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The Crystal and Magnetic Structures of $Ba_3NiRu_2O_9$, $Ba_3CoRu_2O_9$, and $Ba_3ZnRu_2O_9$

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The crystal structures of the 6H perovskites $Ba_3NiRu_2O_9$, $Ba_3ZnRu_2O_9$, and $Ba_3CoRu_2O_9$ have been refined from neutron powder diffraction data collected at 5 or 2 K. $Ba_3NiRu_2O_9$ and $Ba_3ZnRu_2O_9$ have hexagonal symmetry, space group $P6_3/mmc$: $a_{Ni} = 5.7256(2)$. $c_{Ni} = 14.0596(2)$ Å; $a_{Zn} = 5.7549(2)$, $c_{Zn} = 14.1328(2)$ Å. $Ba_3CoRu_2O_9$ undergoes a phase transition from hexagonal symmetry at room temperature to orthorhombic symmetry at 2 K, space group $Cmcm$: $a_{Co} = 5.7456(1)$, $b_{Co} = 9.9177(2)$, $c_{Co} = 14.0862(3)$ Å. In all three compounds the cation sites within the face-sharing octahedra of the 6H structure are occupied by Ru^{5+}; the corner-sharing octahedra are occupied by Zn^{2+}, Ni^{2+}, or Co^{2+}. The neutron diffraction data show that $Ba_3NiRu_2O_9$ is magnetically ordered at 5 K, with antiferromagnetic coupling between Ru^{5+} ions in the Ru_2O_9 dimers and ferromagnetic coupling along approximately linear Ni^{2+}–O–Ru^{5+} superexchange pathways. The magnetic moments align along z. $Ba_3CoRu_2O_9$ is also magnetically ordered with antiferromagnetic coupling in the Ru_2O_9 dimers, but in this case antiferromagnetic superexchange between Co^{2+} ions leads to a more complex magnetic structure.

Introduction

Much of our recent research has been concerned with the magnetic properties of Ru^{5+} in perovskite-like compounds (*1*, *2*). In this paper we turn our attention to the magnetic properties of the same species in the 6H–$BaTiO_3$ structure (*3*). It has been shown (*4*) that in $Ba_3ZnRu_2O_9$, $Ba_3NiRu_2O_9$, and $Ba_3CoRu_2O_9$ the Ru^{5+} ions occupy the face-sharing octahedral sites of the 6H–$BaTiO_3$ structure, thus forming Ru_2O_9 dimers, while the corner-sharing octahedral sites are occupied by the divalent cation. We have studied these three compounds by neutron powder diffraction in order to explore the magnetic interactions that occur both within and between the dimers. In $Ba_3ZnRu_2O_9$ the dimers may be considered to be isolated magnetically by the intervening ZnO_6 octahedra, whereas in $Ba_3NiRu_2O_9$ and $Ba_3CoRu_2O_9$ the presence of the paramagnetic species Ni^{2+} or Co^{2+} increases the likelihood of further, long-range magnetic interaction.

Fernandez *et al.* (*5*) have undertaken a detailed study of these three phases by ^{99}Ru Mössbauer spectroscopy. Their results for $Ba_3CoRu_2O_9$ show the presence of an internal hyperfine field having a strength (H_{int} = 511 kOe) consistent with the presence of magnetically ordered Ru^{5+} at 4.2 K. The

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data for $Ba_3NiRu_2O_9$ also show a hyperfine field, albeit a weak one (H_{int} = 318 kOe), and are thus consistent with the existence of long-range antiferromagnetic order, as suggested by the magnetic susceptibility study of Byrne and Moeller (*6*). The latter observed a complex behavior of $1/\chi$ vs T and concluded that the Ni compound is antiferromagnetic below 95 K. They suggested that there may be a ferromagnetic coupling between Ru^{5+} and Ni^{2+} (d^3–d^8) as predicted by Goodenough (*7*) but these conclusions have never been confirmed by neutron diffraction. In the case of $Ba_3ZnRu_2O_9$, Fernandez *et al.* (*5*) also observed an 18-line pattern at 4.2 K, the linewidths being broad and the magnetic flux density at Ru again being unusually small. This result is more difficult to explain. The observation of magnetic hyperfine splitting in the Mössbauer spectrum implies either the presence of long-range magnetic order despite the replacement of Ni^{2+} and Co^{2+} by diamagnetic Zn^{2+} or a very slow relaxation time for the Ru spins in isolated dimers. A susceptibility study referred to by Fernandez *et al.* (*5*) apparently revealed a pronounced increase in χ at low T, which cannot be explained on the basis of isolated Ru dimers. Long-range order via Ru–O–Zn–O–Ru superexchange therefore seems to be suggested. However, the Mössbauer spectrum of $Ba_3CaRu_2O_9$ shows no hyperfine splitting and is consistent with the presence of isolated Ru_2O_9 dimers. The absence of long-range magnetic order in the Ca compound has been confirmed in neutron scattering experiments (*8*) but the true nature of the zinc compound has not been clarified in this way.

