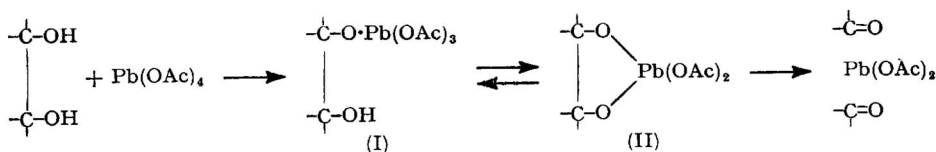


### 180. The Mechanisms of Oxidative Fission of Stereoisomeric 1 : 2-Glycols.

By (MISS) P. LEVESLEY, WILLIAM A. WATERS, and A. N. WRIGHT.

Evidence is brought forward to show that the oxidation of 1 : 2-glycols by manganic pyrophosphate and by lead tetra-acetate does not always proceed through the initial formation of a cyclic organometallic complex. In particular, attention is directed to the fact that *trans*-1 : 2-dimethylcyclopentane-1 : 2-diol is oxidised more easily than *cis*-cyclohexane-1 : 2-diol or *cis*-1 : 2-dimethylcyclohexane-1 : 2-diol. Exploratory studies of glycol oxidation by manganic pyrophosphate indicate that more than one reaction mechanism may be concerned in oxidative glycol fissions. Stereochemical significance should not therefore be attached to simple measurements of relative rates of oxidation.

It is widely thought that the oxidative fission of 1 : 2-glycols by reagents such as lead tetra-acetate, periodic acid, aryl iodoacetates<sup>1</sup> and sodium bismuthate<sup>2</sup> occurs by formation of an intermediate cyclic complex [e.g., (II)] within which an electron redistribution may easily occur by bond fissions which may be written as heterolytic<sup>2,3</sup> or homolytic<sup>4</sup> processes according to choice, no discrimination between these alternatives by experimental means being possible. The evidence depends on observations<sup>1,5,6</sup> that in both the cyclopentane and cyclohexane series *cis*-1 : 2-glycols are cleaved more rapidly than their *trans*-isomers. This stereochemical concept has been applied by Prelog and his colleagues<sup>7</sup> in



assigning conformations to the isomeric 1 : 2-glycols of larger *cycloalkane* rings. However, though cyclic condensation products of 1 : 2-glycols with ketones, and with boric acid, have been prepared no one has, as yet, isolated the cyclic intermediate which is thought to be involved in any oxidative glycol fission.

For oxidations by lead tetra-acetate Criegee and his colleagues<sup>5,8</sup> have suggested that the bimolecular<sup>9</sup> rate-determining stage may really be that of the formation of an uncyclised lead compound (I), analogous to a product  $\text{MeO}\cdot\text{Pb(OAc)}_2\cdot\text{OH}$  obtained from lead tetra-acetate and slightly damp methanol. They have pointed out that in these oxidations slight changes in the composition of the solvent produces changes of the reaction velocity which are far too great to be accounted for by the intramolecular cyclisation (I  $\longrightarrow$  II), and the same idea has been developed further by Pausacker *et al.*<sup>10,11</sup> who suggested that hydrogen bonding between vicinal hydroxyl groups could greatly affect the ease with which a 1 : 2-glycol might give a product of type (I) and that no cyclic lead compound need be formed. For oxidations by aryl iodoacetates the same considerations apply.<sup>1,11</sup>

With periodic acid oxidations the structural effects are much less strongly marked, for both *cis*- and *trans*-glycols can be oxidised and the pH of the solution seems to be the

<sup>1</sup> Criegee and Beuker, *Annalen*, 1939, **541**, 218.

<sup>2</sup> Rigby, *J.*, 1950, 1907.

<sup>3</sup> Criegee, *Annalen*, 1948, **560**, 132.

<sup>4</sup> Dewar, "The Electronic Theory of Organic Chemistry," Oxford, 1949, pp. 276—277.

<sup>5</sup> Criegee, Kraft, and Rank, *Annalen*, 1933, **507**, 159.

<sup>6</sup> Criegee, Büchner, and Walther, *Ber.*, 1940, **73**, 571.

<sup>7</sup> Prelog, Schenker, and Günthard, *Helv. Chim. Acta*, 1952, **35**, 1598.

<sup>8</sup> Criegee and Büchner, *Ber.*, 1940, **73**, 563.

<sup>9</sup> Bell, Sturrock, and Whitehead, *J.*, 1940, 82.

