

high final *R* value is mainly due to the disorder of the polymethylene chain.

The authors thank the CNRS for financial support.

Lists of structure factors, anisotropic displacement parameters, H-atom coordinates and complete geometry have been deposited with the IUCr (Reference: HR1021). Copies may be obtained through The Managing Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

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## Triruthenium Alkylidyne Cluster Complexes [H<sub>2</sub>Ru<sub>3</sub>(CO)<sub>9</sub>( $\mu$ <sub>3</sub>-CX)] (X = Pyridine, 4-Ethylpyridine)

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### Abstract

Crystal structure analyses of nonacarbonyl-1 $\kappa^3$ C-, 2 $\kappa^3$ C, 3 $\kappa^3$ C-di- $\mu$ -hydrido-1:2 $\kappa^2$ H; 2:3 $\kappa^2$ H- $\mu$ <sub>3</sub>-(pyridin-1-

ylmethylidene)-triangulo-triruthenium, [Ru<sub>3</sub>( $\mu$ -H)<sub>2</sub>( $\mu$ <sub>3</sub>-C<sub>6</sub>H<sub>5</sub>N)(CO)<sub>9</sub>], (I), and nonacarbonyl-1 $\kappa^3$ C-, 2 $\kappa^3$ C, 3 $\kappa^3$ C- $\mu$ <sub>3</sub>-[(4-ethylpyridin-1-yl)methylidene]-di- $\mu$ -hydrido-1:2 $\kappa^2$ H; 2:3 $\kappa^2$ H-triangulo-triruthenium, [Ru<sub>3</sub>( $\mu$ -H)<sub>2</sub>( $\mu$ <sub>3</sub>-C<sub>8</sub>H<sub>9</sub>N)(CO)<sub>9</sub>], (II), reveal that both compounds consist of a triruthenium alkylidyne core with the nucleophiles [pyridine in (I) and 4-ethylpyridine in (II)] bonded to the  $\mu$ <sub>3</sub>-bridging alkylidyne C atom.

### Comment

This work is part of our structural and reactivity studies of triruthenium and triosmium alkylidyne carbonyl clusters. Several triosmium alkylidynes with the formula [H<sub>2</sub>O<sub>3</sub>(CO)<sub>9</sub>( $\mu$ <sub>3</sub>-CY)] (Y = pyridine, quinoline or trimethyl phosphite) have been synthesized and fully characterized (Johnson, Lahoz, Lewis, Prior, Raithby & Wong, 1992). The title compounds, (I) and (II), have been prepared by a similar route.

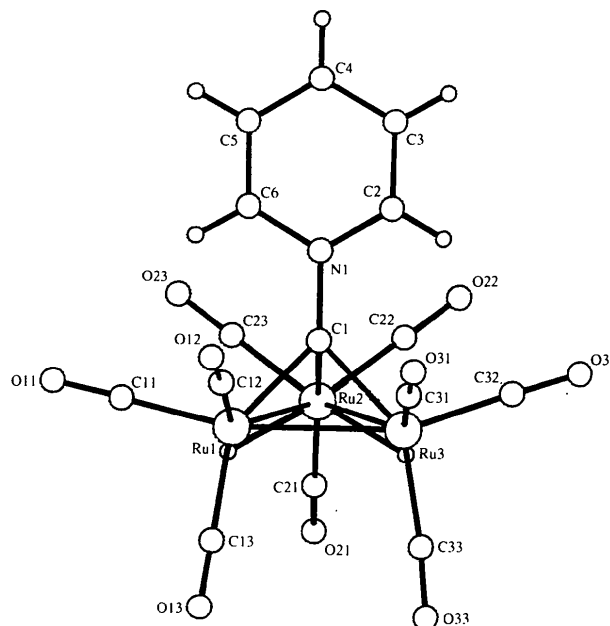
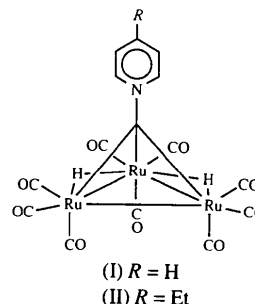


Fig. 1. The molecular structure of [H<sub>2</sub>Ru<sub>3</sub>(CO)<sub>9</sub>( $\mu$ <sub>3</sub>-Cpy)] (I).

