpaired spins of Me. Néel also showed that spin interactions operate through the oxygens separating the metal ions ("superexchange"), and Anderson[5] has shown that the antiferromagnetism of MnO is to be explained similarly.

The author wishes to point out a new hypothesis by means of which the following may be accomplished: (1) the *ad hoc* assumption of Néel that the strongest spin interaction in inverse spinels is between tetrahedrally situated cations (Me_t) and octahedrally situated cations (Me_0) rather than between Me_t and Me_t or between Me_0 and Me_0 may be rationalized; (2) the nonoccurrence of ferromagnetism in normal spinels such as $NiCr_2O_4$ may be explained; and (3) a quantitative relationship may be shown to exist between Curie temperature and interatomic distance in the ferromagnetic spinels and in the rock-salt structure antiferromagnetics. The hypothesis is simply that spin interaction is inversely proportional to the distance from a metal ion to a nearest nelghbor, i.e., an oxygen, and thence to another metal ion. This is similar to the assumption of Zener[6] that direct spin interaction decreases continuously with increasing distance between adjacent atoms in metals.

Geometrical calculations show that in spinels the distance Me_t-O-Me_0 is smaller than the distance Me_t-O-Me_t or the distance Me_0-O-Me_0, provided that the lattice parameter u is less than 31/80 (0.388). Verwey and Heilman[3] have found u to be about 0.380 for inverse spinels. If u is greater than 0.388, however, Me_0-O-Me_0 is now the closest cation-oxygen-cation distance. Verwey and Heilman[3] found u to be greater for most normal spinels than for inverse ones. For example, $NiCr_2O_4$ (in which Ni occupies tetrahedral voids and 2 Cr's occupy octahedral voids) had $u=0.388\pm0.003$. For this substance our hypothesis correctly predicts the absence of ferromagnetism, while if strong tetrahedral-octahedral spin interactions were present, ferromagnetism with a saturation magnetic moment of 4 Bohr magnetons would be expected.

TABLE I. Exchange energy for ferromagnetic spinels.

Spinel	a_0,[c] A	kT exp., ergs	kT calc., ergs	% difference
γ-Fe_2O_3[a]	8.32	1.31×10^{-13}	1.32×10^{-13}	− 0.8
$MnFe_2O_4$	8.55	0.798	0.786	+ 1.5
Fe_3O_4	8.39	1.19	1.17	+ 1.7
$CoFe_2O_4$	8.36	1.096	1.15	− 4.9
$Li_{\frac{1}{2}}Fe_{\frac{1}{2}}O_4$	8.31	1.19	1.32	−10.9
$NiFe_2O_4$	8.36	1.18	1.006	+14.7
$CuFe_2O_4$[b]	8.37	0.943	0.798	+15.4
$MgFe_2O_4$[b]	8.36	0.826	0.710	+14.0

[a] T experimental, extrapolated. See Michel and Chaudron, Compt. rend. 201, 1191 (1935).
[b] $s_t s_0$ computed from experimental data of reference 1.
[c] From reference 3, wherever possible.

The following semi-empirical equation was developed to correlate spin exchange energy as measured by kT with the supposed variables:

$$kT=c_1 s_t s_0 e^{-c_2 d}, \tag{1}$$

where k = Boltzmann's constant, T is the Curie temperature in °K, s_t and s_0 are respectively the number of unpaired spins on Me_t and Me_0, d is the distance Me_t-O-Me_0 in A ($=0.470a_0$, where a_0 is the lattice constant of a spinel with $u=0.388$). With $c_1=5.04\times10^{-3}$ erg and $c_2=7$, the data of Table I were obtained. The agreement (±16 percent) between observed and calculated exchange energies is reasonable, since (1) an error of 0.01A in a_0 (which is less than the disagreement between published values for a given spinel) would cause an error of 5 percent in kT, (2) u values may vary slightly from 0.380 for certain of the spinels,[3] and (3) the value of $s_t s_0$ is not precisely known for $CuFe_2O_4$ and $MgFe_2O_4$.

