

Final

Dec. 14th, Friday, 2 PM to 3:40 PM

Section 1:

Dong Zhong Yuan2-205: 517370910073- 518370910072

Dong Zhong Yuan2-105: 518370910073- 518370990041

Section 2:

Dong Zhong Yuan2-201: 518021910004- 518370910088

Dong Zhong Yuan2-301: 518370910090- 518370990039

All contents
Same rules as previous tests

Recap

- Arrhenius behavior
- Catalyst
- Main group elements (IA to IVA)

Oxides of Carbon

Carbon monoxide, CO, is produced when carbon or organic compounds burn in a limited supply of air. It is a *colorless, odorless, flammable, almost insoluble, and very toxic gas.*

CO is a **Lewis base**. The **lone pair** on the carbon atom forms covalent bonds with d-block atoms and ions.

CO is also a **Lewis acid** because its **empty antibonding π -orbitals** can accept electron density from a metal.

We study this in the next chapter.

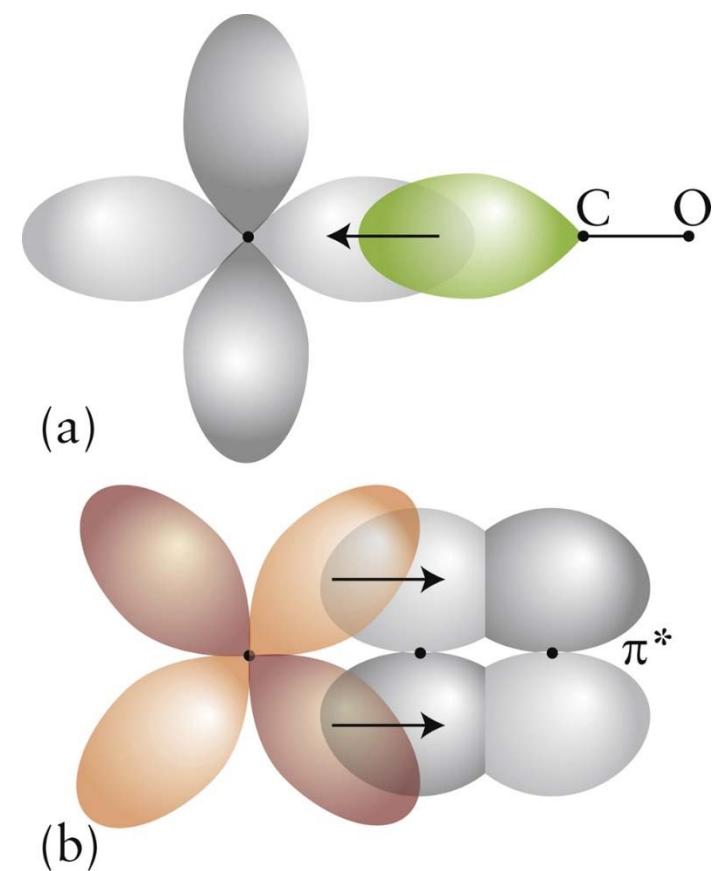


Figure 8F.4
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Group 15: The Nitrogen Family

The chemical and physical properties *vary sharply* in this group. N₂ is inert in air, phosphorus ignites in air, and arsenic, antimony, and bismuth are used in semiconductors.

Oxidation states range from –3 to +5.

TABLE 8G.1 The Group 15 Elements

| Valence configuration: ns^2np^3 | | | | | | | |
|-----------------------------------|------------|--------|---------------------------------------|---------------------|---------------------|-----------------------------------|-------------------------------|
| Z | Name | Symbol | Molar mass/ (g·mol ⁻¹) | Melting point/°C | Boiling point/°C | Density/ (g·cm ⁻³) | Normal form* |
| 7 | nitrogen | N | 14.01 | –210 | –196 | 1.04 [†] | colorless gas |
| 15 | phosphorus | P | 30.97 | 44 | 280 | 1.82 | white or red nonmetal |
| 33 | arsenic | As | 74.92 | 613s [‡] | — | 5.78 | gray metalloid |
| 51 | antimony | Sb | 121.76 | 631 | 1750 | 6.69 | blue-white lustrous metalloid |
| 83 | bismuth | Bi | 208.98 | 271 | 1650 | 8.90 | white-pink metal |

*Normal form means the state and appearance of the element at 25 °C and 1 atm.

[†]For the liquid at its boiling point.

[‡]The letter s denotes that the element sublimes.

Table 8G.1

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The Group 15 Elements

Nitrogen is rare in the Earth's crust, but elemental nitrogen is 76% by mass in our atmosphere.

Pure nitrogen gas (N_2) is obtained by the fractional distillation of liquid air. Air is cooled to below -196°C by repeated expansion and compression in a refrigerator.

The liquid is then warmed, and the nitrogen (b.p. -196°C) boils off while most of the argon (b.p. -186°C) and oxygen (b.p. -183°C) remain liquid.

Nitrogen gas's primary use is as a raw material for the synthesis of ammonia in the Haber process.

The Group 15 Elements

The $\text{N}\equiv\text{N}$ bond is **strong**, it takes $944 \text{ kJ}\cdot\text{mol}^{-1}$ to break the bonds, making nitrogen gas almost as inert as the noble gases.

Nitrogen is **highly electronegative**, $\chi = 3.0$, the same as chlorine, but it's smaller so it's capable of hydrogen-bonding.

Nitrogen's **small size** and lack of any available d-orbitals means the p-orbitals can overlap, *making π-bonds possible*.

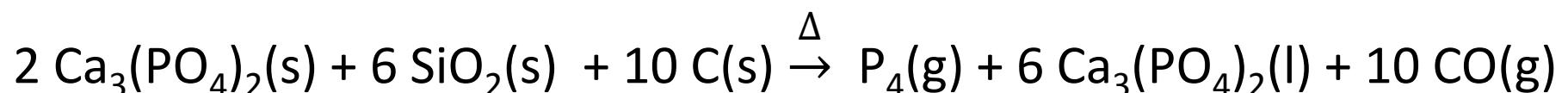
Nitrogen has wide range of **oxidation numbers** from -3 (in NH_3) to $+5$ (in nitric acid and nitrates). It also has fractional oxidation numbers, $-1/3$ in the azide ion, N_3^- .

The Group 15 Elements

Phosphorus is significantly different from nitrogen. It is nearly **50% larger** than nitrogen, too big for π -bonding.

However its large size and **availability of d-orbitals** means it can form as many as six bonds (PCl_6^-). Nitrogen forms four.

Phosphorus is obtained from apatite, a mineral of calcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$:



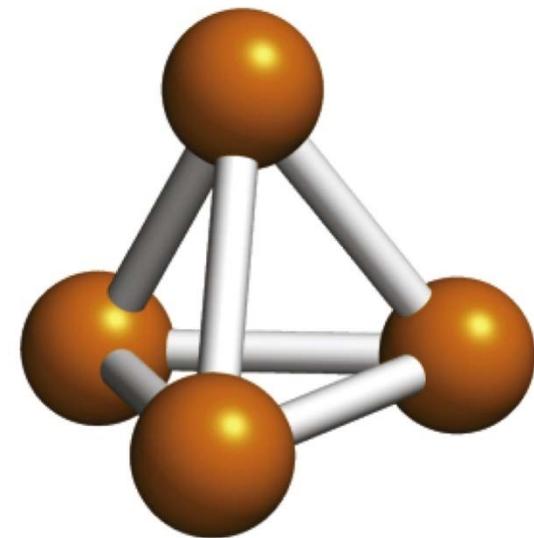
The Group 15 Elements

White phosphorus is a soft, white, poisonous molecular solid.

This allotrope is highly reactive with strained 60° bond angles. It is very dangerous. It **bursts into flame on contact with air** and is thus normally stored under water.

Red phosphorus is a less reactive allotrope and is only *ignited by friction*. It is used on the *surfaces* of matchbooks. It is thought to consist of linked P₄-chains.

tetrahedral



3 Phosphorus, P₄

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The Group 15 Elements

Arsenic and antimony are metalloids, known since antiquity. Their main use is in the **semiconductor industry**.

Ores:

orpiment, As_2S_3

stibnite, Sb_2S_3

realgar, As_4S_4



Figure 8G.3

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Nitrogen Oxides and Oxoacids

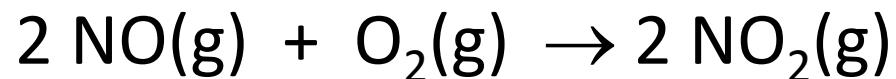
Nitrogen forms several **oxides**, with oxidation numbers ranging from +1 to +5.

Nitrogen oxides **in the atmosphere** are both a **pollutant** but also **helpful** in removing them, and are referred to as NO_x (read “nox”).

Dinitrogen oxide, N_2O (oxidation number +1), is commonly called nitrous oxide. Because it is tasteless, unreactive, nontoxic in small amounts, and soluble in fats, it is used as a **foaming agent** and propellant for whipped cream.

Nitrogen Oxides and Oxoacids

Nitrogen oxide (or nitrogen monoxide), NO, is commonly called nitric oxide and rapidly oxidizes to nitrogen dioxide in air, contributing to **acid rain**:



Nitrogen oxide is both harmful and beneficial.

Combustion engines produce NO which contributes to acid rain, smog, and the destruction of the ozone.

Yet our bodies use small amounts as a **neurotransmitter** to dilate blood vessels, and for other physiological changes.

Group 16: The Oxygen Family

These atoms have the ns^2np^4 valence electron configuration.

Even though the nonmetal trend increases toward the top right side of the periodic table, even polonium is best regarded as a metalloid.

This group is called the *chalcogens*.

The Group 16 Elements

Oxygen is the most abundant element in the Earth's crust, and the oxygen we breathe, O₂, is 23% of the atmosphere's mass.

The combustion of all living organisms in oxygen is thermodynamically spontaneous; however, the high activation energy is why we don't spontaneously combust.

TABLE 8H.1 The Group 16 Elements

Common name: chalcogens

Valence configuration: ns^2np^4

| Z | Name | Symbol | Molar mass/ (g·mol ⁻¹) | Melting point/°C | Boiling point/°C | Density/ (g·cm ⁻³) | Normal form* |
|----|-----------------------|--------|---------------------------------------|---------------------|---------------------|--|---|
| 8 | oxygen | O | 16.00 | -218 -192 | -183 -112 | 1.14 [†] 1.35 [†] | colorless paramagnetic gas (O ₂) blue gas (ozone, O ₃) |
| 16 | sulfur | S | 32.06 | 115 | 445 | 2.09 | yellow nonmetallic solid (S ₈) |
| 34 | selenium | Se | 78.96 | 220 | 685 | 4.79 | gray nonmetallic solid |
| 52 | tellurium | Te | 127.60 | 450 | 990 | 6.25 | silver-white metalloid |
| 84 | polonium [‡] | Po | (209) | 254 | 960 | 9.40 | gray metalloid |

*Normal form means the appearance and state of the element at 25 °C and 1 atm.