The structures of (I) and (II), as shown by X-ray analyses, each consist of a triruthenium alkylidyne core with the nucleophile substituted at the apical C atom. Both molecules have approximate C<sub>s</sub> symmetry. The hydride atoms of (I) and (II), evident from their <sup>1</sup>H NMR spectra, could not be located by X-ray analysis. However, potential-energy calculations (Orpen, 1980) suggested that one bridges the Ru1—Ru2 edge and the other the Ru2—Ru3 edge in both (I) and (II). These two edges [averages 2.844 Å for (I), 2.835 Å for (II)] are significantly longer than the unbridged Ru1—Ru3 bonds [2.739 (1) for (I), 2.729 (1) Å for (II)]. This is consistent with the general observation that M—M distances are increased when bridged by a hydride atom (Humphries & Kaesz, 1979). The N—C(alkylidyne) bond lengths in both (I) [1.46 (1) Å] and (II) [1.458 (9) Å] are comparable to those of the triosmium alkylidynes with other N-donors substituted on the apical C atom.

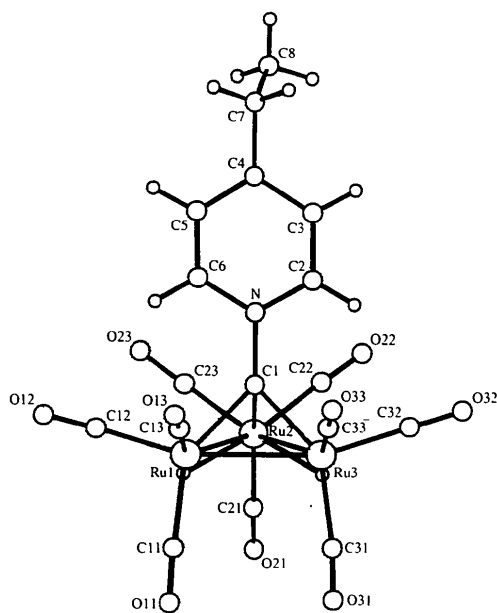


Fig. 2. The molecular structure of [H<sub>2</sub>Ru<sub>3</sub>(CO)<sub>9</sub>(μ<sub>3</sub>-C{4-Etpy})] (II).

## Experimental

### Compound (I)

#### Crystal data

[Ru<sub>3</sub>H<sub>2</sub>(C<sub>6</sub>H<sub>5</sub>N)(CO)<sub>9</sub>]

*M<sub>r</sub>* = 648.43

Monoclinic

*Cc*

*a* = 18.585 (3) Å

*b* = 9.562 (1) Å

*c* = 15.012 (4) Å

β = 131.83 (3)°

*V* = 1987.8 (12) Å<sup>3</sup>

Mo Kα radiation

λ = 0.71073 Å

Cell parameters from 25 reflections

θ = 10–12°

μ = 2.25 mm<sup>-1</sup>

*T* = 293 K

Block

0.22 × 0.16 × 0.14 mm

*Z* = 4

*D<sub>x</sub>* = 2.163 Mg m<sup>-3</sup>

#### Data collection

Enraf–Nonius CAD-4

diffractometer

ω–2θ scans

Absorption correction:

empirical

*T<sub>min</sub>* = 0.901, *T<sub>max</sub>* =

0.999

1456 measured reflections

1395 independent reflections

1295 observed reflections

[*F<sub>o</sub>* > 3σ(*F<sub>o</sub>*)]

#### Refinement

Refinement on *F*

*R* = 0.037

*wR* = 0.050

*S* = 1.876

1295 reflections

126 parameters

H-atom parameters not refined

*w* = 4*F<sub>o</sub>*<sup>2</sup>/[σ<sup>2</sup>(*F<sub>o</sub>*<sup>2</sup>) + (0.04*F<sub>o</sub>*<sup>2</sup>)<sup>2</sup>]