An equation similar to (1) but with $c_1=6.5\times10^7$ ergs and $c_2=12$ holds for the antiferromagnetic oxides MeO (Me = Mn, Fe, Co, Ni) to ±27 percent. The difference in c_2 for the 2 structures shows that (1) does not account for all the factors involved. Indeed, Anderson[5] has shown that as a consequence of superexchange a strong directionality exists such that the strongest interaction is between magnetic ions on opposite sides of an oxygen. The angle Me-O-Me is 180° for the rock salt structure and 126° for Me_t-O-Me_0 in inverse spinels with $u=0.380$.

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Evidence for Non-Additivity of Nucleon Moments*

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THE existence of a change in the nucleon intrinsic moments due to the interaction with other nucleons has for some time been rather well established by the H^3, He^3 moment anomaly. It has been pointed out[1] that this change will lead both to a modification of the magnetic moments of most nuclei and to marked changes in the lifetimes for nuclear magnetic dipole transitions. A possible connection between the deviations of magnetic moments from the Schmidt lines and non-additivity of the nucleon moments has recently been emphasized by Miyazawa,[2] de-Shalit,[3] and Bloch.[4]

TABLE I. Isomeric magnetic dipole transitions.[a]

Nucleus	Energy (kev)	Conversion coefficient	Assignment	Lifetime (sec)	References
Sn^{117}	162	0.10 ±0.03	$d_{\frac{3}{2}}\rightarrow s_{\frac{1}{2}}$	$<10^{-6}$	b
Sn^{119}	24.2	7.3 ±1.7	$d_{\frac{3}{2}}\rightarrow s_{\frac{1}{2}}$	$<10^{-6}$	c
Te^{121}	213	0.085±0.035	$d_{\frac{3}{2}}\rightarrow s_{\frac{1}{2}}$	$<3\times10^{-9}$	d
Te^{123}	159	0.18 ±0.08	$d_{\frac{3}{2}}\rightarrow s_{\frac{1}{2}}$	$<4\times10^{-9}$	e
Te^{125}	35.4	~15	$d_{\frac{3}{2}}\rightarrow s_{\frac{1}{2}}$	$<4\times10^{-9}$	f
Xe^{131}	80	~0.7	$s_{\frac{1}{2}}\rightarrow d_{\frac{3}{2}}$	$(5\pm1)\times10^{-10}$	g
Ba^{133}	11.7	130±30	$d_{\frac{3}{2}}\rightarrow s_{\frac{1}{2}}$	$<5\times10^{-7}$	h

[a] See reference 5.
[b] See reference 6.
[c] See references 7, 8, and 9.
[d] See references 10, 11, and 12.
[e] See references 10, 11, and 13.
[f] See references 13, 14, and 15.
[g] See references 16, 17, and 18.
[h] See reference 19.

Very striking evidence for a non-additivity effect is provided by the observation of magnetic dipole transitions in a number of nuclear isomers. The isomers in question are listed with relevant data in Table I;[5-19] these and other data fit very well with the predications of the spin-orbit coupled shell model.[20] On the basis of this model the magnetic dipole transitions are ascribed to one-particle transitions with

$$\Delta l=2. \tag{1}$$

If the states were pure, the transition would be strictly forbidden for ordinary magnetic dipole effects.

Such transitions are allowed for certain forms of the interaction moment. Forms[1,21] of magnetic moment operator that have been considered in connection with H^3, He^3 are:

$$\Delta\mathbf{M}=\Sigma_{\pi,\nu}(\boldsymbol{\sigma}_\pi-\boldsymbol{\sigma}_\nu)\Phi(r_{\pi\nu})\times\begin{cases}1, & (2)\\ P_{\pi\nu}, & (2')\end{cases}$$

$$\Delta\mathbf{M}=\Sigma_{\pi,\nu}([\boldsymbol{\sigma}_\pi-\boldsymbol{\sigma}_\nu]\cdot\mathbf{r}_{\pi\nu})\mathbf{r}_{\pi\nu}\Phi(r_{\pi\nu})\times\begin{cases}1, & (3)\\ P_{\pi\nu}, & (3')\end{cases}$$

where the labels π and ν refer to protons and neutrons, respectively, Φ is a scalar function of distance, and $P_{\pi\nu}$ is the Majorana exchange operator. In addition to these terms, which are here interpreted as modifications of the intrinsic moments produced by interactions between pairs, one must also consider the exchange term[22]

$$\Delta\mathbf{M}=(ie/2\hbar c)\Sigma_{\pi,\nu}(\mathbf{r}_\pi\times\mathbf{r}_\nu)J_{\pi\nu}P_{\pi\nu}, \tag{4}$$

where $J_{\pi\nu}$ is the neutron-proton exchange potential.

