LECTURE № 14

METALS

18.04.2016

Lecture Plan:

- Metal definition
- Categories of various metals
- The structure of metal. Metallic bond
- Properties of metals: physical, chemical
- Extraction of metals
- Applications and role of metals. Alloys

OBJECTIVES:

- Understand the physical properties of metals.
- Explains the chemical properties of metals.
- Explain how the reactivity of metals changes across the periodic table
- List out the uses of metals and alloys.


Copper


Lead


Tin


Nickel


Steel


Zinc

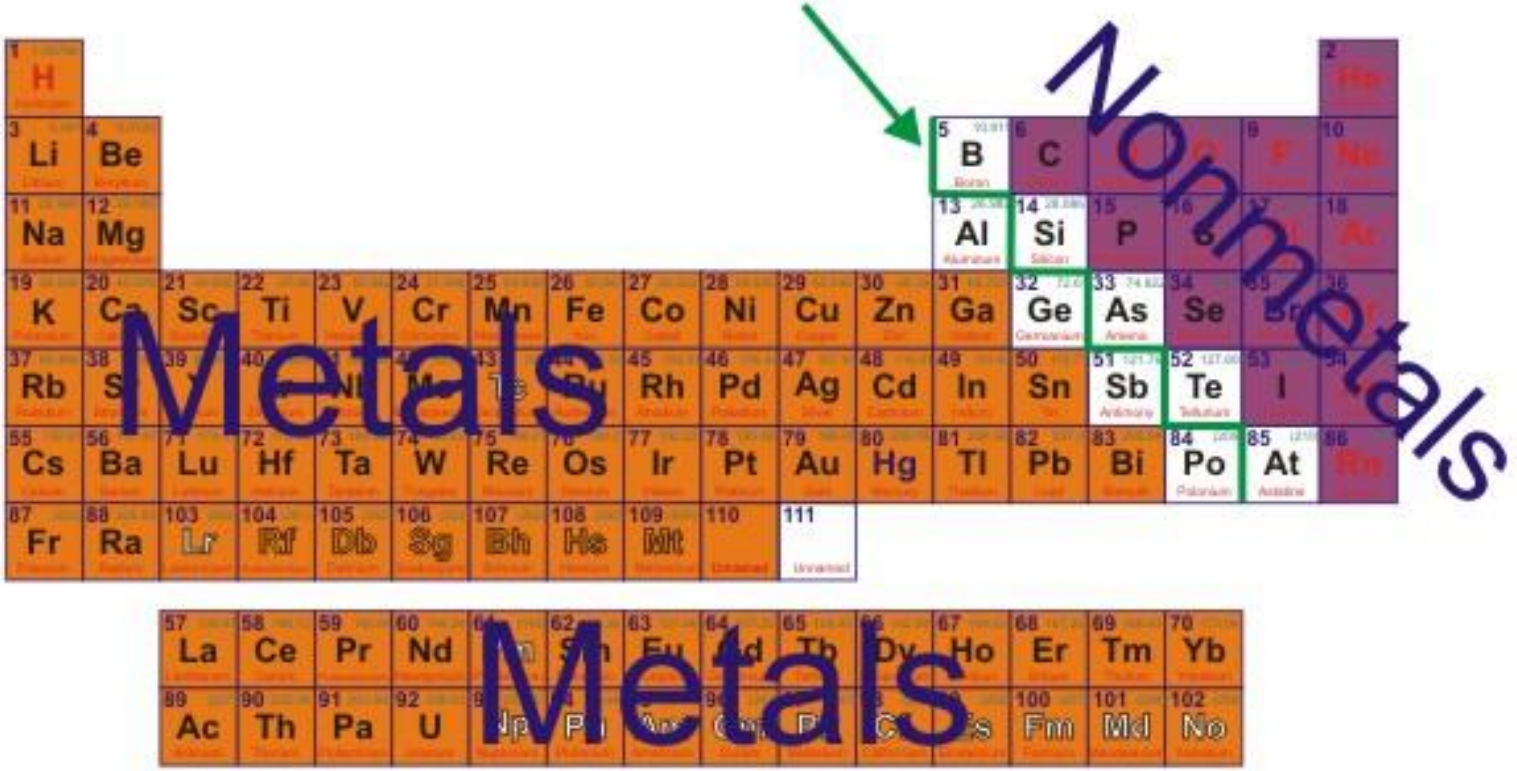
A metal *(from Greek μέταλλον métallon, "mine, quarry, metal")* **is a material (an element, compound, or alloy) that is typically hard, opaque, shiny, and has good electrical and thermal conductivity**.