[†]For the liquid at its boiling point.

[‡]Radioactive.

Table 8H.1

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The Group 16 Elements

Oxygen, O_2 , is a colorless, tasteless, odorless gas; it condenses as a pale-blue liquid at $-183\text{ }^\circ\text{C}$. It is ***paramagnetic***; it behaves like a tiny magnet in a magnetic field.

The biggest consumer of oxygen is the steel industry, where 1 t of oxygen ($1\text{ t} = 10^3\text{ kg}$) produces 1 t of steel.

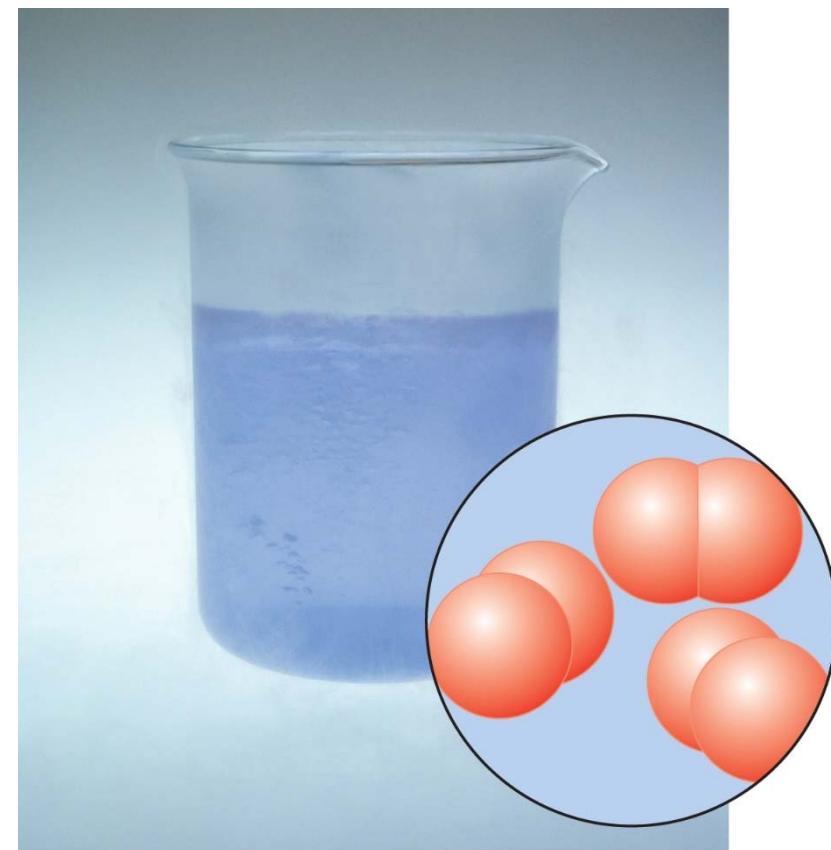
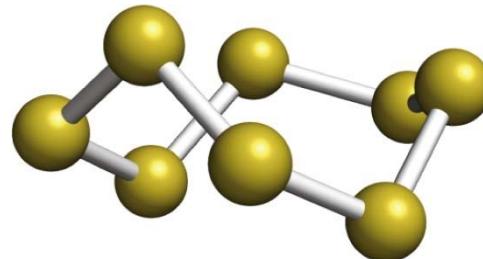


Figure 8H.3
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The Group 16 Elements

Sulfur has a striking ability to catenate, that is to form chains of atoms, whereas, oxygen is limited to H_2O_2 , O_3 , and the anions O_2^- , O_3^{2-} , and O_3^{2-} .

Sulfur's S_8 rings form long strands of “plastic sulfur” when sulfur is heated to about 200 °C and suddenly cooled.



2 Sulfur, S_8

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The Group 16 Elements

Sulfur is widely distributed as sulfide ores, including:

galena, PbS



Figure 8H.6

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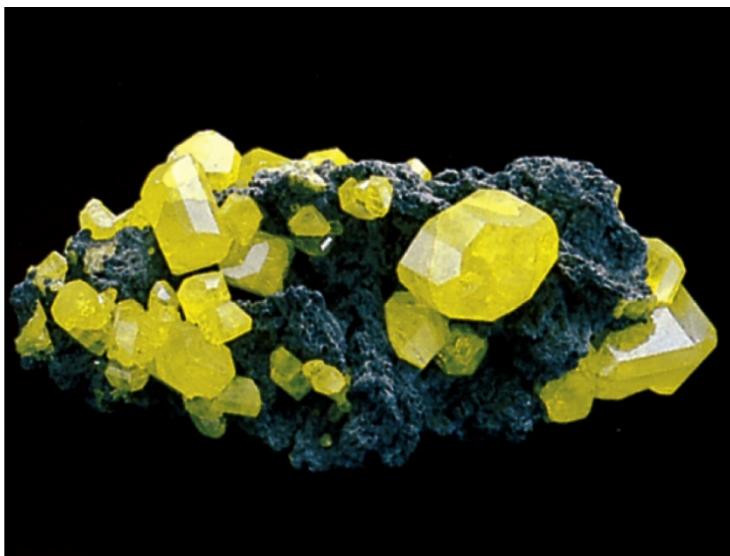
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cinnabar, HgS

sphalerite, ZnS

The Group 16 Elements

Sulfur is found in its elemental solid or crystalline state, called brimstone, formed by bacterial action on H_2S .



(a)

Figure 8H.7a
Atkins, *Chemical Principles: The Quest for Insight*, 7e
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(b)

Figure 8H.7b
Atkins, *Chemical Principles: The Quest for Insight*, 7e
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The rhombic form is the most stable. The needles are monoclinic.

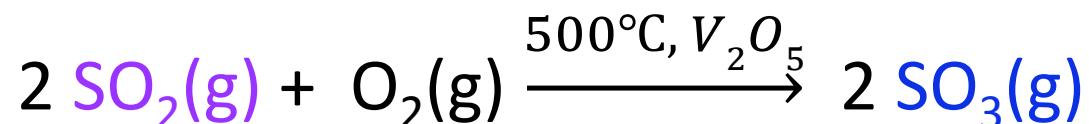
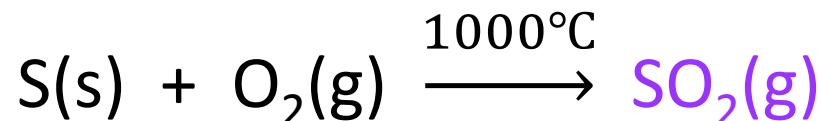
The Group 16 Elements

Selenium and tellurium occur in sulfide ores; they are recovered during the electrolytic refining of copper. They are poor conductors, but when selenium is exposed to light its conductivity increases, so it is found in solar cells.

Polonium is radioactive, a source of He-4 nuclei. The He nuclei is a good antistatic material used in the textiles industry.

Sulfur Oxides and Oxoacids

The **contact process** burns sulfur in oxygen, then uses a vanadium (V) oxide catalyst to make SO₃:



SO₃ reacts with water vapor in the air. It transforms into **oleum**, a dense oily liquid which is an easier form to transport:



When need, it is added to water to make sulfuric acid:



Sulfur Oxides and Oxoacids

Sulfuric acid, H_2SO_4 , is worldwide the *most heavily produced* inorganic chemical.

The low cost of sulfuric acid production leads to its widespread use for the production of fertilizers, petrochemicals, dyestuffs, and detergents.

About two-thirds is used to manufacture phosphate and ammonium sulfate fertilizers.

H_2SO_4 , is a very strong acid, and even its conjugate base HSO_4^- has a $\text{p}K_a$ of 1.92, which is a strong acid.

Group 17: The Halogens

All halogens from F_2 through I_2 are diatomic. Fluorine always gains one electron, yet the others have oxidation numbers between -1 to $+7$.

The chemical and physical trends are consistent (unlike Groups 15 and 16). London forces dominate these elements.

TABLE 8I.1 The Group 17 Elements

| Z | Name | Symbol | Molar mass/ (g·mol ⁻¹) | Melting point/°C | Boiling point/°C | Density/ (g·cm ⁻³) | Normal form* |
|----|-----------------------|--------|---------------------------------------|---------------------|---------------------|-----------------------------------|--------------------------------|
| 9 | fluorine | F | 19.00 | -220 | -188 | 1.51 [†] | almost colorless gas |
| 17 | chlorine | Cl | 35.45 | -101 | -34 | 1.66 [†] | yellow-green gas |
| 35 | bromine | Br | 79.90 | 27 | 59 | 3.12 | red-brown liquid |
| 53 | iodine | I | 126.90 | 114 | 184 | 4.95 | purple-black nonmetallic solid |
| 85 | astatine [‡] | At | (210) | 300 | 350 | — | nonmetallic solid |

*Normal form means the appearance and state of the element at 25 °C and 1 atm.

[†]For the liquid at its boiling point.

[‡]Radioactive.

Table 8I.1

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Group 17 Elements

Fluorine is a reactive, almost colorless gas of F_2 molecules.

Most of the fluorine is used to make volatile **solid UF_6** for processing nuclear fuel. The rest is used for producing **SF_6** for electrical equipment.

Fluorine is **small** and has a **high effective nuclear charge**. Therefore, its ***lattice energies*** are **high**, and its ***solubilities*** are **low**. Low **solubilities** is why the *oceans are primarily chloride*.

An exception being AgF . It is soluble because the molecule is completely ionic, whereas AgI is polarizable and not soluble.

Group 17 Elements

Chlorine is one of the most heavily manufactured chemicals.

It is obtained from sodium chloride by electrolysis of molten rock salt or brine.

It is a pale yellow-green gas.

It reacts directly with nearly all the elements (except for carbon, nitrogen, oxygen, and the noble gases).

Group 17 Elements

Bromine is a corrosive, red-brown fuming liquid of Br₂ molecules and has a penetrating odor.

Bromine is used widely in synthetic organic chemistry.

Organic bromides are incorporated into textiles as fire retardants and are used as pesticides; inorganic bromides, particularly silver bromide, are used in photographic emulsions.

Group 17 Elements

Iodine occurs as iodide ions in brines and as an impurity in Chile saltpeter (NaNO_3). It was once obtained from seaweed.

2000 kg of seaweed produces about 1 kg of iodine.

Iodine, I_2 , is recovered from the brine of oil wells.
Elemental iodine is produced by oxidation with chlorine:



Group 17 Elements

I₂ is a blue-black lustrous solid that sublimes easily, forming a purple vapor.

I₂ is slightly soluble in water, more so in ethanol. It is used as an antiseptic. Living organisms need trace amounts for the proper function of the thyroid gland, and is one reason for buying “iodized salt.”

