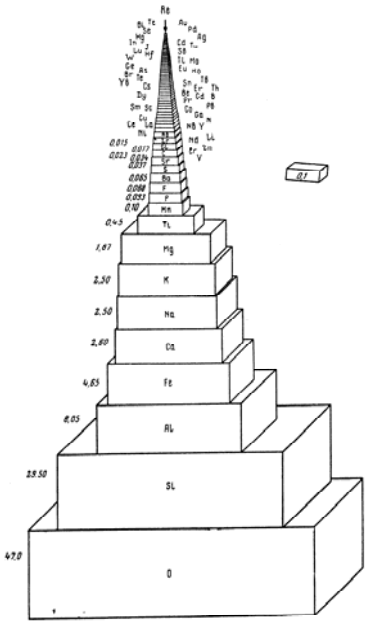
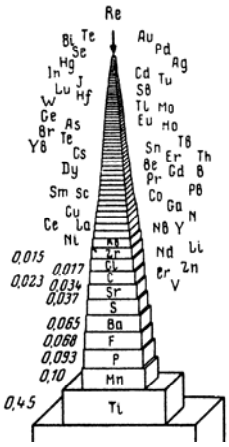
RECENT RESULTS IN RHENIUM CLUSTER CHEMISTRY

V.E. Fedorov, Yu.V. Mironov,
N.G. Naumov, K.A. Brylev

Nikolaev Institute of Inorganic Chemistry
Siberian Branch of Russian Academy of Sciences
Novosibirsk, Russia

Elements content in the earth's crust (weigh%)



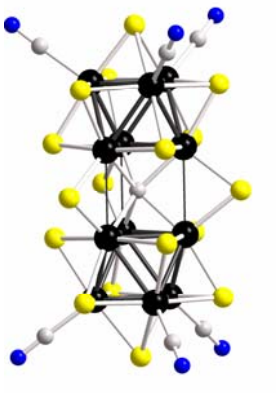


weigh clarke of rhenium:

~ 5 ·10^{-7} %

Discovery of rhenium:

W.Noddack, I.Tacke,
***Naturwiss.*, 1925, 13, 567.**

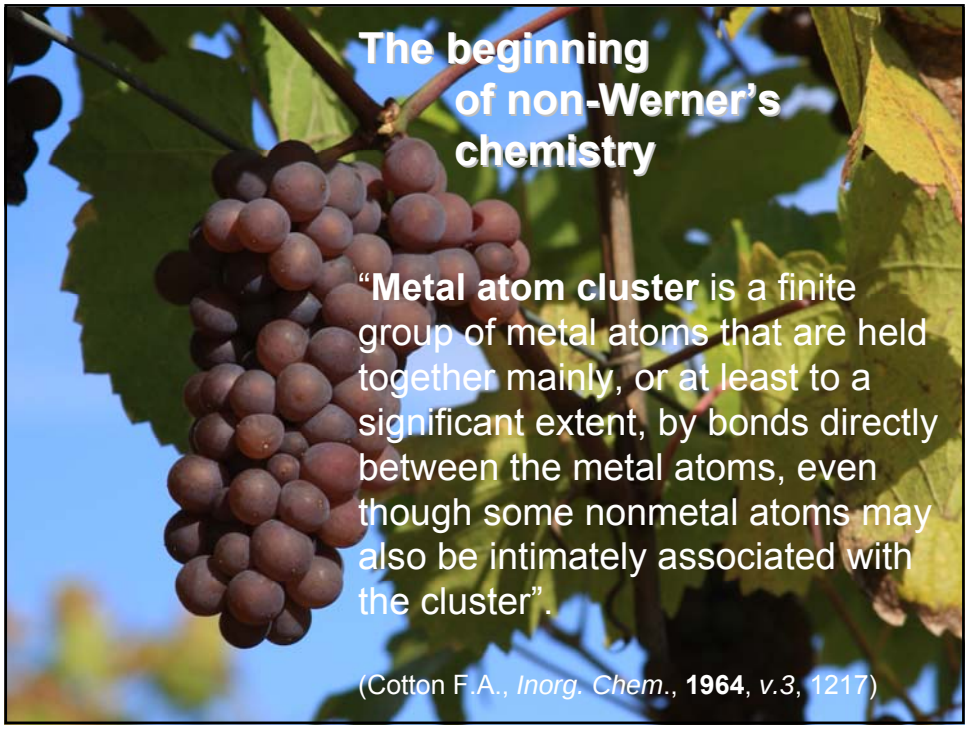


Laboratory of
SYNTHESIS
of cluster compounds and materials

Coordination Chemistry Department

“In the beginning was the WORD…”
The Bible. The Word of God.

In the beginning of chemistry was **SYNTHESIS**



Chalcogenides, halides and chalcohalides of the early transition metals (V, Nb, Ta, Mo, W, Re) are typical cluster compounds.

Ionic radii of chalcogenide and halide ligands, Å

S^{2-}	1.82	Cl^{-}	1.81
Se^{2-}	1.93	Br^{-}	1.96
Te^{2-}	2.11	I^{-}	2.20

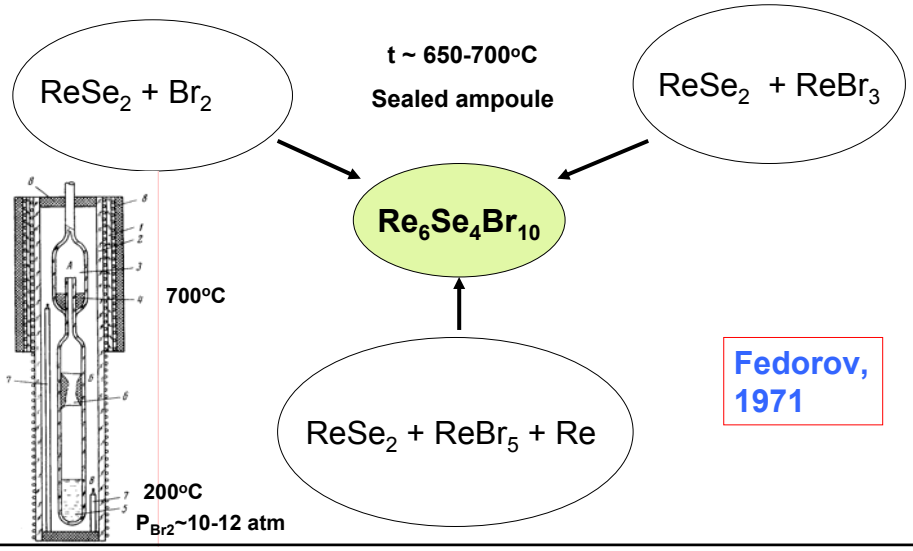
Crystallo-chemical similarity of chalcogenide and halide ions

but

Difference of their electronic properties

Chalcogenide and halide anions are stabilizing π-ligands for "high-valency" cluster complexes of the transition metals.

Syntheses of octahedral rhenium cluster complex $Re_6Se_4Br_{10}$

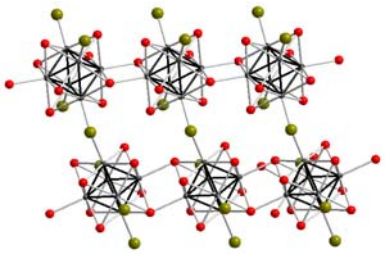


About thermodynamic stability of cluster compounds…

- $ReSe_2 + 5\ Br_2$ (excess) → $\mathbf{Re_6Se_4Br_{10}}$
  Re^{4+} → Re^{3+}

- $2ReSe_2 + 4\ ReBr_3$ → $\mathbf{Re_6Se_4Br_{10}} + Br_2$
  Re^{4+} Re^{3+} → Re^{3+}

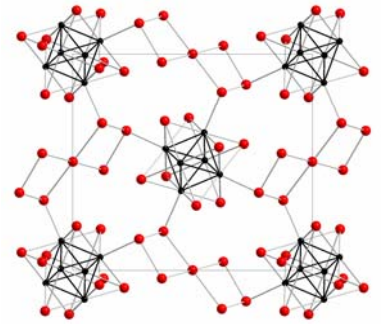
High temperature solid state synthesis of cluster rhenium compounds having polymeric structures



$$6\ Re + 8\ Q + Br_2 \xrightarrow{t = 850\ ^oC} Re_6Q_8Br_2$$

(Q=S, Se)

Ampoule synthesis



$$6\ Re + 15\ Te \xrightarrow{t=850\ ^oC} \{Re_6Te_8\}Te_7$$

The main problem in the chemistry of chalcogenide and chalcohalide cluster compounds is:

Metal cluster compounds with polymeric structures are not soluble in water and organic solvents

therefore

similar compounds have a very low chemical reactivity.

Discovery of octahedral rhenium cluster chalcocyanide complexes $[Re_6Q_8(CN)_6]^{4-}$ (Q=S, Se, Te)

Excision of $\{Re_6Q_8\}$ cluster core from polymeric compounds:

$$\{Re_6Te_8\}Te_7 + KCN\ (molten) \xrightarrow{650\ ^oC} [\{Re_6Te_8\}(CN)_6]^{4-}$$

A. Slougui, Yu.V. Mironov, A. Perrin, V.E. Fedorov, *Croatica Chemica Acta*, 1995, v. 68, pp. 885-890.

Yu.V. Mironov, A.V. Virovets, V.E. Fedorov, N.V. Podberezskaya, O.V. Shishkin, Yu.T. Struchkov, *Polyhedron*, 1995, v.14, pp.3171-3173.

$$\{Re_6Q_8\}Br_2 + KCN\ (molten) \xrightarrow{650\ ^oC} [\{Re_6Q_8\}(CN)_6]^{4-}$$

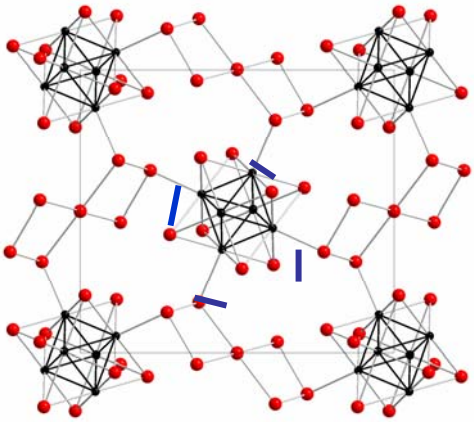
Q=S, Se

N.G. Naumov, A.V. Virovets, N.V. Podberezskaya, V.E. Fedorov, *Russ. J. Struct. Chem.*, 1997, v.38, pp.857-862.

