

Terre rare: cosa sono e loro posizione nella tavola periodica

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Sfide e opportunità per le tecnologie future

Sabato 14 Marzo 2026

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REE: definition and properties... according to AI

Copilot

Definition

Rare earths are a group of **17 metallic elements that are chemically similar** and extremely important for modern technology.

General macroscopic characteristics

- Silvery-white metals, tarnish in air
- Medium-high density; increases with atomic number
- High melting points
- Strong magnetism for many; basis for super-magnets
- Good electrical and thermal conductors
- **Usually found together in the same minerals**
- Form stable, high-melting oxides; react with water and acids
- Bright distinctive colors

ChatGPT

Definition

Rare earth elements are a set of **17 metallic elements** that include the lanthanide series from Lanthanum to Lutetium together with Scandium and Yttrium, **which have very similar chemical properties.**

- **General macroscopic characteristics**
- Silvery metallic appearance
- Medium-high density
- High melting points
- Often paramagnetic or ferromagnetic
- Good metallic conductors
- Oxidize easily
- **Similar chemical behavior**
- Characteristic colors

Official definition

Nomenclature of Inorganic Compounds

IUPAC Recommendations 2005 (IR-3.5)

Red book

The following collective names for like elements are IUPAC-approved: alkali metals (Li, Na, K, Rb, Cs, Fr), alkaline earth metals (Be, Mg, Ca, Sr, Ba, Ra), pnictogens (N, P, As, Sb, Bi), chalcogens (O, S, Se, Te, Po), halogens (F, Cl, Br, I, At), noble gases (He, Ne, Ar, Kr, Xe, Rn), lanthanoids (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu), **rare earth metals (Sc, Y and the lanthanoids)** and actinoids (Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr).

“Lanthanoids (La to Lu) is preferred over lanthanide, and although lanthanoid means ‘like lanthanum’ and so should not include lanthanum, lanthanum has become included by common usage, however.”

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Rare earth metals or rare earth elements (REE)

«Sc, Y and the lanthanoids»

Sc	Scandium	Z = 21
Y	Yttrium	Z = 39
La	Lanthanum	Z = 57
Ce	Cerium	
Pr	Praseodymium	
Nd	Neodymium	
Pm	Promethium	
Sm	Samarium	
Eu	Europium	
Gd	Gadolinium	
Tb	Terbium	
Dy	Dysprosium	
Ho	Holmium	
Er	Erbium	
Tm	Thulium	
Yb	Ytterbium	
Lu	Lutetium	Z = 71

17 elements

REE and the EU Critical Raw Material Act



Official Journal
of the European Union

EN
L series

2024/1252

3.5.2024

REGULATION (EU) 2024/1252 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 11 April 2024

establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020

«Access to raw materials is essential for the Union economy and the functioning of the internal market. **There is a set of non-energy, non-agricultural raw materials that are considered to be critical due to their high economic importance and their exposure to high supply risk, often caused by a high concentration of supply from a few third countries.** Given the **key role** of many such critical raw materials in realising the **green and digital transitions** and in light of their use for **defence** and **aerospace applications** demand is likely to increase exponentially in the coming decades. At the same time, the risk of supply disruptions is increasing against the background of rising geopolitical tensions and resource competition. Furthermore, if not managed properly, increased demand for critical raw materials could lead to negative environmental and social impacts.»

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ANNEX II

Critical raw materials

Section 1

List of critical raw materials

The following raw materials shall be considered critical:

- | | | |
|-------------------------------|-------------------------------|----------------------------|
| (a) antimony | | |
| (b) arsenic | (o) hafnium | (y) phosphate rock |
| (c) bauxite/alumina/aluminium | (p) helium | (z) phosphorus |
| (d) baryte | | (aa) platinum group metals |
| (e) beryllium | (q) heavy rare earth elements | (ab) scandium |
| (f) bismuth | (r) light rare earth elements | (ac) silicon metal |
| (g) boron | (s) lithium | (ad) strontium |
| (h) cobalt | (t) magnesium | (ae) tantalum |
| (i) coking coal | (u) manganese | (af) titanium metal |
| (j) copper | (v) graphite | (ag) tungsten |
| (k) feldspar | (w) nickel — battery grade | (ah) vanadium. |
| (l) fluorspar | (x) niobium | |
| (m) gallium | | |
| (n) germanium | | |

ANNEX I

Strategic raw materials

Section 1

List of strategic raw materials

The following raw materials shall be considered strategic:

- (a) bauxite/alumina/aluminium
- (b) bismuth
- (c) boron — metallurgy grade
- (d) cobalt
- (e) copper
- (f) gallium
- (g) germanium
- (h) lithium — battery grade
- (i) magnesium metal
- (j) manganese — battery grade
- (k) graphite — battery grade
- (l) nickel — battery grade
- (m) platinum group metals
- (n) rare earth elements for permanent magnets (Nd, Pr, Tb, Dy, Gd, Sm, and Ce)
- (o) silicon metal
- (p) titanium metal
- (q) tungsten.

strategic raw materials
are relevant for:

- defence
- aerospace applications
- green and digital transition

Why «rare earths»?

Name coined between the late 18th and the early 19th century, when these elements were first discovered and isolated.

- 1789, Carl Axel Arrhenius, Ytterby Mine, Sweden
- Johan Gadolin, Finland



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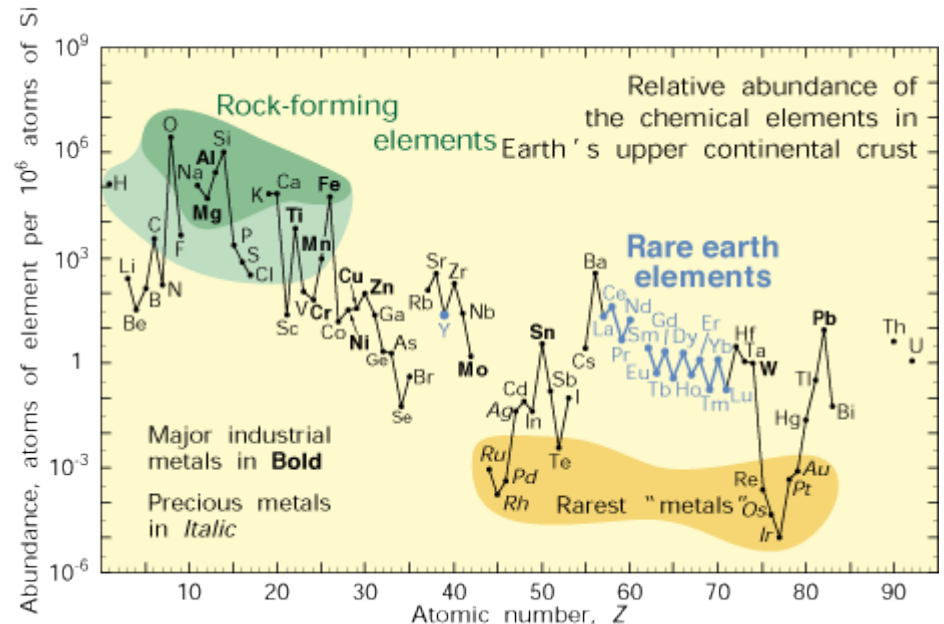
Why «rare earths»?

rare ≠ scarce in nature

- rarity of the minerals (uncommon and only in few locations)
- difficult to obtain in pure form and to separate

earth = metallic oxide

- they are found in nature as mixtures of oxides RE_2O_3



Gordon B. Haxel, Sara Boore, and Susan Mayfield from USGS Fact sheet 087-02 2002

Discovery



1735-1843

1843-1886

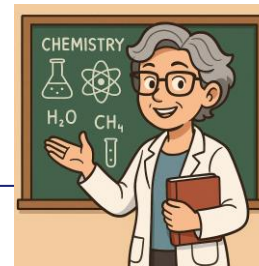
1894-1918

1923-1961

Nonnaturally occurring, human-made in 1947

- Challenging for Mendeleev's theory (separated group? In d-block?)
- Positioned in f-block only after the development of Bohr's atomic model and Moseley's x-ray spectroscopy studies