In chemical reaction: "Metals are the elements which form positive ions by losing electrons.“ They are also known as *electropositive elements*.

Metals are generally malleable — that is, they can be hammered or pressed permanently out of shape without breaking or cracking — as well as fusible (able to be fused or melted) and ductile (able to be drawn out into a thin wire).

About 91 of the 118 elements in the periodic table are metals (some elements appear in both metallic and non-metallic forms).

Elements that border on the amphoteric line (shown in green) are metalloids. They have characteristics of both metals and nonmetals. Aluminum (Al), however, definitely has mostly metallic characteristics, and boron (B) is mostly nonmetallic.



Metals

1. Have luster
2. Are malleable and ductile
3. Conduct heat and electricity
4. Tend to lose electrons

Nonmetals

1. Are dull
2. Are brittle
3. Do not conduct heat or electricity very well
4. Tend to gain electrons

Metallic Elements:

1) **Alkali metals** (group IA): Li, Na, K, Rb, Cs, Fr
2) **Alkali earth metals** (group IIA): Be, Mg, Ca, Sr, Ba, Ra
3) **Transition metals** (Group 3 – 12, d-elements): Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ag, Cd, Os, Hg, Pt, Au, W

- **Iron Triad** (Group 8, 9,10): Fe, Co & Ni = They create the magnetic field
- **Coinage Metals** (Group 11): Cu, Ag, Au = They are used to make coins.

copper

silver

gold

Metallic Elements:

4) Post-transition metals: Al, In, Ga, Sn, Tl, Pb, Bi, Po

5) Lanthanides

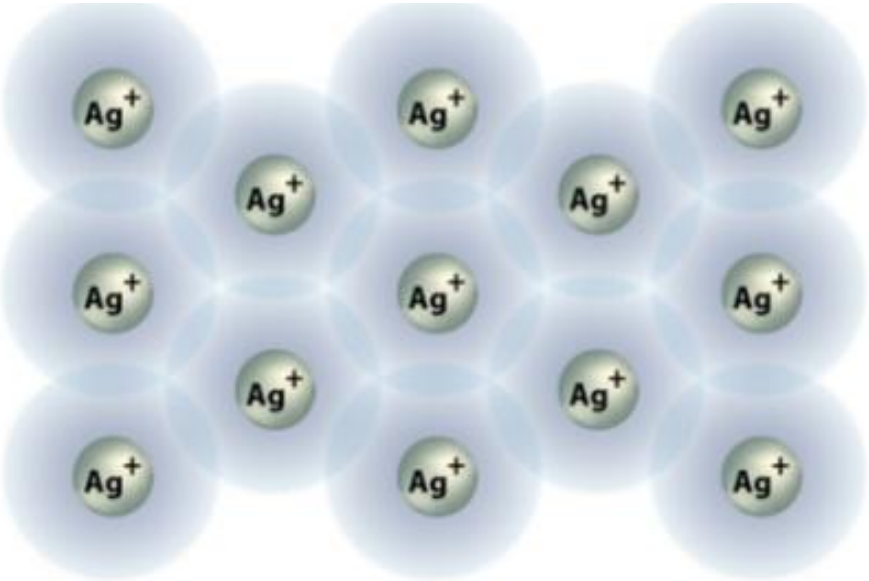
6) Actinides

7) Elements which are possibly metals: meitnerium, darmstadtium, roentgenium, ununtrium, ununpentium, livermorium, ununseptium

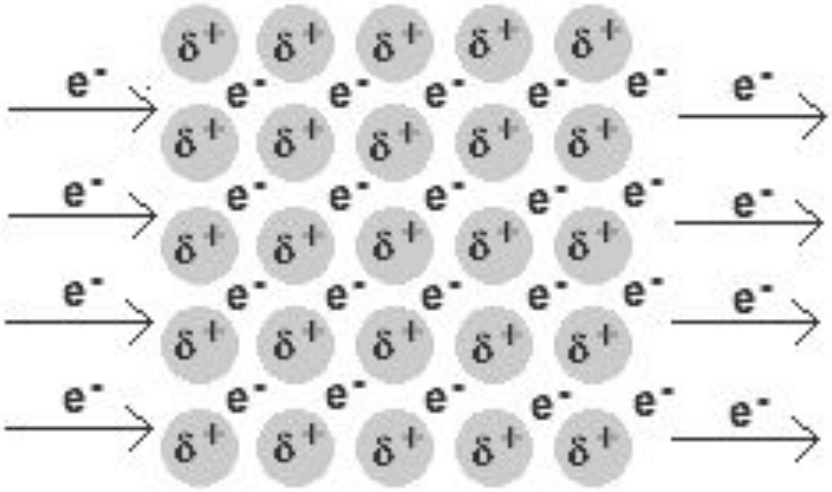
8) Elements which are sometimes considered metals: Ge, As, At, Sb

Metallic Bonding

Metallic bonding is the force of attraction between valence electrons and the metal positive ions.