<sup>10</sup> Corder and Pausacker, *J.*, 1953, 102.

<sup>11</sup> Pausacker, *J.*, 1953, 107.

main rate-controlling factor. Kinetic studies however indicate that some complex formation does precede the actual carbon-carbon bond fission.<sup>12</sup> Again with sodium bismuthate there is no outstanding difference between the rates of oxidation of isomeric *cis*- and *trans*-cyclohexane-1 : 2-diols, though few studies have as yet been made with this reagent.<sup>2</sup>

The recent kinetic study by Drummond and Waters<sup>13</sup> of the oxidation of pinacol by manganic pyrophosphate indicated that chelate-ring formation, with a pinacol molecule displacing a bidentate pyrophosphate group,



was a necessary initial step in this oxidation, for the reaction velocity was proportional to  $[\text{Glycol}]/([\text{H}_2\text{P}_2\text{O}_7^{2-}] + a[\text{Glycol}])$  as would be the case if the rate-determining stage of the reaction sequence were the slow breakdown of the complex  $\text{Mn}(\text{Pin})(\text{H}_2\text{P}_2\text{O}_7)_2^-$ . Oxidations by manganic pyrophosphate of typical  $\alpha$ -hydroxy-acids<sup>14</sup> and of malonic<sup>15</sup> and pyruvic<sup>16</sup> acid also seem to involve chelate-ring formation, though the oxidations of simple aldehydes<sup>17</sup> and ketones<sup>16</sup> can be represented as direct electron abstractions from enols that clearly cannot be bidentate chelating agents. Since the equilibrium constant for chelate-ring formation from a 1 : 2-glycol (cf. the reaction scheme above) should be closely connected with its stereochemical conformation it was considered that kinetic studies of the ease of oxidative fission of stereoisomeric 1 : 2-glycols by manganic pyrophosphate would yield data of superior quantitative value to those provided by any of the kinetic measurements of glycol fission recorded hitherto.

Exploratory work showed that, as expected, manganic pyrophosphate oxidised methyl  $\alpha$ -D-mannoside more rapidly than the all-*trans* methyl  $\alpha$ -D-glucoside, but that the oxidation of *trans*-1 : 2-dimethylcyclohexane-1 : 2-diol did not quite parallel that of pinacol, for it was evidently a reaction of first order with respect to the glycol concentration. The work has therefore been continued. The rates of oxidation of the *cis*- and the *trans*-isomers of cyclohexane-1 : 2-diol and 1 : 2-dimethylcyclohexane-1 : 2-diol and of *trans*-1 : 2-dimethylcyclopentane-1 : 2-diol have been compared. Fig. 1 shows oxidation curves obtained at 40° with equimolar concentrations of these glycols and manganic pyrophosphate at pH 0.2, and Fig. 2 shows similar curves obtained with lead tetra-acetate in glacial acetic acid at 25°. The outstanding features of the manganic pyrophosphate oxidations are (i) that *trans*-1 : 2-dimethylcyclopentane-1 : 2-diol is oxidised so easily and (ii) that *cis*-1 : 2-dimethylcyclohexane-1 : 2-diol is oxidised much more slowly than is its *trans*-isomer; however, as expected, *cis*-cyclohexane-1 : 2-diol is oxidised more rapidly than the *trans*-compound, but consumes four, and not two, equivalents of the oxidant. With lead tetra-acetate the relative reactivities of these compounds are different : with both pairs of cyclohexanediols the *cis*-isomer is oxidised more rapidly, but again *trans*-1 : 2-dimethylcyclopentane-1 : 2-diol is oxidised very easily.

The observations with *trans*-1 : 2-dimethylcyclopentane-1 : 2-diol were unexpected, for, though in a few compounds a cyclohexane ring is able to pucker sufficiently to allow a *trans*-1 : 2-diol to condense to a 5-membered ring derivative,<sup>18</sup> it was thought that the cyclopentane ring would be so much more rigidly planar that *trans*-hydroxyl groups could not easily be forced into sufficiently close proximity for junction by any single atom. Ring complexes of vicinal *trans*-diols in the cyclopentane series (e.g., furanoses) with boric acid or acetone are unknown, though Barrett and Linstead<sup>19</sup> have made both *cis*- and *trans*-bicyclo[3 : 3 : 0]-octanes and -octanones, and Owen and Peto<sup>20</sup> the corresponding 3-oxa- and 3-thia-compounds. Nevertheless the successful *trans*-union of two 5-membered rings

<sup>12</sup> Price and Knell, *J. Amer. Chem. Soc.*, 1942, **64**, 552; Price and Kroll, *ibid.*, 1938, **60**, 2726; Duke, *ibid.*, 1947, **69**, 3054; Buist and Bunton, *J.*, 1954, 1406.