The periodic table



IUPAC Periodic Table, latest version 4th May 2022 groups 1-18

periods 1-7

1 2 3 4 5 6 7	1 H hydrogen 1.0080 ± 0.0002	2 He helium 4.0026 ± 0.0001	<p>s-block main group</p> <p>d-block transition metals</p> <p>p-block main group</p> <p>f-block inner transitions metals</p>										13 B boron 10.81 ± 0.02	14 C carbon 12.011 ± 0.002	15 N nitrogen 14.007 ± 0.001	16 O oxygen 15.999 ± 0.001	17 F fluorine 18.998 ± 0.001	18 Ne neon 20.180 ± 0.001		
	3 Li lithium 6.94 ± 0.06	4 Be beryllium 9.0122 ± 0.0001	5 Sc scandium 44.956 ± 0.001	6 Ti titanium 47.867 ± 0.001	7 V vanadium 50.942 ± 0.001	8 Cr chromium 51.996 ± 0.001	9 Mn manganese 54.938 ± 0.001	10 Fe iron 55.845 ± 0.002	11 Co cobalt 58.933 ± 0.001	12 Ni nickel 58.693 ± 0.001	13 Cu copper 63.546 ± 0.003	14 Zn zinc 65.38 ± 0.02	13 Al aluminum 26.982 ± 0.001	14 Si silicon 28.085 ± 0.001	15 P phosphorus 30.974 ± 0.001	16 S sulfur 32.06 ± 0.02	17 Cl chlorine 35.45 ± 0.01	18 Ar argon 39.95 ± 0.16		
	11 Na sodium 22.990 ± 0.001	12 Mg magnesium 24.305 ± 0.002	19 K potassium 39.098 ± 0.001	20 Ca calcium 40.078 ± 0.004	21 Sc scandium 44.956 ± 0.001	22 Ti titanium 47.867 ± 0.001	23 V vanadium 50.942 ± 0.001	24 Cr chromium 51.996 ± 0.001	25 Mn manganese 54.938 ± 0.001	26 Fe iron 55.845 ± 0.002	27 Co cobalt 58.933 ± 0.001	28 Ni nickel 58.693 ± 0.001	29 Cu copper 63.546 ± 0.003	30 Zn zinc 65.38 ± 0.02	31 Ga gallium 69.723 ± 0.001	32 Ge germanium 72.630 ± 0.008	33 As arsenic 74.922 ± 0.001	34 Se selenium 78.971 ± 0.008	35 Br bromine 79.904 ± 0.003	36 Kr krypton 83.798 ± 0.002
	37 Rb rubidium 85.468 ± 0.001	38 Sr strontium 87.62 ± 0.01	39 Y yttrium 88.906 ± 0.001	40 Zr zirconium 91.224 ± 0.002	41 Nb niobium 92.906 ± 0.001	42 Mo molybdenum 95.95 ± 0.01	43 Tc technetium [97]	44 Ru ruthenium 101.07 ± 0.02	45 Rh rhodium 102.91 ± 0.01	46 Pd palladium 106.42 ± 0.01	47 Ag silver 107.87 ± 0.01	48 Cd cadmium 112.41 ± 0.01	49 In indium 114.82 ± 0.01	50 Sn tin 118.71 ± 0.01	51 Sb antimony 121.76 ± 0.01	52 Te tellurium 127.60 ± 0.03	53 I iodine 126.90 ± 0.01	54 Xe xenon 131.29 ± 0.01		
	55 Cs caesium 132.91 ± 0.01	56 Ba barium 137.33 ± 0.01	57-71 lanthanoids	72 Hf hafnium 178.49 ± 0.01	73 Ta tantalum 180.95 ± 0.01	74 W tungsten 183.84 ± 0.01	75 Re rhenium 186.21 ± 0.01	76 Os osmium 190.23 ± 0.03	77 Ir iridium 192.22 ± 0.01	78 Pt platinum 195.08 ± 0.02	79 Au gold 196.97 ± 0.01	80 Hg mercury 200.59 ± 0.01	81 Tl thallium 204.38 ± 0.01	82 Pb lead 207.2 ± 1.1	83 Bi bismuth 208.98 ± 0.01	84 Po polonium [209]	85 At astatine [210]	86 Rn radon [222]		
	87 Fr francium [223]	88 Ra radium [226]	89-103 actinoids	104 Rf rutherfordium [267]	105 Db dubnium [268]	106 Sg seaborgium [269]	107 Bh bohrium [270]	108 Hs hassium [269]	109 Mt meitnerium [277]	110 Ds darmstadtium [281]	111 Rg roentgenium [282]	112 Cn copernicium [285]	113 Nh nihonium [286]	114 Fl flerovium [290]	115 Mc moscovium [290]	116 Lv livermorium [293]	117 Ts tennessine [294]	118 Og oganesson [294]		



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57 La lanthanum 138.91 ± 0.01	58 Ce cerium 140.12 ± 0.01	59 Pr praseodymium 140.91 ± 0.01	60 Nd neodymium 144.24 ± 0.01	61 Pm promethium [145]	62 Sm samarium 150.36 ± 0.02	63 Eu europium 151.96 ± 0.01	64 Gd gadolinium 157.25 ± 0.03	65 Tb terbium 158.93 ± 0.01	66 Dy dysprosium 162.50 ± 0.01	67 Ho holmium 164.93 ± 0.01	68 Er erbium 167.26 ± 0.01	69 Tm thulium 168.93 ± 0.01	70 Yb ytterbium 173.05 ± 0.02	71 Lu lutetium 174.97 ± 0.01
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Location of REE within the periodic table

3
21 Sc scandium 44.956 ± 0.001
39 Y yttrium 88.906 ± 0.001

group 3

first inner transition

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From **macro** to micro level...

Macroscopic level

Difficult separation and purification
Similar chemical properties



Microscopic level

- Ionic chemistry
- Mainly M^{3+} oxidation state
- Continuous and steady decrease in the size of their atomic and ionic radii (lanthanide contraction)
- Large coordination numbers (8 to 12)
- Large electropositivity
- Strong Lewis acidity

electronic configuration!

Electronic configuration of Sc, Y, La

1	1 H hydrogen 1.0080 ± 0.0002	2											13	14	15	16	17	18 2 He helium 4.0026 ± 0.0001
2	3 Li lithium 6.94 ± 0.06	4 Be beryllium 9.0122 ± 0.0001	$[Ar]3d^14s^2$ $[Kr]4d^15s^2$ $[Xe]5d^16s^2$										5 B boron 10.81 ± 0.02	6 C carbon 12.011 ± 0.002	7 N nitrogen 14.007 ± 0.001	8 O oxygen 15.999 ± 0.001	9 F fluorine 18.998 ± 0.001	10 Ne neon 20.180 ± 0.001
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And then?

Progressive filling of 4f orbitals

$$n = 4 \quad l = 3 \quad m_l = -3, -2, -1, 0, +1, +2, +3$$

7 shapes → 14 electrons
(Pauli's Exclusion Principle)

The periodic table displays elements from Hydrogen (1) to Oganesson (118). The f-block, containing lanthanides (57-71) and actinides (89-103), is highlighted in orange. A red arrow points from the main body of the table to the lanthanide series. The table includes atomic numbers, element symbols, names, and atomic weights.

Ln	Z	Electronic configuration
La	57	[Xe]5d ¹ 6s ²
Ce	58	[Xe]4f ¹ 5d ¹ 6s ²
Pr	59	[Xe]4f ³ 6s ²
Nd	60	[Xe]4f ⁴ 6s ²
Pm	61	[Xe]4f ⁵ 6s ²
Sm	62	[Xe]4f ⁶ 6s ²
Eu	63	[Xe]4f ⁷ 6s ²
Gd	64	[Xe]4f ⁷ 5d ¹ 6s ²
Tb	65	[Xe]4f ⁹ 6s ²
Dy	66	[Xe]4f ¹⁰ 6s ²
Ho	67	[Xe]4f ¹¹ 6s ²
Er	68	[Xe]4f ¹² 6s ²
Tm	69	[Xe]4f ¹³ 6s ²
Yb	70	[Xe]4f ¹⁴ 6s ²
Lu	71	[Xe]4f ¹⁴ 5d ¹ 6s ²

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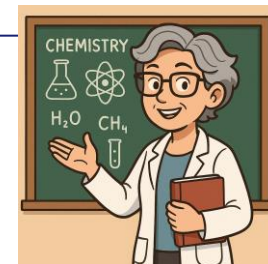
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Why 4f after 6s and 5d? The Aufbau Principle

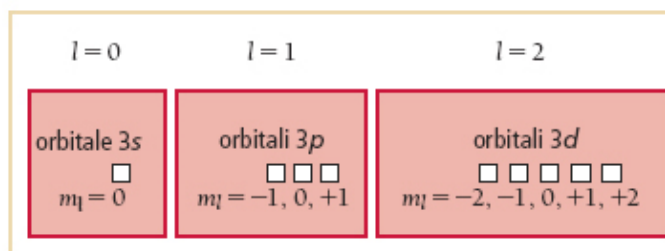


Hydrogen-like atoms ($1 e^-$)

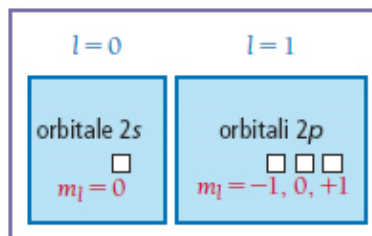
Livello principale
(specificato da n)

Sottolivello
(specificato da l)