Astatine (Ac) is radioactive and occurs with heavy elements like uranium.

The d-block elements

d-block metals are the workhorse elements

- ❖ Iron and copper helped civilization rise from the Stone Age;
- ❖ Titanium for the aerospace industry;
- ❖ Vanadium for catalysts in the petrochemical industry;
- ❖ The precious metals—silver, platinum, and gold—are prized as much for their appearance, rarity, and durability;
- ❖ Compounds of d-block metals
 - give color to paint;
 - turn sunlight into electricity.

Trends in Physical Properties

All the d-block elements are **metals**.

Most are good electrical conductors—**silver** is the best *electrical conductor* of all elements.

Most are *malleable, ductile, lustrous, and silver white in color*.

Their *melting and boiling points are high*.

The exceptions: **copper** is red-brown, gold is yellow, and mercury is a liquid at room temperature.

Trends in Chemical Properties

The d-block elements tend to lose their valence s-electrons first when forming compounds.

Most lose a variable number of d-electrons and exist in a variety of oxidation states.

Only Group 12 (zinc, cadmium, and mercury) lose their s-electrons and no d-electrons.

Most have
multiple
oxidation
state.

Common.
Known.

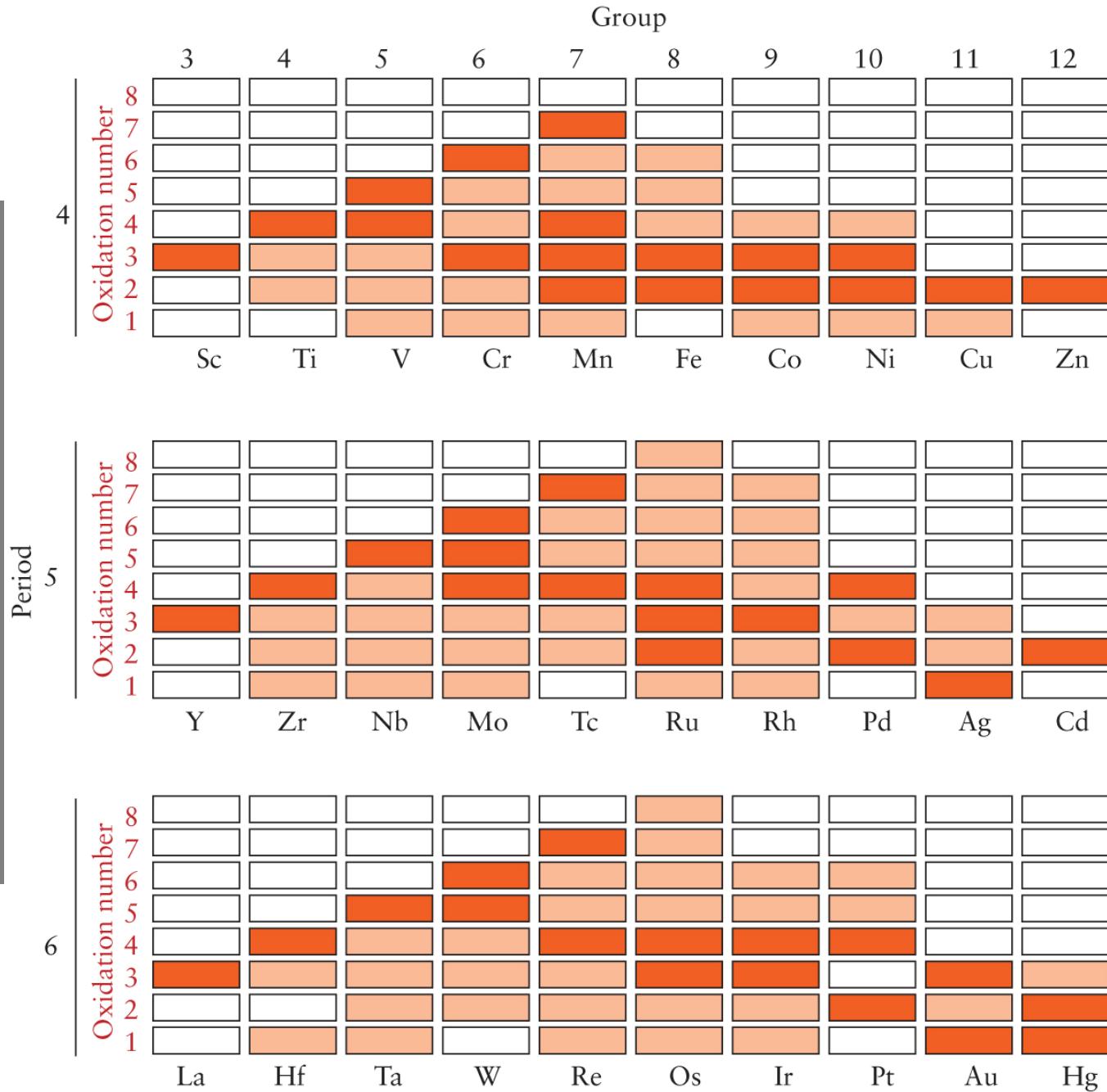


Figure 9A.7

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Coordination Compounds

Many d-block elements form colored solutions in water.

Solid copper(II) chloride is **brown** but in water it is **blue**.

Solid copper(II) bromide is **black** but in water it is **blue**.

The water is a complex, coordinated to the metal in a **Lewis acid-Lewis base** interaction called a ***coordination compound***.

Coordination Compounds

Ligands are either **molecules or ions** coordinating to d-metal ions in a **Lewis acid-Lewis base interaction**.

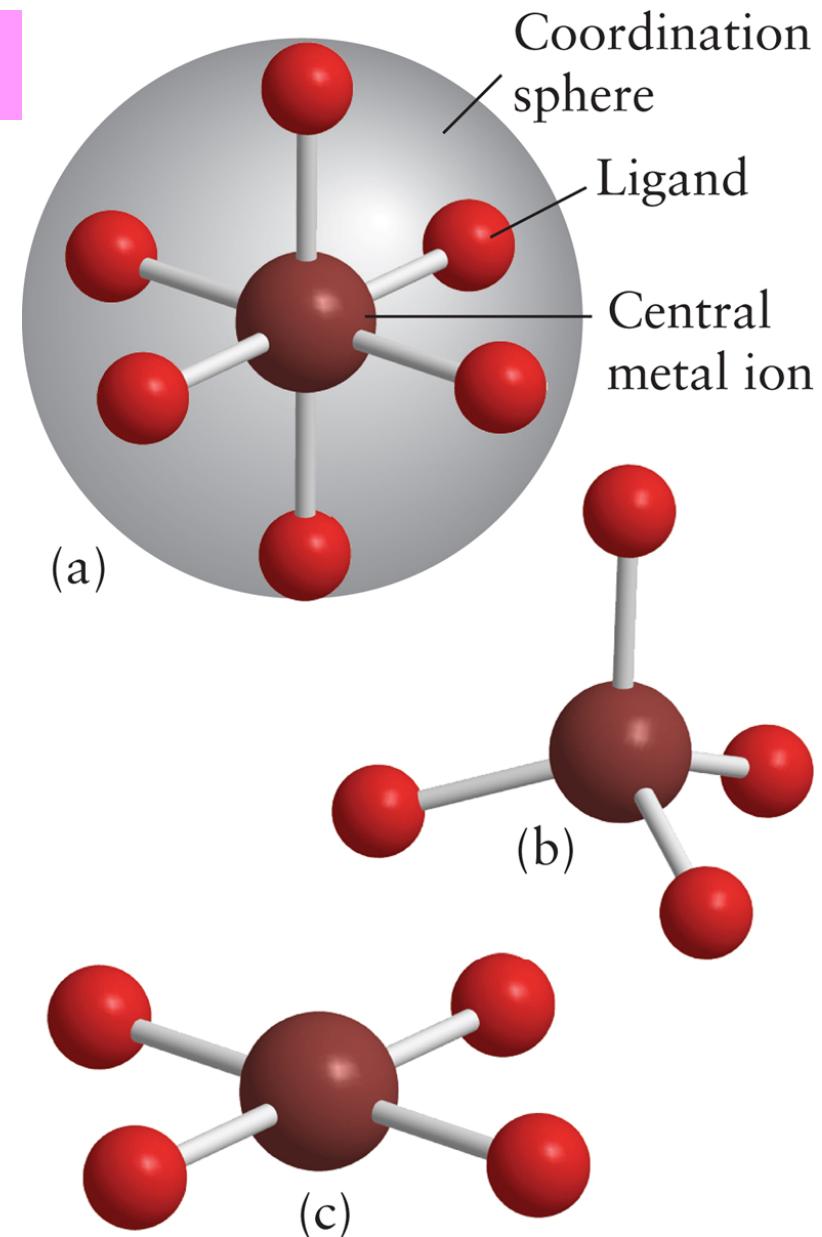


Figure 9C.1

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Coordination Complexes

Ligands are Lewis bases attached to d-metal ions.

Ligand means to bind. They can be ionic or molecular.

Cyanide is ionic $[\text{Fe}(\text{CN})_6]^{4-}$.

Carbon monoxide is molecular $\text{Ni}(\text{CO})_4$.

Ligands coordinate to the metal center to form a complex.

In a complex formula, ligands attach directly to the metal so we enclose them in a [], except for neutral complexes with nickel above.

Coordination Complexes

The coordination number is the number of ligands, *directly attached* to the metal.

$[\text{Fe}(\text{CN})_6]^{4-}$ has a coordination number of 6 and $\text{Ni}(\text{CO})_4$ has a coordination number of 4.

Aqueous solutions of d-metal ions are usually solutions of their H_2O complexes: $\text{Fe}^{2+}(\text{aq})$, for instance, is more accurately $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$.

Water is a Lewis base, it forms complexes with most d-block ions when they dissolve in it.