<sup>13</sup> Drummond and Waters, *J.*, 1953, 3119.

<sup>14</sup> Levesley and Waters, *J.*, 1955, 217.

<sup>15</sup> Drummond and Waters, *J.*, 1954, 2456.

<sup>16</sup> *Idem*, *J.*, 1955, 497.

<sup>17</sup> *Idem*, *J.*, 1953, 440.

<sup>18</sup> Angyal and Macdonald, *J.*, 1952, 686.

<sup>19</sup> Barrett and Linstead, *J.*, 1935, 436.

<sup>20</sup> Owen and Peto, *J.*, 1955, 2383.

involves considerable intramolecular strain, for the heat of combustion of the *trans*-dicyclic ketone is 6.8 kcal. more than that of its *cis*-isomer.<sup>19</sup>

However our present measurements with *trans*-1 : 2-dimethylcyclopentane-1 : 2-diol are in full accord with results reported several years ago by Criegee and his colleagues<sup>5,6</sup> which are collected in Table 1. These show that the activation energy for the oxidation of *trans*-cyclopentane-1 : 2-diol is in fact less than that required for either of the 1 : 2-cyclohexanediols and that the *trans*-diphenylacenaphthenediol, in which the naphthalene

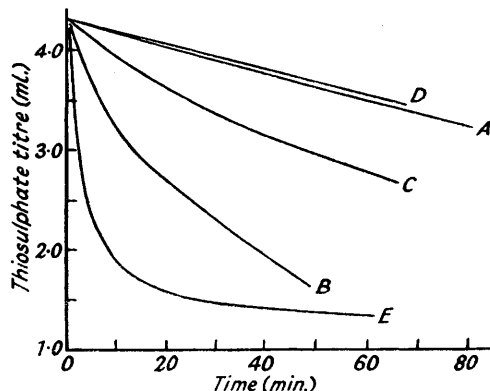


FIG. 1. Oxidations with manganic pyrophosphate.

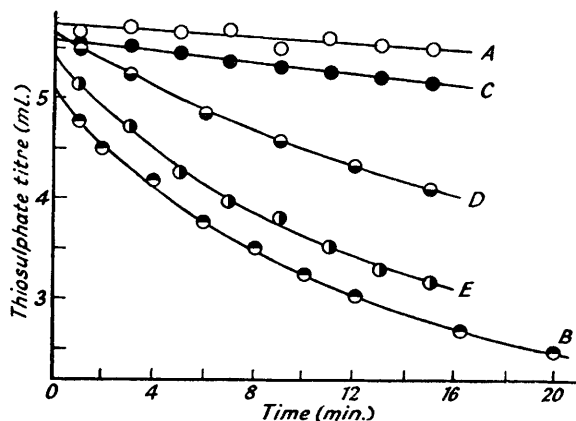
pH 0.20. Temp. 40°.

Initial [Glycol]  $5.9 \times 10^{-3}M$ .

Initial [Mn<sup>III</sup>]  $1.7 \times 10^{-2}M$ .

[Pyrophosphate] 0.119M.

FIG. 2. Oxidations with lead tetra-acetate.  
Glacial acetic acid solution at 25°.  
Initial [Glycol]  $4.93 \times 10^{-2}M$ .  
[Lead tetra-acetate]  $2.65 \times 10^{-2}M$ .



Curves A, *trans*-cycloHexane-1 : 2-diol.  
Curves B, *cis*-cycloHexane-1 : 2-diol.  
Curves C, *trans*-1 : 2-Dimethylcyclohexane-1 : 2-diol.

