
Isolation of complexes with protonated
bases as cations.

Ligand substitution in metallic complexes is a nucleophilic process. It may proceed through a first order displacement mechanism with a pentacoordinated intermediate, termed SN_1 , or through a second order addition mechanism with a heptacoordinated intermediate, termed SN_2 reaction. If the substitution is fast, the system is termed labile, otherwise inert.

The addition of a secondary ligand, monodentate L or bidentate L-L to a complex $[M(A-A)_2]$ may result in a complete displacement of (A-A) and the complex $[ML_4]$ or $[M(L-L)_2]$ may be formed. If (A-A) happens to be a neutral base and L or (L-L) are charged ions, resulting complex anion $[ML_4]^{2-}$ or $[M(L-L)_2]^{2-}$ is formed and the liberated base gets protonated. The charge on the complex anion is neutralised by the protonated base, acting as the cation and the compound precipitates out.

The cases of displacement of the basic ligand from the coordination sphere by another ligand¹ and also isolation in solid state of complexes with protonated primary or ternary bases as a cation have been reported earlier.²⁻⁴ However, the reactions of the type wherein the bases replaced from the coordination sphere go out to the outer sphere as protonated cation, were first reported by Bhattacharya and Patel⁵ in case of Ni(II) complexes. A similar study in Zn(II) and Cd(II) complexes has been carried out in the present investigation. The catechol, pyrogallol or 2,3-dihydroxy-naphthalene complexes of Zn(II) and Cd(II), with protonated

ethylenediamine or protonated propylenediamine as cation, or with neutral base in the coordination sphere have been isolated and characterised.

Addition of sodium hydroxide or ethylenediamine or propylenediamine to the mixture of Zn(II) or Cd(II) and the above ligands (i.e. catechol, pyrogallol or 2,3-dihydroxy-naphthalene) results in the formation of metallic hydroxides. The isolation has therefore, been carried out by ligand displacement reactions.

Isolation of solids :

1. To the zinc chloride solution, ethylenediamine was added resulting in the formation of Zn(OH)_2 precipitates. Further addition of ethylenediamine led to the dissolution of Zn(OH)_2 and bis ethylenediamine zinc chloride solution $[\text{Zn(en)}_2]^{2+}\text{Cl}_2$ was formed. To this solution was added two equivalents of catechol solution. The solution was refluxed for some time. Whitish green coloured compound got separated. The solution was cooled, filtered and the solid was washed with water. This was dried and analysed for the metal and nitrogen contents.

$[\text{Zn(cat)}_2]^{2-}\text{enH}_2^{2+}$ requires Zn = 19.60; N = 8.50 %.

found Zn = 19.70; N = 8.33 %.

2. To the bis ethylenediamine zinc chloride solution i.e. $[\text{Zn(en)}_2]^{2+}\text{Cl}_2$, was added two equivalents of pyrogallol solution. The solution was refluxed for some time. Whitish yellow coloured complex got precipitated. The solution was cooled and the precipitate was filtered out. The solid was washed with water. It was dried and analysed for the metal

and nitrogen contents.

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$[\text{Zn}(\text{pyro})_2]^{2-} \cdot \text{enH}_2^{2+}$ requires Zn = 17.20; N = 7.42 %,
found Zn = 17.00; N = 7.22 %.

3. To the bis ethylenediamine zinc chloride solution was added two equivalents of 2,3-dihydroxynaphthalene dissolved in 50% ethyl alcohol. White coloured complex got separated out which was filtered and washed with water and also with 50% ethyl alcohol solution to remove excess of 2,3-dihydroxynaphthalene. It was dried and analysed for the metal and nitrogen contents.

$[\text{Zn}(2,3\text{-di-naph})(\text{en})]$ requires Zn = 20.20; N = 8.60 %,
found Zn = 20.42; N = 8.40 %.

4. To the cadmium chloride solution was added an excess of ethylenediamine to dissolve the metallic hydroxide and to form bis ethylenediamine cadmium chloride solution i.e.

$[\text{Cd}(\text{en})_2]^{2+} \cdot \text{Cl}_2$. Two equivalents of catechol were added to the above solution and it was refluxed for some time. Whitish green coloured compound precipitated out which was filtered after cooling. It was washed with water, dried and analysed for metal and nitrogen contents.