H. Imoto, N.G. Naumov, A.V. Virovets, T. Saito, V.E. Fedorov, *Russ. J. Struct. Chem.*, 1998, v.39, pp.720-727.

Schematic presentation of excision of cluster core $\{Re_6Te_8\}$ from polymeric rhenium telluride $[\{Re_6Te_8\}Te_7]$ and its transformation in anionic complex $[\{Re_6Te_8\}(CN)_6]^{4-}$

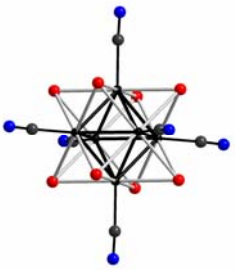
$\{\{Re_6Te_8\}Te_7\}_{\infty\infty\infty}$



Polymeric Re_6Te_{15} is **not soluble**

+ KCN (molten)

650°C

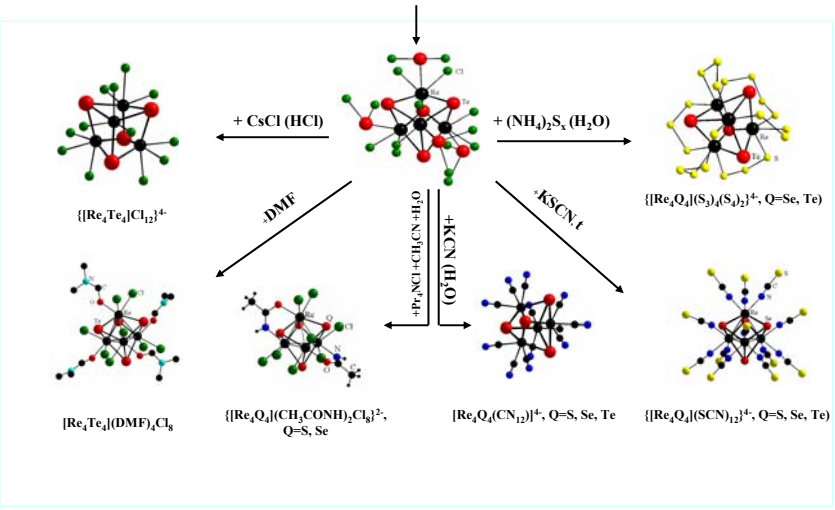


$[\{Re_6Te_8\}(CN)_6]^{4-}$

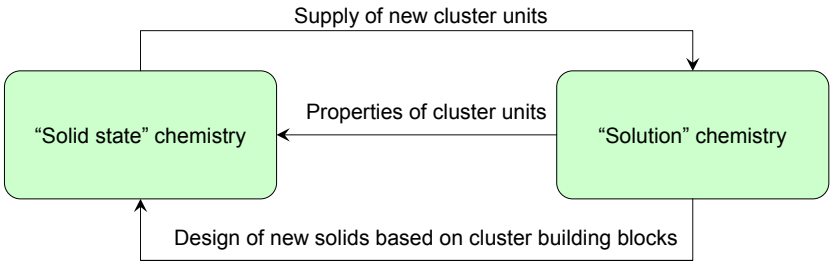
The salts containing this anion are **high soluble** in water and some organic solvents.

Transformations of tetrahedral cluster rhenium complexes

$ReCl_5 + 4Q + 5Te \longrightarrow Re_4Q_4(TeCl_2)_4Cl_8 + TeCl_4$ (Q = S, Se, Te)

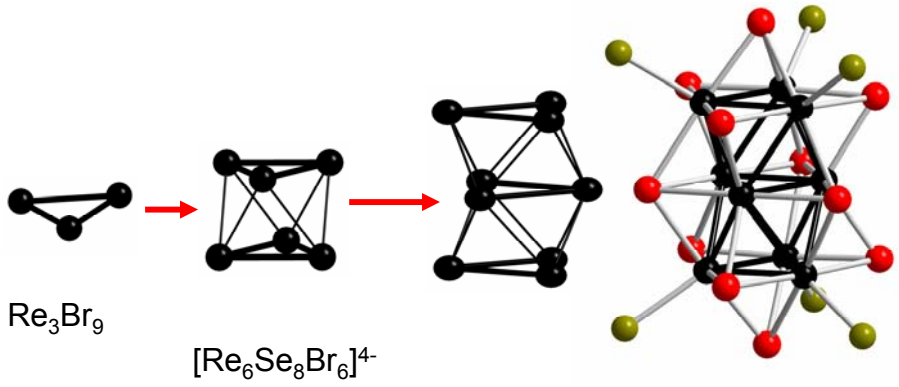


Interconnections between "solid state" and "solution" cluster chemistries



Properties of clusters that should be studied in molecular form:
- Local symmetry / disorder in cluster core;
- Redox properties;
- Electronic spectroscopy / vibrational spectroscopy / NMR
- Others…

Progressive condensation of cluster fragments in the high temperature reaction Re_3Br_9 + CdSe

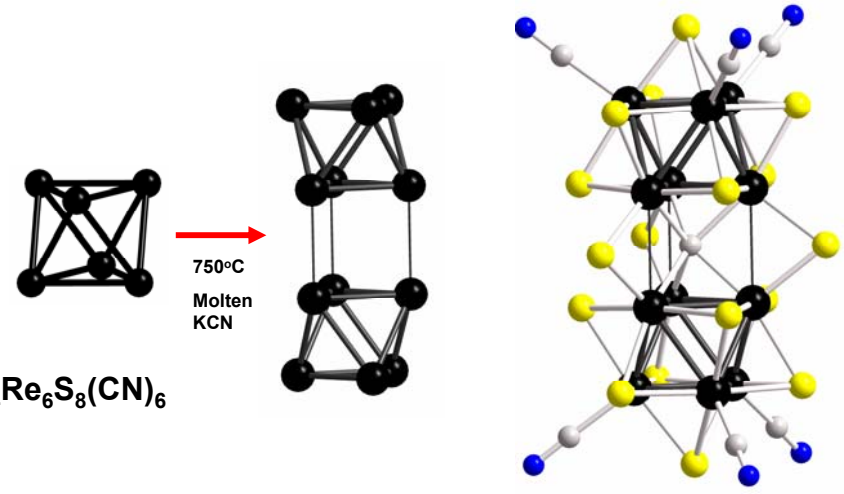


Re_3Br_9

$[Re_6Se_8Br_6]^{4-}$

$[Re_9Se_{11}Br_6]^{2-}$

"Condensation" of octahedral cluster fragments

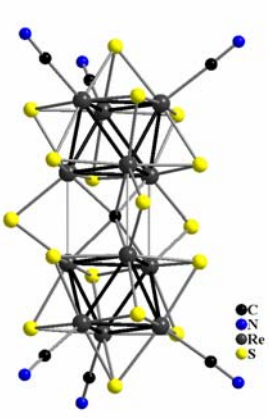


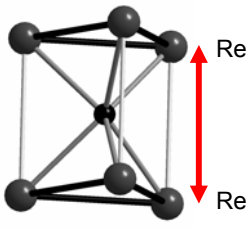
$K_4Re_6S_8(CN)_6$

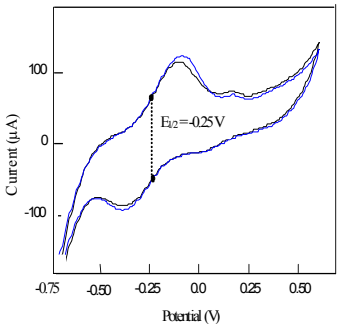
$K_8[Re_{12}CS_{17}(CN)_6]$

- Y.V. Mironov, N.G. Naumov, S.G. Kozlova, Sung-Jin Kim, V.E. Fedorov, *Angew. Chem., Int. Ed. Engl.*, **2005**, v.44, pp.6867-6871.

The structure of cluster anions $[Re_{12}CS_{17}(CN)_6]^{6-/8-}$



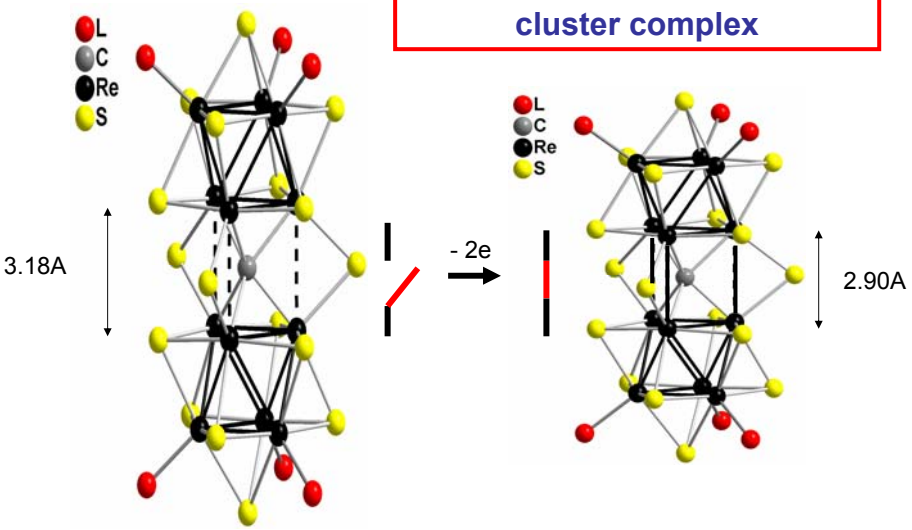




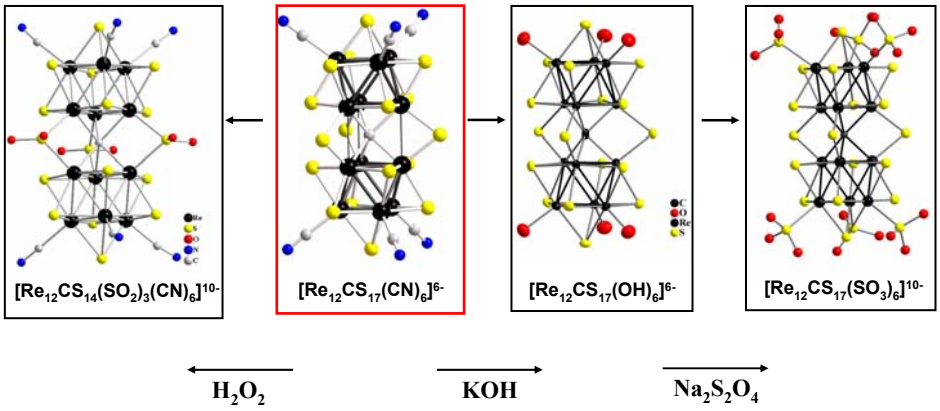
Anion 8- **Re-Re = 3.178-3.184Å**

Anion 6- **Re-Re = 2.904 Å**

One molecule electronic switch based on rhenium cluster complex

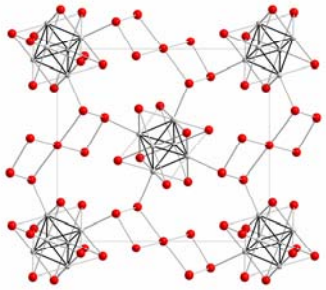


Chemical modification of ligand environment in cluster complex $K_6[Re_{12}CS_{17}(CN)_6]$