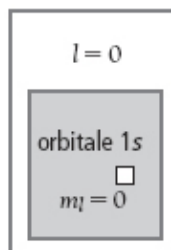
$n = 3$



$n = 2$

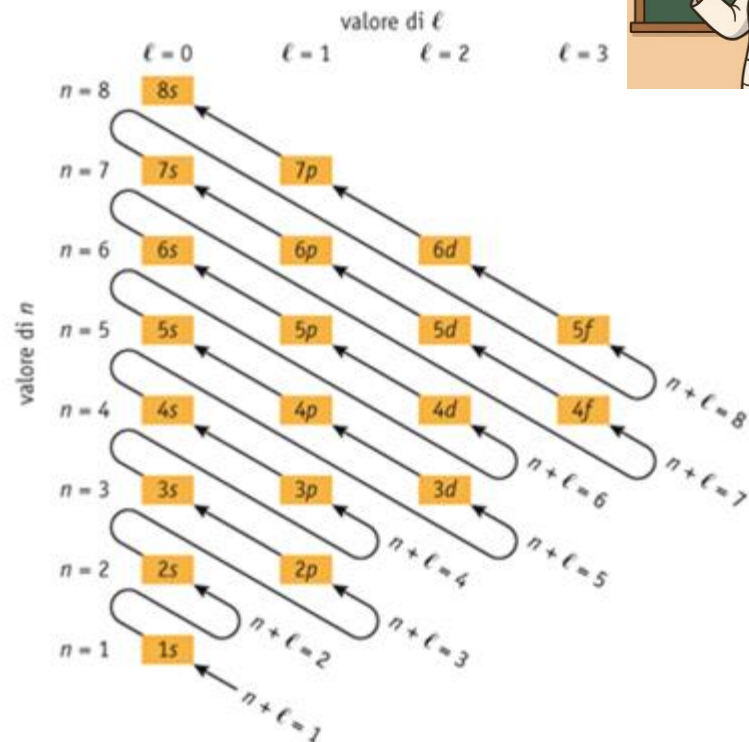
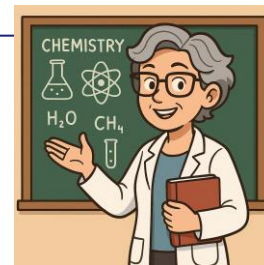
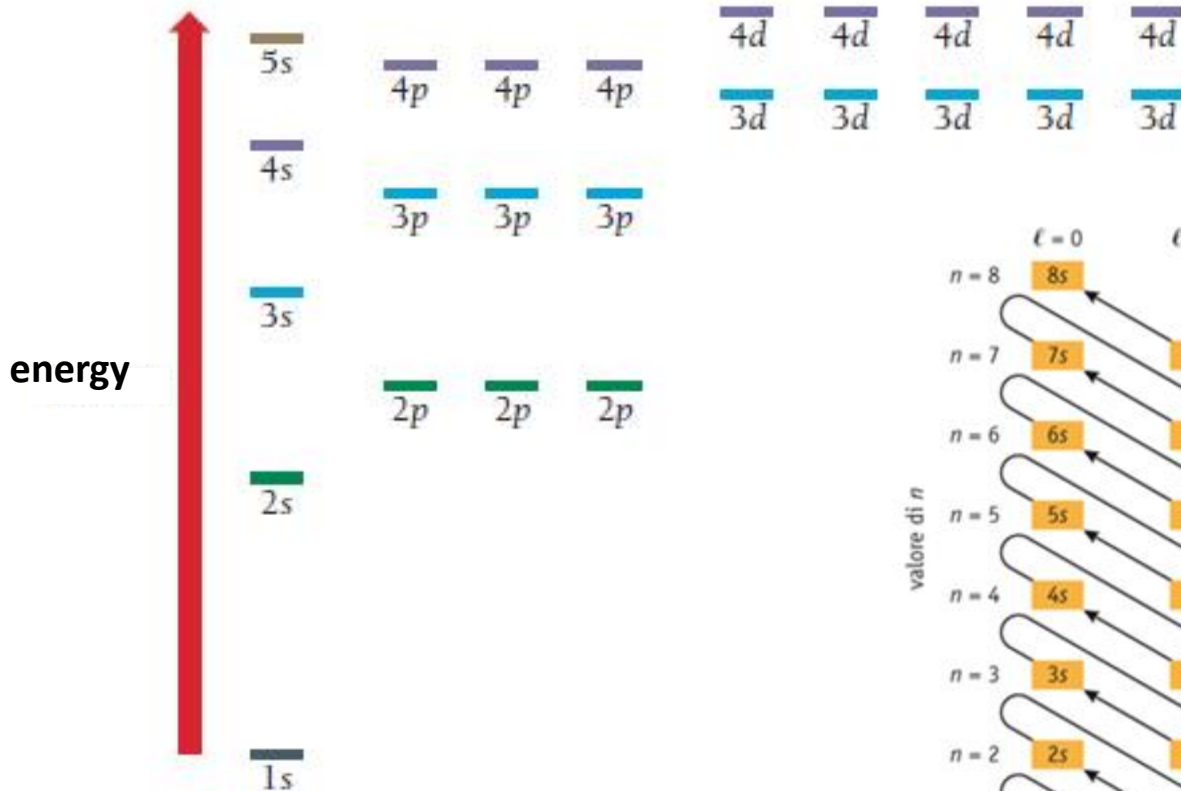


$n = 1$



orbital filling depends only on n

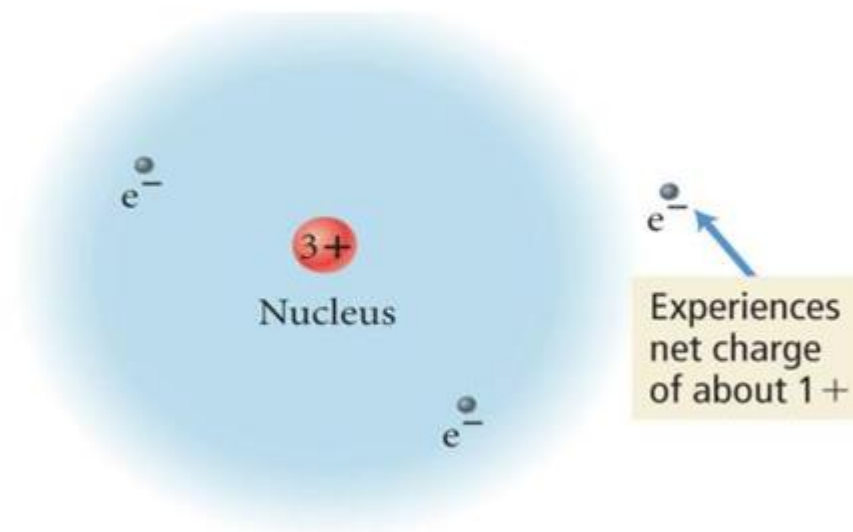
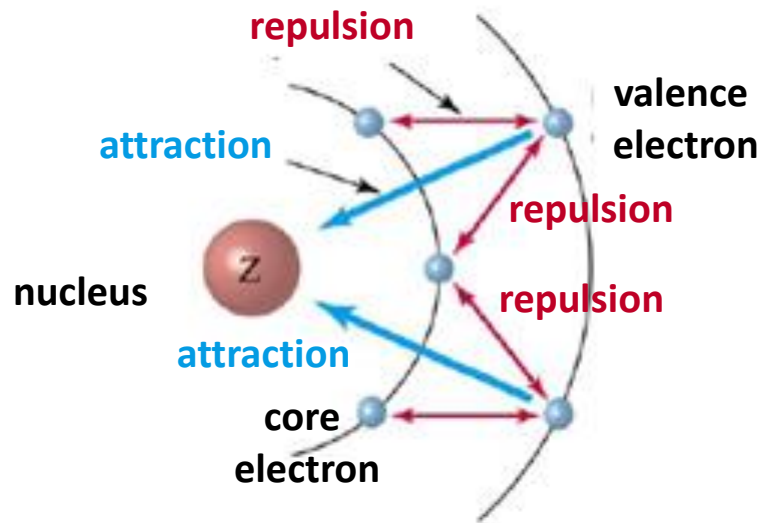
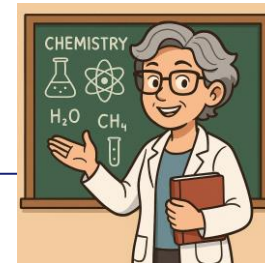
Multi-electron atoms



Role of shielding and penetration

Orbital filling follows the increase of $n+l$ value (same $n+l$ value \rightarrow lower n value)