$[\text{Cd}(\text{cat})_2]^{2-} \cdot \text{enH}_2^{2+}$ requires Cd = 28.00; N = 7.03 %,
found Cd = 28.22; N = 6.92 %.

5. To the bis ethylenediamine cadmium chloride solution i.e. $[\text{Cd}(\text{en})_2]^{2+} \cdot \text{Cl}_2$, was added two equivalents of pyrogallol solution. It was refluxed for some time. Whitish yellow coloured complex precipitated out. It was filtered after cooling. It was washed with water, dried and analysed for the metal and nitrogen contents.

$[\text{Cd}(\text{pyro})_2]^{2-} \text{enH}_2^{2+}$ requires Cd = 26.00; N = 6.63 %, 84
found Cd = 25.89; N = 6.42 %.

6. To the bis ethylenediamine cadmium chloride solution i.e. $[\text{Cd}(\text{en})_2]^{2+} \text{Cl}_2$, was added two equivalents of 2,3-dihydroxy-naphthalene. dissolved in 50% ethyl alcohol. White coloured complex separated out which was filtered, washed with water and 50% ethyl alcohol. It was dried and analysed for the metal and nitrogen contents.

$[\text{Cd}(2,3\text{-di-naph})(\text{en})]$ requires Cd = 22.70; N = 5.70 %,
found Cd = 22.90; N = 5.79 %.

Similar reactions as in case of ethylenediamine were attempted using propylenediamine as follows :

7. To the zinc chloride solution, propylenediamine was added. The formation of $\text{Zn}(\text{OH})_2$ took place. $\text{Zn}(\text{OH})_2$ was dissolved by the addition of excess of propylenediamine. This led to the formation of bis propylenediamine zinc chloride solution i.e. $[\text{Zn}(\text{pn})_2]^{2-} \text{Cl}_2$. To this was added two equivalents of catechol solution. Whitish green coloured compound separated out. This was filtered, washed with water, dried and analysed for the metal and nitrogen contents.

$[\text{Zn}(\text{cat})_2]^{2-} \text{pnH}_2^{2+} \cdot 4\text{H}_2\text{O}$ requires Zn = 15.00; N = 6.40 %,
found Zn = 15.30; N = 5.71 %.

8. To $[\text{Zn}(\text{pn})_2]^{2-} \text{Cl}_2$ solution was added two equivalents of pyrogallol solution. The yellowish white coloured compound precipitated out. It was filtered and washed with water. It was dried and analysed for the metal and nitrogen contents.

$[\text{Zn}(\text{pyro})_2]^{2-} \text{pnH}_2^{2+}$ requires Zn = 13.70; N = 7.17 %,
found Zn = 13.62; N = 7.26 %.

9. Two equivalents of 2,3-dihydroxynaphthalene dissolved in 50% ethyl alcohol were added to $[\text{Zn}(\text{pn})_2]^{2+}\text{Cl}_2$ solution. This resulted in the precipitation of white coloured complex. It was filtered out, washed with water and 50% ethyl alcohol solution to remove excess of 2,3-dihydroxynaphthalene. It was dried and analysed for the metal and nitrogen contents.

$[\text{Zn}(2,3\text{-di-naph})(\text{pn})]\cdot\text{H}_2\text{O}$ requires Zn = 20.05; N = 8.83 %,
found Zn = 20.00; N = 8.45 %.

10. To the cadmium chloride solution was added an excess of propylenediamine to dissolve $\text{Cd}(\text{OH})_2$ and to form bis propylenediamine cadmium chloride solution i.e. $[\text{Cd}(\text{pn})_2]^{2+}\text{Cl}_2$. To this was added two equivalents of catechol solution. Whitish green coloured complex separated out. It was filtered, washed with water and analysed for the metal and nitrogen contents.

$[\text{Cd}(\text{cat})_2]^{2+}\text{pnH}_2^{2+}\cdot 5\text{H}_2\text{O}$ requires Cd = 21.10; N = 5.20 %,
found Cd = 21.70; N = 5.23 %.

11. To $[\text{Cd}(\text{pn})_2]^{2+}\text{Cl}_2$ solution was added two equivalents of pyrogallol solution. The yellowish white coloured compound precipitated out. It was filtered, washed with water, dried and analysed for the metal and nitrogen contents.