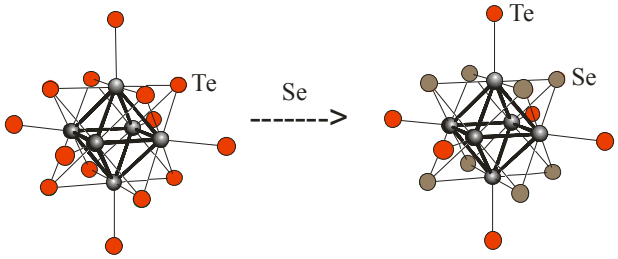
6 Re + 15 Te → $\{Re_6Te_8\}Te_7$

(900°C, molten tellurium)



Substitution of inner μ_3-Te ligands in cluster core $\{Re_6Te_8\}$ by Se atoms:

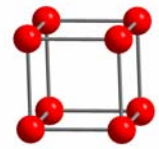
$\{Re_6Te_8\}Te_7$ + 8 Se + → $\{Re_6Te_{8-x}Se_x\}Te_7$ + 8 Te $(0 \leq x \leq 8)$

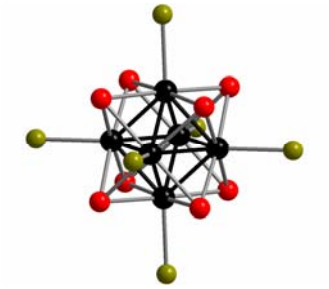


Octahedral mixed-ligands clusters

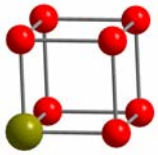
Distribution of inner ligands in cluster core $[Re_6Te_{8-x}Se_x]$

$[Re_6Te^i_8]$

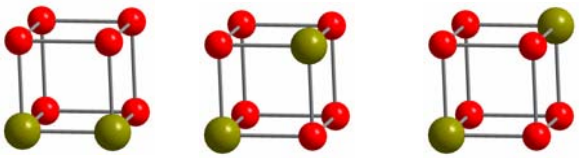




$[Re_6Te^i_7Se^i]$

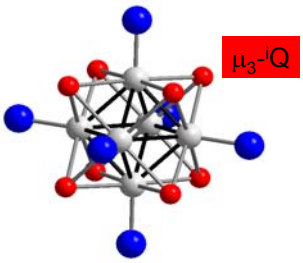


$[Re_6Te^i_6Se^i_2]$



Expected ratio of isomers 3 : 3 :1

Possible numbers of isomers in mixed ligand cluster cores $[Re_6(\mu_3\text{-}Q)_8]$ (Q = Te, Se)



Re_6Te_8	1
$Re_6Te_7Se_1$	1
$Re_6Te_6Se_2$	3
$Re_6Te_5Se_3$	3
$Re_6Te_4Se_4$	6
$Re_6Te_3Se_5$	3
$Re_6Te_2Se_6$	3
$Re_6Te_1Se_7$	1
Re_6Se_8	1
In sum :	**22**

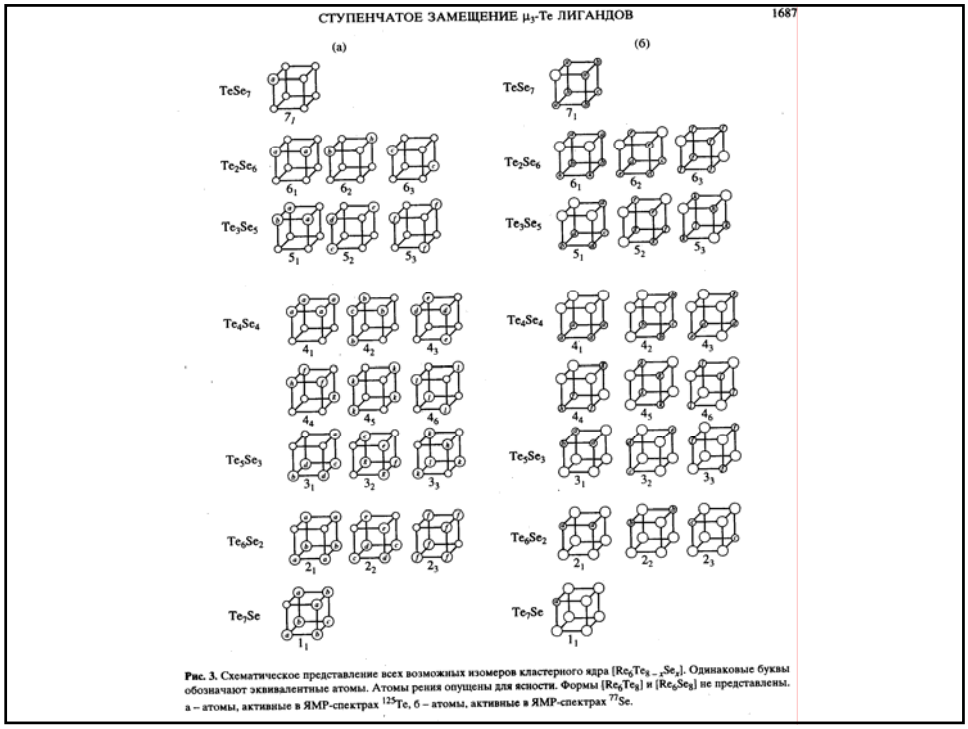
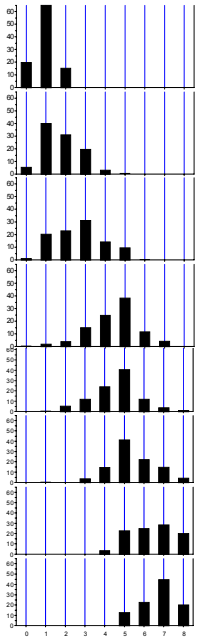


Рис. 3. Схематическое представление всех возможных изомеров кластерного ядра $[Re_6Te_{8-x}Se_x]$. Одинаковые буквы обозначают эквивалентные атомы. Атомы рения опущены для ясности. Формы $[Re_6Te_8]$ и $[Re_6Se_8]$ не представлены. а – атомы, активные в ЯМР-спектрах ^{125}Te, б – атомы, активные в ЯМР-спектрах ^{77}Se.



x in $\{Re_6Te_{8-x}Se_x\}Te_7$

1

2

3

4

5

6

7

8

y in $[Re_6Te_{8-y}Se_y(CN)_6]^{4-}$

Mixed ligand compounds

At high temperature substitution of inner ligands in the cluster core

$\{Re_6Te_8\}Te_7 + x\ Y\ (Y=S, Se) \longrightarrow \{Re_6Te_{8-x}Y_x\}Te_7 + x\ Te$

and further transformation of solids $\{Re_6Te_{8-x}Y_x\}Te_7$ into cyano complexes

$[Re_6Te_{8-x}Y_x]Te_7 + 6KCN\ (molten) \longrightarrow K_4[Re_6Te_{8-x}Y_x](CN)_6 + K_2Te_n + (7-n)Te$

a series of mixed ligand cluster complexes are formed.

It was established by NMR study of water soluble cyano complexes that there is an equilibrium between similar mixed ligand complexes. It means that any solid with *fixed* composition is an *averaged* mixture not only *geometrical* isomers, but also clusters with *different* composition. For example, a compound with nominal composition of cluster core $\{Re_6Te_8Se_2\}$ should be described as the compound containing a set of cluster core units:

$\{Re_6Te_8\}$, $\{Re_6Te_7Se_1\}$, **$\{Re_6Te_6Se_2\}$**, $\{Re_6Te_5Se_3\}$, $\{Re_6Te_4Se_4\}$ …

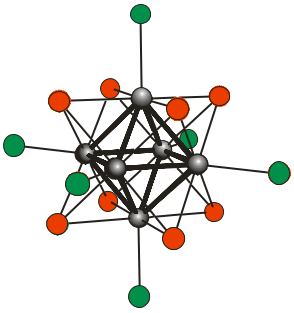
Such compounds will have *average* properties: structural, vibrational, electronic, redox, etc.

Y.V. Mironov, J.A. Cody, T.E. Albrecht-Schmitt, J.A. Ibers, *JACS*, 1997, v.119, pp.493-498.

V.E. Fedorov, S.V. Tkachev, N.G. Naumov, Y.V. Mironov, Y.I. Mironov, *Russ. J. Inorg. Chem.*, 1998, v.43, pp.1562-1571.

Octahedral rhenium(III) cluster complexes

Re - Re 2.60-2.66A



$[\{Re_6Q_8\}L_6]$

Q=S, Se, Te, Cl, Br, O

L=Cl, Br, I, OH, CN, SCN…

N-, P-, O-, S- donor organic ligands

Cluster cores:

$\{Re_6Se_4Br_4\}^{6+}$

$\{Re_5OsSe_8\}^{3+}$

$\{Re_6Se_8\}^{2+/3+}$ VEC=24 / 23 e per Re_6

$\{Re_5MoSe_8\}^{+}$

Cluster complexes:

$[Re_6S_8(H_2O)_6]^{2+}$ cationic complex

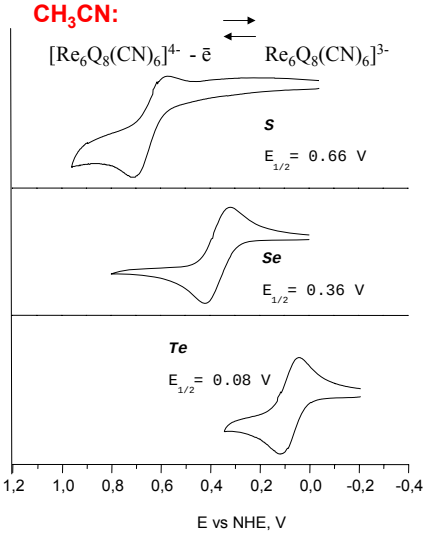
$[Re_6S_8(H_2O)_4(OH)_2]^{0}$ neutral complex

$[Re_6S_8Br_6]^{4-}$ anionic complex

$[Re_6S_8(SO_3)_6]^{10-}$ anionic complex

Properties of cluster anions $[Re_6Q_8(CN)_6]^{n-}$ (Q= S, Se, Te)

Electro-chemical behavior in CH_3CN:



Chemical oxidation:

$$[Re_6Q_8(CN)_6]^{4-} + \tfrac{1}{2}\,Br_2 \xrightarrow{CH_3CN \text{ or } H_2O} Re_6Q_8(CN)_6]^{3-} + Br^-$$