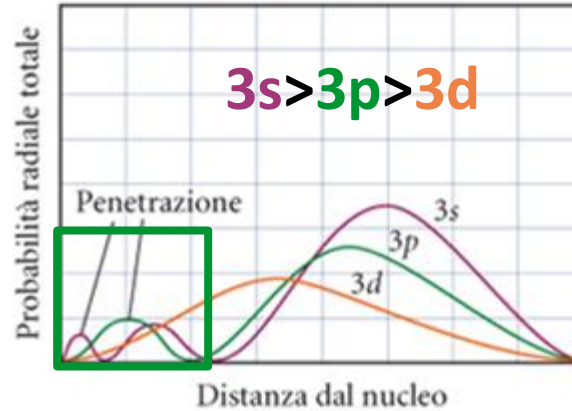
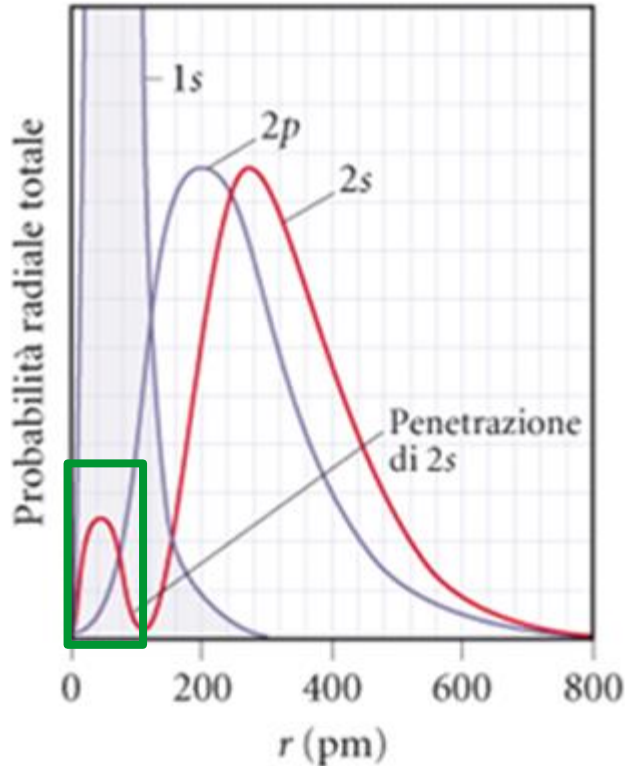
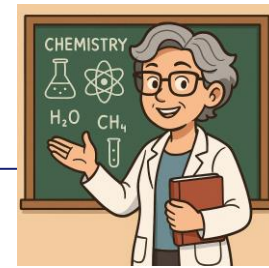
Shielding



$$Z_{\text{eff}} = Z - S$$

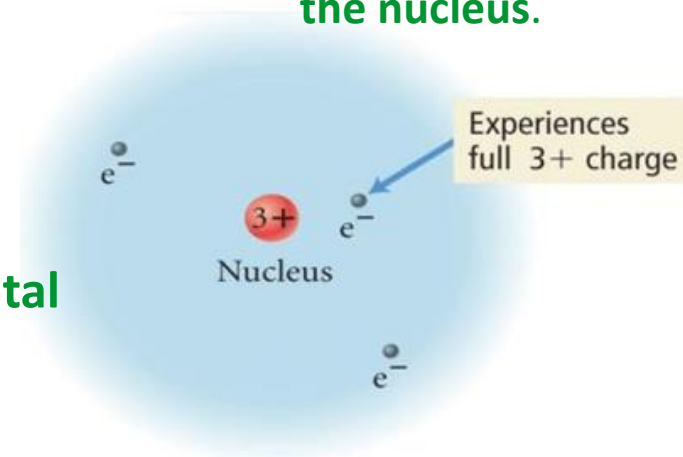
nuclear effective charge nuclear charge shielding constant

Penetration

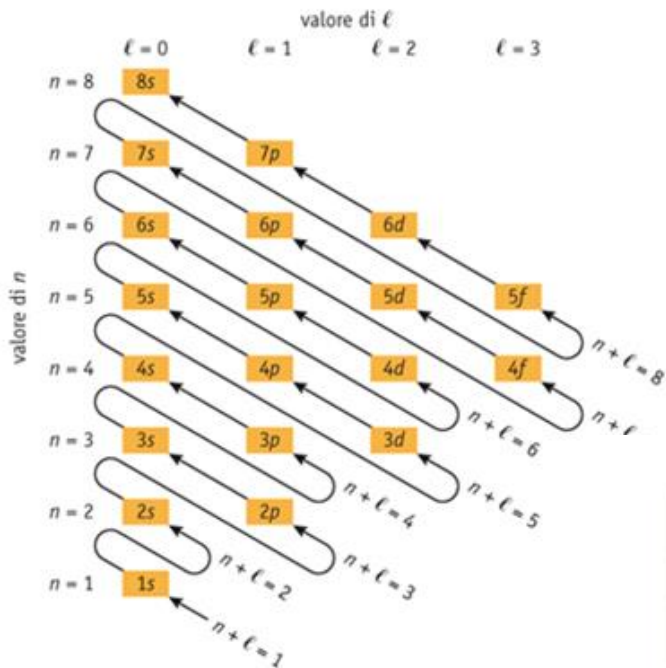
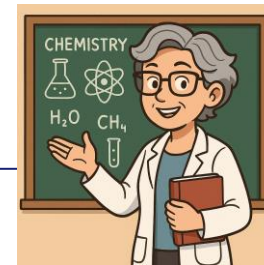


Penetration is the **extent** to which an electron's **probability density** is found **near the nucleus**. Penetration describes the **ability of an electron** in a given subshell to penetrate within other shells and subshells **to get close to the nucleus**.

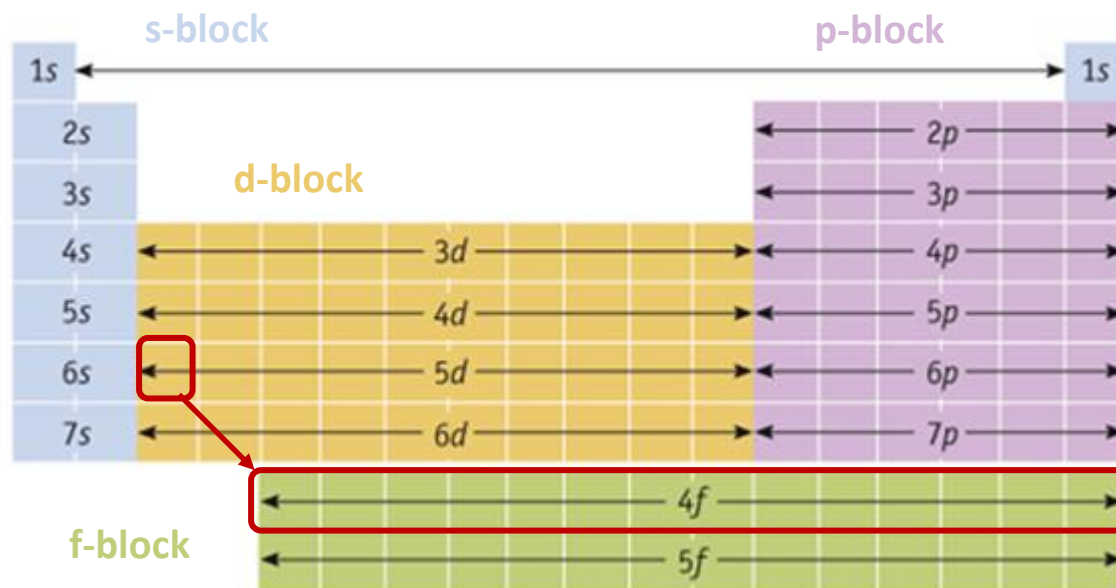
An electron in a **more penetrating orbital** experiences a **higher Z_{eff}** because it is nearer to the nucleus, so less shielded



Periodic table and orbital filling



The position of an element in the periodic table is directly determined by its electronic configuration



TERRE RARE

Sfide e opportunità per le tecnologie future

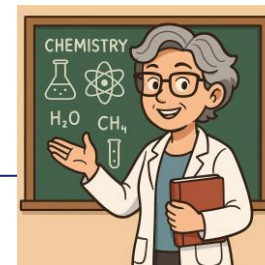
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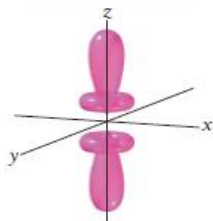


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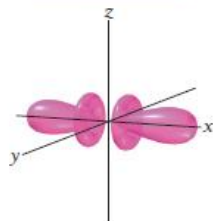
4f orbitals characteristics