Coordination Complexes

Many complexes are prepared simply by mixing aqueous solutions of a d-metal ion with the appropriate Lewis base (*spectator ions* are not written):

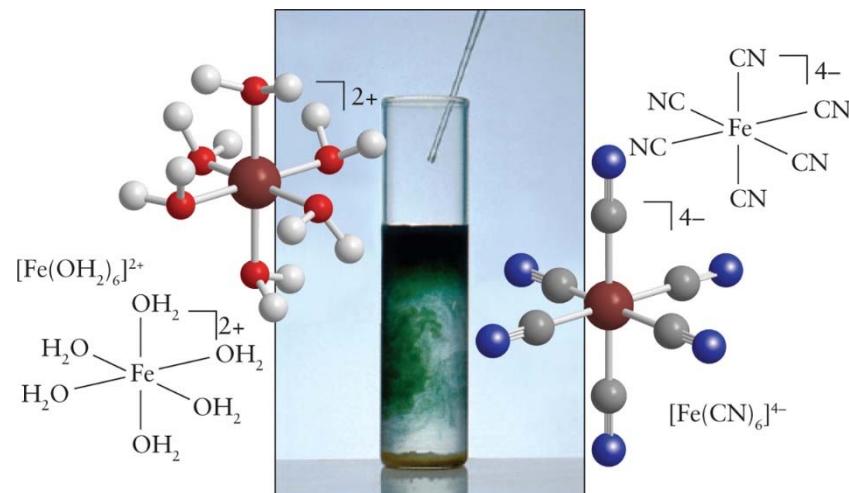
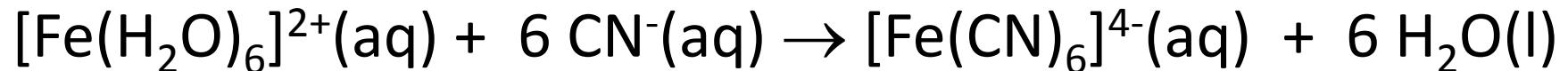


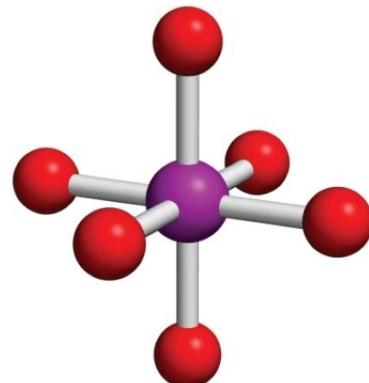
Figure 9C.2
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W. H. Freeman photo by Ken Karp

Typically **substitution reactions**, a Lewis base replacing another Lewis base.

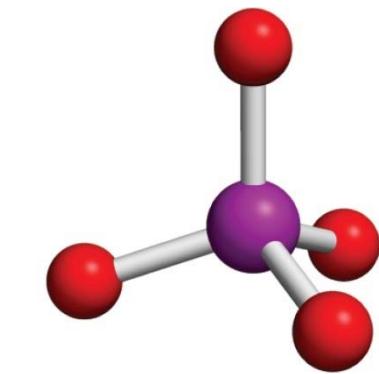
The Shapes of Complexes

Most common complexes have 6 as a coordination number and are called octahedral complexes.

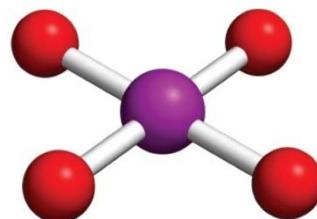
Tetrahedral complex, the four ligands are found at the vertices of a tetrahedron. An alternative is a square planar complex seen in d⁸ electron configurations for Pt²⁺ and Au³⁺.



1 An octahedral complex



2 A tetrahedral complex



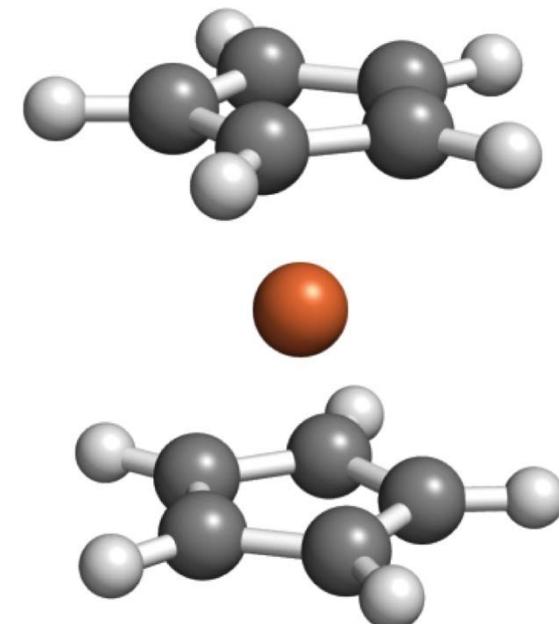
3 A square planar complex

The Shapes of Complexes

An interesting d-metal compound with 10 links between the ligands and the central metal ion is ferrocene, dicyclopentadienyliron(0), $[\text{Fe}(\text{C}_5\text{H}_5)_2]$.

Ferrocene is an aptly named a "sandwich compound," with the two planar cyclopentadienyl ligands the "bread" and the metal atom the "filling." The formal name for a sandwich compound is a **metallocene**.

The rings rapidly spin, as if on an axis, at room temperature.

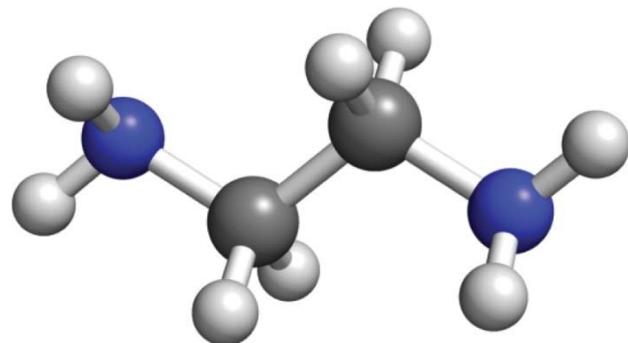


5 Ferrocene, $\text{Fe}(\text{C}_5\text{H}_5)_2$

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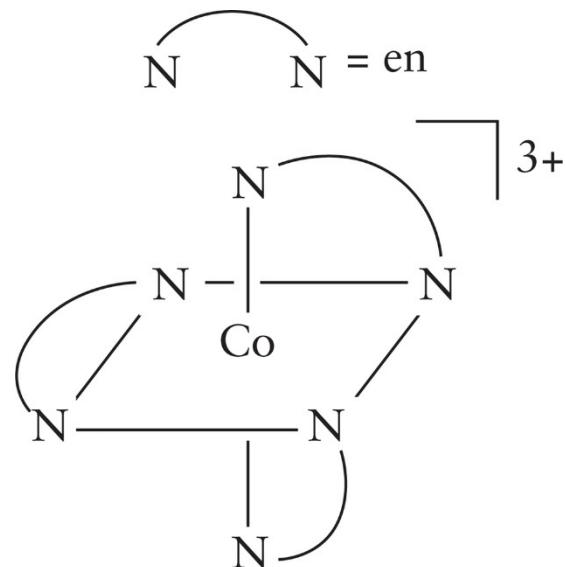
The Shapes of Complexes

Polydentate ligands ("many toothed") occupy more than one binding site simultaneously. Ethylenediamine is a two-toothed (**bidentate**) molecule, $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$.



8 Ethylenediamine, $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$

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9 $[\text{Co}(\text{en})_3]^{3+}$

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Three ligands pinch or claw the metal. It is an example of a **chelate** (from the Greek word for "claw").

The electronic structure of complexes

The striking feature of many coordination compounds is their color and magnetic properties.

There are two major theories of bonding in d-metal complexes.

Crystal field theory was first devised to explain the colors of solids. Crystal field theory is simple to apply, is useful to make predictions, but does not account for all the properties of complexes.

Coordination Complexes

Example of highly colored d-metal complexes.

$[\text{Fe}(\text{SCN})(\text{H}_2\text{O})_5]^{2+}$, $[\text{Co}(\text{SCN})_4(\text{H}_2\text{O})_2]^{2-}$, $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$, and $[\text{CuBr}_4]^{2-}$.

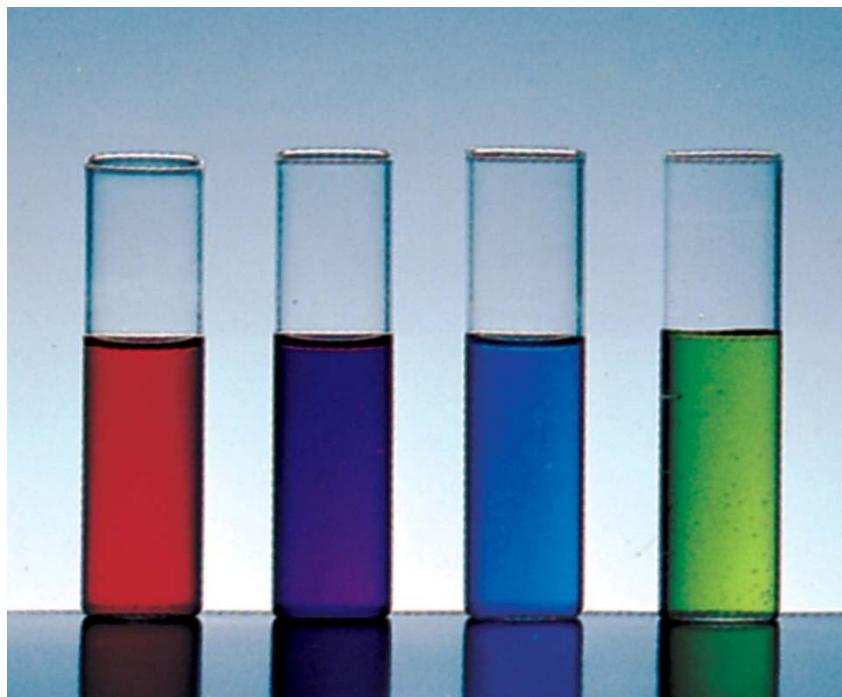


Figure 9C.3
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W. H. Freeman photo by Ken Karp.

The Colors of Complexes

White light is a mixture of all wavelengths of electromagnetic radiation from about 400 nm (violet) to about 800 nm (red).

If we **remove** one of the colors, the light will no longer be white.

The Colors of Complexes

If we remove red light from white light, then the light that remains appears green. Conversely, removing green appears as red light.

We say that red and green are each other's complementary color—each is the color that white light appears as when the other is removed.