$[\text{Cd}(\text{pyro})_2]^{2+}\text{pnH}_2^{2+}\cdot 4\text{H}_2\text{O}$ requires Cd = 23.60; N = 5.90 %,
found Cd = 23.10; N = 6.13 %.

12. Two equivalents of 2,3-dihydroxynaphthalene dissolved in 50% ethyl alcohol, were added to the $[\text{Cd}(\text{pn})_2]^{2+}\text{Cl}_2$ solution. The white coloured complex separated out. It was filtered, washed with water and also with 50% ethyl alcohol solution to remove excess of 2,3-dihydroxynaphthalene. It was dried and analysed for the metal and nitrogen contents.

$[\text{Cd}(2,3\text{-di-naph})(\text{pn})]\cdot\text{H}_2\text{O}$ requires Cd = 30.00; N = 7.50 %,
found Cd = 29.85; N = 6.95 %.

The pyrogallol complexes have a tendency to change colour from yellowish white to greenish black on exposure to air. Since sensitivity of Zn(II) or Cd(II) complexes to atmospheric oxygen is very unusual, the change in colour is possibly because of the oxidation of the ligand. Freshly prepared compounds were, therefore, used in all the cases.

The water molecules are present as water of crystallisation because they are lost at $\sim 110^\circ\text{C}$.

I.R. Spectral studies :

The I.R. spectra of the compounds were obtained in KBr phase. The characteristic bands obtained are as follows :

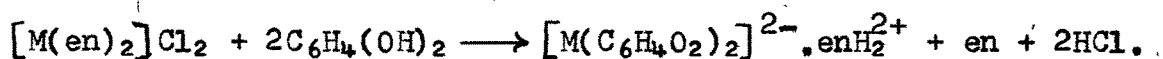
Compound	Characteristic bands cm^{-1}
1. $[\text{Zn}(\text{cat})_2]^{2-}\text{enH}_2^{2+}$	$\sim 3300(\text{m}), \sim 2900(\text{m}), \sim 1590(\text{m}),$ $\sim 1480(\text{m}), \sim 1300(\text{m}), \sim 1240(\text{m}),$ $\sim 1170(\text{w}), \sim 1040(\text{m}), \sim 850(\text{m}),$ $\sim 780(\text{m}), \sim 750(\text{s}), \sim 710(\text{w}),$ $\sim 650(\text{w}), \sim 560(\text{w}), \sim 500(\text{w}),$ $\sim 430(\text{m}).$
2. $[\text{Zn}(\text{pyro})_2]^{2-}\text{enH}_2^{2+}$	$\sim 3300(\text{w}), \sim 2900(\text{m}), \sim 1600(\text{m}),$ $\sim 1400(\text{m}), \sim 1380(\text{m}), \sim 1080(\text{w}),$ $\sim 950(\text{w}), \sim 800(\text{m}), \sim 720(\text{m}),$ $\sim 420(\text{m}).$
3. $[\text{Zn}(2,3\text{-di-naph})(\text{en})]$	$\sim 3370(\text{s}), \sim 3280(\text{s}), \sim 3270(\text{m}),$ $\sim 3080(\text{w}), \sim 3060(\text{m}), \sim 3000(\text{w}),$ $\sim 2940(\text{m}), \sim 2890(\text{m}), \sim 1630(\text{m}),$ $\sim 1600(\text{s}), \sim 1580(\text{m}), \sim 1480(\text{m}),$ $\sim 1370(\text{m}), \sim 1340(\text{s}), \sim 1290(\text{m}),$ $\sim 1280(\text{s}), \sim 1120(\text{s}), \sim 1040(\text{s}),$