Experimental

Approximately 10 g polycrystalline batches of $Ba_3ZnRu_2O_9$, $Ba_3CoRu_2O_9$, and $Ba_3NiRu_2O_9$ were prepared from appropriate stoichiometric mixtures of $BaCO_3$, ZnO, NiO, Co_3O_4, and dried RuO_2 (Johnson Matthey 'Specpure' Reagents). The mixtures were thoroughly ground in an agate mortar, pelleted, and fired in platinum crucibles, initially at 800°C, then to 1200°C at a rate of 1°/min. After regrinding and repelleting the samples were heated for a total of 10 days at 1200°C (Zn) and 1300°C (Ni and Co) with two intermediate regrindings. Room-temperature X-ray powder diffraction patterns of all three products could be indexed on the basis of a 6H–$BaTiO_3$-like hexagonal unit cell. Neutron diffraction data were collected at 5 K (Ni and Zn) or 2 K (Co) on the medium resolution diffractometer D1a and ILL, Grenoble. Samples were contained in thin-walled vanadium cans and held in a cryostat with an Al tail. Data were collected at 2θ intervals of 0.05° over the angular range $0 < 2\theta < 156$, each experiment taking approximately 11 hr.

Results

Profile analysis of the diffraction data was carried out by the Rietveld (*9*) method, assuming a Gaussian shape for the Bragg peaks and using the following coherent scattering lengths: b(Ba) = 0.52, b(Zn) = 0.57, b(Ni) = 1.03, b(Co) = 0.25, b(Ru) = 0.73, b(O) = 0.58×10^{-12} cm. The background level was estimated by interpolation between regions of the profile where there were no Bragg peaks, and statistical variations were taken into account in assigning a weight to each profile point. The starting model for the refinement of all three structures was the structure of $Ba_3NiSb_2O_9$ as determined by Jacobson and Calvert (*10*), with Ru occupying the cation positions in the face-sharing octahedra, and Ni, Zn, or Co occupying the vertex-sharing sites.

(*i*) *Structure Refinement of $Ba_3NiRu_2O_9$ and $Ba_3ZnRu_2O_9$*

Initially it was assumed that there was no magnetic scattering in the data. Refinements

of the nuclear structures in space group $P6_3/mmc$ (giving a total of 18 variable parameters) converged smoothly to agreement factors $R_{wp} = 8.62\%$, $R_I = 2.9\%$, $R_{exp} = 3.95\%$ for $Ba_3ZnRu_2O_9$, and $R_{wp} = 9.90\%$, $R_I = 3.47\%$, $R_{exp} = 2.73\%$ for $Ba_3NiRu_2O_9$. No evidence was found either for disorder of Ru/M^{2+} over their respective sites or for partial occupancy of the oxygen sites. It was apparent at this stage, however, that a small amount of additional (magnetic) scattering was present in the case of the Ni compound. The predicted (*7*) Ru^{5+}–O–Ru^{5+} 90° superexchange is antiferromagnetic, whereas that predicted for a 180°Ni^{2+}–O–Ru^{5+} pathway is ferromagnetic. The magnetic model drawn (*12*) in Fig. 3 is consistent with these predictions and was therefore tested for $Ba_3NiRu_2O_9$. The model is composed of ferromagnetic sheets of Ni^{2+} ions, each of which is coupled ferromagnetically to six Ru^{5+} ions in different Ru_2O_9 dimers; the antiferromagnetic coupling within each dimer ensures that successive Ni^{2+} layers have opposite spin directions. The Ni^{2+} and Ru^{5+} magnetic moments were constrained to lie along the z axis of the hexagonal unit cell. The free-ion form factor for Ni^{2+} was taken from Watson and Freeman (*11*), while the curve derived during a study of Sr_2ErRuO_6 (*13*) was used for Ru^{5+}. This model refined to give reasonable values for the magnetic moments on both cations ($\mu_{Ru} = 1.5(2)$, $\mu_{Ni} = 1.7(1)$ μ_B), and a significant improvement in the overall profile fit ($R_{wp} = 9.56\%$, $R_I = 3.11\%$, $R_{mag} = 12.6\%$). Attempted refinements with the Ni–O–Ru interaction antiferromagnetic, or with the moments constrained to lie in the xy plane, gave poorer fits. Magnetic models for $Ba_3ZnRu_2O_9$, with antiferromagnetic intracluster interactions and either ferro- or antiferromagnetic intercluster interactions, did not lead to significant improvements in the overall fits, and on this basis we conclude that any long-range magnetic order present in this compound requires an ordered moment of no more than 0.4 μ_B per Ru^{5+}. The final observed, calculated, and difference diffraction profiles are plotted in Figs. 1 and 2 for $Ba_3NiRu_2O_9$ and $Ba_3ZnRu_2O_9$, respectively.