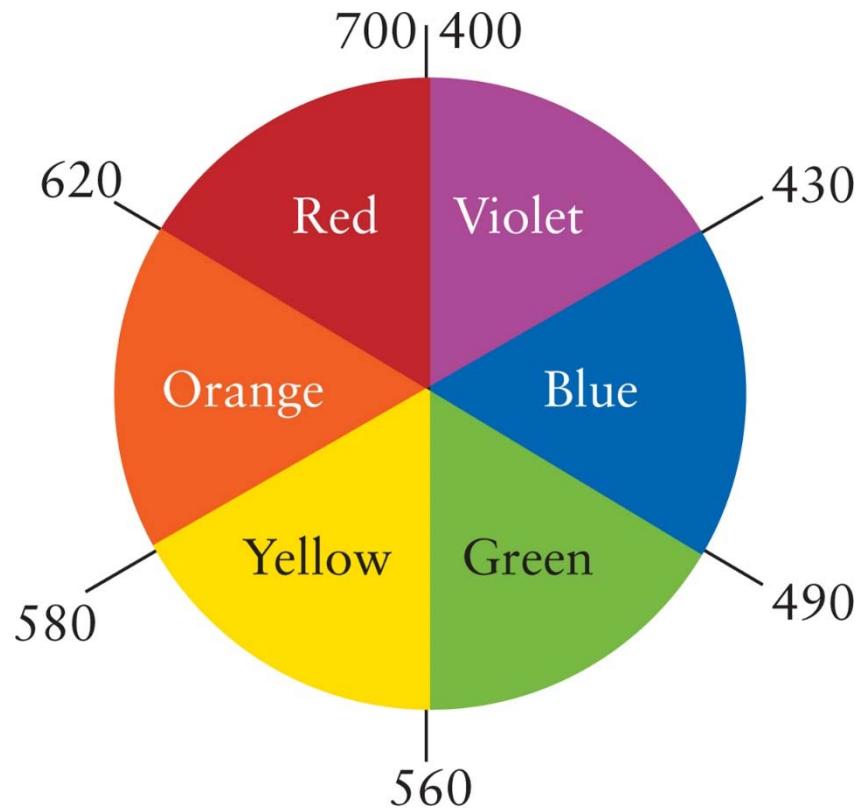


Figure 9D.7
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The Colors of Complexes

If we know the wavelength (and therefore the color) of the light that a substance absorbs, then we can predict the color of the substance by noting the complementary color on the color wheel. Because $[\text{Ti}(\text{H}_2\text{O})_6]^{3+}$ absorbs 570-nm light, which is yellow light, the complex looks violet.

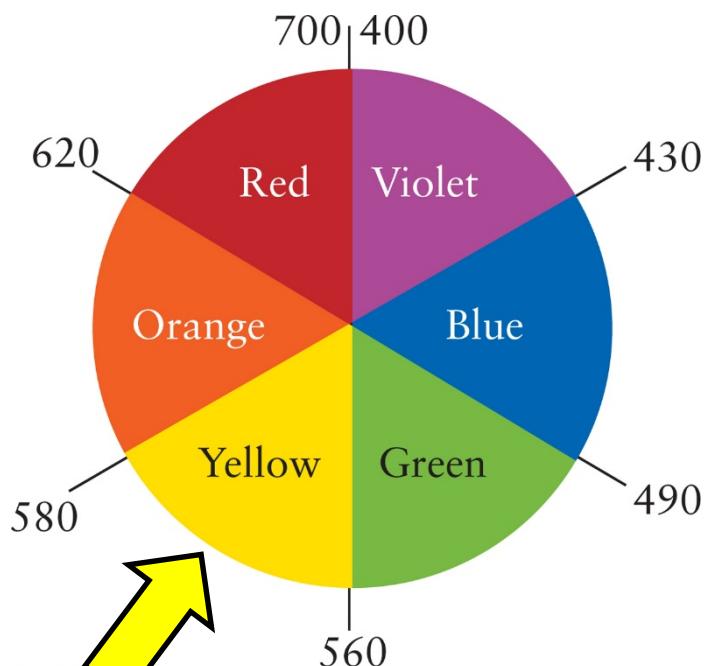


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Figure 9D.8
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Crystal Field Theory

- (a) In crystal field theory, the **lone pairs on a Lewis base** are ligands, and
- (b) each ligand is treated equivalently as a **point negative charges**.

Basically, you have a positive metal center with negative charges around it. This **resembles** a VESPR Lewis structure.

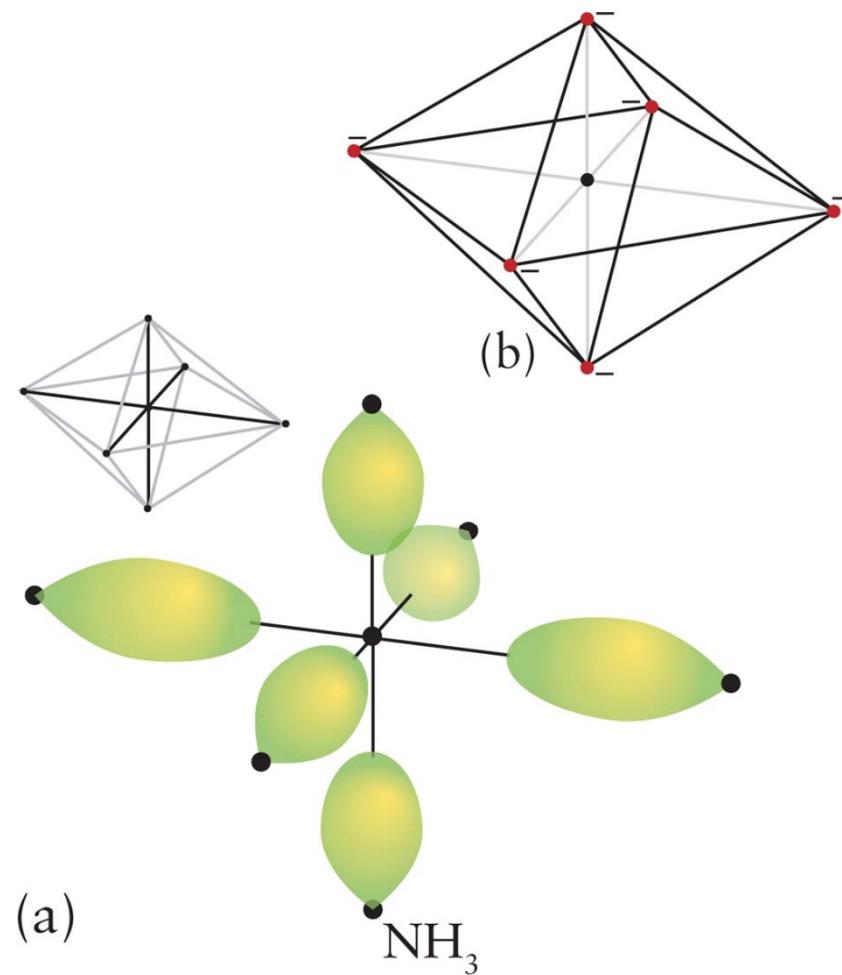


Figure 9D.1
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Crystal Field Theory

The ligands align themselves, to minimize repulsions, and when they do so, they end up being more around the d_z^2 and $d_{x^2-y^2}$ orbitals more than the other three d orbitals.

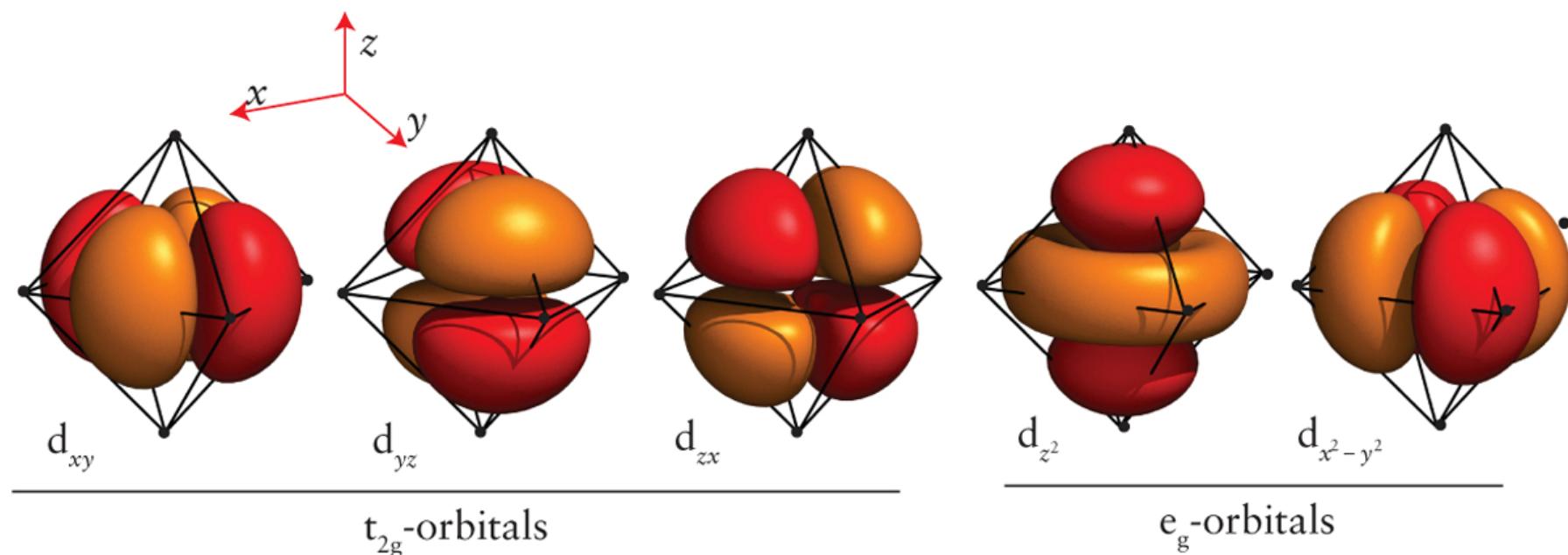


Figure 9D.2

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The dark dots represent ligands.

Crystal Field Theory

The name e_g stands for double **degenerate**, and t_{2g} stands for triple degenerate. Degenerate just means they all have the same energy.