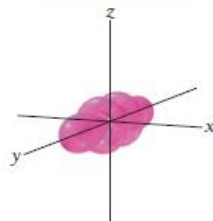
orbitale $f_z^3 - \frac{3}{2} z r^2$



orbitale $f_x^3 - \frac{3}{2} x r^2$

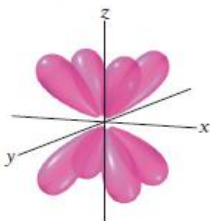


orbitale $f_y^3 - \frac{3}{2} y r^2$

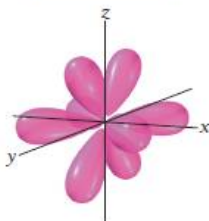


◀ FIGURE 8.29
Gli orbitali 4f

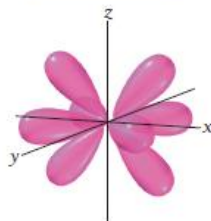
orbitale f_{xyz}



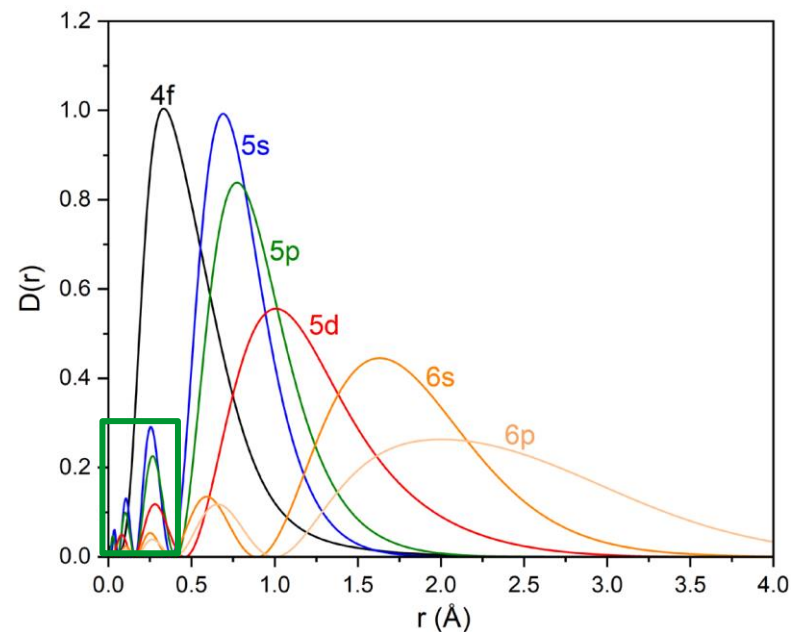
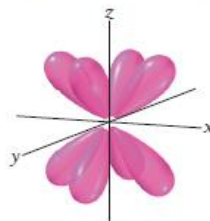
orbitale $f_y(x^2 - z^2)$



orbitale $f_x(z^2 - y^2)$



orbitale $f_z(x^2 - y^2)$



J. Theor. Chem. Comput. **2023**, *19*, 82



Nivaldo. J. Tro
Chimica - Un approccio molecolare, III Ed.
Edises Edizioni

- very complex structure with multiple nodes
- highly diffused

- low penetrating
- highly shielded
- inner orbitals



Filling of 4f orbitals effects

La → Ce 1 e⁻ is added in 4f orbital

then progressive filling of 4f orbitals

n = 4

4f are inner, not valence orbitals
(two energy levels below 6s)



4f electrons experience a high Z_{eff}



4f electrons scarcely interact
with the environment

similar chemical properties

Ln	Z	Electronic configuration
La	57	[Xe]5d ¹ 6s ²
Ce	58	[Xe]4f ¹ 5d ¹ 6s ²
Pr	59	[Xe]4f ³ 6s ²
Nd	60	[Xe]4f ⁴ 6s ²
Pm	61	[Xe]4f ⁵ 6s ²
Sm	62	[Xe]4f ⁶ 6s ²
Eu	63	[Xe]4f ⁷ 6s ²
Gd	64	[Xe]4f ⁷ 5d ¹ 6s ²
Tb	65	[Xe]4f ⁹ 6s ²
Dy	66	[Xe]4f ¹⁰ 6s ²
Ho	67	[Xe]4f ¹¹ 6s ²
Er	68	[Xe]4f ¹² 6s ²
Tm	69	[Xe]4f ¹³ 6s ²
Yb	70	[Xe]4f ¹⁴ 6s ²
Lu	71	[Xe]4f ¹⁴ 5d ¹ 6s ²

Filling of 4f orbitals effects



scarce superimposition with other orbitals



not available for covalent bonding

ionic chemistry

REE ions

REE are metals and typically form **+3 ions** ($E^0 < 0$)

$E^0 \text{ Al} = -1.66\text{V}$

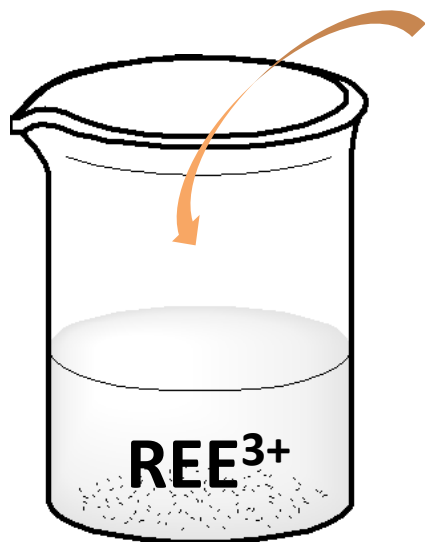
REE	Z	Electronic configuration of REE	Electronic configuration of REE ³⁺	Ln ³⁺ radius (Å)	E ⁰ REE ³⁺ /RE E vs SHE (V)
Sc	21	[Ar]3d ¹ 4s ²	[Ar]	0.700	-2.07
Y	39	[Kr]4d ¹ 5s ²	[Kr]	0.900	-2.37
La	57	[Xe]5d ¹ 6s ²	[Xe]	1.061	-2.37
Ce	58	[Xe]4f ¹ 5d ¹ 6s ²	[Xe]4f ¹	1.034	-2.34
Pr	59	[Xe]4f ³ 6s ²	[Xe]4f ²	1.013	-2.35
Nd	60	[Xe]4f ⁴ 6s ²	[Xe]4f ³	0.995	-2.32
Pm	61	[Xe]4f ⁵ 6s ²	[Xe]4f ⁴	0.979	-2.29
Sm	62	[Xe]4f ⁶ 6s ²	[Xe]4f ⁵	0.964	-2.30
Eu	63	[Xe]4f ⁷ 6s ²	[Xe]4f ⁶	0.950	-1.99
Gd	64	[Xe]4f ⁷ 5d ¹ 6s ²	[Xe]4f ⁷	0.938	-2.29
Tb	65	[Xe]4f ⁹ 6s ²	[Xe]4f ⁸	0.923	-2.30
Dy	66	[Xe]4f ¹⁰ 6s ²	[Xe]4f ⁹	0.908	-2.29
Ho	67	[Xe]4f ¹¹ 6s ²	[Xe]4f ¹⁰	0.894	-2.33
Er	68	[Xe]4f ¹² 6s ²	[Xe]4f ¹¹	0.881	-2.34
Tm	69	[Xe]4f ¹³ 6s ²	[Xe]4f ¹²	0.869	-2.31
Yb	70	[Xe]4f ¹⁴ 6s ²	[Xe]4f ¹³	0.858	-2.22
Lu	71	[Xe]4f ¹⁴ 5d ¹ 6s ²	[Xe]4f ¹⁴	0.848	-2.30

Ce⁴⁺ : [Xe]f⁰

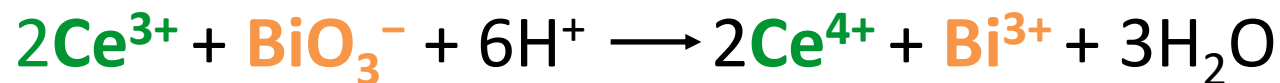
Eu²⁺ : [Xe]f⁷

exchange energy!