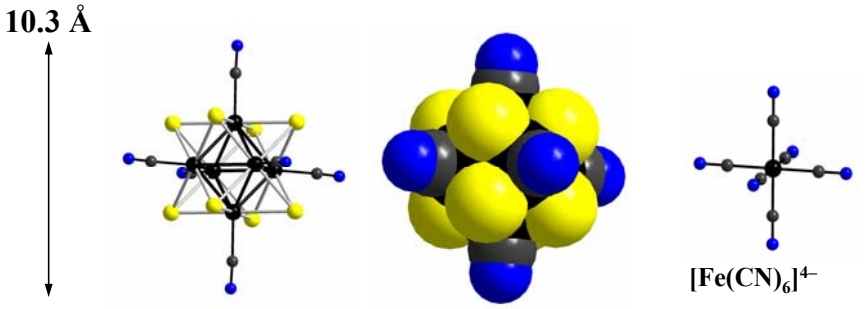
VEC=24 VEC=23

Magnetic moments of the compounds containing oxidized anions $[Re_6Q_8(CN)_6]^{3-}$ (VEC=23)

Compounds	μ_{eff}, BM (T=298K)
$(PPh_4)_3[Re_6S_8(CN)_6]$	1.9
$(PPh_4)_2(H)[Re_6Se_8(CN)_6]\cdot 4H_2O$	1.8
$(NBu_4)_2(H)[Re_6Te_8(CN)_6]$	1.9

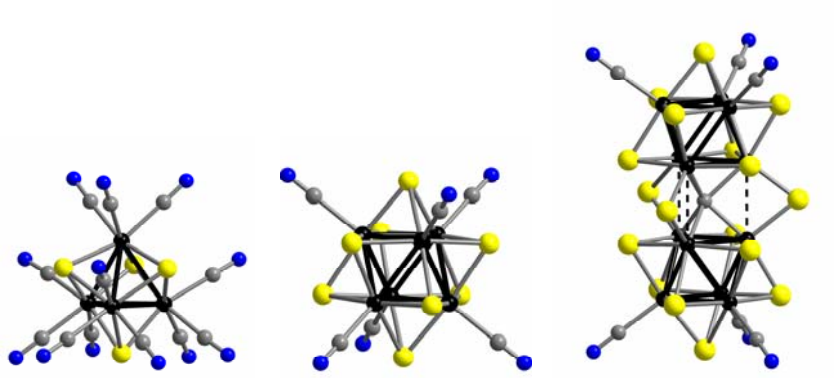
In rhenium chalcocyanide complexes $[Re_6(\mu_3\text{-}Q)_8(CN)_6]^{n-}$
six metal atoms form an octahedron cluster Re_6.
Eight μ_3 chalcogene ligands (S, Se, or Te) form a cube around the octahedron Re_6.
Six terminal CN-ligands are coordinated to each rhenium atom via carbon.
CN ligands are ambidentate and able to coordinate to other metals via N atoms.
The anions $[Re_6(\mu_3\text{-}Q)_8(CN)_6]^{n-}$ can be considered as geometrical analogs
of mononuclear cyanide complex $[Fe(CN)_6]^{4-}$ but possessing larger linear
and voluminous sizes due to cluster core $\{Re_6Q_8\}^{2+}$.

These cluster anions can be used as building blocks in design of coordination polymers.



Cyanide cluster rhenium complexes

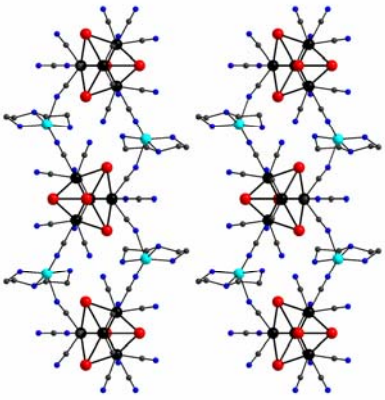
$[Re_4S_4(CN)_{12}]^{4-}$, $[Re_6S_8(CN)_6]^{4-/3-}$ and $[Re_{12}CS_{17}(CN)_6]^{8-/6-}$ as building blocks in the design of coordination polymers



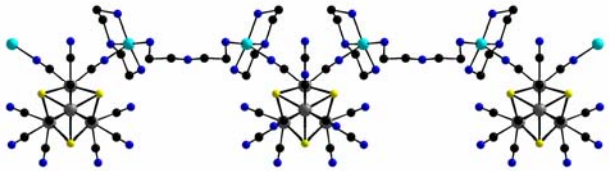
Synthetic approach:

From polymeric compounds
towards molecular complexes
and back again

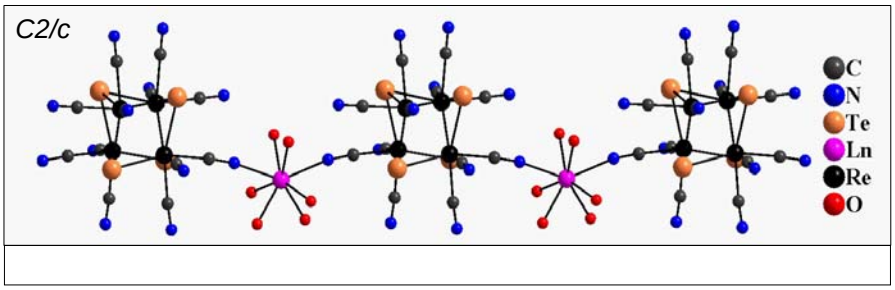
Chain-like structures based on chalcocyanide anions $[Re_4Q_4(CN)_{12}]^{4-}$



$[\{Cu(trien)\}_2Re_4Te_4(CN)_{12}]$

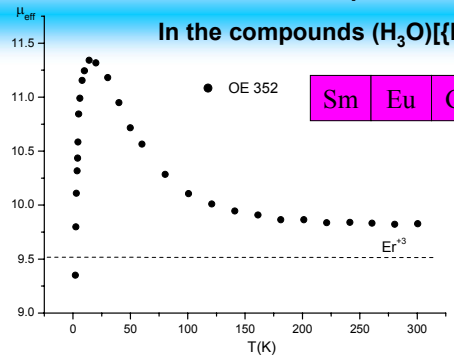


$[\{Cu_2(dien)_3\}Re_4S_4(CN)_{12}]$

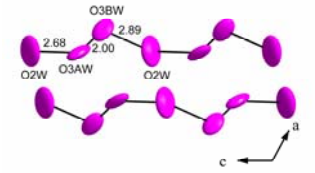


The chain of composition $\{[\{Ln(H_2O)_6\}Re_4Te_4(CN)_{12}]^{-}\}_\infty$

In the compounds $(H_3O)[\{Ln(H_2O)_6\}Re_4Q_4(CN)_{12}]\cdot xH_2O$



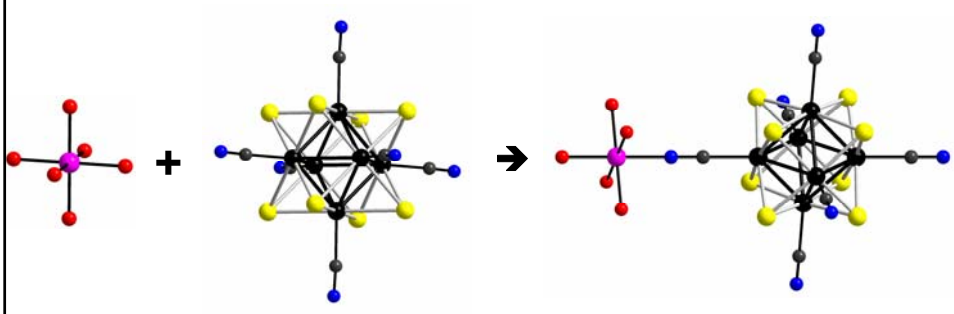
Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu



Design of solids based on octahedral chalcocyanide cluster complexes $[Re_6Q_8(CN)_6]^{4-/3-}$

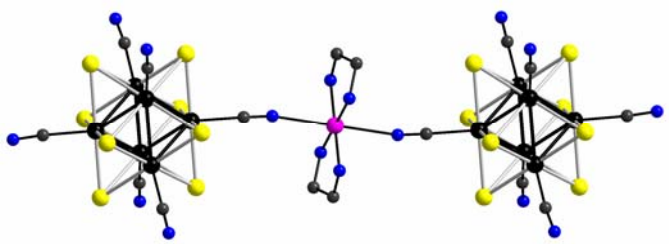
(use of ambidentate properties of cyanide ligands)

$[M(H_2O)_6]^{2+} + [Re_6Q_8(CN)_6]^{4-/3-}$



Anionic fragment $[Cu(en)_2\{Re_6Te_8(CN)_6\}_2]^{6-}$

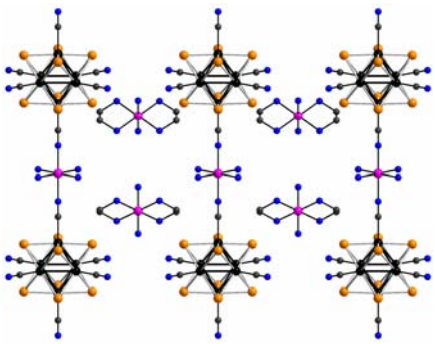
in the structure $(Et_4N)_2[CuNH_3(en)_2]_2\,[Cu(en)_2\{Re_6Te_8(CN)_6\}_2]\cdot 2H_2O$



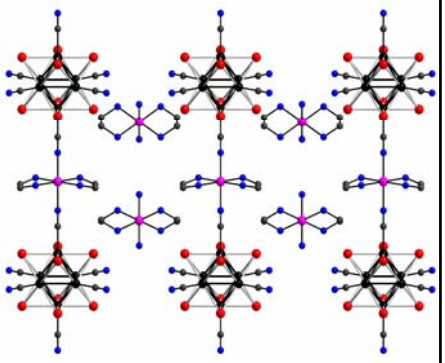
Cluster compounds with infinite cyano-bridged linear chains

$[Ni(NH_3)_2(en)_2]_2[\{Ni(NH_3)_4\}Re_6Q_8(CN)_6]Cl_2\cdot nH_2O$

(Q = Se, Te)