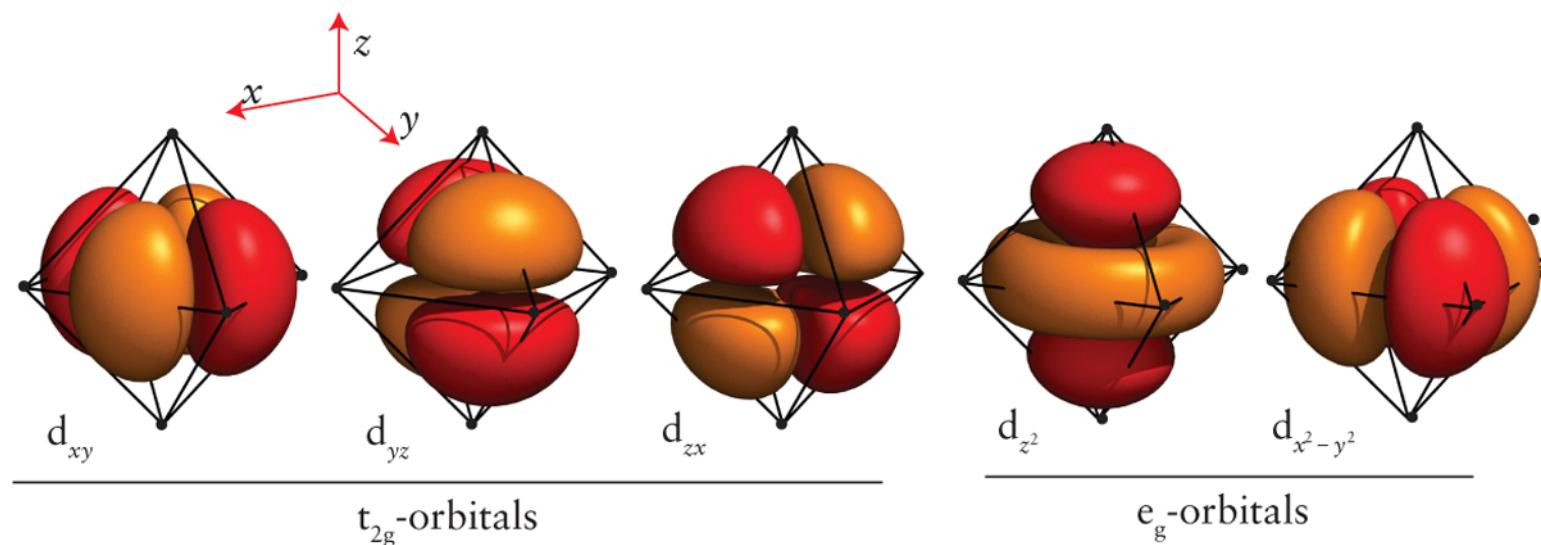


Figure 9D.2

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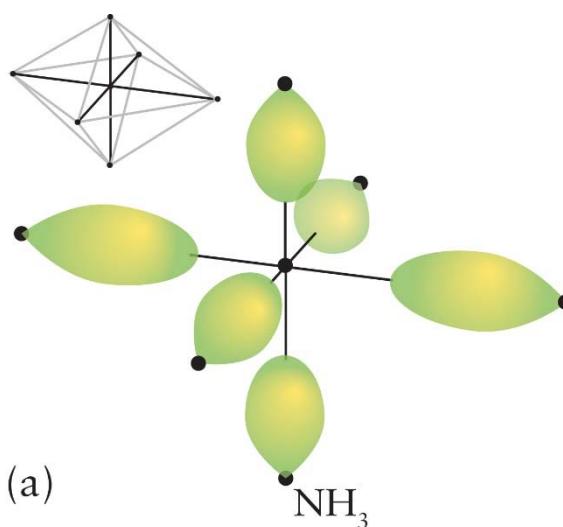
Notice how the ligands are pointing right at the d_{z^2} and $d_{x^2-y^2}$ orbitals. The t_{2g} are basically left alone.

Crystal Field Theory

Ligands pointing at the d_z^2 and $d_{x^2-y^2}$ orbitals raise them in energy, whereas the t_{2g} lower them in energy.

| d | -2 | -1 | 0 | +1 | +2 |
|---|----|----|---|----|----|
|---|----|----|---|----|----|

Unmodified d-orbitals



(a)

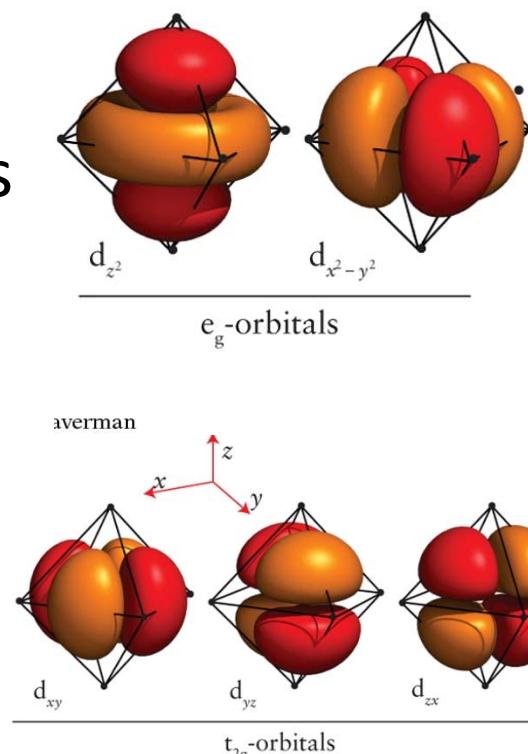
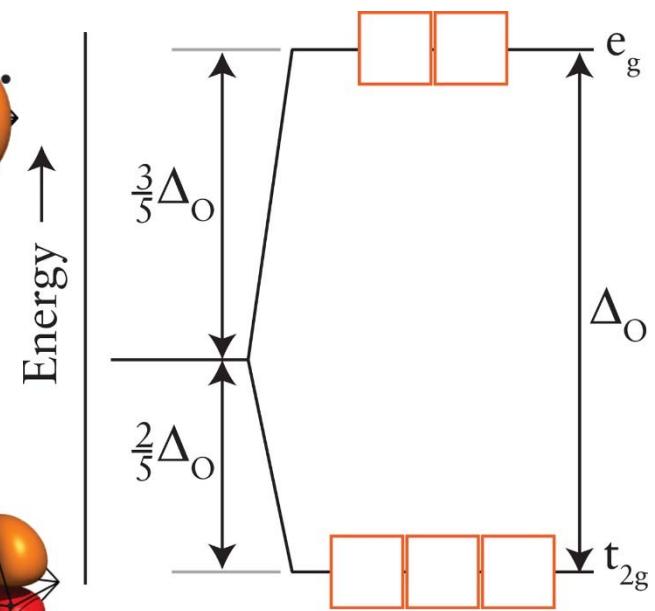


Figure 9D.2

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Modified d-orbitals

Figure 9D.1a
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Crystal Field Theory

In an octahedral complex, we call the difference in energy the Δ_O , pronounced octahedral field splitting.

The three t_{2g} -orbitals lie at an energy that is $\frac{2}{5} \Delta_O$ below, lower than the average d-orbital energy; the two e_g -orbitals lie at an energy $\frac{3}{5} \Delta_O$ above the average.

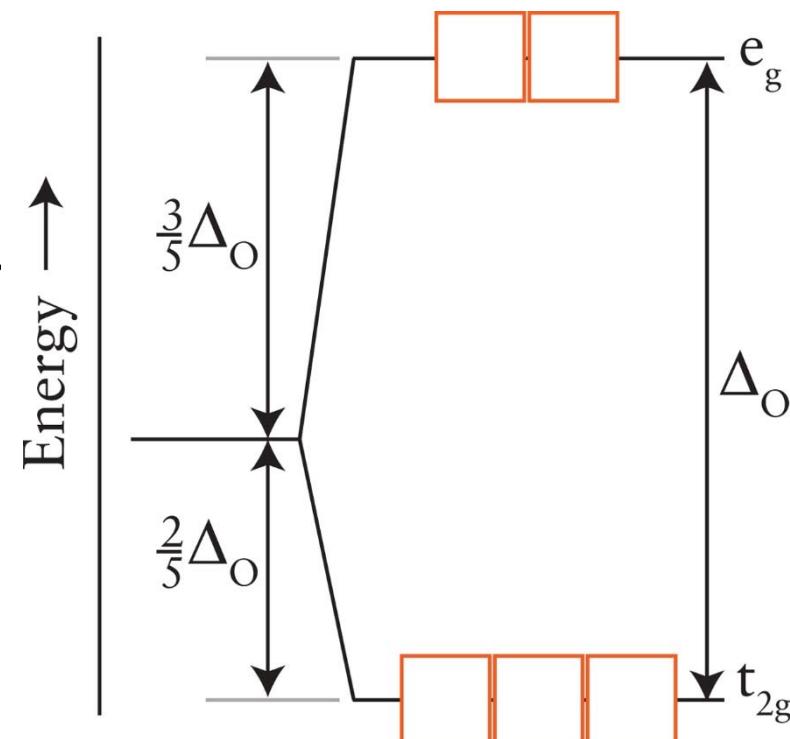


Figure 9D.3
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Crystal Field Theory

Light can excite an electron from the t_{2g} -orbitals to the e_g -orbitals.

We can use the wavelength of the electromagnetic radiation absorbed by a complex to determine the ligand field splitting.

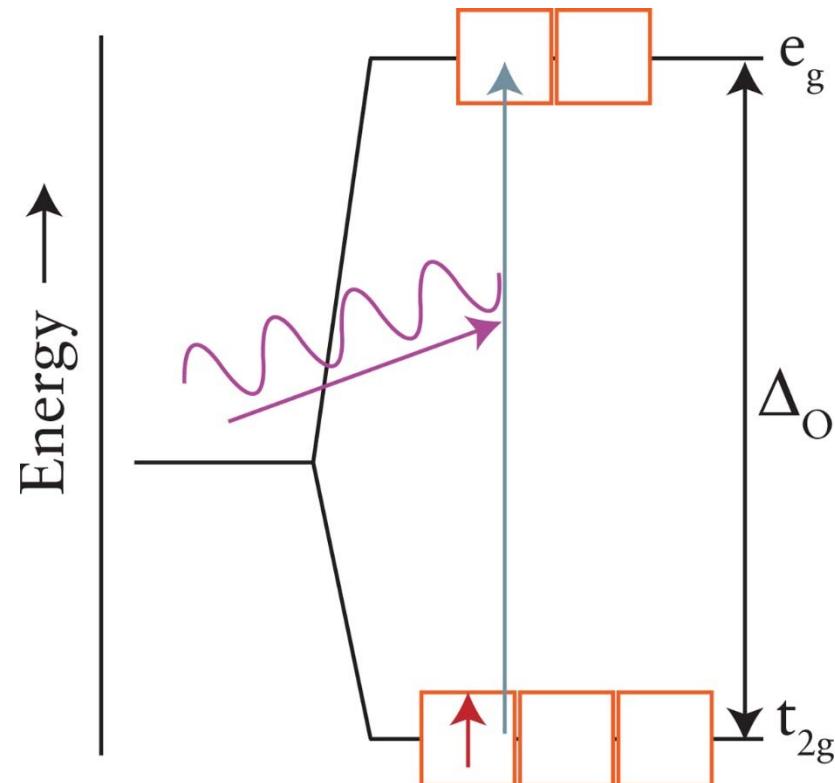


Figure 9D.4
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Crystal Field Theory

A tetrahedral complex only has ligands pointing at the three t_2 -orbitals. The ligand field splitting, Δ_T , is generally smaller than in octahedral complexes, in part because there are fewer repelling ligands.