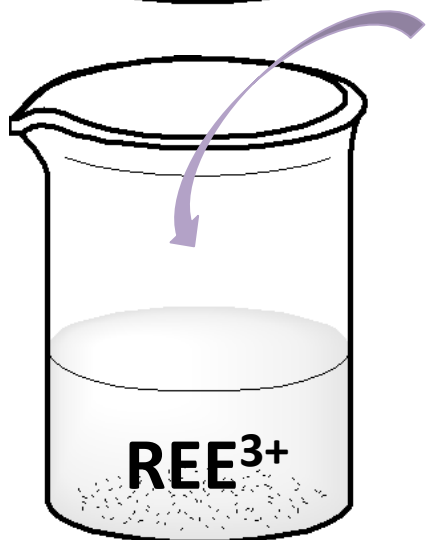
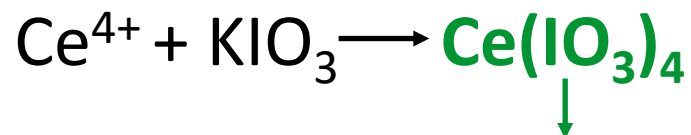
Redox chemistry for separation of Ce and Eu



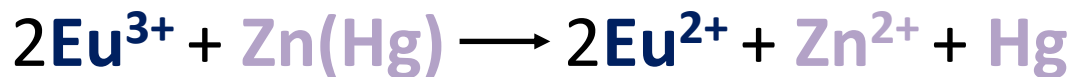
NaBiO₃



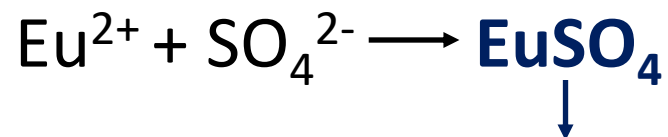
(H⁺ = H₂SO₄ o HNO₃)



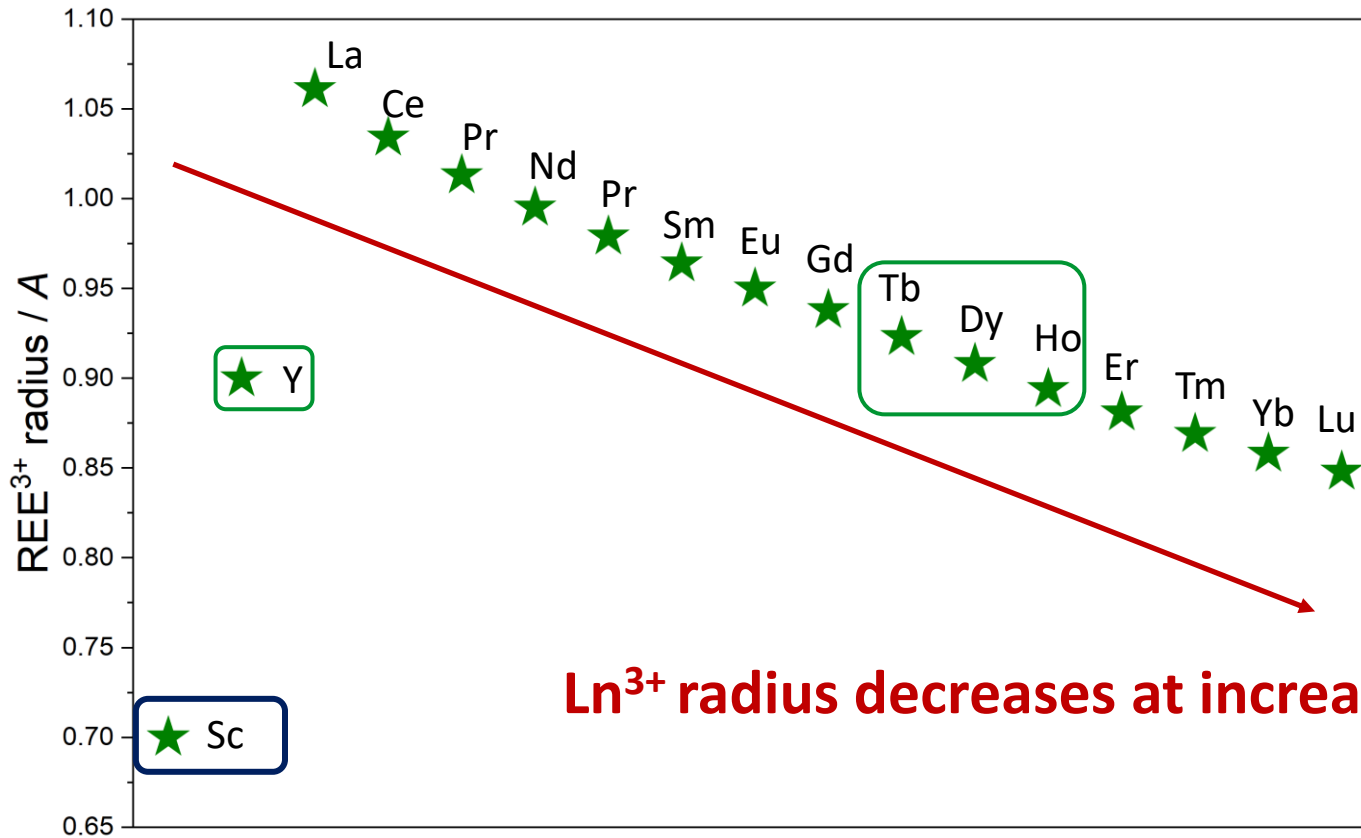
Zn(Hg)



(in HCl)



Another effect of 4f orbitals filling...



similar ionic radius
=
similar properties

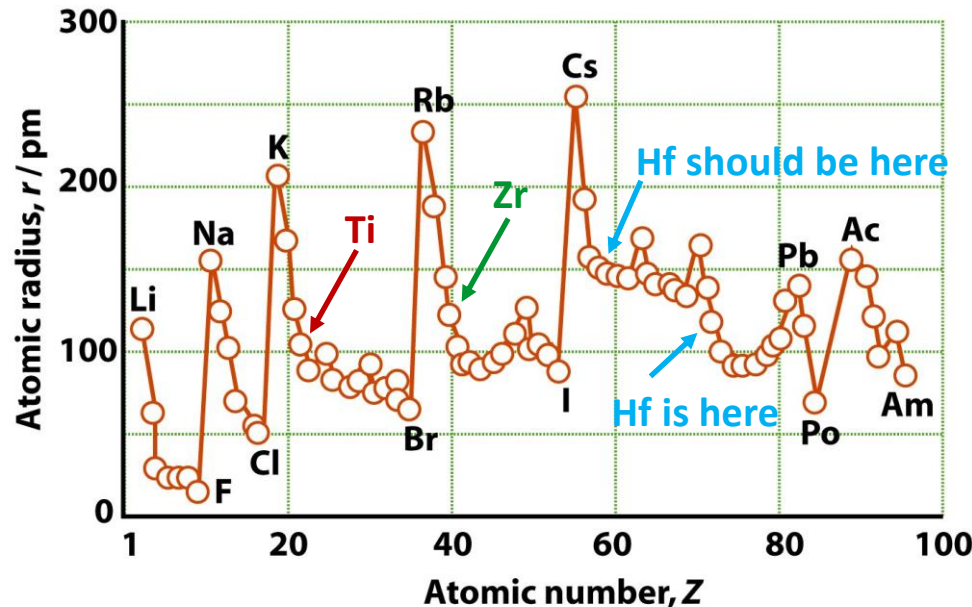
intermediate behavior
between Al and Y

**lanthanoid
contraction**

Due to the diffuse shape of f orbitals, the shielding of one f electron by another is poor. With increasing Z and nuclear charge, Z_{eff} of 4f electrons increases and there is a shrinkage in the (atom) or ion radii