The metallic bond causes many of the traits of metals, such as strength, malleability, ductility, luster, conduction of heat and electricity.



$$Me^{\square} - n\,\bar{e} <=> Me^{+n}$$

$$Na^{\square}...3s^{1} \xrightarrow{-1\bar{e}} Na^{+1}...3s^{\square}$$

In a piece of metal, all the atoms lose their outer electrons to gain full shells, and become positive ions. These negative “sea of electrons” move around between the metal ions. The negative electrons attract the positive ions, making the structure strong.

Metals are good at conducting electricity and heat because of the free electrons which are able to move around.

GIVE 3 REASONS WHY TUNGSTEN IS USED TO MAKE THE FILAMENT INSIDE AN ELECTRIC BULB?

REASONS:

1) Tungsten can be drawn into very thin metal wires.

2) Tungsten has the highest melting point (3422°C).

3) Tungsten has strong resistance to high temperature.

PHYSICAL PROPERTIES OF METALS

- Good *electrical and heat conductors*.
- *Malleable* - can be beaten into thin sheets.
- *Ductile* - can be stretched into wire.
- Metals have a *high melting point*. They are also *very dense*.
- Possess *metallic luster*.
- *Opaque* as thin sheet.
- *Solid at room temperature* (except Hg).

Density of Metals

Light metals

Heavy metals

Lithium
0,53 g/cm3

Magnesium
1,74 g/cm3

Lead
11,3 g/cm3

Gold
19,3 g/cm3

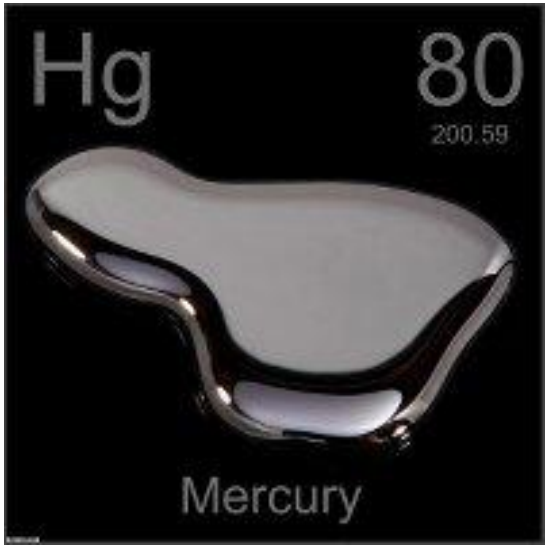
Osmium
22,5 g/cm3

Light metals have density less than 5 g/cm3

Heavy metals have density greater than 5 g/cm3

Melting point metals

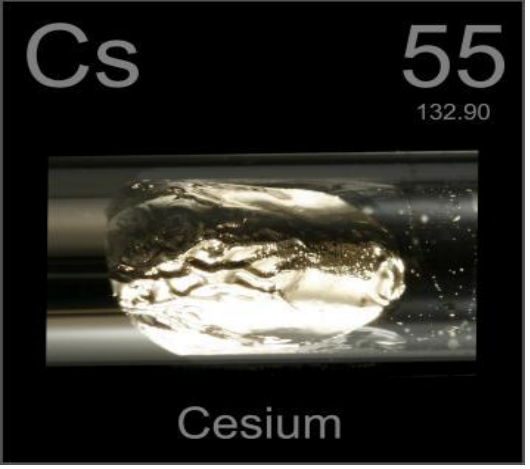
Fusible metals



$$t_{melt} = -39^{\circ}C$$

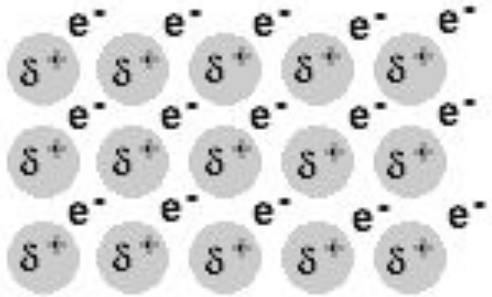
Refractory metals

$$t_{melt} = 3420^{\circ}C$$



Metals have luster. This means they are **shiny**.

Ductile metals can be drawn into wire.