- $\sim 1020(\text{m}), \sim 950(\text{s}), \sim 870(\text{m}),$
 $\sim 760(\text{s}), \sim 750(\text{s}), \sim 730(\text{s}),$
 $\sim 710(\text{w}), \sim 630(\text{s}), \sim 510(\text{m}),$
 $\sim 480(\text{m}), \sim 430(\text{w}), \sim 400(\text{w}).$
4. $[\text{Cd}(\text{cat})_2]^{2-}\text{enH}_2^{2+}$
- $\sim 3300(\text{m}), \sim 2900(\text{m}), \sim 1600(\text{w}),$
 $\sim 1480(\text{w}), \sim 1410(\text{w}), \sim 1380(\text{w}),$
 $\sim 1080(\text{w}), \sim 840(\text{m}), \sim 790(\text{w}),$
 $\sim 710(\text{m}).$
5. $[\text{Cd}(\text{pyro})_2]^{2-}\text{enH}_2^{2+}$
- $\sim 3300(\text{m}), \sim 2900(\text{m}), \sim 1600(\text{w}),$
 $\sim 1400(\text{w}), \sim 1370(\text{m}), \sim 1120(\text{w}),$
 $\sim 1080(\text{w}), \sim 870(\text{w}), \sim 800(\text{w}),$
 $\sim 750(\text{w}).$
6. $[\text{Cd}(2,3\text{-di-naph})(\text{en})]$
- $\sim 3370(\text{w}), \sim 3280(\text{w}), \sim 3060(\text{w}),$
 $\sim 2940(\text{w}), \sim 2890(\text{m}), \sim 2600(\text{m}),$
 $\sim 1480(\text{s}), \sim 1370(\text{m}), \sim 1340(\text{m}),$
 $\sim 1280(\text{s}), \sim 1180(\text{m}), \sim 1120(\text{m}),$
 $\sim 1000(\text{m}), \sim 960(\text{m}), \sim 870(\text{s}),$
 $\sim 760(\text{s}), \sim 740(\text{w}), \sim 630(\text{s}),$
 $\sim 480(\text{m}), \sim 440(\text{w}).$
7. $[\text{Zn}(\text{cat})_2]^{2-}\text{pnH}_2^{2+} \cdot 4\text{H}_2\text{O}$
- $\sim 3300(\text{w}), \sim 2900(\text{m}), \sim 1500(\text{m}),$
 $\sim 1270(\text{m}), \sim 1110(\text{s}), \sim 1040(\text{s}),$
 $\sim 990(\text{m}), \sim 940(\text{m}), \sim 880(\text{m}),$
 $\sim 790(\text{s}), \sim 770(\text{m}), \sim 630(\text{s}),$
 $\sim 500(\text{w}).$
8. $[\text{Zn}(\text{pyro})_2]^{2-}\text{pnH}_2^{2+}$
- $\sim 3300(\text{w}), \sim 2900(\text{m}), \sim 1600(\text{m}),$
 $\sim 1400(\text{m}), \sim 1380(\text{m}), \sim 1080(\text{w}),$
 $\sim 940(\text{w}), \sim 800(\text{m}), \sim 720(\text{m}),$
 $\sim 420(\text{m}).$
9. $[\text{Zn}(2,3\text{-di-naph})(\text{pn})] \cdot \text{H}_2\text{O}$
- $\sim 3340(\text{s}), \sim 3270(\text{s}), \sim 3120(\text{m}),$
 $\sim 3060(\text{m}), \sim 3040(\text{m}), \sim 3020(\text{m}),$
 $\sim 2980(\text{s}), \sim 2960(\text{m}), \sim 2880(\text{m}),$
 $\sim 1620(\text{m}), \sim 1580(\text{s}), \sim 1480(\text{m}),$
 $\sim 1400(\text{m}), \sim 1380(\text{m}), \sim 1340(\text{s}),$
 $\sim 1280(\text{m}), \sim 1240(\text{s}), \sim 1180(\text{s}),$
 $\sim 1120(\text{s}), \sim 1030(\text{s}), \sim 940(\text{m}),$
 $\sim 850(\text{s}), \sim 780(\text{m}), \sim 770(\text{s}),$