(*ii*) *Structure Refinement of* $Ba_3CoRu_2O_9$

The appearance of the diffraction pattern of $Ba_3CoRu_2O_9$ was very different from that of $Ba_3NiRu_2O_9$. In order to index all the Bragg peaks, it was necessary to lower the symmetry from hexagonal to orthorhombic, using a primitive unit cell having $a = 5.7456(1)$, $b = 9.9177(2)$, and $c = 14.0862(3)$ Å, i.e., $a_{ortho} \sim a_{hex}$, $b_{ortho} \sim \sqrt{3}b_{hex}$, $c_{ortho} \sim c_{hex}$. In devising a magnetic structure consistent with this symmetry we again made the assumption that the magnetic coupling within the Ru_2O_9 dimers would be antiferromagnetic. Furthermore, because the crystal structure of a 6H perovskite is C-centered in this orthorhombic unit-cell (space group *Cmcm*) we assumed that the reflections having $h + k = 2n + 1$ must be magnetic in origin, i.e., the C-centering is absent from the magnetic symmetry. A structure consistent with these conditions is drawn in Fig. 4. Each Co atom is coupled to six others along a superexchange pathway of the form Co–O–O–Co. Of these six linkages, four are antiferromagnetic and two are ferromagnetic; the distance between antiferromagnetically coupled Co atoms being slightly shorter than that between ferromagnetic pairs. Each Ru atom is coupled to three Co atoms via a Ru–O–Co linkage; two of these interactions are ferromagnetic, the third is antiferromagnetic. The superexchange within the Ru_2O_9 dimers is always antiferromagnetic as required. Subsequent profile analysis showed that this is a valid model for the crystal and magnetic structures of $Ba_3CoRu_2O_9$, with refinements of 13 atomic parameters, an overall temperature factor, the ordered magnetic moments of the Ru^{5+} and Co^{2+} ions, and the usual profile parameters converging to the following agreement factors: $R_{wpr} = 11.8\%$, $R_I = 4.7\%$, $R_{mag} =$