$[Co(NH_3)_2(en)_2]_2[\{Co(en)_2\}Re_6Te_8(CN)_6]Cl_2\cdot H_2O$

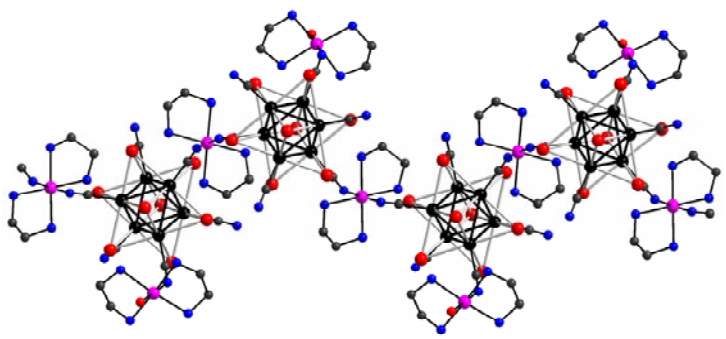


H, Se, Te, Cl atoms and water molecules are omitted for clarity

***trans*-connections**

Structures with infinite zig-zag cyano-bridged chains

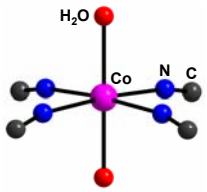
$$Zn^{2+} + [Re_6Te_8(CN)_6]^{4-} + en \xrightarrow{H_2O} [\{Zn(H_2O)(en)_2\}\{Zn(en)_2\}Re_6Te_8(CN)_6]\cdot 3H_2O$$



***cis*-connections**

Layered structure of compounds $Cs_2[\{M(H_2O)_2\}\{Re_6S_8(CN)_6\}]$ ($M=Mn^{2+}$, Fe^{2+}, Co^{2+}, Cd^{2+})

Orthorhombic, Space group *Imma*



Coordination environment of Co^{2+} cation

Co-N(NC) 2.16 Å
Co-O(OH_2) 2.05; 2.09 Å
O-Co-O 180°

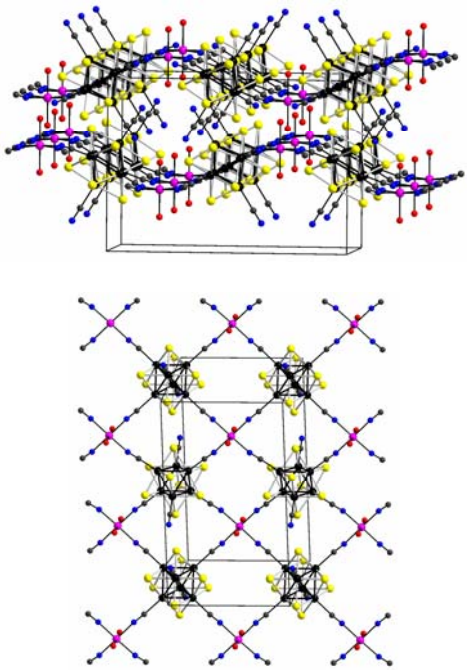
Short S-S contacts:

3.32 Å within layer;
3.67 Å between adjacent layers

Similar structure is not realized for Se

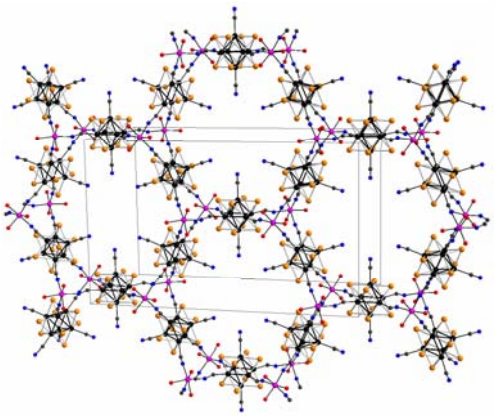
N.G. Naumov, A.V. Virovets, Y.I. Mironov, S.B. Artemkina, V.E. Fedorov,

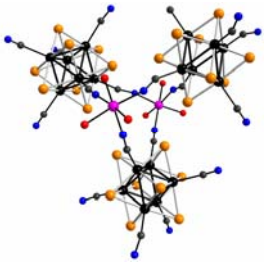
Ukraine Chem. J., **1999**, v.65, pp.21-27.

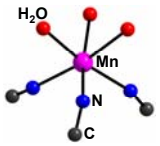


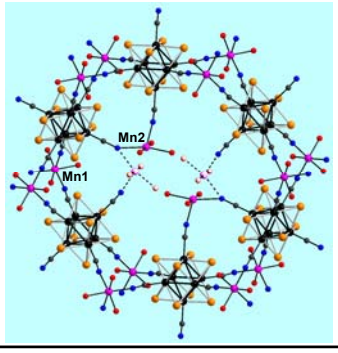
Polymeric structure of compound $[\{Mn(H_2O)_3\}_2\{Re_6Se_8(CN)_6\}]\cdot 3.3H_2O$

One layer of composition
$\{\{Mn(H_2O)_3\}_4\{Re_6Se_8(CN)_6\}_3\}^{4-}{}_{\infty\infty}$

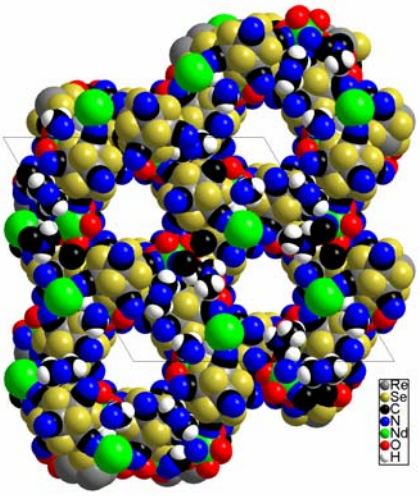


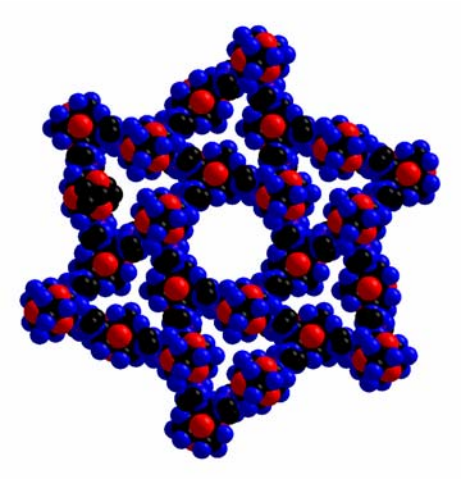






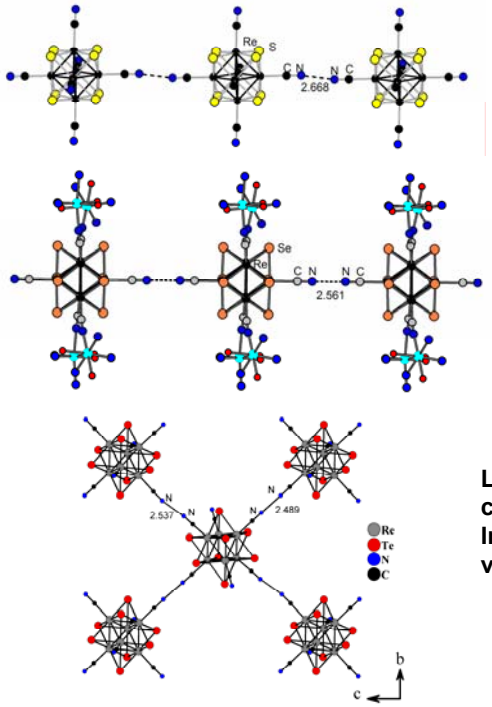
Structures having large one-dimensional channels (~ 8-12 Å)





$(H_3O)[\{Ln(H_2O)_3(dmf)_3\}\{Re_6Q_8(CN)_6]$
(Ln = Pr, Nd, Sm, Ho; Q=S, Se, Te)

$(NH_4)_2[\{Ni(en)_2\}_3\{Re_4Te_4(CN)_{12}\}_2]$



Hydrogen bonding in chain-like structures of compounds

$[(H)\{Lu(H_2O)_4\}\{Re_6S_8(CN)_6\}]\ 2H_2O$

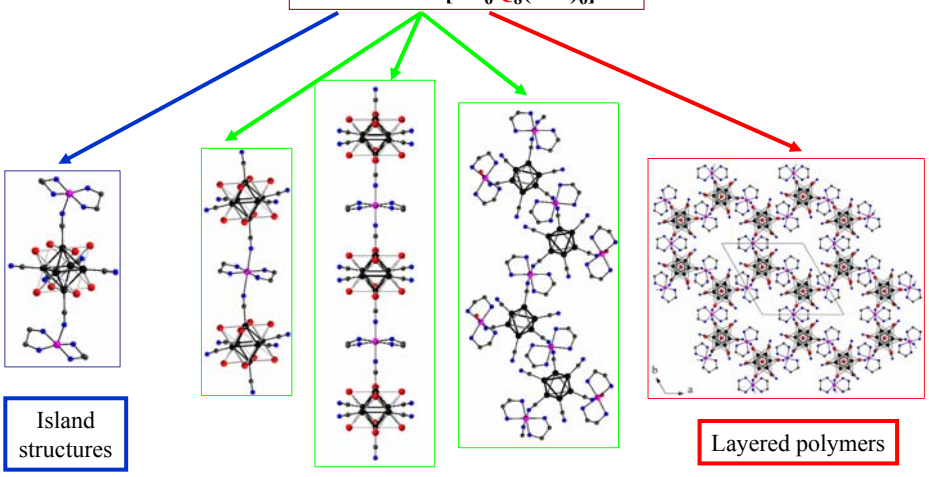
and

$[(H)\{Zn(H_2O)_2\}\{Re_6Se_8(CN)_6\}]\ 2H_2O$

Layers forming by connection of cluster anions $[Re_6Te_8(CN)_6]^{3-}$
In compound $[H_2Re_6Te_8(CN)_6]\ H_3O$
via **strong hydrogen bonding**

Complexes containing ethylenediamine ligands

$M^{2+} + en + [Re_6Q_8(CN)_6]^{4-}$



Island structures

Chain-like polymers

Layered polymers

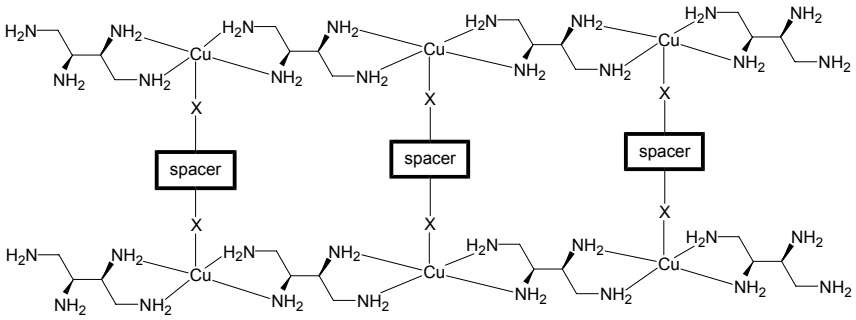
Reactions of cluster anions $[Re_6Q_8(CN)_6]^{4-}$ with cations Cu^{2+} and chiral tetraaminebuthane (1,2S,3S,4,- *threo*-tab)