Malleable metals can be hammered into sheets

The ability of metals to produce a particular sound when it is tapped on a hard surface is termed **sonority**.

A chemical property of metal is its reaction with water and oxygen. This results in **corrosion** and **rust:**

$$Me + O_2 = Me_xO_y$$

$$Me + [O] + H_2O = Me(OH)_n$$

These properties make metals most useful in daily life.

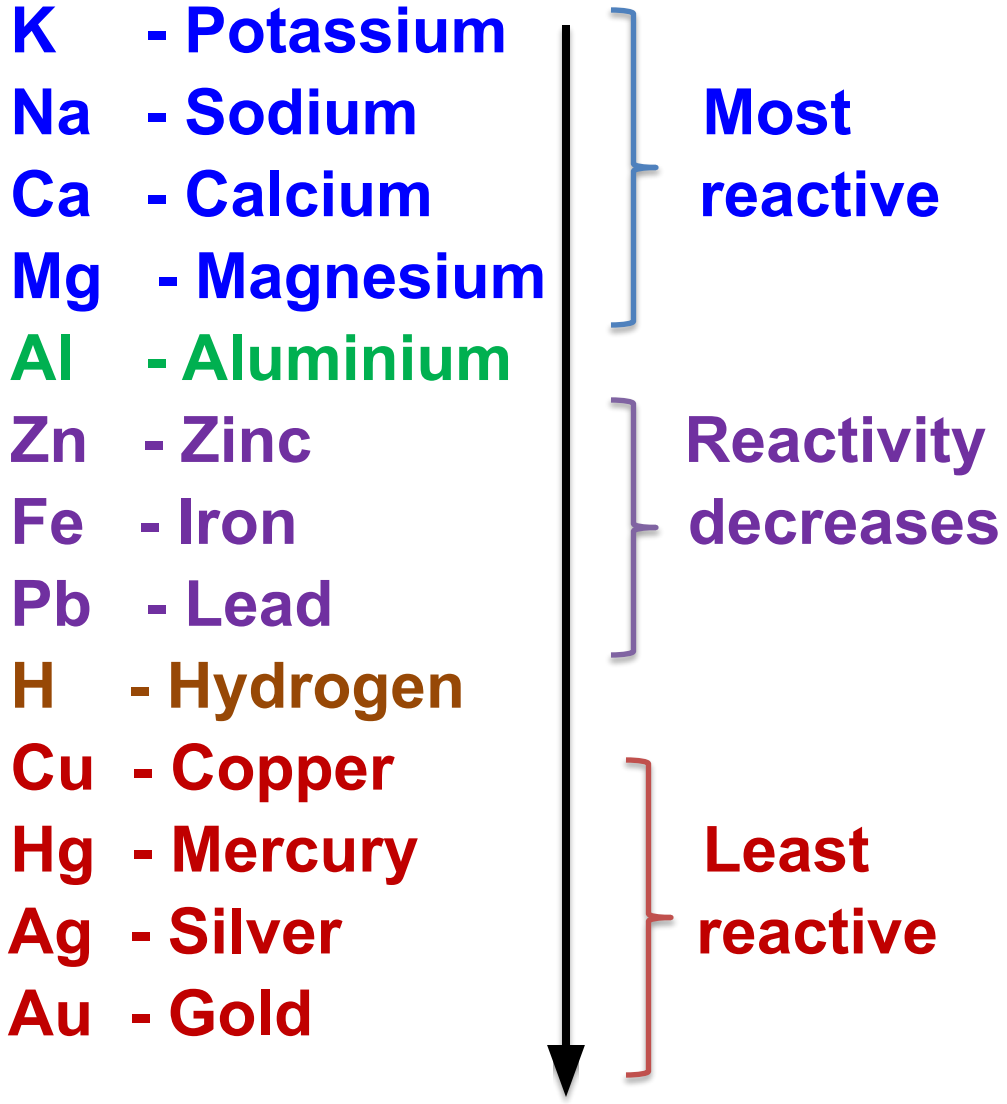
METAL	PHYSICAL PROPERTY	USE
Iron	High tensile strength	Railways track
Aluminum	-Light -Good conductor of electricity and heat	Kitchen utensils
Copper	Ductile and malleable	Electrical wire
Tin	Does not rust	Electroplating of food cans
Gold	Does not rust and shiny	Jewellery
Lead	Ductile Malleable	Cable casing

CHEMICAL PROPERTIES OF METALS

- **Usually have 1-3 electrons in their outer shell.**
- Lose their valence electrons easily.
- Form oxides that are basic.
- **Are good reducing agents**
- Have lower (EN<1,5) electronegativities.