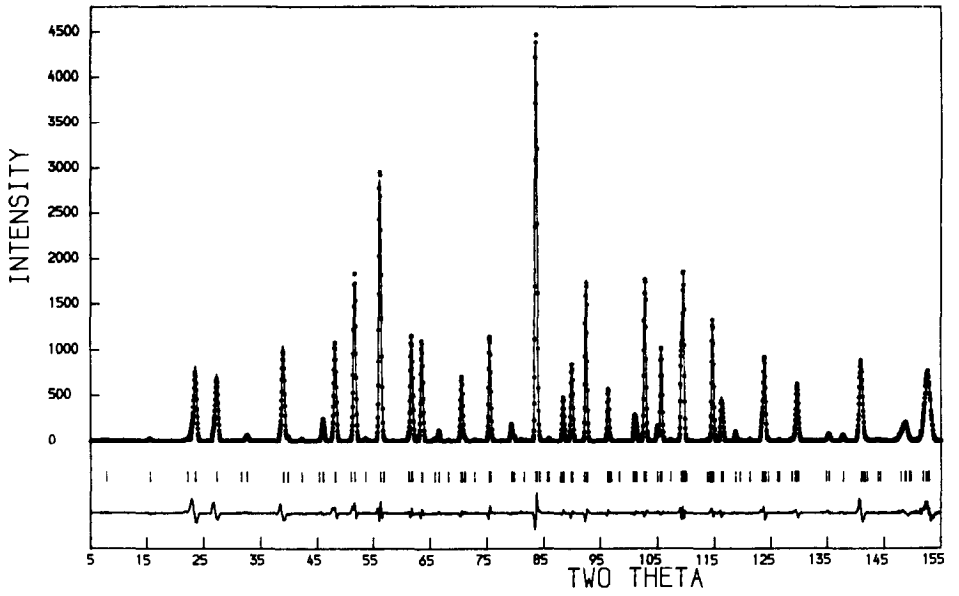

FIG. 1. The observed, calculated, and difference neutron powder diffraction profiles of $Ba_3NiRu_2O_9$ at 5 K. Reflection positions are marked.

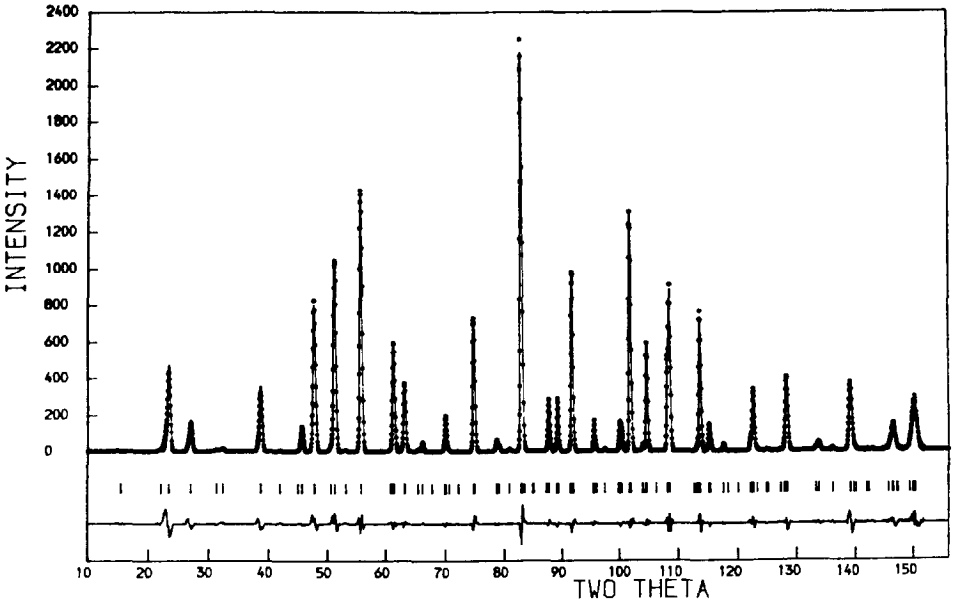

FIG. 2. The observed, calculated, and difference neutron powder diffraction profiles of $Ba_3ZnRu_2O_9$ at 5 K. Reflection positions are marked.

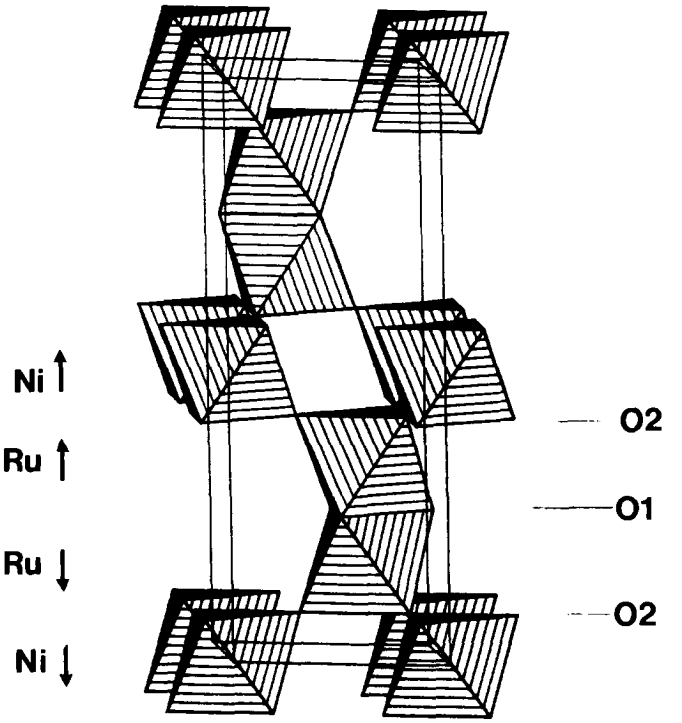

FIG. 3. The crystal structure of $Ba_3MRu_2O_9$ (M = Ni or Zn) with Ba atoms omitted. The directions of the ordered atomic magnetic moments in $Ba_3NiRu_2O_9$ are shown.