Y. Mironov, N. Naumov, K. Brylev, O. Efremova, V. Fedorov, K. Hegetschweiler,
Angew. Chem., Int. Ed., 2004, v.43, N10, pp.1297-1300.

$$K_4Re_6Te_8(CN)_6 + CuCl_2 + tab + NH_4OH \rightarrow [\{Cu(tab)\}_2Re_6Te_8(CN)_6]$$

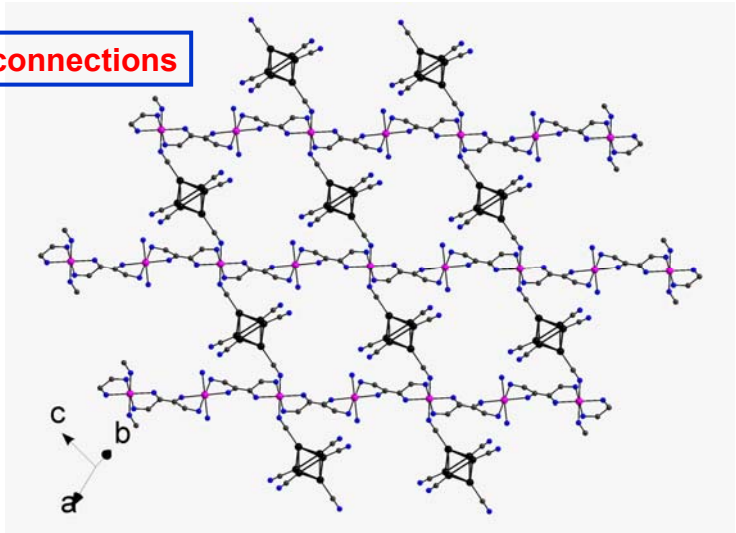
$$K_4Re_6Q_8(CN)_6 + CuCl_2 + tab + NH_4OH \rightarrow [\{Cu_2(tab)\}_3(NH_3)\}Re_6Q_8(CN)_6]$$

Q=S, Se



Flat layer in structure of compound $[\{Cu_2(tab)_3(NH_3)\}Re_6Se_8(CN)_6]\cdot 2.5H_2O$

***trans*-connections**

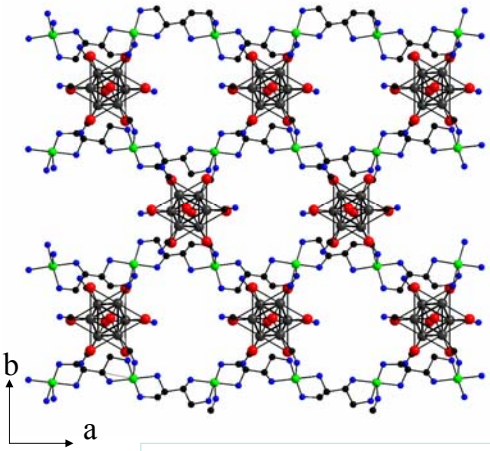


Миронов Ю.В., Наумов Н.Г., Брылев К.А., Ефремова О.А., Федоров В.Е., Хегечвайлер К., *Координационная химия*, 2005, т. 31, №4, с.289-301.

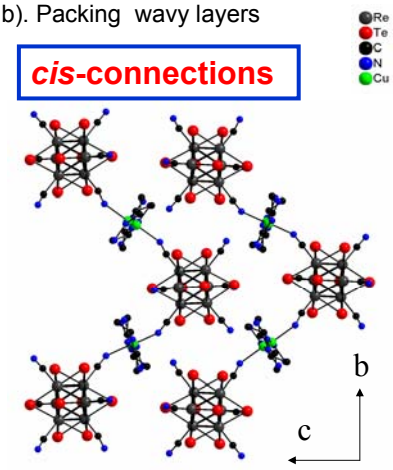
Structure of $[\{Cu(tab)\}_2Re_6Te_8(CN)_6]\cdot 13.5\ H_2O$

Orthorhombic, Space group $P2_12_12_1$, a = 13.767, b = 19.692, c = 21.780 Å

a). One layer



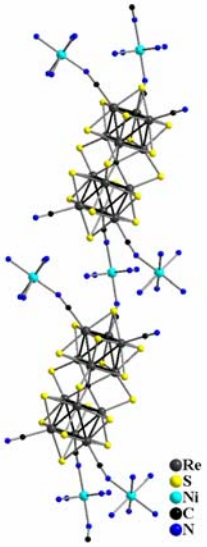
b). Packing wavy layers

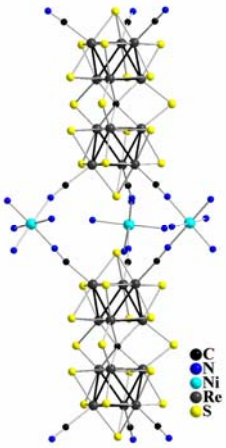


Y. Mironov, N. Naumov, K. Brylev, O. Efremova, V. Fedorov, K. Hegetschweiler, *Angew. Chem., Int. Ed.*, 2004, v.43, N10, pp.1297-1300.

Cyano-bridged complexes based on anion $[Re_{12}CS_{17}(CN)_6]^{6-}$

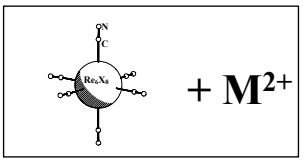
$[\{Ni(NH_3)_5\}_2\{Ni(NH_3)_4\}Re_{12}CS_{17}(CN)_6]$

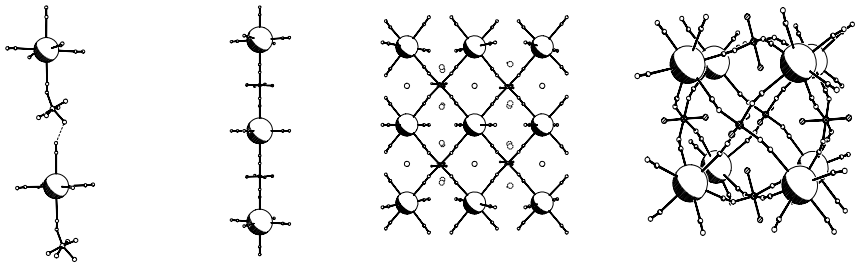




$[\{Ni(NH_3)_4\}_3\{Re_{12}CS_{17}(CN)_6\}_2]$

Design philosophy of cyano-bridged coordination polymers





0D 1D 2D 3D

Cancer therapy

Radiotherapy

$^{186}_{75}Re \xrightarrow{\tau_{1/2}= 90ч.} {}^{186}_{76}Os + \bar{e}$

$^{188}_{75}Re \xrightarrow{\tau_{1/2}= 17ч.} {}^{188}_{76}Os + \bar{e}$

lung

^{188}Re

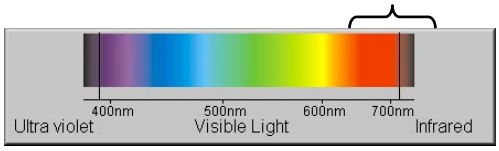
Photodynamic therapy (PDT)

$A + h\nu \longrightarrow A^*$

$A^* \longrightarrow h\nu_1 + A$

$h\nu_1 + O_2(T) \longrightarrow O_2(S)$

Field of application PDT



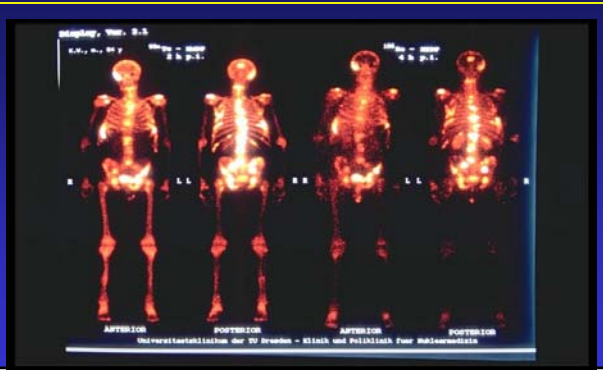
Cancer therapy

Radiotherapy

$$^{186}_{75}Re \xrightarrow{\tau_{1/2}= 90\text{ч.}} {}^{186}_{76}Os + \bar{e}$$

$$^{188}_{75}Re \xrightarrow{\tau_{1/2}= 17\text{ч.}} {}^{188}_{76}Os + \bar{e}$$

Technetium-Diagnostika und Rhenium-Therapeutika



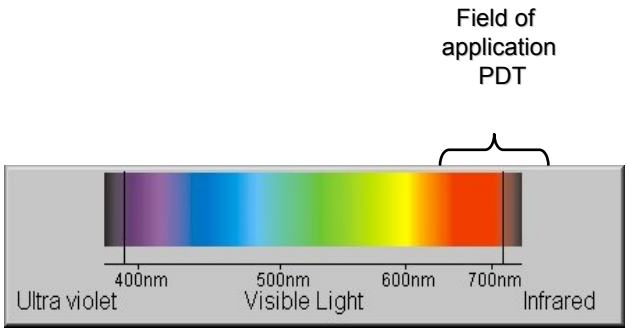
Cancer therapy

Photodynamic therapy (PDT)