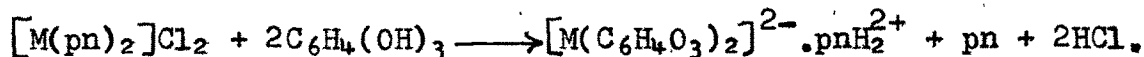
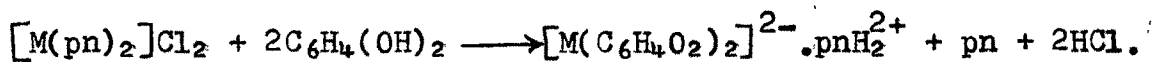
	$\sim 760(s), \sim 720(m), \sim 630(m),$ $\sim 530(m), \sim 480(s), \sim 440(m).$
10. $[\text{Cd}(\text{cat})_2]^{2-} \cdot \text{pnH}_2^{2+} \cdot 5\text{H}_2\text{O}$	$\sim 3300(m), \sim 2900(m), \sim 1600(m),$ $\sim 1500(w), \sim 1380(w), \sim 1080(w),$ $\sim 860(m), \sim 800(w), \sim 730(w),$ $\sim 420(w),$
11. $[\text{Cd}(\text{pyro})_2]^{2-} \cdot \text{pnH}_2^{2+} \cdot 4\text{H}_2\text{O}$	$\sim 3400(w), \sim 2900(m), \sim 1600(m),$ $\sim 1400(m), \sim 1380(m), \sim 1080(w),$ $\sim 870(w), \sim 800(w).$
12. $[\text{Cd}(2,3\text{-di-naph})(\text{pn})] \cdot \text{H}_2\text{O}$	$\sim 3350(m), \sim 3290(w), \sim 2980(w),$ $\sim 1600(s), \sim 1480(s), \sim 1400(w),$ $\sim 1380(m), \sim 1340(s), \sim 1280(m),$ $\sim 1180(s), \sim 1110(m), \sim 1000(s),$ $\sim 940(m), \sim 860(s), \sim 770(m),$ $\sim 760(s), \sim 720(w), \sim 630(s),$ $\sim 520(w), \sim 480(m), \sim 440(w).$

Discussion :

The addition of polyhydroxy derivatives of benzene or naphthalene to $[\text{M}(\text{A})_2]^{2+}$ where $\text{M} = \text{Zn}(\text{II})$ or $\text{Cd}(\text{II})$; $\text{A} =$ ethylenediamine or propylenediamine results in the formation of $[\text{M}(\text{L})_2] \cdot \text{enH}_2^{2+}$ or $[\text{M}(\text{L})_2] \cdot \text{pnH}_2^{2+}$ (where $\text{LH}_2 =$ catechol or pyrogallol) and $[\text{M}(\text{L})(\text{en})]$ or $[\text{M}(\text{L})(\text{pn})] \cdot \text{H}_2\text{O}$ (where $\text{LH}_2 = 2,3\text{-dihydroxynaphthalene}$). It shows that ethylenediamine or propylenediamine is displaced on the addition of catechol or pyrogallol and ^{this} results in the formation of the ion $[\text{M}(\text{cat})_2]^{2-}$ or $[\text{M}(\text{pyro})_2]^{2-}$. The liberated ethylenediamine or propylenediamine form the protonated ions enH_2^{2+} or pnH_2^{2+} and neutralize the charge on the complex anions. The reactions can be represented by the following equations :

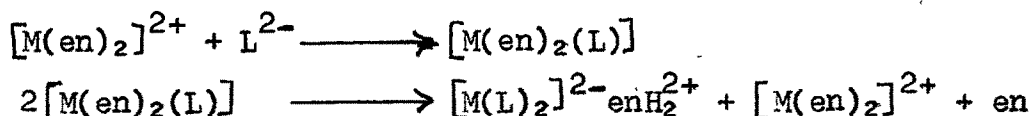


and

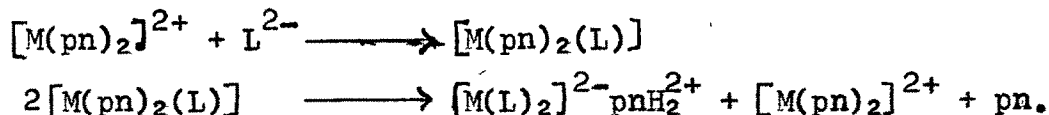


where en = ethylenediamine and pn = propylenediamine.

The replacement of ethylenediamine or propylenediamine cannot be due to decomposition of $[M(en)_2]Cl_2$ or $[M(pn)_2]Cl_2$ by excess acidity contributed by the added phenolic derivatives. This is indicated by the fact that $[M(en)_2]Cl_2$ or $[M(pn)_2]Cl_2$ is stable upto quite low pH and the formation of the above solids starts on the addition of even two drops of the ligands, the pH till being sufficiently high. The formation of the precipitate is also not very prompt. As the polyhydroxy derivatives of benzene do not differ very much in their complexing tendency from ethylenediamine or propylenediamine and the base is replaced in the zinc or cadmium complex on the addition of small quantity of the above ligands, it can be indicated that the reaction may be proceeding through some intermediate. The probable mechanism could be



and



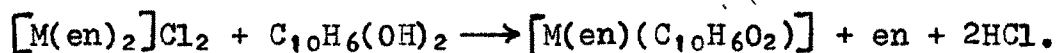
where LH_2 = catechol, or pyrogallol; en = ethylenediamine and pn = propylenediamine.