Curves D, *cis*-1 : 2-Dimethylcyclohexane-1 : 2-diol.  
Curves E, *trans*-1 : 2-Dimethylcyclopentane-1 : 2-diol.

system confers rigidity on the 5-membered ring fused to it, is oxidised still more easily. Again *trans*-decalin-9 : 10-diol as well as its isomer can be oxidised at a reasonable rate to cyclodecanedione.<sup>6</sup>

Thus the results shown in Table 1 and in Figs. 1 and 2 give no basis for the view that stereochemical factors, *per se*, rather than polar factors connected with the electronic

TABLE 1. Records of glycol oxidation by lead tetra-acetate.<sup>5,6,9</sup>

(*k* in mole l.<sup>-1</sup> min.<sup>-1</sup>; *E* in kcal. mole<sup>-1</sup>)

Diol	<i>cis</i>		<i>trans</i>	
	<i>k</i> <sub>20</sub>	<i>E</i>	<i>k</i> <sub>20</sub>	<i>E</i>
<i>cyclo</i> Hexane-1 : 2-diol .....	5.04	20.5	0.224	21.4
<i>cyclo</i> Pentane-1 : 2-diol .....	40,000	—	12.8	19.8
Tetralin-1 : 2-diol .....	40.2	18.8	1.86	20.3
Indane-1 : 2-diol .....	27,800	—	0.467	20.9
7 : 8-Diphenylacenaphthene-7 : 8-diol .....	33,100	8.3	284	15.5
Decalin-9 : 10-diol .....	15.0	—	0.148	—

structures of neighbouring groups, are primarily responsible for observed changes of oxidation rate. Similar conclusions have been reached from computations of bond distances in cyclic 1 : 2-diols.<sup>21</sup>

Since glycol fission by manganic pyrophosphate has demonstrated that 1-electron transitions in which free radicals are formed can be involved in the oxidation process, attention may be directed to the observation<sup>22</sup> that glycol fission by chromyl chloride involves the 1-electron transition from Cr<sup>VI</sup> to Cr<sup>V</sup>, to the fact that hydroxyl radicals, which cannot promote cyclic complex formation, can effect some carbon-carbon bond fission of 1 : 2-glycols<sup>23</sup> and to evidence that some oxidations involving periodic acid involve 1-electron transitions.<sup>24</sup> Consequently homolytic oxidation mechanisms involving two successive 1-electron transitions, developing those vaguely indicated by Criegee<sup>25</sup> in 1935, outlined by Waters<sup>26</sup> in 1939, and advanced again by Cordner and Pausacker<sup>10</sup> in 1953, must be given serious consideration. If glycol fission is visualised as a two-stage process then the stages may be concerted (when current stereochemical ideas would indicate that *trans*-reaction might be favoured) or consecutive, passing through a transient radical intermediate, and predominantly controlled by the nature of the solvent.<sup>10</sup>

Whenever a series of consecutive reactions is involved it cannot safely be inferred that the same stage in the reaction sequence is rate-determining for each member of an isomeric, or homologous, series. It has only been possible for us to examine the reaction mechanisms of oxidation of cyclic 1 : 2-glycols in a preliminary way, but the results given in the following Experimental section show that with manganic pyrophosphate oxidation the rate-determining stage is not the same for all glycols and that no general correlation between stereochemical conformation and ease of oxidation should therefore be made. We suggest that theoretical deductions made from rate measurements of other glycol fission reactions should, pending thorough physicochemical studies, be viewed with similar scepticism, and that kinetic evidence of (glycol-oxidant) complex formation should not be taken as diagnostic of *cyclic* complex formation.

#### EXPERIMENTAL

*Preparation of the Cyclic 1 : 2-Glycols.*—(i) *trans*-1 : 2-Dimethylcyclopentane-1 : 2-diol. Ethyl 1-methyl-2-oxocyclopentanecarboxylate was converted in 65–70% yield by the method of Shive, Crouch, and Lochte<sup>27</sup> into 2-methylcyclopentanone which was treated with methylmagnesium iodide and then dehydrated to 1 : 2-dimethylcyclopentene. This olefin (10 g.) was oxidised to the *trans*-glycol by cold 30% hydrogen peroxide (20 ml.) and 99% formic acid (50 ml.) in 25% yield. After distillation in a vacuum this diol crystallised from light petroleum (b. p. 60–80°) and had m. p. 99–102°.

*trans*-1 : 2-Dimethylcyclohexane-1 : 2-diol, prepared similarly from 1 : 2-dimethylcyclohexene, had b. p. 78°/12 mm. and m. p. 92–93°, whilst *trans*-cyclohexane-1 : 2-diol had m. p. 104° (dibenzoate, m. p. 94°).

(ii) *cis*-cycloHexane-1 : 2-diol was prepared in small quantity from the *trans*-monotoluene-*p*-sulphonate as described by Criegee and Stanger,<sup>28</sup> but in better quantity (yield 33%) by the oxidation at –15° to –20° of cyclohexene with potassium permanganate in aqueous ethanol containing magnesium sulphate, as described by Clarke and Owen;<sup>29</sup> it had m. p. 98°. *cis*-1 : 2-Dimethylcyclohexane-1 : 2-diol was prepared by a similar oxidation of 1 : 2-dimethylcyclohexene following the detailed procedure of Meerwein,<sup>30</sup> which involves a purification with semicarbazide to remove 2 : 7-dioxo-octane. The final product had b. p. 102°/10 mm. and m. p. 50°.