29.8%. The final observed, calculated, and difference diffraction profiles are drawn in Fig. 5. The most obvious discrepancy, a sharp peak at $2\theta \sim 84°$, is likely to be a (220) reflection from the Al cryostat which was left unshielded during the collection of this particular data set. The relatively high magnetic R-factor is a reflection of the weakness of the magnetic scattering. The ordered magnetic moments of the Co^{2+} and Ru^{5+} ions were found to lie along the y axis of the unit cell with refined magnitudes of 2.71(5) and 1.44(5) μ_B, respectively, when the free ion form factor (*11*) was used for Co^{2+}.

Discussion

The refined atomic coordinates and bond distances/angles for $Ba_3ZnRu_2O_9$ (Tables I and II) and $Ba_3NiRu_2O_9$ (Tables III and IV) confirm the basic structural features of the proposed 6H–$BaTiO_3$ structure. Ru exclusively occupies the face-sharing octahedral sites in both cases, with the metal atoms being displaced away from the centers of the octahedra in opposite directions to give Ru–Ru distances of 2.685 and 2.681 Å in $Ba_3ZnRu_2O_9$ and $Ba_3NiRu_2O_9$, respectively. It may also be noted that the O(1)–O(1) distances within the shared face are comparatively short, at 2.641 and 2.634 Å, respectively, thus helping to 'shield' the Ru^{5+}–Ru^{5+} repulsion. The average Ru–O bond length of 1.965 Å is very similar to that found in other Ru^{5+} oxides (*2, 14, 15*), although the RuO_6 octahedra are less regular than those reported previously.

Although $Ba_3CoRu_2O_9$ undergoes a transformation to orthorhombic symmetry between room temperature and 2 K, the crys-

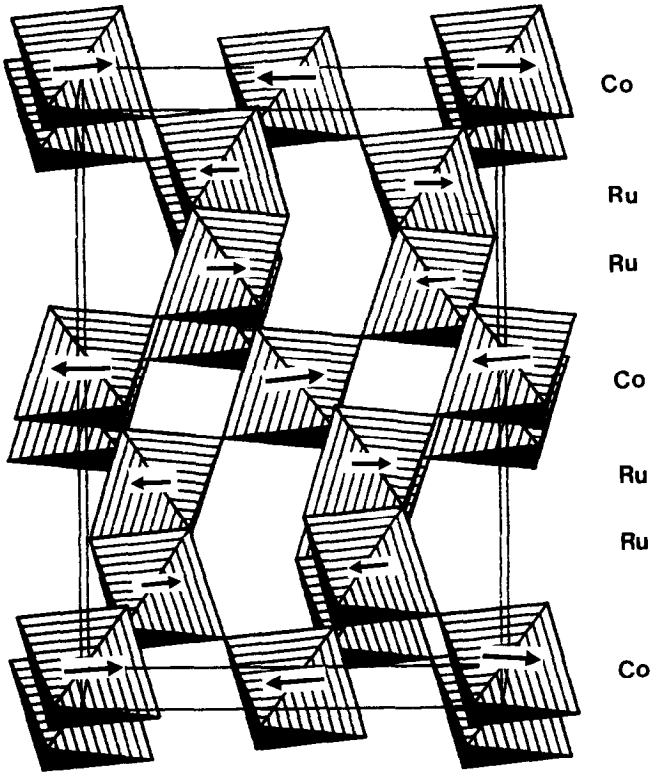

FIG. 4. The crystal and magnetic structures of $Ba_3CoRu_2O_9$ viewed along x. The directions of the ordered magnetic moments are shown.

tal structure is still essentially that of a 6H hexagonal perovskite, as can be seen from Fig. 4 and the atomic parameters and bond distances presented in Tables V and VI. The shortest Ru–Ru distance is 2.677 Å and once again the oxygen–oxygen distances within the shared octahedral face are relatively short at 2.67 Å (O1–O2). There are now four different Ru–O distances in the first coordination shell of the transition metal,