Reactivity series of metals

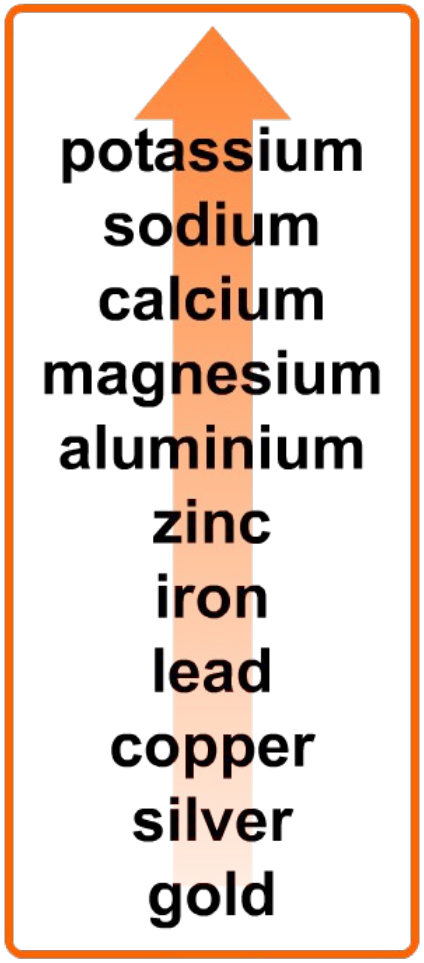
The arranging of metals in the decreasing order of their reactivity is called reactivity series of metals:



The activity series of metals is an empirical tool used to predict products in displacement reactions and reactivity of metals with water and acids in replacement reactions and ore extraction.

Use the reactivity series to predict if a reaction will take place and how intense the reaction will be:

metal	reacts with	prediction
gold	acid	no reaction
calcium	water	fizzing
sodium	oxygen	burns vigorously
silver	oxygen	very slow reaction
zinc	oxygen	burns moderately



Reaction with oxygen :

Metals react with oxygen to form metal oxides:

$$2Cu + O_2 = 2CuO - Q$$
$$4Al + 3O_2 = 2Al_2O_3 - Q$$
$$4Na + O_2 = 2Na_2O + Q$$

The most reactive metals as K, Na, Li, Ca and Mg react with oxygen and burn in air.

Metals from Al to Cu in the activity series of metals, react slowly when heated in air to form the metal oxides. Aluminium is the fastest and copper is the slowest of them.

Iron metal does not burn in dry air even on strong heating. In moist air, iron is oxidized to give rust:

$$3Fe_{(s)} + 2O_2 + xH_2O = FeO \cdot Fe_2O_3 \cdot xH_2O$$

Gold and platinum do not react with oxygen in air.

Reaction of metals with water

Those metals staying above hydrogen in electrochemical series react with cold water or steam to produce hydrogen:

1) **Active metals at room temperature are formed hydroxides:**

$$Me_{(s)} + nH_2O_{(l)} = Me(OH)_{n\ (aq)} + H_{2\ (gas)} \uparrow$$

2) **Medium active metals at high temperature with steam are formed oxides:**

$$Me_{(s)} + nH_2O_{(vapor)} = MeO_{(s)} + H_{2\ (gas)} \uparrow$$

3) **Sn, Pb, Cu, Ag, Au and Pt do not react with water or steam.**

REACTION WITH ACIDS

K, Na, Li and Ca react violently with dilute H_2SO_4 and dilute HCl, forming the metal salt (either sulfate or chloride) and hydrogen gas:

$$2Na + 2HCl = 2NaCl + H_2 \uparrow$$

$$Mg + H_2SO_4 = MgSO_4 + H_2 \uparrow$$

$$Zn + H_2SO_4 = ZnSO_4 + H_2 \uparrow$$

Zinc with dilute sulphuric acid is often used for the laboratory preparation of hydrogen. The reaction is slow at room temperature, but its rate can be increased by the addition of a little copper (II) sulphate. Zinc displaces copper metal, which acts as a catalyst.

Metals below hydrogen (Cu, Ag, Au, Pt), will not react with dilute acids. They cannot displace hydrogen from the non-metal anion.