1 H hydrogen 1.008 +0.0002	2 He helium 4.002 +0.0001											13 B boron 10.81 +0.02	14 C carbon 12.011 +0.002	15 N nitrogen 14.007 +0.001	16 O oxygen 15.999 +0.001	17 F fluorine 18.998 +0.001	18 Ne neon 20.180 +0.001												
3 Li lithium 6.94 +0.06	4 Be beryllium 9.012 +0.0001											19 K potassium 39.098 +0.001	20 Ca calcium 40.078 +0.001	21 Sc scandium 44.956 +0.001	22 Ti titanium 47.867 +0.001	23 V vanadium 50.942 +0.001	24 Cr chromium 51.996 +0.001	25 Mn manganese 54.938 +0.001	26 Fe iron 55.845 +0.002	27 Co cobalt 58.933 +0.001	28 Ni nickel 58.693 +0.001	29 Cu copper 63.546 +0.002	30 Zn zinc 65.38 +0.002	31 Ga gallium 69.723 +0.001	32 Ge germanium 72.630 +0.001	33 As arsenic 74.922 +0.001	34 Se selenium 78.971 +0.001	35 Br bromine 79.904 +0.001	36 Kr krypton 83.798 +0.002
11 Na sodium 22.990 +0.001	12 Mg magnesium 24.305 +0.002	3 La lanthanides 138-175	4 Rf rutherfordium (261)	5 Db dubnium (262)	6 Sg seaborgium (266)	7 Bh bohrium (264)	8 Hs hassium (265)	9 Mt meitnerium (270)	10 Ds darmstadtium (271)	11 Rg roentgenium (272)	12 Cn copernicium (285)	13 Nh nihonium (286)	14 Fl flerovium (289)	15 Mc moscovium (288)	16 Lv livermorium (293)	17 Ts tennessine (294)	18 Og oganeson (294)												
19 K potassium 39.098 +0.001	20 Ca calcium 40.078 +0.001	21 Sc scandium 44.956 +0.001	22 Ti titanium 47.867 +0.001	23 V vanadium 50.942 +0.001	24 Cr chromium 51.996 +0.001	25 Mn manganese 54.938 +0.001	26 Fe iron 55.845 +0.002	27 Co cobalt 58.933 +0.001	28 Ni nickel 58.693 +0.001	29 Cu copper 63.546 +0.002	30 Zn zinc 65.38 +0.002	31 Ga gallium 69.723 +0.001	32 Ge germanium 72.630 +0.001	33 As arsenic 74.922 +0.001	34 Se selenium 78.971 +0.001	35 Br bromine 79.904 +0.001	36 Kr krypton 83.798 +0.002												
37 Rb rubidium 85.468 +0.001	38 Sr strontium 87.62 +0.001	39 Y yttrium 88.906 +0.001	40 Zr zirconium 91.224 +0.002	41 Nb niobium 92.906 +0.001	42 Mo molybdenum 95.94 +0.001	43 Tc technetium (98)	44 Ru ruthenium 101.07 +0.002	45 Rh rhodium 102.91 +0.001	46 Pd palladium 106.42 +0.001	47 Ag silver 107.87 +0.001	48 Cd cadmium 112.41 +0.001	49 In indium 114.82 +0.001	50 Sn tin 118.71 +0.001	51 Sb antimony 121.76 +0.001	52 Te tellurium 127.60 +0.001	53 I iodine 126.90 +0.001	54 Xe xenon 131.29 +0.001												
55 Cs cesium 132.91 +0.001	56 Ba barium 137.33 +0.001	57-71 La lanthanides	72 Hf hafnium 178.49 +0.001	73 Ta tantalum 180.95 +0.001	74 W tungsten 183.84 +0.001	75 Re rhenium 186.21 +0.001	76 Os osmium 190.23 +0.001	77 Ir iridium 192.22 +0.001	78 Pt platinum 195.08 +0.002	79 Au gold 196.97 +0.001	80 Hg mercury 200.59 +0.001	81 Tl thallium 204.38 +0.001	82 Pb lead 207.2 +0.001	83 Bi bismuth 208.98 +0.001	84 Po polonium (209)	85 At astatine (210)	86 Rn radon (222)												
87 Fr francium (223)	88 Ra radium (226)	89-103 La actinides	104 Rf rutherfordium (261)	105 Db dubnium (262)	106 Sg seaborgium (266)	107 Bh bohrium (264)	108 Hs hassium (265)	109 Mt meitnerium (270)	110 Ds darmstadtium (271)	111 Rg roentgenium (272)	112 Cn copernicium (285)	113 Nh nihonium (286)	114 Fl flerovium (289)	115 Mc moscovium (288)	116 Lv livermorium (293)	117 Ts tennessine (294)	118 Og oganeson (294)												

57 La lanthanum 138.91 +0.01	58 Ce cerium 140.12 +0.01	59 Pr praseodymium 140.91 +0.01	60 Nd neodymium 144.24 +0.01	61 Pm promethium (145)	62 Sm samarium 150.36 +0.02	63 Eu europium 151.96 +0.01	64 Gd gadolinium 157.25 +0.03	65 Tb terbium 158.93 +0.01	66 Dy dysprosium 162.50 +0.01	67 Ho holmium 164.93 +0.01	68 Er erbium 167.26 +0.01	69 Tm thulium 168.93 +0.02	70 Yb ytterbium 173.05 +0.01	71 Lu lutetium 174.97 +0.01
89 Ac actinium (227)	90 Th thorium 232.04 +0.01	91 Pa protactinium 231.04 +0.01	92 U uranium 238.03 +0.01	93 Np neptunium (237)	94 Pu plutonium (244)	95 Am americium (243)	96 Cm curium (247)	97 Bk berkelium (247)	98 Cf californium (251)	99 Es einsteinium (252)	100 Fm fermium (257)	101 Md mendelevium (288)	102 No nobelium (289)	103 Lr lawrencium (260)



elements after lanthanides are smaller than expected

4d and 5d elements show similar chemical properties!

Figure 1-24
Shriver & Atkins Inorganic Chemistry, Fourth Edition
© 2006 by D.F. Shriver, P.W. Atkins, T.L. Overton, J.P. Rourke, M.T. Weller, and F.A. Armstrong

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Light and heavy REE

3
21 Sc scandium 44.956 ± 0.001
39 Y yttrium 88.906 ± 0.001

Light Rare Earth (LRE or Cerium group)

Heavy Rare Earth (HRE or Yttrium group)

57 La lanthanum 138.91 ± 0.01	58 Ce cerium 140.12 ± 0.01	59 Pr praseodymium 140.91 ± 0.01	60 Nd neodymium 144.24 ± 0.01	61 Pm promethium [145]	62 Sm samarium 150.36 ± 0.02	63 Eu europium 151.96 ± 0.01	64 Gd gadolinium 157.25 ± 0.03	65 Tb terbium 158.93 ± 0.01	66 Dy dysprosium 162.50 ± 0.01	67 Ho holmium 164.93 ± 0.01	68 Er erbium 167.26 ± 0.01	69 Tm thulium 168.93 ± 0.01	70 Yb ytterbium 173.05 ± 0.02	71 Lu lutetium 174.97 ± 0.01
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INTERNATIONAL UNION OF
PURE AND APPLIED CHEMISTRY

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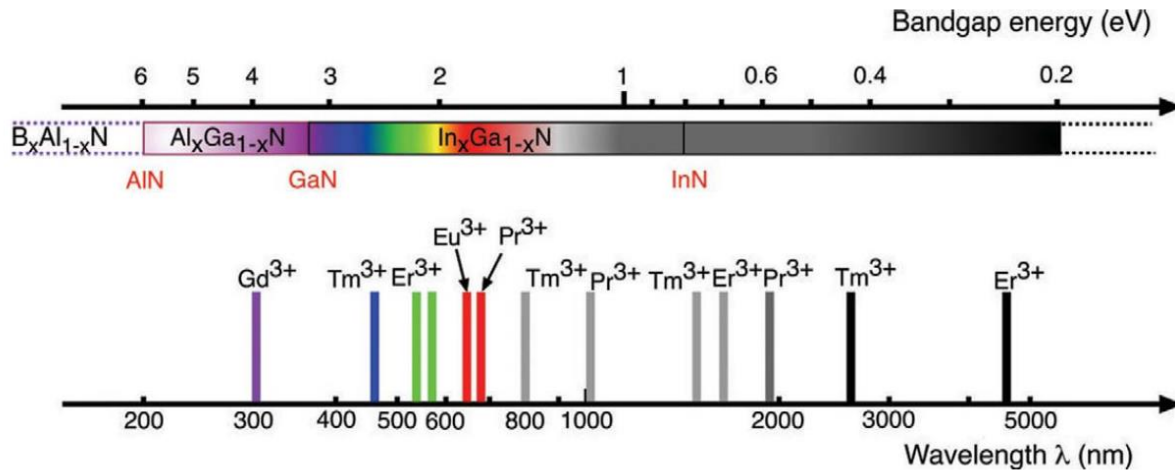
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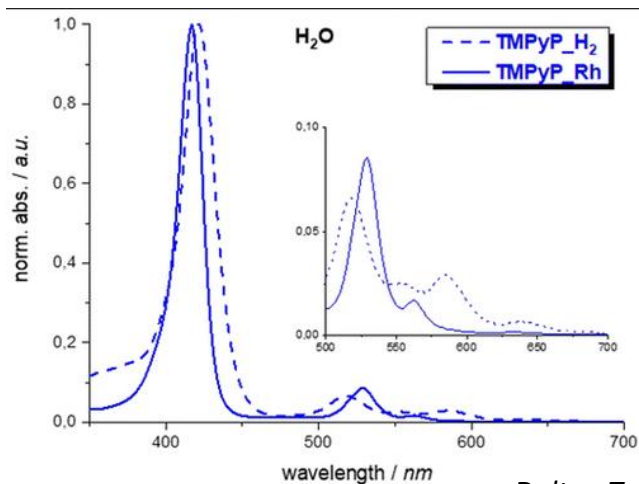
Another effect of 4f orbitals filling...



Ln³⁺ ions
Sharp emissions
Well defined colors

Fig. 3 Emission wavelengths from selected transitions in rare earth ions and associated bandgap energies of alloys of III-N compound semiconductors.