TABLE I

STRUCTURAL PARAMETERS FOR $Ba_3ZnRu_2O_9$ AT 5 K (SPACE GROUP $P6_3/mmc$)

Atom	Site	x	y	z	B_{iso} (Å^2)
Ba1	2*b*	0	0	1/4	0.12(7)
Ba2	4*f*	1/3	2/3	0.9101(2)	0.08(6)
Ni	2*a*	0	0	0	0.18(7)
Ru	4*f*	1/3	2/3	0.1551(1)	0.16(4)
O1	6*h*	0.4864(3)	−0.0273(5)	1/4	0.29(4)
O2	12*k*	0.1715(2)	0.3430(4)	0.41571(9)	0.25(3)

Note. a = 5.7549(2), c = 14.1328(2) Å.

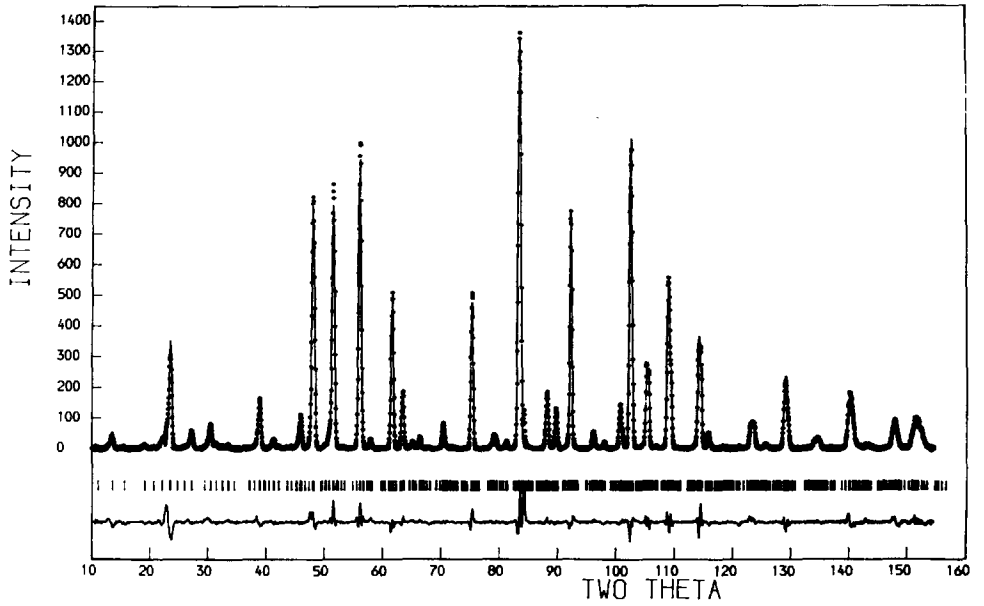

FIG. 5. The observed, calculated, and difference neutron powder diffraction profiles of $Ba_3CoRu_2O_9$ at 2 K. Reflection positions are marked.

but they fall into two distinct groups, as found in the hexagonal Ni and Zn analogues.

Our neutron diffraction data prove that $Ba_3NiRu_2O_9$ is antiferromagnetic at 5 K, as has been suggested previously on the basis of Mössbauer and susceptibility data. The ordered magnetic moment of the Ru^{5+} ions is somewhat smaller than the value of ca. 1.9 μ_B found previously in cubic and pseudocubic perovskites (*12, 14*), although a value of only 1.2 μ_B was found in Ca_2YRuO_6 (*15*). The magnetic moment of 1.7(1) μ_B found for Ni^{2+} in this work is only slightly lower than that found in other Ni^{2+} oxides (*16*). Inadequencies in the chosen form factors may, in part, account for these reductions, but it is worth noting that the hyperfine field measured in the Mössbauer study of Ba_3Ni Ru_2O_9 was anomalously low. $Ba_3NiRu_2O_9$ is the first compound containing Ru_2O_9 dimers in which the presence of long-range magnetic order has been proved by neutron diffraction, although spin pairing within individual dimers is well-established (*17*). The observation of ferromagnetic coupling between Ru^{5+} and Ni^{2+} was postulated by Byrne and Moeller (*6*) in the interpretation of their magnetic susceptibility data. The strength of this interaction will be enhanced by the almost-linear Ni–O–Ru superexchange pathway (NiÔRu = 177.2°). Similar