This indicates the formation of a hexa coordinated intermediate. Hexa coordination of Zn(II) and Cd(II) is known.⁶

The formation of the intermediate, however, is only an assumption based on the composition of the starting and the resulting compounds. It requires further experimental support.

The addition of two equivalents of protocatechuic acid to $[M(en)_2]Cl_2$ or $[M(pn)_2]Cl_2$ (where $M = Zn(II)$ or $Cd(II)$, en = ethylenediamine and pn = propylenediamine) does not result in the formation of solid. This may be because of the greater solubility of the resulting compounds.

In case of 2,3-dihydroxynaphthalene, however, though displacement reaction takes place, the displacing ligand being bigger in size, two molecules of it cannot be accommodated around the metal ion. This results in the formation of mixed ligand complex with one 2,3-dihydroxynaphthalene molecule and ethylenediamine or propylenediamine molecule around the metal ion. The reactions can be represented as follows :



Zn^{2+} and Cd^{2+} are known to undergo sp^3 hybridization. So in the compounds $[M(cat)_2]^{2-}enH_2^{2+}$, $[M(pyro)_2]^{2-}enH_2^{2+}$, $[M(cat)_2]^{2-}pnH_2^{2+}$ and $[M(pyro)_2]^{2-}pnH_2^{2+}$ (where $M = Zn(II)$ or $Cd(II)$), two catechol or two pyrogallol ions may be disposed in the tetrahedral way around the zinc or cadmium ion. In the mixed ligand complex there is one 2,3-dihydroxynaphthalene and one ethylenediamine or propylenediamine molecule in the coordination sphere.

The I.R. spectra of the complexes also exhibit the characteristic bands. The bands in the region $\sim 3370-3270\text{ cm}^{-1}$

correspond to N-H assymetrical and symmetrical stretches. This shows the presence of aliphatic amine in the structure. The bands in the region nearly 3080 cm^{-1} and 2940 cm^{-1} correspond to aromatic and aliphatic C-H stretching frequencies. The bands in the region $\sim 1600-1300\text{ cm}^{-1}$ correspond to the N-H, C-H bending vibrations. Number of the bands in this region correspond to stretching vibrations of the aromatic ring. The bands in the region $\sim 1200-1000\text{ cm}^{-1}$ correspond to C-N, C-C and C-O stretches. The bands in the region below 800 cm^{-1} correspond to deformation modes of C-N, C-C and C-O and out of plane deformations of C-H and N-H bonds.

The spectra in case of pyrogallol complexes have much less bands.

The infrared spectrum below 600 cm^{-1} corresponds to M-L vibrations. The spectra in this region could be obtained for few compounds. The bands in the region $\sim 500\text{ cm}^{-1}$ correspond to Zn-O and Cd-O stretching. In mixed ligand complexes additional bands is expected at lower frequency corresponding to M-N stretching. In the compounds with aliphatic amine in the coordination sphere, there are bands observed at nearly 480 cm^{-1} in Zn^{2+} - compounds and 440 cm^{-1} in Cd^{2+} - compounds. The fact that the ethylenediamine is chelated in these compounds and is not bridging is indicated because there are number of bands observed in the N-H and C-H bending region and is comparable with the compounds having chelated ethylenediamine⁷. This complexity is because of the fact that chelated ethylenediamine has a gauche conformation and due to the dissymmetry, the number of

the ir active vibrations are more. In bridging ethylenediamine with trans conformation symmetry is more and hence number of bands are much less.

In $[\text{Zn}(\text{cat})_2]\text{enH}_2^{2+}$ also a very weak band is observed at 470 cm^{-1} . This may be due to some out of plane deformation mode. This, however, leaves a doubt that there may be some coordination of ethylenediamine and the band may be due to stretching of Zn-N bond. X-ray studies can throw some light on the fact.

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