If, in accordance with the shell model, it is assumed that all nucleons except the single odd one are coupled to total angular momentum zero, it can be shown that neither Eq. (2) nor Eq. (4) can lead to the transition (1). Furthermore Eq. (3) leads to a transition matrix element, μ, of the same order as the magnetic moment anomaly in H^3 and He^3, i.e., $\frac{1}{4}$ nm. Since the magnetic dipole transition probability is

$$w=8.5\times10^{11}(\hbar\omega/mc^2)^3|\mu|^2(1+\beta)\ \text{sec}^{-1},$$

where β is the conversion coefficient, this value of μ is too small to account for some of the lifetime values. It seems likely that either Eq. (2') or Eq. (3') can lead to sufficiently short lifetimes. This point is being investigated in detail.

An investigation of the non-additivity effect on the static nuclear moments has led to the conclusion that Eqs. (2) and (3) produce a correction to the moment of only $\frac{1}{4}$ to $\frac{1}{2}$ nm. This is much too small to account for the deviations from the Schmidt lines. Contributions to static moments from Eq. (4) have been estimated by Spruch[23] but no reliable estimates were obtained for the heavy nuclei. Equations (2') and (3') may yield larger contributions to the static moments, but the calculation of these terms has still to be completed.

In summary, it can be said that the isomeric transitions give strong evidence for a departure from additivity of the intrinsic nucleon moments, and they impose certain restrictions on the possible forms of the interaction moment. However, it must be kept in mind that these conclusions depend on the assumption that the states are rather pure shell model states.

In order to investigate further the validity of these ideas, more precise determinations of lifetimes and of conversion coefficients for the listed transitions and other similar transitions are required. Lifetimes may provide information concerning the mixing of states or concerning the magnitude of the interaction moment. Conversion coefficients are needed to fix the magnetic dipole character of the transitions. At present this property has been established in some cases by means of the K/L conversion ratio.[20]

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Half-Lives of Excited States of Hg^{199}, Xe^{131}, and Hg^{198}

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THE delayed coincidence techniques described previously[1] have been used to measure the half-lives of the 158-kev excited state of Hg^{199}, the 80-kev excited state of Xe^{131} and the 411-kev excited state of Hg^{198}, using sources of Au^{199}, I^{131}, and Au^{198}, respectively. In all cases thin radioactive sources were mounted at the center of a pair of lens beta-ray spectrometers placed end to end, so that the radiations falling on both stilbene counters of the coincidence circuit were magnetically selected. Resolving times $2\tau_0$ ranged from 2 to 6×10^{-9} second.

When the 145-kev L-conversion peak of the 158-kev gamma-ray of Hg^{199} was focused in the north spectrometer, while the south spectrometer was focused on a point of the beta-continuum of Au^{199}, the delayed resolution curve $F(x)$ of Fig. 1 was obtained. The prompt resolution curve $P(x)$ was obtained by replacing the source of Au^{199} by a source of ThB and using the 147-kev F-line, shown separately to have a half-life less than 10^{-10} second. A least-squares fit of the part of $F(x)$ lying to the right of $x=4\times10^{-9}$ second yields $T_{\frac{1}{2}}=(2.26\pm0.12)\times10^{-9}$ second, while the shift of the centroid[2] of $F(x)$ to the right of that of $P(x)$ yields $T_{\frac{1}{2}}=(2.43\pm0.12)\times10^{-9}$ second. Making an allowance for systematic errors, we quote for the half-life of the 158-kev excited state of Hg^{199},

$$T_{\frac{1}{2}}=(2.35\pm0.20)\times10^{-9}\ \text{second},$$

consistent with the theoretical expectation for electric quadrupole radiation.[3]

Figure 2 shows a similar pair of curves for the 45-kev K-conversion line of the 80-kev gamma-ray of Xe^{131}. The prompt curve $P(x)$ in this case was obtained from the same source using the 364-kev gamma-ray of Xe^{131}, shown separately to have a half-life less than 10^{-10} second. The centroid-shift analysis yields $T_{\frac{1}{2}}=(4.8\pm0.8)$