TABLE II

BOND LENGTHS (Å) AND BOND ANGLES (°) IN $Ba_3ZnRu_2O_9$ AT 5 K

Ba1–O1	2.881(3) × 6	Ba2–O1	2.891(4) × 3
Ba1–O2	2.899(3) × 6	Ba2–O2	2.879(4) × 6
		Ba2–O2′	2.943(4) × 3
Zn-O2	2.083(3) × 6	Ru–O1	2.032(4) × 3
Ru–Ru′	2.685(2)	Ru–O2	1.898(3) × 3
O1–O1	2.641(5) × 2	O1–O2	2.820(4) × 4
O1–O1′	3.114(5) × 2		
O2–Zn–O2	90.6	O1–Ru–O1′	81.1
Zn–O2–Ru	176.9	O1–Ru–O2	170.4
		O2–Ru–O1	91.7

TABLE III

STRUCTURAL PARAMETERS FOR $Ba_3NiRu_2O_9$ AT 5 K (SPACE GROUP $P6_3/mmc$)

Atom	Site	x	y	z	B_{iso} (Å^2)	$\|\mu\|$ (μ_B)
Ba1	2*b*	0	0	1/4	0.00(8)	
Ba2	4*f*	1/3	2/3	0.9110(2)	0.10(7)	
Ni	2*a*	0	0	0	0.20(4)	1.7(1)
Ru	4*f*	1/3	2/3	0.1546(1)	0.18(5)	1.5(2)
O1	6*h*	0.4867(3)	−0.0266(6)	1/4	0.27(4)	
O2	12*k*	0.1708(2)	0.3415(4)	0.4170(1)	0.15(3)	

Note. a = 5.7256(2), c = 14.0596(2) Å.

ferromagnetic coupling has also been proposed to account for the unusual magnetic properties of the perovskite $BaLaNiRuO_6$ (*1*). The alignment of the spins along z rather than in xy plane is perhaps due to the second order spin–orbit coupling associated with both Ni^{2+} and Ru^{5+}, although likely to be stronger in the latter.

The difference between the magnetic structures of $Ba_3NiRu_2O_9$ and $Ba_3CoRu_2O_9$ is quite striking. Our results show that both compounds exhibit antiferromagnetic coupling within the Ru_2O_9 dimers, but that the magnetic ordering observed among the divalent cations is quite different in the two cases. This presumably stems from the fact that the t_{2g} orbitals are not completely filled in the case of Co^{2+}, thus increasing the strength of the antiferromagnetic M^{2+}–O–O–M^{2+} superexchange within the layers of corner-sharing octahedra which lie perpendicular to the z axis (Fig. 4). The filled t_{2g} orbitals of Ni^{2+} cannot take part in such an interaction, and we therefore find ferromagnetic layers in $Ba_3NiRu_2O_9$, thus maximizing the number of ferromagnetic, ~180° Ni–Ô–Ru linkages. The Co–O–Ru superexchange pathways are also almost linear (Ru–Ô3–Co = 176.8°, Ru–Ô4–Co = 177.2°) and so ferromagnetic coupling between Ru and Co is predicted in $Ba_3CoRu_2O_9$. However, the antiferromagnetic Co–O–O–Co coupling and the ferromagnetic Co–O–Ru coupling cannot be completely satisfied simultaneously, and the re-

TABLE IV

BOND LENGTHS (Å) AND BOND ANGLES (°) IN $Ba_3NiRu_2O_9$ AT 5 K

Ba1–O1	2.866(4) × 6	Ba2–O1	2.883(5) × 3
Ba1–O2	2.895(3) × 6	Ba2–O2	2.864(4) ×6
		Ba2–O2′	2.906(4) × 3
Ni–O2	2.056(3) × 6	Ru–O1	2.027(4) × 3
Ru–Ru′	2.681(2)	Ru–O2	1.902(3) × 3
O1–O1	2.634(5) × 2	O1–O2	2.824(5) × 4
O1–O1′	3.091(5) × 2		
O2–Ni–O2	90.9	O1–Ru–O1′	81.0
Ni–O2–Ru	177.2	O2–Ru–O1	91.9
		O1–Ru–O2	170.6

TABLE V

STRUCTURAL PARAMETERS FOR $Ba_3CoRu_2O_9$ AT 2 K (SPACE GROUP *Cmcm*)