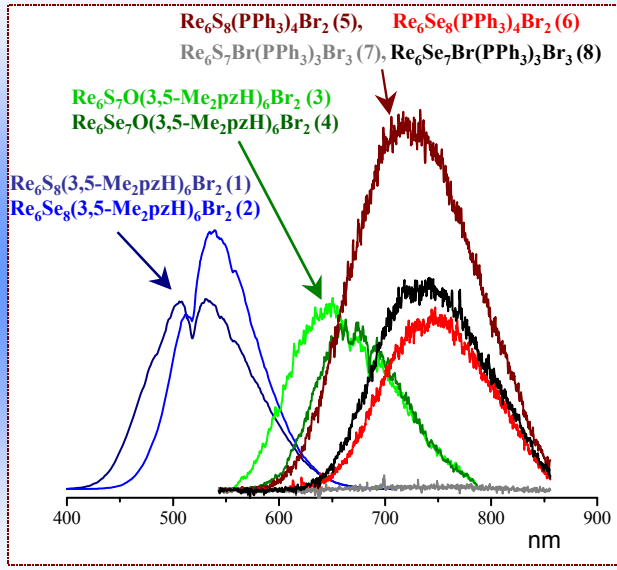
$$A + h\nu \longrightarrow A^*$$

$$A^* \longrightarrow h\nu_1 + A$$

$$h\nu_1 + O_2(T) \longrightarrow O_2(S)$$

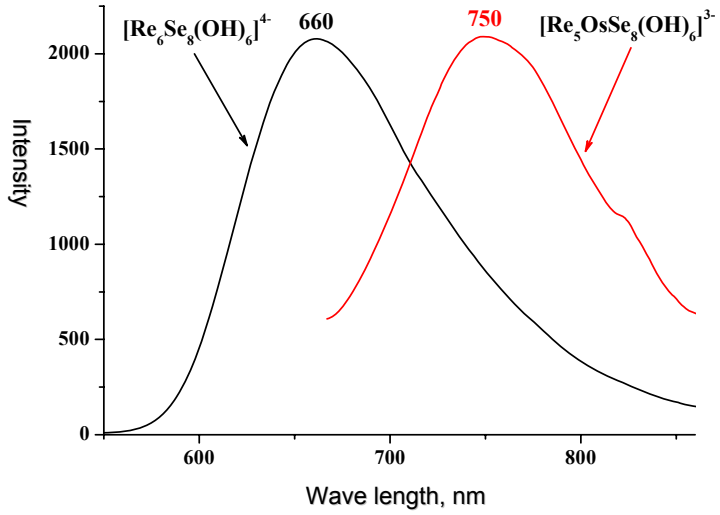


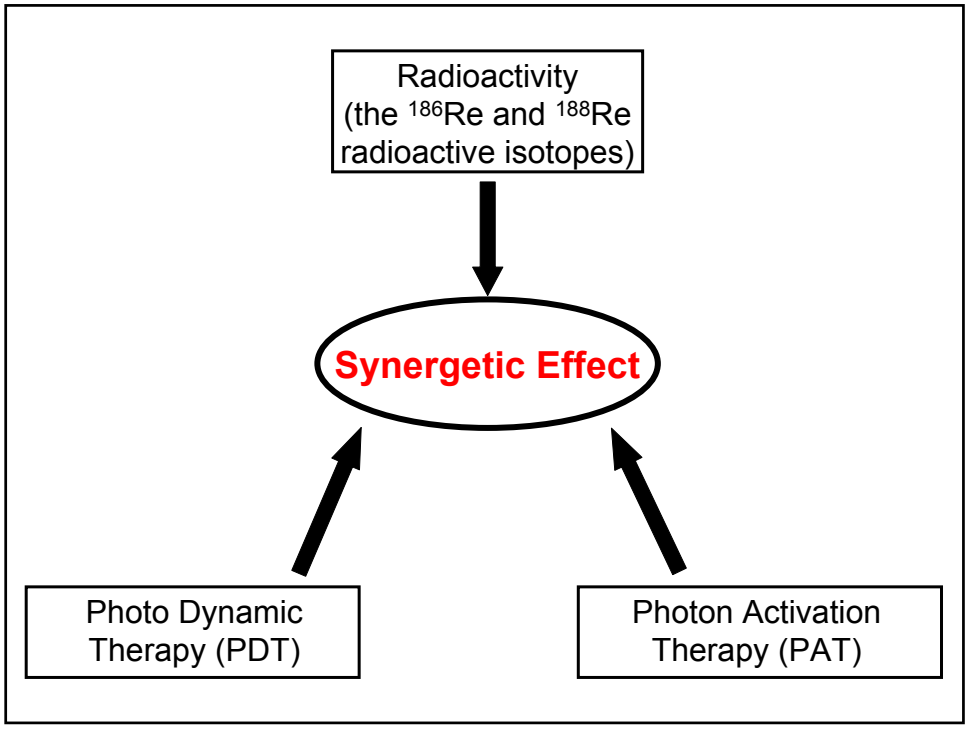
Luminescent properties of octahedral cluster rhenium complexes



№	Инт-ть (усл.ед.)	$\tau_{жизни}$ (мкс)	λ (нм)
1	5525	3.25	505 530
2	7552	4.31	511 539
3	93	0.62	650
4	82	0.49	679
5	43389	5.52	720
6	19726	3.21	742
7	-	-	-
8	23717	1.02	734

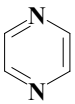
Influence of substitution of metal atoms in cluster core on luminescent properties of cluster complexes





Reactions in molten organic ligands

Pyrazine
(pyz)

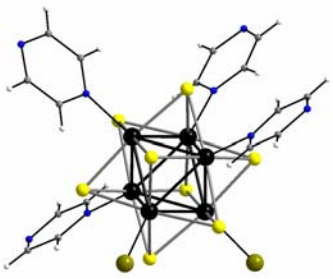


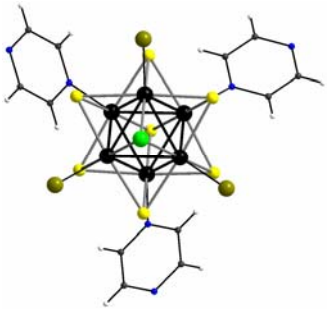
m.p.=52°C

$Cs_4[\{Re_6S_8\}Br_6]$ | $Cs_3[\{Re_6Q_7Br\}Br_6]$ (Q=S, Se)

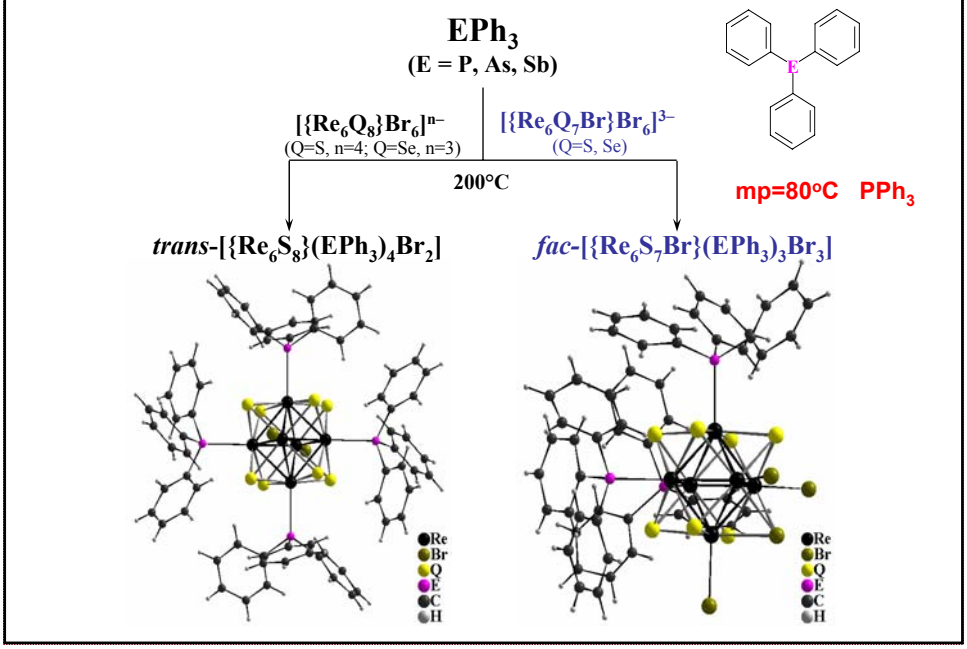
160°C

цис-$[\{Re_6S_8\}(pyz)_4Br_2]\cdot pyz$ | *гран*-$[\{Re_6Q_7Br\}(pyz)_3Br_3]$

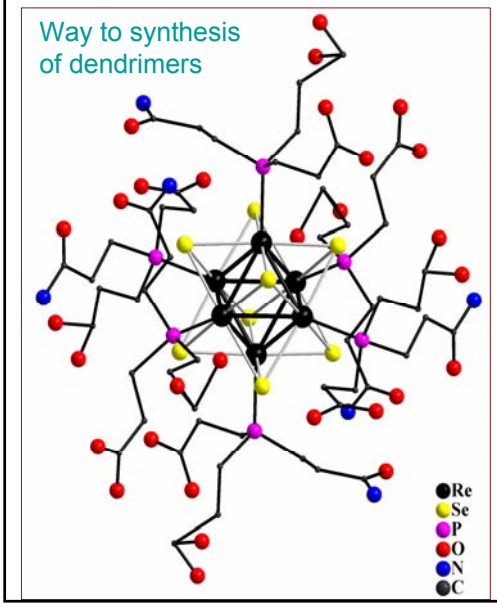


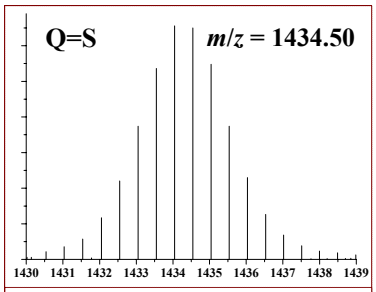


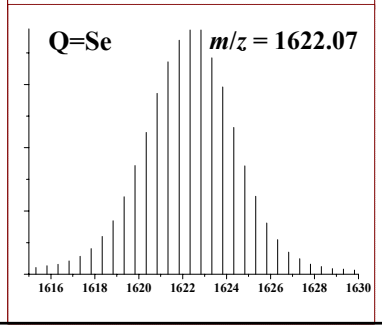
Reactions within molten EPh_3 (E = P, As, Sb)



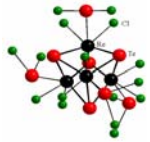
Structure and mass-spectra of anion $[\{Re_6Q_8\}\{P(C_2H_4COO)_2(C_2H_4CONH_2)\}_6(H)_8]^{2-}$ (Q=S, Se)







Tetrahedral rhenium cluster complexes with organic ligands (*L*)

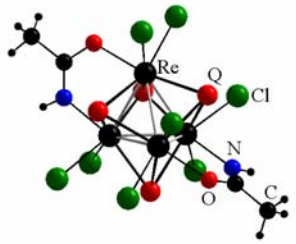


$[Re_4Q_4(TeCl_2)_4Cl_8]$

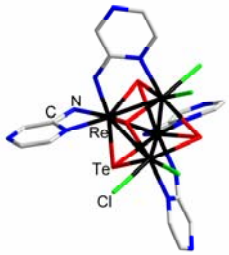
+ MeCN

+ $C_4H_5N_3$ (in DMF)

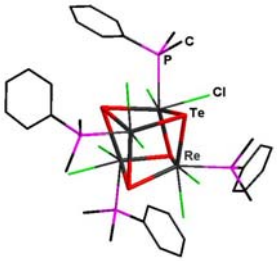
+ PMe_2Ph (in CH_2Cl_2)