Orange

Crystal source: recrystallized from CH<sub>2</sub>Cl<sub>2</sub>/*n*-hexane

*R<sub>int</sub>* = 0.022

θ<sub>max</sub> = 22.5°

*h* = –20 – 20

*k* = 0 – 10

*l* = 0 – 16

3 standard reflections

frequency: 120 min

intensity variation: <2%

(Δ/σ)<sub>max</sub> = 0.04

Δρ<sub>max</sub> = 0.98 e Å<sup>-3</sup>

Δρ<sub>min</sub> = –0.65 e Å<sup>-3</sup>

Extinction correction: none

Atomic scattering factors

from *International Tables for X-ray Crystallography* (1974, Vol. IV)

### Compound (II)

#### Crystal data

[Ru<sub>3</sub>H<sub>2</sub>(C<sub>8</sub>H<sub>9</sub>N)(CO)<sub>9</sub>]

*M<sub>r</sub>* = 676.49

Orthorhombic

*P*2<sub>1</sub>2<sub>1</sub>2<sub>1</sub>

*a* = 10.971 (2) Å

*b* = 11.034 (2) Å

*c* = 18.100 (5) Å

*V* = 2191.0 (14) Å<sup>3</sup>

*Z* = 4

*D<sub>x</sub>* = 2.051 Mg m<sup>-3</sup>

Mo Kα radiation

λ = 0.71073 Å

Cell parameters from 25 reflections

θ = 11–13°

μ = 2.05 mm<sup>-1</sup>

*T* = 293 K

Block

0.32 × 0.22 × 0.20 mm

Orange

Crystal source: recrystallized from CH<sub>2</sub>Cl<sub>2</sub>/*n*-hexane

#### Data collection

Enraf–Nonius CAD-4

diffractometer

ω–2θ scans

Absorption correction:

empirical

*T<sub>min</sub>* = 0.895, *T<sub>max</sub>* =

0.999

2221 measured reflections

2221 independent reflections

2046 observed reflections

[*F<sub>o</sub>* > 3σ(*F<sub>o</sub>*)]

#### Refinement

Refinement on *F*

*R* = 0.028

*wR* = 0.040

θ<sub>max</sub> = 25°

*h* = 0 – 13

*k* = 0 – 13

*l* = 0 – 21

3 standard reflections

frequency: 120 min

intensity variation: <3%

(Δ/σ)<sub>max</sub> = 0.01

Δρ<sub>max</sub> = 0.37 e Å<sup>-3</sup>

Δρ<sub>min</sub> = –0.71 e Å<sup>-3</sup>

$S = 1.394$   
 2046 reflections  
 271 parameters  
 H-atom parameters not refined  
 $w = 4F_o^2 / [\sigma^2(F_o^2) + (0.04F_o^2)^2]$

Extinction correction: none  
 Atomic scattering factors and anomalous-dispersion corrections from *International Tables for X-ray Crystallography* (1974, Vol. IV)

C31	0.1897 (7)	-0.0263 (7)	0.0835 (5)	4.7 (2)
C32	0.3525 (9)	-0.1655 (8)	0.1920 (5)	5.5 (2)
C33	0.3433 (8)	0.0856 (8)	0.1890 (4)	4.8 (2)
HA†	0.4864	-0.0214	-0.0477	5
HB†	0.3811	-0.1720	0.0592	5

† Coordinate fixed to define origin.

‡ These atoms were not located in the analyses. Their positions were deduced from potential-energy calculations (Orpen, 1980).

Table 1. Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters ( $\text{\AA}^2$ )

$B_{\text{eq}} = (8\pi^2/3) \sum_i \sum_j U_{ij} a_i^* a_j^* \mathbf{a}_i \cdot \mathbf{a}_j$  for Ru atoms in (I) and all non-H atoms in (II);  $B_{\text{iso}}$  for all others.