Reaction with Concentrated Acids: HNO_3 and H_2SO_4

Hydrogen gas is not evolved when metals react with nitric acid (HNO_3) because it is **a strong oxidising agent** and it oxidizes the H_2 produced to water and is itself reduced to nitrogen dioxide:

1) **With active metals:**

$$Mg + HNO_{3(dilut)} = Mg(NO_3)_2 + H_2O + NH_3\,(NH_4NO_3)$$

$$Mg + HNO_{3(conc)} = Mg(NO_3)_2 + 4H_2O + 2N_2O$$

2) **With passive metals:**

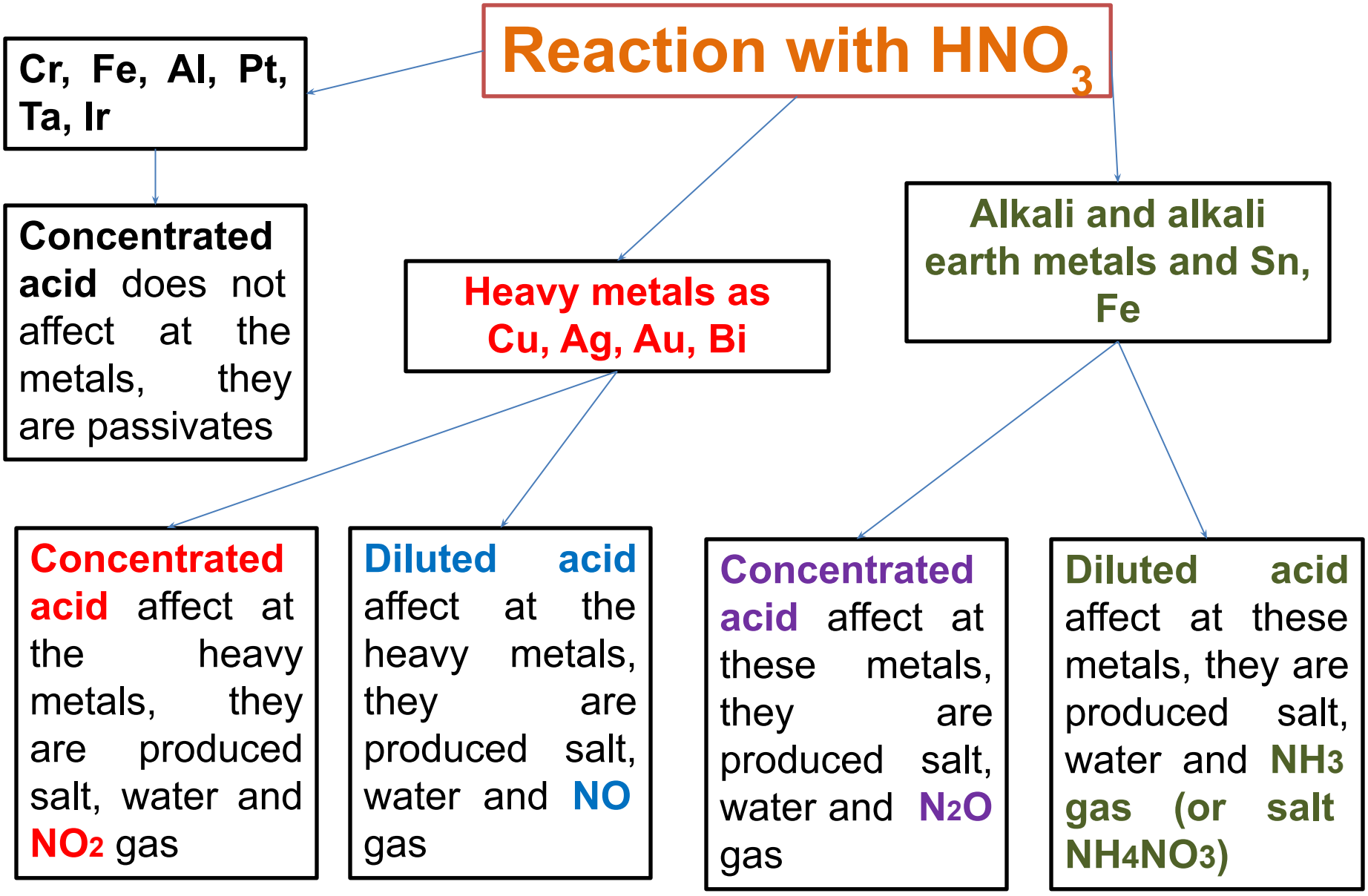
$$Cu + HNO_{3(dilut)} = Cu(NO_3)_2 + H_2O + NO$$

$$3Cu + 8HNO_{3(conc)} = 3Cu(NO_3)_2 + 4H_2O + 2NO_2$$

- **Reaction with concentrated sulfuric acid:**

$$\mathbf{Me + H_2SO_{4\,(conc)} = MeSO_4 + H_2O + (H_2S, S, SO_2)}$$

Fe and Al will not react with conc H_2SO_4 acid, they are passivated.