Atom	Site	x	y	z	$\|\mu\|$ (μ_B)
Ba1	4*c*	0	0.000(1)	1/4	
Ba2	8*f*	0	0.3342(8)	0.0897(2)	
Co	4*a*	0	0	0	2.71(4)
Ru	8*f*	0	0.3284(5)	0.8450(1)	1.44(5)
O1	4*c*	0	0.5136(9)	1/4	
O2	8*g*	0.270(1)	0.2477(6)	1/4	
O3	8*f*	0	0.8335(6)	0.0833(8)	
O4	16*h*	0.2547(9)	0.0892(5)	0.0833(4)	

Note. Overall B_{iso} = 0.13(3) Å^2. a = 5.7456(1), b = 9.9177(2), c = 14.0862(3) Å.

TABLE VI

BOND LENGTHS (Å) AND BOND ANGLES (°) IN $Ba_3CoRu_2O_9$ AT 2 K

Ba1–O1	2.88(1) × 2	Ba2–O1	2.88(1)
Ba1–O2	2.90(1) × 2	Ba2–O2	2.87(1) × 2
Ba1–O2′	2.83(1) × 2	Ba2–O3	2.95(2)
Ba1–O3	2.87(1) × 2	Ba2–O3′	2.87(2) × 2
Ba1–O4	2.91(1) × 4	Ba2–O4	2.84(1) × 2
		Ba2–O4′	2.90(1) × 2
		Ba2–O4″	2.92(1) × 2
Co–O3	2.03(1) × 2	Ru–O1	2.06(1)
Co–O4	2.074(9) × 4	Ru–O2	2.03(1) × 2
		Ru–O3	1.90(1)
Ru–Ru	2.677(7)	Ru–O4	1.92(1) × 2
O1–O2	3.06(1) × 2	O2–O2	3.10(1)
O1–O2′	2.67(1) × 2	O2–O2′	2.64(1)
O1–O4	2.84(1) × 4	O2–O3	2.83(2) × 2
		O2–O4	2.83(1) × 2
O3–O4	2.93(2) × 2	O4–O4	2.94(1)
O3–O4′	2.87(2) × 2	O4–O4′	2.93(1)
O4–O4″	2.80(2) × 2	O4–O4″	2.82(1)
O3–Co–O3	180.0	O1–Ru–O2	81.6
O3–Co–O4	91.2	O1–Ru–O3	171.7
O4–Co–O4	90.2	O1–Ru–O4	91.0
		O2–Ru–O3	92.1
Ru–O3–Co	176.8	O2–Ru–O4	91.6
Ru–O4–Co	177.2	O2–Ru–O4′	170.5
		O3–Ru–O4	94.6

sultant structure represents a compromise in which 2/3 of the Ru–O–Co couplings are ferromagnetic, 1/3 antiferromagnetic, whereas 2/3 of the Co–O–O–Co couplings are antiferromagnetic, 1/3 ferromagnetic. The antiferromagnetic coupling in the latter case is stabilized by the orthorhombic distortion, which reduces the distance between antiferromagnetic Co pairs. The magnitude of the ordered magnetic moment of the Ru^{5+} ions in $Ba_3CoRu_2O_9$ is similar to values reported previously (*2, 14, 15*) whereas the value of 2.7 μ_B found for Co^{2+} is perhaps lower than expected for an ion with a $3d^7$ electron configuration. It may be that the reduction in site symmetry has essentially quenched any orbital contribution to the magnetic moment. Alternatively, the low value of the moment (and the high value of R_{mag}) may arise from the use of a collinear-spin model for the magnetic structure.

Our failure to detect any magnetic Bragg scattering in the diffraction pattern of $Ba_3ZnRu_2O_9$ indicates that there is no long-range magnetic order in this compound at 5 K. This is consistent with the suggestion by Fernandez *et al.* (*5*) that the Neel temperature of $Ba_3ZnRu_2O_9$ is only slightly higher than 4.2 K. The weak hyperfine field and the relatively large linewidths observed in the Mössbauer data collected at that temperature can then be explained as arising from an unsaturated spin system displaying time-dependent relaxation phenomena just below the ordering temperature. Further neutron diffraction experiments at lower temperatures are needed to confirm this model. Finally, we note that this interpretation of our neutron data gives no explanation for the anomalous increase in magnetic susceptibility which occurs for many of these hexagonal Ru^{5+} perovskites at very low temperatures. The cause of this increase is still uncertain.

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