(I)	x	y	z	$B_{\text{iso}}/B_{\text{eq}}$
Ru1	0.646†	0.06082 (9)	0.107†	2.58 (2)
Ru2	0.44197 (5)	0.05228 (9)	-0.08242 (6)	2.50 (2)
Ru3	0.56793 (6)	-0.12780 (8)	-0.07440 (8)	2.76 (2)
O11	0.6638 (6)	0.328 (1)	0.2320 (7)	5.1 (2)
O12	0.8308 (8)	0.109 (2)	0.1591 (9)	7.3 (3)
O13	0.7431 (8)	-0.147 (2)	0.316 (1)	8.1 (4)
O21	0.3069 (7)	-0.054 (1)	-0.0450 (8)	5.9 (3)
O22	0.2944 (7)	0.052 (1)	-0.3519 (8)	5.6 (2)
O23	0.4194 (6)	0.359 (1)	-0.0558 (7)	5.0 (2)
O31	0.7477 (7)	-0.130 (1)	-0.0419 (9)	6.4 (3)
O32	0.4451 (8)	-0.237 (2)	-0.3263 (9)	7.5 (3)
O33	0.6159 (7)	-0.396 (2)	0.0713 (9)	6.4 (3)
N1	0.5553 (5)	0.193 (1)	-0.1453 (6)	2.6 (2)
C1	0.5564 (5)	0.086 (1)	-0.0753 (7)	1.9 (2)
C2	0.5185 (7)	0.168 (2)	-0.2559 (9)	3.8 (2)
C3	0.5112 (8)	0.271 (2)	-0.328 (1)	4.6 (3)
C4	0.5407 (7)	0.404 (1)	-0.2841 (9)	3.3 (2)
C5	0.5813 (8)	0.429 (1)	-0.170 (1)	3.9 (2)
C6	0.5875 (6)	0.325 (1)	-0.1021 (8)	3.0 (2)
C11	0.6582 (6)	0.226 (1)	0.1844 (8)	3.3 (2)
C12	0.7584 (8)	0.090 (2)	0.1354 (9)	4.2 (3)
C13	0.7039 (8)	-0.069 (2)	0.237 (1)	4.2 (3)
C21	0.3601 (7)	-0.017 (1)	-0.0550 (8)	3.3 (2)
C22	0.3470 (7)	0.055 (1)	-0.2497 (8)	3.3 (2)
C23	0.4258 (6)	0.243 (1)	-0.0664 (8)	3.1 (2)
C31	0.6789 (7)	-0.129 (1)	-0.0529 (9)	3.3 (2)
C32	0.4919 (7)	-0.194 (1)	-0.2314 (8)	3.8 (2)
C33	0.5953 (8)	-0.298 (2)	0.012 (1)	4.9 (3)
HA†	0.5329	0.0736	0.0749	5
HB†	0.4519	-0.1223	-0.1133	5
(II)				
Ru1	0.46060 (5)	0.10649 (4)	0.01346 (3)	2.873 (9)
Ru2	0.51780 (5)	-0.14357 (4)	0.01192 (3)	3.15 (1)
Ru3	0.35897 (5)	-0.03952 (5)	0.11844 (3)	3.47 (1)
O11	0.2242 (5)	0.1436 (5)	-0.0758 (4)	5.9 (1)
O12	0.6472 (5)	0.2137 (5)	-0.0903 (3)	5.5 (1)
O13	0.4423 (6)	0.3338 (5)	0.1077 (3)	6.4 (1)
O21	0.3920 (7)	-0.2921 (5)	-0.1087 (3)	6.4 (2)
O22	0.6052 (9)	-0.3539 (5)	0.1065 (3)	8.4 (2)
O23	0.7658 (6)	-0.0990 (6)	-0.0580 (4)	6.7 (2)
O31	0.0981 (5)	-0.0095 (6)	0.0612 (4)	6.8 (2)
O32	0.3460 (9)	-0.2397 (6)	0.2361 (4)	8.3 (2)
O33	0.3354 (8)	0.1612 (6)	0.2315 (3)	7.8 (2)
N1	0.6455 (5)	0.0084 (5)	0.1384 (3)	3.0 (1)
C1	0.5378 (7)	-0.0062 (5)	0.0921 (3)	3.2 (1)
C2	0.6499 (7)	-0.0434 (7)	0.2050 (4)	4.4 (2)
C3	0.753 (1)	-0.0316 (7)	0.2479 (4)	5.6 (2)
C4	0.8542 (8)	0.0341 (7)	0.2241 (4)	4.5 (2)
C5	0.8469 (7)	0.0842 (7)	0.1547 (4)	4.3 (2)
C6	0.7427 (7)	0.0729 (6)	0.1142 (4)	3.7 (1)
C7	0.964 (1)	0.050 (1)	0.2727 (5)	8.5 (3)
C8	1.049 (1)	-0.056 (2)	0.2694 (6)	12.7 (5)
C11	0.3127 (7)	0.1336 (6)	-0.0435 (4)	4.0 (1)
C12	0.5825 (7)	0.1724 (6)	-0.0517 (4)	3.4 (1)
C13	0.4503 (7)	0.2484 (7)	0.0738 (4)	4.1 (1)
C21	0.4404 (7)	-0.2409 (6)	-0.0665 (4)	4.0 (1)
C22	0.5750 (9)	-0.2752 (6)	0.0718 (4)	5.0 (2)
C23	0.6713 (7)	-0.1211 (6)	-0.0332 (4)	3.9 (1)