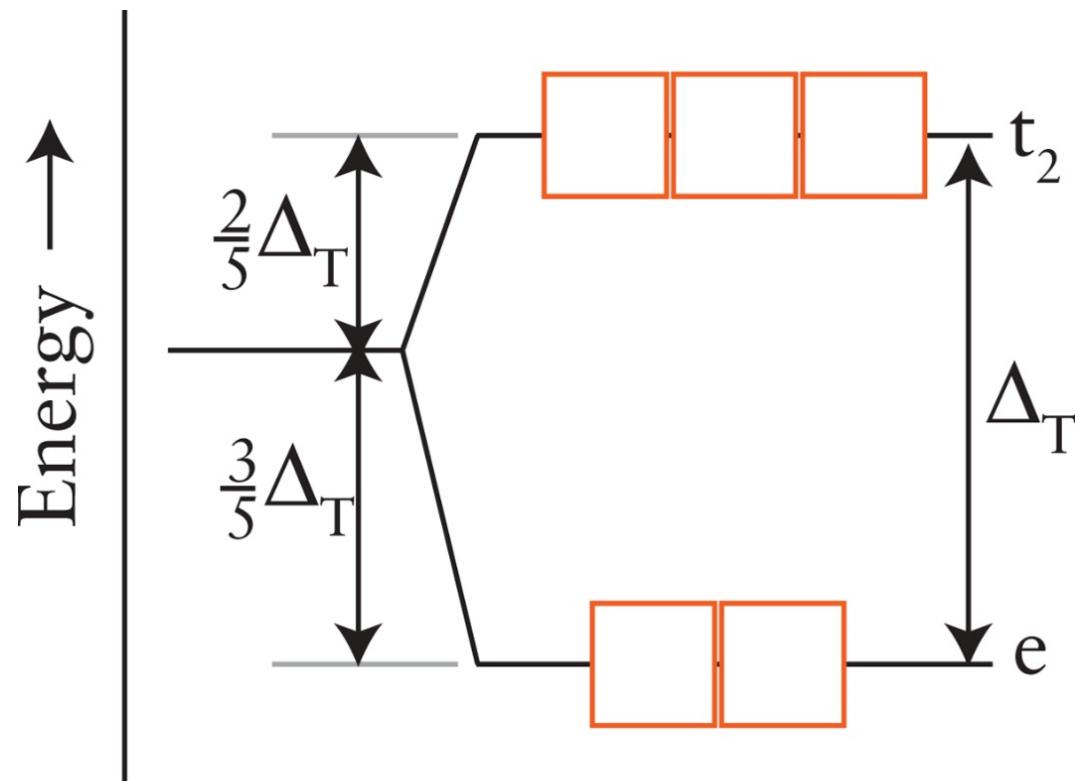


Figure 9D.5

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The Spectrochemical Series

Different ligands affect the d-orbitals and produce differences in the ligand field splitting; the ligand field splitting is much greater in $[\text{Fe}(\text{CN})_6]^{4-}$ than it is in $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$.

Spectrochemical series arranges ligands according to their *magnitude* of the ligand field splitting.

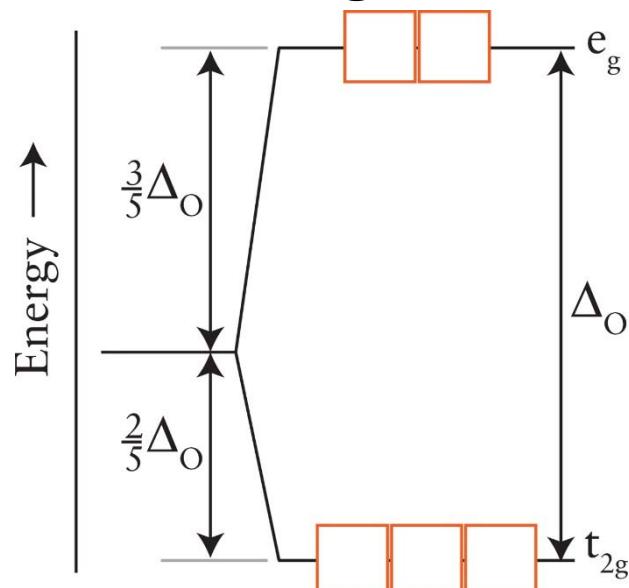


Figure 9D.3
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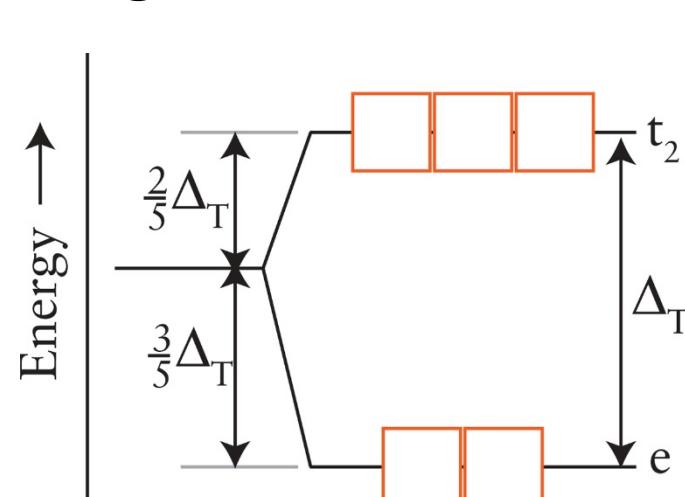


Figure 9D.5
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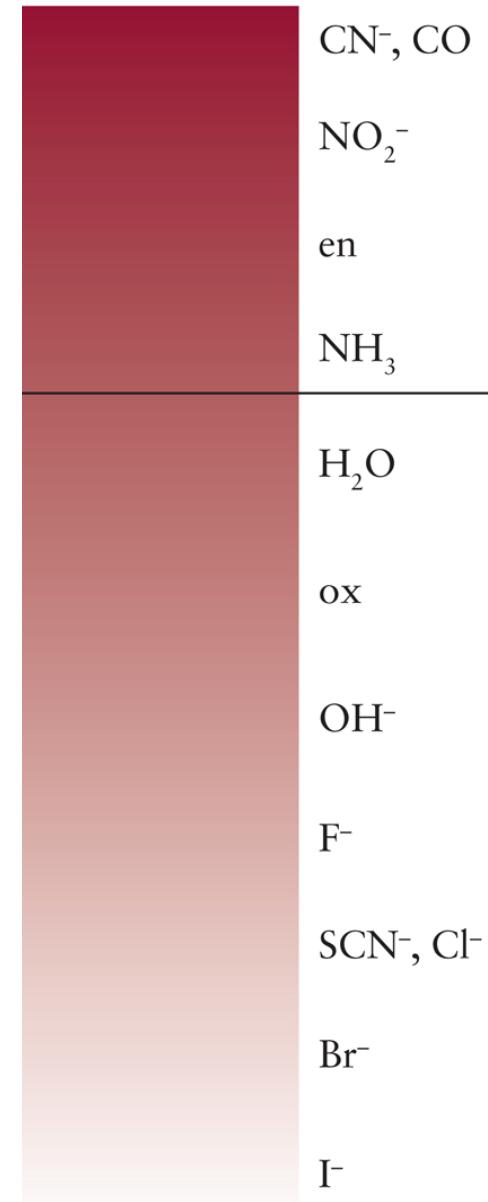
The Spectrochemical Series

Ligands *above* the line produce a **larger splitting** and are called **strong-field** ligands. A CN^- ion is a strong-field ligand.

Ligands *below* the horizontal line produce only a **small ligand field** splitting, and so they are called **weak-field** ligands;

Note that NH_3 is a strong-field and H_2O molecule is a weak-field ligand.

Strong-field ligands



Weak-field ligands

Figure 9D.6

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The Spectrochemical Series

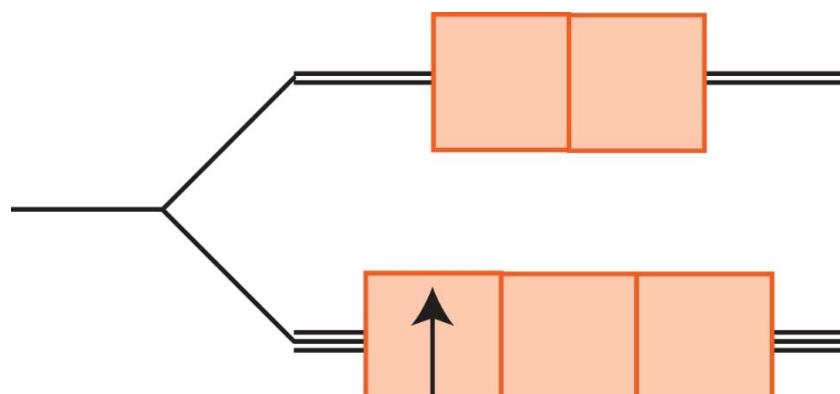
Replacing one ligand for another gives us **chemical control**.

Substitution weak-field for strong-field ligands (or vice versa) acts like a chemical switch for turning paramagnetism on and off.

The **key** being the ligand field splitting affects the electron configuration of the complex.

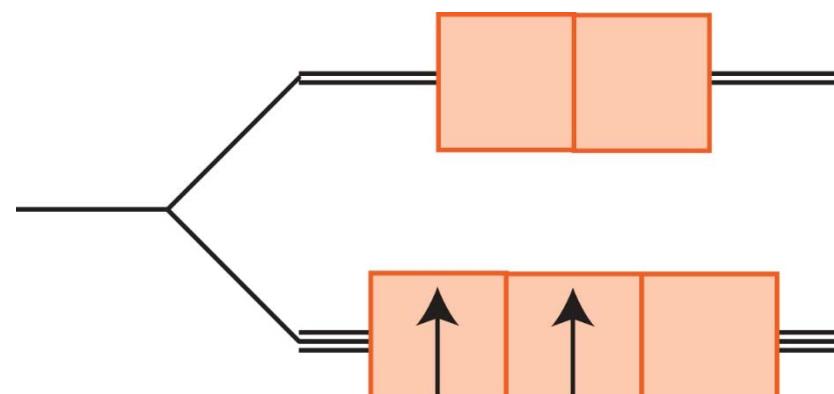
The Spectrochemical Series

The one and two d-electrons of a d^1 and d^2 complex occupy separate orbitals and give rise to the configuration t_{2g}^1 and t_{2g}^2 . Hund's rule states they have the same parallel spin.