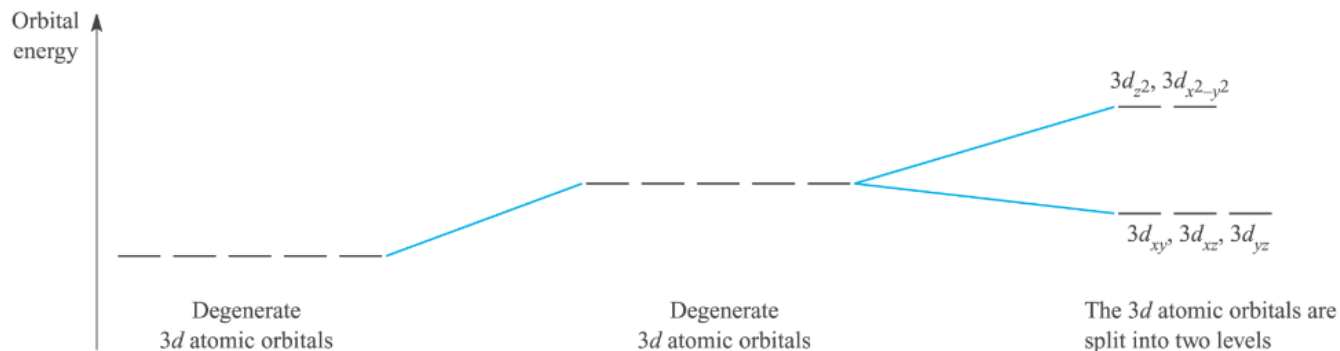
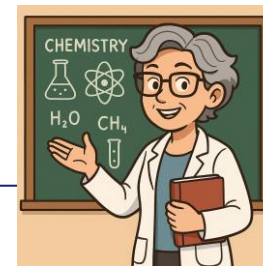
Materials Today **2007**, 10, 20



Dalton Trans **2026**

d-transition metal ions
Broad emissions
Range of colors

Why?



Metal ion M^{n+} and six ligands L at an infinite distance away



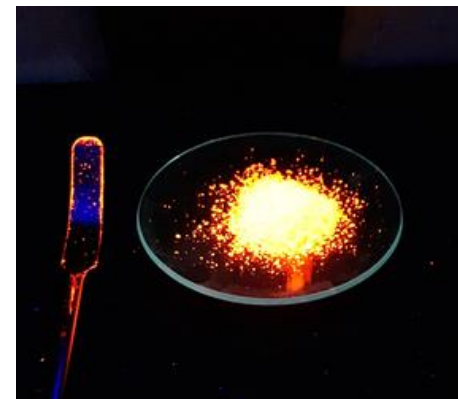
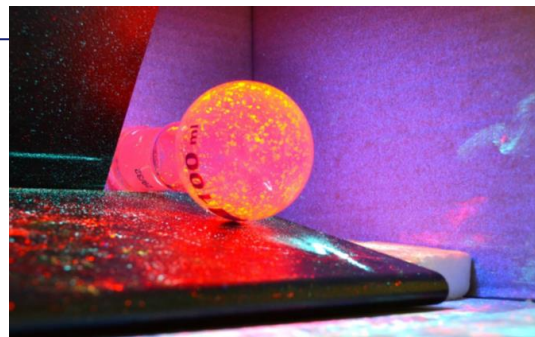
If the electrostatic field created by the point charge ligands is *spherical*, the energies of the electrons in the $3d$ orbitals are raised uniformly



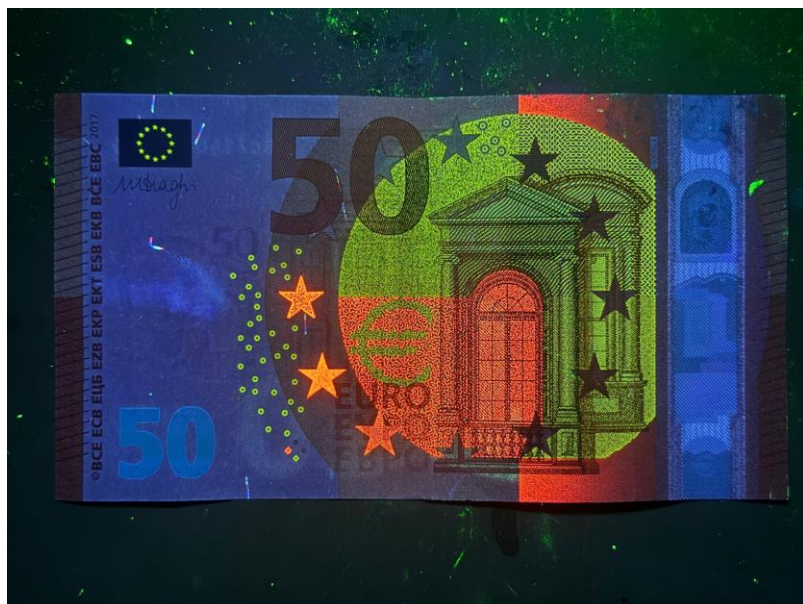
If the electrostatic field created by the point charge ligands is *octahedral*, the energy of the electrons in the $3d$ orbitals that point *directly* at the ligands is raised with respect to that in the spherical field, while the energy of the electrons in the orbitals that point *between* the ligands is lowered with respect to the spherical field

4f are inner orbitals and scarcely interact with the environment

From our labs... to practical use!



Eu³⁺ complex



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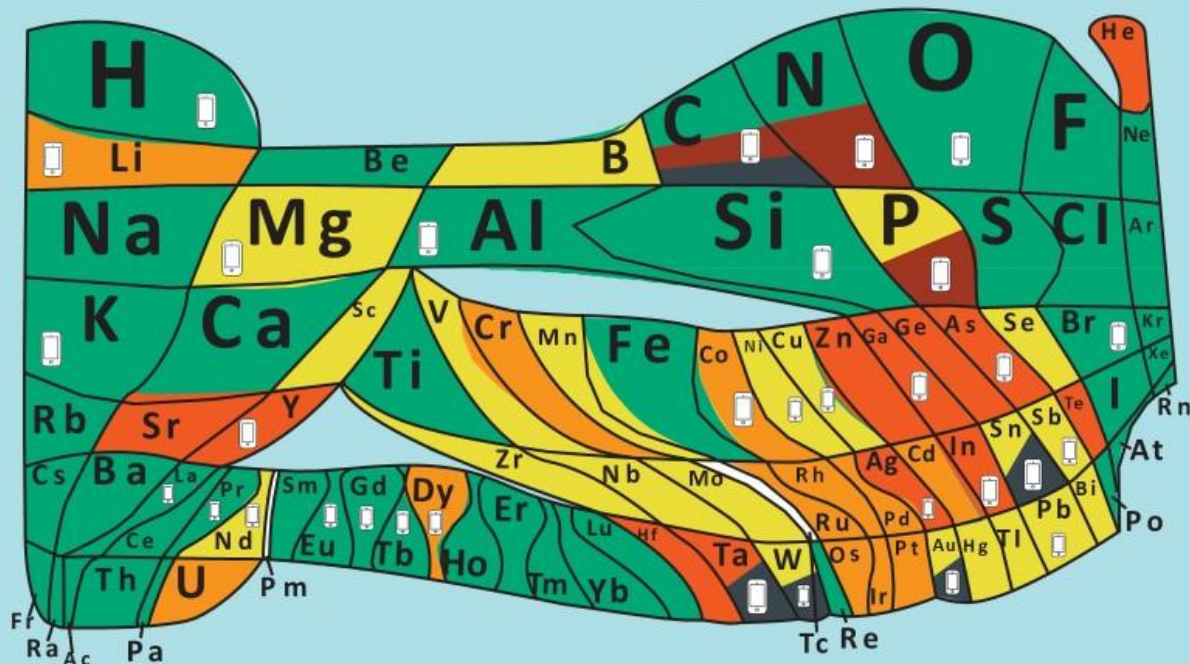


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Another point of view

EuChemS Periodic Table, latest edition 2.0 2023

The 90 natural elements that make up everything
How much is there? Is that enough? Is it sustainable?



Availability



Sustainability



Read more and play the video game <http://bit.ly/euchems-pt>

Edition 2.0 (2023)



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EuChemS
European Chemical Society

Inspired by WF Sheehan's 'A Periodic Table with Emphasis', published in Chemistry, 1976, 49, 17-18'



Conclusions

Copilot

Definition

Rare earths are a group of **17 metallic elements that are chemically similar** and extremely important for modern technology.

ChatGPT

Definition

Rare earth elements are a set of **17 metallic elements** that include the lanthanide series from Lanthanum to Lutetium together with Scandium and Yttrium, **which have very similar chemical properties.**



The very similar and peculiar chemical properties are all due to the filling of highly shielded, low penetrating, inner 4f orbitals



The SunLab group develops advanced functional materials, mainly based on porphyrins, for solar energy harvesting and photoinduced charge-transfer applications. Our research spans energy, catalysis, and sensing technologies, with strong potential for industrial innovation. Main research lines include: [1] Solar energy conversion, from third-generation photovoltaic devices to artificial photosynthesis. [2] Porphyrin sensitizers for advanced sensor technologies. [3] Sustainable catalysis, focusing on porphyrin-based systems for CO₂ reduction and valorisation, and green H₂ production. [4] 3D porphyrin-based architectures, exploiting supramolecular features

Francesca Tessore: francesca.tessore@unimi.it

Gabriele Di Carlo: gabriele.dicarlo@unimi.it



[sunlab_chem](https://www.instagram.com/sunlab_chem)

such as porosity for energy and catalytic applications. [5] Porphyrin chromophores for second-order nonlinear optics.

<https://sun-lab.unimi.it>