Table 2. Selected geometric parameters ( $\text{\AA}$ , °)

	(I)	(II)
Ru1—Ru2	2.8440 (6)	2.8297 (7)
Ru1—Ru3	2.739 (1)	2.7291 (8)
Ru2—Ru3	2.843 (2)	2.8409 (8)
Ru1—C1	2.060 (8)	2.071 (6)
Ru2—C1	2.08 (1)	2.109 (7)
Ru3—C1	2.06 (2)	2.052 (7)
N1—C1	1.46 (1)	1.458 (9)
N1—C2	1.33 (2)	1.335 (9)
N1—C6	1.35 (2)	1.35 (1)
C2—C3	1.40 (2)	1.38 (1)
C3—C4	1.36 (3)	1.39 (1)
C4—C5	1.36 (2)	1.37 (2)
C5—C6	1.38 (3)	1.51 (1)
C5—C6	—	1.36 (2)
C7—C8	—	1.50 (2)
Ru1—HA	1.82	1.82
Ru2—HA	1.78	1.76
Ru2—HB	1.78	1.76
Ru3—HB	1.82	1.83
Ru2—Ru1—Ru3	61.19 (4)	61.44 (2)
Ru1—Ru2—Ru3	57.59 (3)	57.54 (2)
Ru1—Ru3—Ru2	61.22 (3)	61.02 (2)
Ru1—C1—Ru2	86.7 (5)	85.3 (2)
Ru1—C1—Ru3	83.4 (3)	82.9 (3)
Ru2—C1—Ru3	86.7 (5)	86.1 (3)
C1—N1—C2	121 (1)	120.0 (6)
C1—N1—C6	122 (1)	120.7 (5)
C2—N1—C6	118 (2)	119.3 (6)
C4—C7—C8	—	112 (2)
Ru1—HA—Ru2	104.5	104.2
Ru2—HB—Ru3	104.6	104.0

The metal-atom positions were obtained by direct methods using *MULTAN*11/82 (Main, Fiske, Hull, Lessinger, Germain, Declercq & Woolfson, 1982). Each structure was refined by a full-matrix least-squares method with anisotropic displacement parameters for the Ru atoms in (I) and for all non-H atoms in (II). All calculations were performed using the *SDP* system (Enraf-Nonius, 1985) on a MicroVAX II computer. The absolute structures were assigned on the basis of the lowest  $R$  values after identical refinements.

We thank the Hong Kong Research Grants Council and the University of Hong Kong for support.