*Kinetic Measurements.*—Measurements with manganic pyrophosphate were made by the procedure used by Drummond and Waters.<sup>13</sup> The steady reproducible values for the initial

<sup>21</sup> Kuhn, *J. Amer. Chem. Soc.*, 1954, **76**, 4323.

<sup>22</sup> Slack and Waters, *J.*, 1949, 594.

<sup>23</sup> Waters, *Nature*, 1946, **158**, 380.

<sup>24</sup> Symons, *J.*, 1955, 2794.

<sup>25</sup> Criegee, *Ber.*, 1935, **68**, 665.

<sup>26</sup> Waters, *J.*, 1939, 1805; *Trans. Faraday Soc.*, 1946, **42**, 185.

<sup>27</sup> Shive, Crouch, and Lochte, *J. Amer. Chem. Soc.*, 1941, **63**, 2983.

<sup>28</sup> Criegee and Stanger, *Ber.*, 1936, **69**, 2753.

<sup>29</sup> Clarke and Owen, *J.*, 1949, 318.

<sup>30</sup> Meerwein, *Annalen*, 1939, **542**, 123.

reaction rates showed that oxygen did not affect the reaction velocity. Tests with dinitrophenylhydrazine showed that *trans*-dimethyl-cyclopentane-1,2-diol and -cyclohexane-1,2-diol were oxidised to ketones but that *cis*-cyclohexane-1,2-diol was further oxidised to adipic acid. This confirmed measurements of the stoichiometry of completed oxidations.

Lead tetra-acetate oxidations were carried out in glacial acetic acid at 25°, following the procedure of Cordner and Pausacker.<sup>10</sup> One batch of purified acetic acid was used for preparing all solutions.

*Investigations of Reaction Orders for Glycol Oxidation by Manganic Pyrophosphate by Means of Initial-rate Measurements.*—(a) *Oxidations of methyl  $\alpha$ -D-pyranosides.* The results in Table 2

TABLE 2. *Oxidation of pyranosides.*pH 0.04. Temp. 45.5°. Initial [Mn<sup>III</sup>] 0.0135M. [P<sub>2</sub>O<sub>7</sub>] 0.109M.*Methyl  $\alpha$ -D-glucopyranoside.*

Initial concn. (10 <sup>-3</sup> M) .....	10.65	6.95	5.26	4.21	3.49	2.63	1.74	1.58	1.32	0.87	0.75
Initial rate (mole of Mn l. <sup>-1</sup> hr. <sup>-1</sup> ) ...	4.55	4.15	3.75	3.21	2.94	2.65	2.04	1.94	1.83	1.22	1.02

*Methyl  $\alpha$ -D-mannopyranoside.*

Initial concn. (10 <sup>-3</sup> M) .....	1.58	0.83	0.65	0.53	0.42	0.35	0.29	0.26
Initial rate (mole of Mn l. <sup>-1</sup> hr. <sup>-1</sup> ) .....	1.58	1.08	0.92	0.80	0.74	0.61	0.54	0.48

show that the order with respect to the pyranoside is less than unity, particularly when the organic compound is present in excess. A reciprocal plot shows that the observed kinetic relationship is similar to that found for pinacol.<sup>13</sup>

(b) *Oxidations of trans-1 : 2-dimethylcyclopentane-1 : 2-diol.* Results showing the order with respect to the diol and tervalent manganese are in Tables 3 and 4 respectively. These indicate a bimolecular reaction between the reactants without any initial complex formation.

(c) *Oxidations of trans-1 : 2-dimethylcyclohexane-1 : 2-diol.* The first-order relation with respect to the diol (Table 5) shows that the diol does not form a complex with the manganic salt.

TABLE 3.

	Initial [Mn <sup>III</sup> ] 0.0162M. [P <sub>2</sub> O <sub>7</sub> ] 0.119M. pH 1.01 (glass electrode). Temp. 40°.						
Diol concn. (10 <sup>-3</sup> M) .....	1.44	1.44	2.88	4.32	5.76	7.32	8.64
Initial rate (10 <sup>-3</sup> mole l. <sup>-1</sup> hr. <sup>-1</sup> ) .....	1.58	1.37	3.56	5.03	6.50	7.83	9.90
Rate/[Diol] .....	1.10	0.95	1.23	1.16	1.13	1.07	1.15

TABLE 4. (Units as in Table 3.)