1 t_{2g}^1

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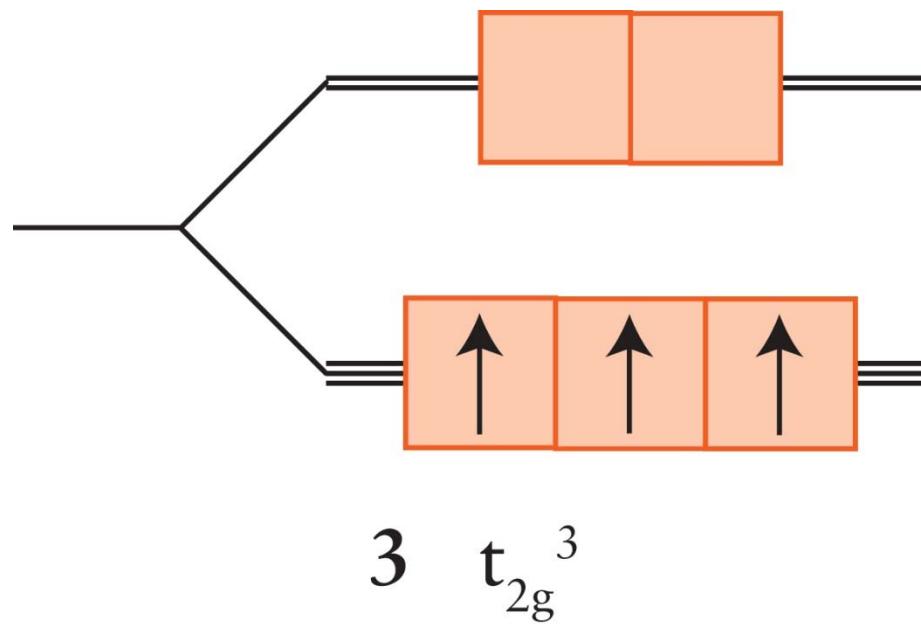


2 t_{2g}^2

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The Spectrochemical Series

Similarly, a d³ complex will have the ground-state configuration t_{2g}³.



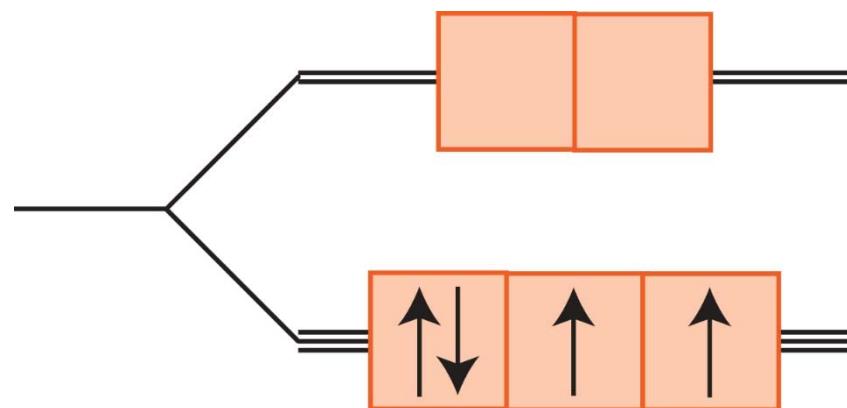
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Next is the d⁴.

The Spectrochemical Series

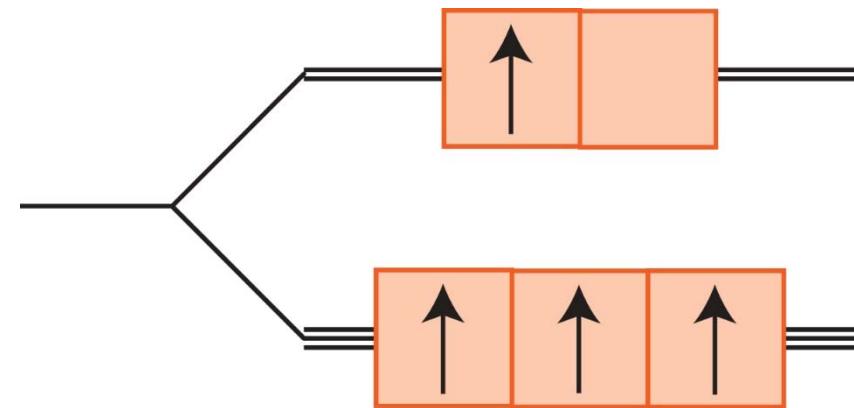
A d⁴ octahedral complex presents a problem.

The fourth electron could produce either the t_{2g}⁴ or t_{2g}³e_g¹ orbital.



4 t_{2g}⁴

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5 t_{2g}³e_g¹

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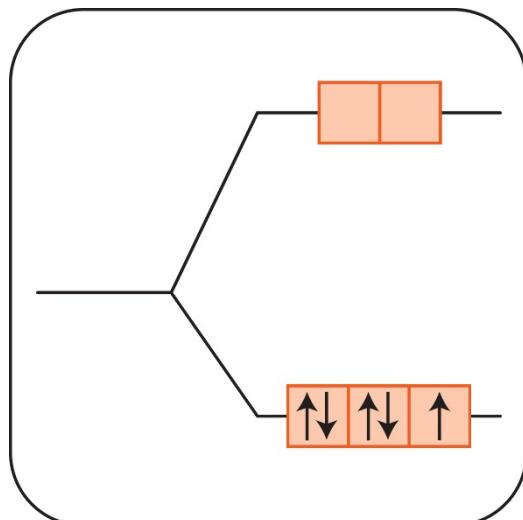
Strong-field ligands produce a large Δ_0 (figure 19) and weak-field ligands produce a small Δ_0 (figure 20).

Ligand field splitting vs. electron-pairing

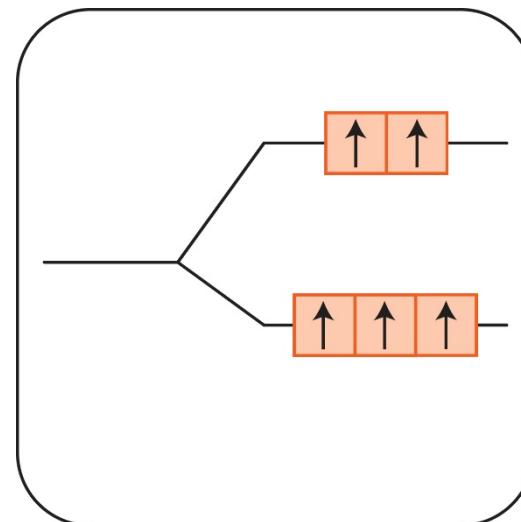
The Spectrochemical Series

High-spin complexes have the maximum number of unpaired spins. Low-spin complexes have the minimum number of unpaired spins.

A d^5 complex with strong-field ligands is a low-spin complex, and weak-field ligand complex is high spin.



d^5 low spin, strong field



d^5 high spin, weak field

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When determining the electron configurations of d-block metal atoms we take into account the strength of the ligand field splitting.

TABLE 9D.1 The Electron Configurations of d^N Complexes

| Number of d-electrons, d^N | Configuration | |
|---------------------------------|----------------------|-----------------------|
| | Octahedral complexes | Tetrahedral complexes |
| d^1 | t_{2g}^1 | e^1 |
| d^2 | t_{2g}^2 | e^2 |
| d^3 | t_{2g}^3 | $e^2t_2^1$ |
| | low spin | high spin |
| d^4 | t_{2g}^4 | $t_{2g}^3e_g^1$ |
| d^5 | t_{2g}^5 | $t_{2g}^3e_g^2$ |
| d^6 | t_{2g}^6 | $t_{2g}^4e_g^2$ |
| d^7 | $t_{2g}^6e_g^1$ | $t_{2g}^5e_g^2$ |
| d^8 | | $t_{2g}^6e_g^2$ |
| d^9 | | $t_{2g}^6e_g^3$ |
| d^{10} | | $t_{2g}^6e_g^4$ |

Table 9D.1

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The Colors of Complexes

Here we see the color effect on aqueous **cobalt(III)** complexes by substituting different ligands into the octahedral structure.

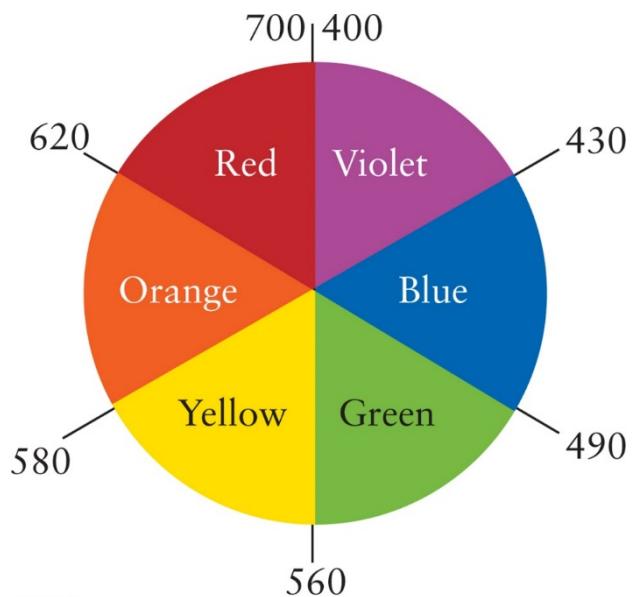


Figure 9D.7
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High spin, weak field

Low spin, strong field



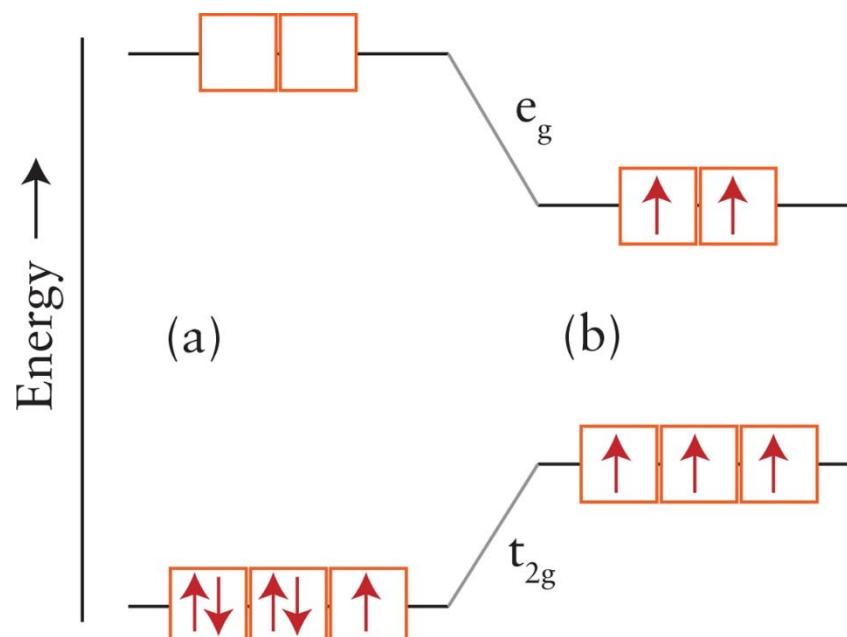
Figure 9D.9
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Magnetic Properties of Complexes

Unpaired electrons are paramagnetic and are pulled into a magnetic field. If all electrons are **paired** the substance is **diamagnetic**.

Many d-metal complexes have unpaired d-electrons so are **paramagnetic**.

Low spin,
strong-field
ligands



High spin,
weak-field
ligands

Figure 9D.12
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KEY QUESTIONS TO BE ADDRESSED:

1. What determine the properties of matters?
2. How to manipulate chemical reactions?
3. How science (*technology*) evolves?