Lists of structure factors, anisotropic displacement parameters, H-atom coordinates and bond distances and angles involving non-H atoms have been deposited with the IUCr (Reference: MU1090). Copies may be obtained through The Managing Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

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but there were discrepancies between the data sets reported. Besides, since photographic methods were used, both studies were not very precise. The value of  $R_f$  was not reported by Griffith (1943) but can be calculated from his published  $F_o$  and  $F_c$  values as 0.299 for 84  $F_{hkl}$ . The value of  $R_f$  in the study of Kolesnikov & Baumer (1975) was 0.133 for 735  $F_{hkl}$ . Since the precise data on the structure of  $2Ag^+ \cdot C_2O_4^{2-}$ , (I), are very important for understanding the mechanism of the photochemical and thermal decomposition of this salt (Boldyrev, 1993), we have undertaken a new structural study.

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## Silver Oxalate, $2Ag^+ \cdot C_2O_4^{2-}$

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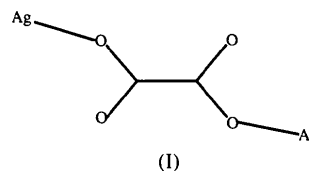
### Abstract

The early data of Griffith [*J. Chem. Phys.* (1943), pp. 499–505] and of Kolesnikov & Baumer [*Vestn. Khar'k. Univ. Ser. Khim.* (1975), **127**, 38–41] on the structure of silver oxalate,  $2Ag^+ \cdot C_2O_4^{2-}$ , are revised and refined. In the structure, the oxalate anions form a framework with channels extended along [100] and  $Ag^+$  cations are located in these channels, forming dimers with an  $Ag—Ag$  bond distance of 2.945 (1) Å (close to that in metallic Ag). A noticeable elongation of C—C bond is observed.

### Comment

Metal oxalates have been used in studies of the various aspects of solid-state reactivity since the early 1940's and are still attracting attention today (Brown, Dollimore & Galwey, 1980). The first structural studies of oxalates were reported 60 years ago (Hendricks, 1935); however, crystal structures of many metal oxalates remain unknown, mainly because of the experimental difficulties in obtaining single crystals.

Early structural studies of  $2Ag^+ \cdot C_2O_4^{2-}$  were reported by Griffith (1943) and by Kolesnikov & Baumer (1975),



According to our data, the anion in the structure of silver oxalate is practically flat (deviations of C and O atoms from the common plane do not exceed 0.006 Å). The site symmetry is  $\bar{1}$ , but the geometry of the oxalate anion is very close to being idealized, with point symmetry  $mmm$ . The value of the C—C bond length (Table 2) somewhat exceeds the statistically averaged value [1.56 (2) Å] reported by Allen *et al.* (1987) for oxalate groups in various structures. The elongation of the C—C bond may be essential for the decomposition of silver oxalate, since, according to the model suggested, the primary step of the reaction is the cleaving of this bond (Boldyrev, 1993).

Each oxalate anion in the structure is coordinated to six  $Ag^+$  cations. Two different types of  $Ag—O$  bonds are observed (Table 2). Oxalate anions form a framework with the layers in the (200) planes and the channels extended along [100].  $Ag—Ag$  dimers are located in these channels; the  $Ag—Ag$  distance of 2.945 (1) Å is close to that in metallic silver (2.889 Å; Guinier, 1956). Each Ag atom is coordinated to four O atoms of three oxalate anions (forming a flattened tetrahedron) and another Ag atom (Fig. 1). Ag atoms in the structure form strips of a 'stair type' extended along [100] at  $y = \frac{1}{2}$  and  $y = 0$  (corresponding values of  $z$  are  $\pm 0.15$  and  $\frac{1}{2} \pm 0.15$ ). The width of a stair step is determined by the short  $Ag—Ag$  distance; the height of a step is equal to the translation along  $x$ .

The results of our study allow revision of the data of Griffith (1943) and refinement of that of Kolesnikov & Baumer (1975). The values of the lattice parameters and the structure of the silver sub-lattice obtained in our study are in reasonable agreement with the data reported by Kolesnikov & Baumer (1975). They can be correlated also with the model of Griffith (1943) if one assumes that the value of the  $\beta$  angle is  $104^\circ$  (and not  $76^\circ$ , as stated in the text of the Griffith's paper). The structure of the oxalate sub-lattice in our