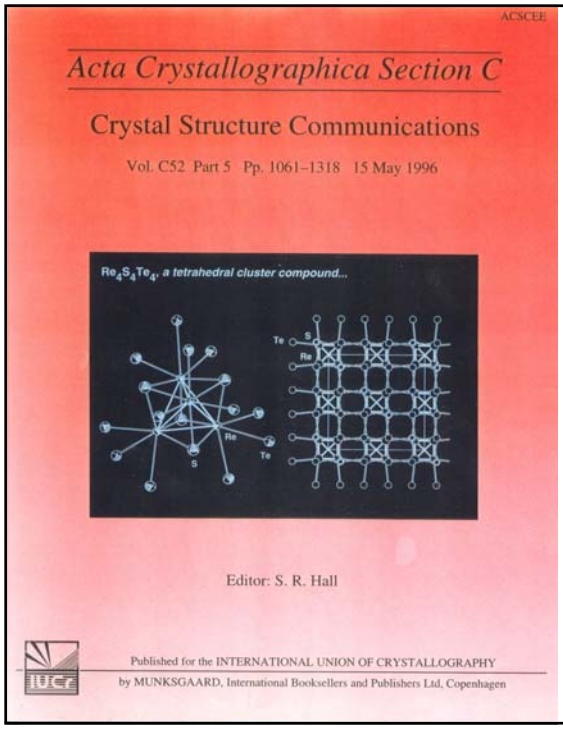
$[Re_4Q_4(CH_3CONH)_2Cl_8]^{2-}$
L=acetamide



$[Re_4Q_4Cl_4(C_4N_3H_4)_4]$
L=2-aminopyrazine



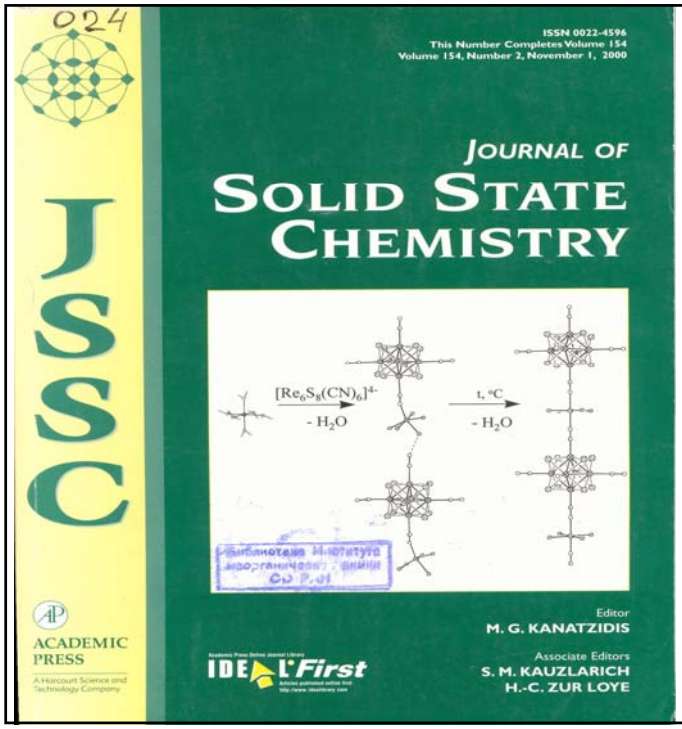
$[Re_4Q_4(PMe_2Ph)_4Cl_4]$
L=dimethylphenylphosphine



V.E. Fedorov,
Yu.V. Mironov,
V.P. Fedin,
H. Imoto,
T. Saito

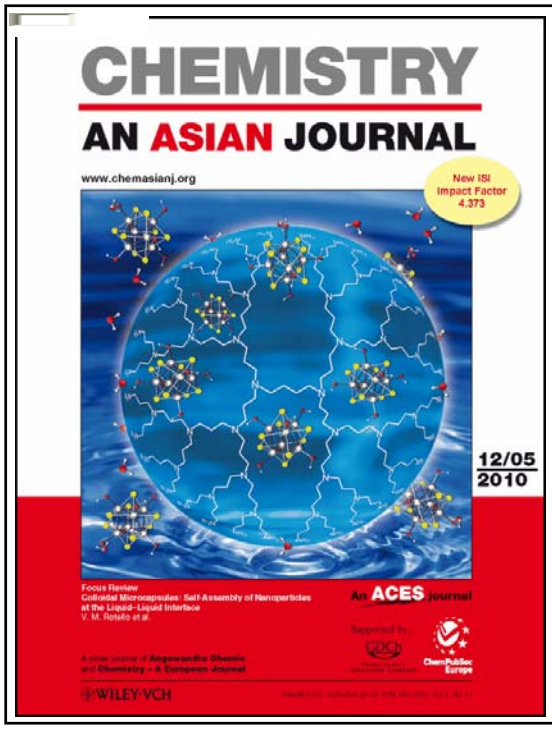
$Re_4S_4Te_4$

Acta Cryst., **1996**, v.C52, pp.1065-1067.



N.G. Naumov, S.B. Artemkina, A.V. Virovets, V.E. Fedorov

J. Solid State Chem., **2000**, v.153, N2, pp.195-204.

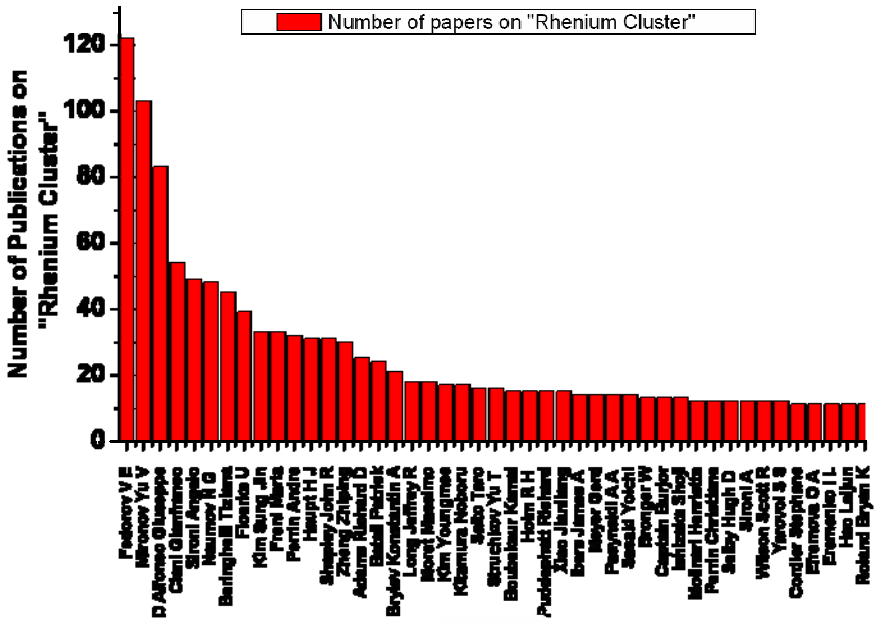


Cover Picture: Sugar-Decorated Dendritic Nanocarriers: Encapsulation and Release of the Octahedral Rhenium Cluster Complex [Re**6**S**8**(OH)**6**]**4−** (Chem. Asian J. 12/2010) *(page 2429)*

Manja Kubeil, Holger Stephan, Hans-Jürgen Pietzsch, Gerhard Geipel, Dietmar Appelhans, Brigitte Voit, Jan Hoffmann, Bernhard Brutschy, Yuri V. Mironov, Konstantin A. Brylev and Vladimir E. Fedorov

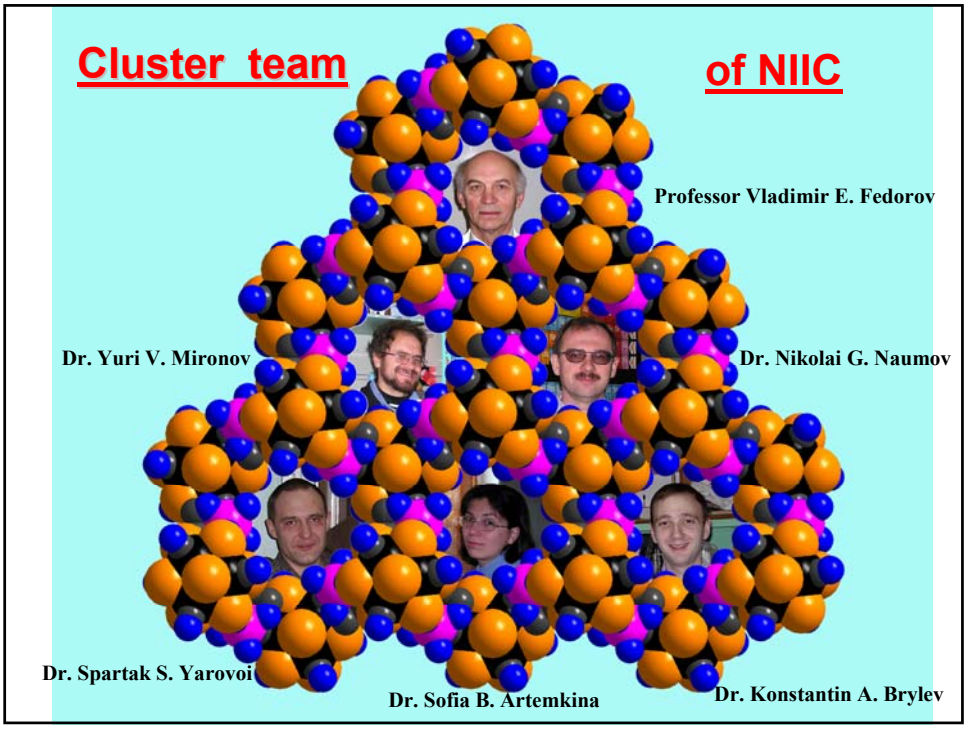
Article first published online: 1 DEC 2010 | DOI: 10.1002/asia.201090041

Our contribution to cluster science of rhenium



CONCLUSION:

- More than two hundreds of new complex cluster rhenium compounds are synthesized; some complexes playing key role in cluster chemistry of transition metals were discovered.
- Structures and properties of all compounds obtained were studied by a set of modern high informative methods.
- More than two hundreds articles including several reviews have been published in high level journals.
- 3 dissertations of Doctor of Chemical Sciences and 11 dissertations of Candidate of Chemical Sciences were prepared and defended successfully.
- Many reports including invited lectures were presented on different international scientific conferences.



International cooperation

Castellon, Spain:
Prof. R. Llusar

Stuttgart, Germany:
Prof. A. Simon

Evanston, USA:
Prof. J. Ibers

Seoul, Korea:
Prof. S.J. Kim

Sapporo, Japan:
Prof. N. Kitamura

Rennes, France:
Prof. A. Perrin
Dr. C. Perrin

Dresden, Germany:
Dr. H.-Ju. Pietsch

Bochum, Germany:
Prof. W.S. Sheldrick

Financial support:
- **Russian Foundation for Basic Research**
- **INTAS**
- **International research projects with Germany, USA, France, Korea, Taiwan**


Спасибо за внимание!