	Diol concn. 2.03 × 10 <sup>-3</sup> M. pH 0.60.						
Mn <sup>III</sup> concn. ....	2.82	5.64	8.46	11.3	14.1	16.9	
Initial rate .....	0.89	2.00	2.6	3.3	5.0	5.8	
Rate/[Mn] .....	0.32	0.36	0.31	0.29	0.36	0.34	
	Diol concn. 6.88 × 10 <sup>-3</sup> M. pH 1.01.						
Mn <sup>III</sup> concn. ....	6.5	8.5	9.75	13.0	13.7	16.2	17.1
Initial rate .....	2.9	3.8	4.8	5.9	7.5	9.1	9.9
Rate/[Mn] .....	0.45	0.45	0.49	0.45	0.55	0.56	0.59

TABLE 5. (Units as in Table 3.)

	Initial [Mn <sup>III</sup> ] 0.0135M. [P <sub>2</sub> O <sub>7</sub> ] 0.109M. pH 0.04. Temp. 40°.							
Diol concn. ....	7.02	3.51	2.38	1.82	1.40	1.12	0.91	0.70
Initial rate .....	9.78	3.96	3.64	2.01	1.85	1.61	1.21	0.91
Rate/[Diol] .....	1.39	1.13	1.53	1.10	1.32	1.44	1.33	1.30

TABLE 6. (Units as in Table 3.)

	Initial [Diol] 16.7 × 10 <sup>-3</sup> M. [P <sub>2</sub> O <sub>7</sub> ] 0.119M. pH 0.20. Temp. 39.8°.						
Mn <sup>III</sup> concn. ....	3.4	6.8	10.2	10.2	13.6	16.2	
Initial rate .....	4.8	9.0	15.3	16.7	19.9	27.8	
Rate/[Mn <sup>III</sup> ] .....	1.4	1.3	1.5	1.6	1.5	1.7	
	Initial [Diol] 3.51 × 10 <sup>-3</sup> M. [P <sub>2</sub> O <sub>7</sub> ] 0.11M. pH 0.04. Temp. 45°.						
Mn <sup>III</sup> concn. ....	2.75	4.13	5.51	6.89	8.27	9.65	13.8
Initial rate .....	3.66	3.70	3.71	4.38	4.32	4.43	4.80

TABLE 7. (Units as in Table 3.)

Initial $[\text{Mn}^{\text{III}}]$ $16.2 \times 10^{-3}\text{M}$ . $[\text{P}_2\text{O}_7]$ $0.12\text{M}$ . pH 0.19. Temp. $40^\circ$ .				
Diol concn. ....	2.66	3.33	6.65	10.0
Initial rate .....	3.12	4.8	10.8	13.1
Rate/[Diol] .....	1.2	1.4	1.6	1.3

TABLE 8. (Units as in Table 3.)

Initial [Diol] = $13.3 \times 10^{-3}\text{M}$ . $[\text{P}_2\text{O}_7]$ $0.12\text{M}$ . pH 0.19. Temp. $40^\circ$ .				
$\text{Mn}^{\text{III}}$ concn. ....	3.25	6.5	9.75	13.0
Initial rate .....	0.36	1.5	3.2	6.3
Rate/ $[\text{Mn}^{\text{III}}]^2$ .....	0.34	0.36	0.34	0.37

At low  $[\text{Mn}^{\text{III}}]/[\text{Diol}]$  ratios the first-order relation is again found (Table 6), but the reaction order decreases when  $[\text{Mn}^{\text{III}}]$  is present in excess. A highly speculative interpretation of this would be that the dimethylcyclohexanediol molecules have to attain a particular conformation before complete oxidation can occur.

(d) *Oxidations of cis-cyclohexane-1 : 2-diol.* The reaction seems to be a second-order process with respect to  $[\text{Mn}^{\text{III}}]$  (Table 8). This would accord with a rate-determining stage in which a complex ion  $\text{Mn}(\text{diol})(\text{pyrophosphate})_2$  was attacked by a second molecule of manganic pyrophosphate. Reaction is of first order with respect to the diol (Table 7).

*cis-1 : 2-Dimethylcyclohexane-1 : 2-diol* was oxidised extremely slowly. This would be the case if the chelated complex proved to be very stable.

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