Reaction with HNO_3
Cr, Fe, Al, Pt, Ta, Ir
Concentrated acid does not affect at the metals, they are passivates
Heavy metals as Cu, Ag, Au, Bi
Alkali and alkali earth metals and Sn, Fe
Concentrated acid affect at the heavy metals, they are produced salt, water and NO_2 gas
Diluted acid affect at the heavy metals, they are produced salt, water and NO gas
Concentrated acid affect at these metals, they are produced salt, water and N_2O gas
Diluted acid affect at these metals, they are produced salt, water and NH_3 gas (or salt NH_4NO_3)

Explaining displacement reactions

The reactivity series can be used to predict if a metal will react with a metal compound. If the metal is more reactive than the metal in the compound, it pushes out, or displaces, the less reactive metal from its compound.

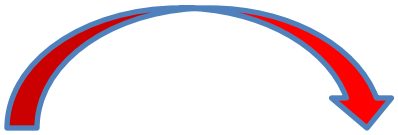
more reactive metal + **less reactive metal compound** → **more reactive metal compound** + **less reactive metal**

If the metal is less reactive than the metal in the compound, it will not compete and so there is no reaction.

less reactive metal + **more reactive metal compound** → **no reaction**

Reaction of metals with metal salt solutions and oxides

A displacement reaction is one where a more reactive metal will displace a cation of less reactive metal from a compound (salt, oxide:



$$Mg + CuSO_4 = MgSO_4 + Cu$$

-2,37 V active metal

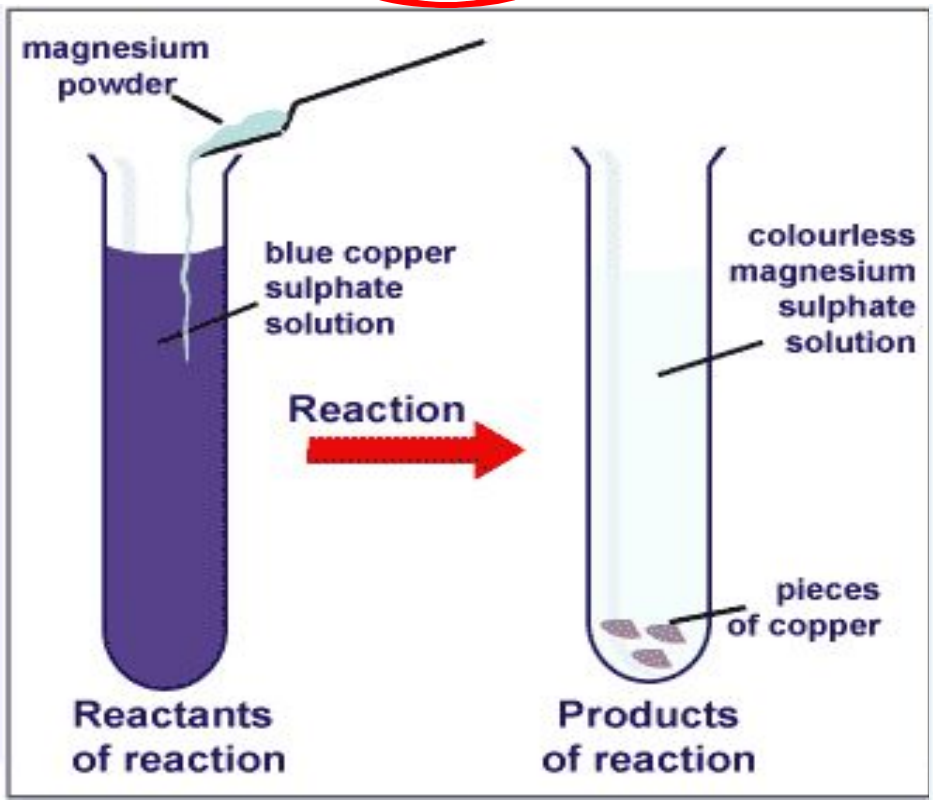
+0,34 V passive metal

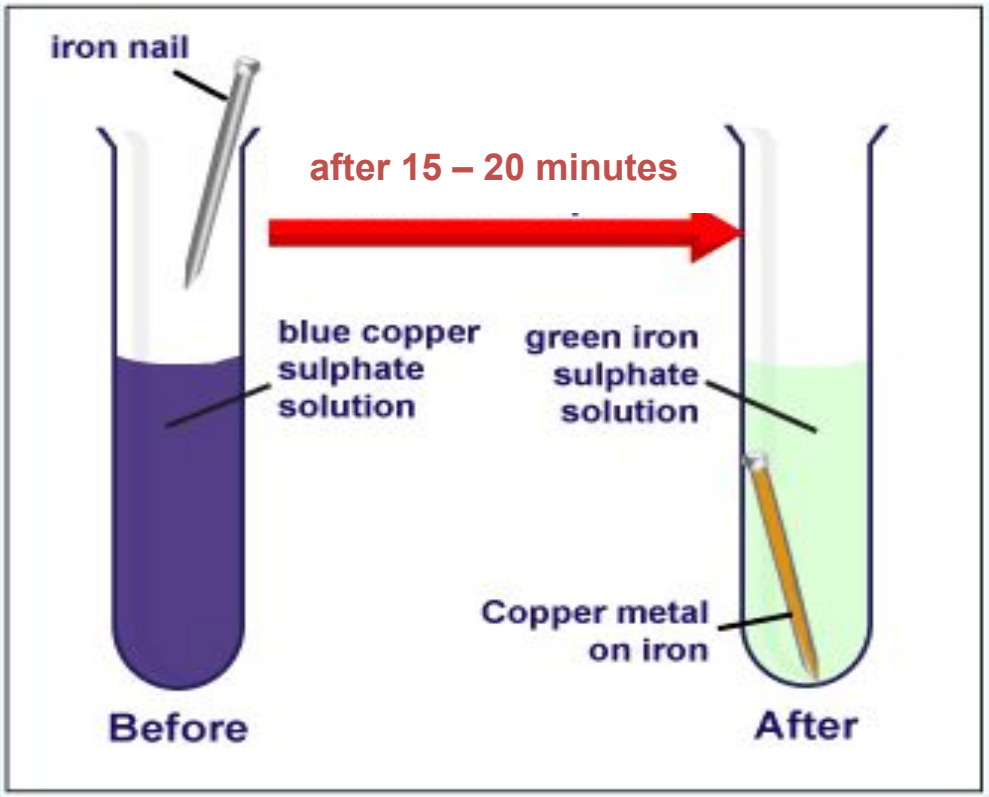
Displacement reaction

Zinc displaces copper from copper sulfate solution: $Zn + CuSO_4 \longrightarrow ZnSO_4 + Cu$

Iron displaces copper from copper (II) sulfate:

$Fe + CuSO_4 \longrightarrow FeSO_4 + Cu$





In this reaction, aluminium reacts with iron oxide to make aluminium oxide and iron:

Aluminium + Iron oxide => Aluminium oxide + Iron

$$2Al + 3FeO = Al_2O_3 + 3Fe + Q$$

The more reactive aluminium takes the oxygen from the less reactive iron.

The reaction gets so hot that the iron melts! It is used to weld railway tracks.

Occurrence of metals :

Some metals like gold, silver, platinum etc are found in the free state (**nugget**) in the earth's crust because they are least reactive. Most metals are found as oxides, carbonates, sulfides, halides etc.

Minerals: are elements or compounds which occur naturally inside the earth's crust.

Ore: is a mineral from which metals can be extracted profitably.

Gangue: is the impurities present in the ore like rock particles, sand particles, clay particles etc.

Occurrence of metals in nature

High active metals

are found in the salt types (chloride, sulfate, carbonate, silicate, phosphate):

$KCl \cdot NaCl, NaNO_3, KNO_3$

$CaSO_4 \cdot 2H_2O, MgSO_4 \cdot 7H_2O$

$CaCO_3 \cdot MgCO_3, Fe(HCO_3)_2$

$Ca_3(PO_4)_2$

$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$

$K_2O \cdot Al_2O_3 \cdot 6SiO_2$

Medium active metals

are found in the oxides and sulfides types:

$Fe_2O_3 \cdot nH_2O,$

Fe_3O_4, Cr_2O_3, SnO_2

ZnS, PbS, HgS

CuS, FeS

Passive, noble or precious metals

are found in the free state (nuggets)

Au, Pt, Ag

Extraction of metals from their ores :

The various processes involved in the extraction of metals from their ores and refining them are known as **metallurgy**.

Metals are extracted from their ores in three main steps. They are :

1) **Concentration of the ore** (Enrichment of the ore).
2) **Reducing the metal compound to the metal** (by O_2, H_2, C, CO, Al and electrolysis)
3) **Refining** (Purification of the metal by electrolysis).

Ways of Metal Extraction

- Potassium K
- Sodium Na
- Calcium Ca
- Magnesium Mg

Extracted by electrolysis of molten chlorides

Extraction by electrolysis of molten Al_2O_3 dissolved in cryolite

- Aluminium Al

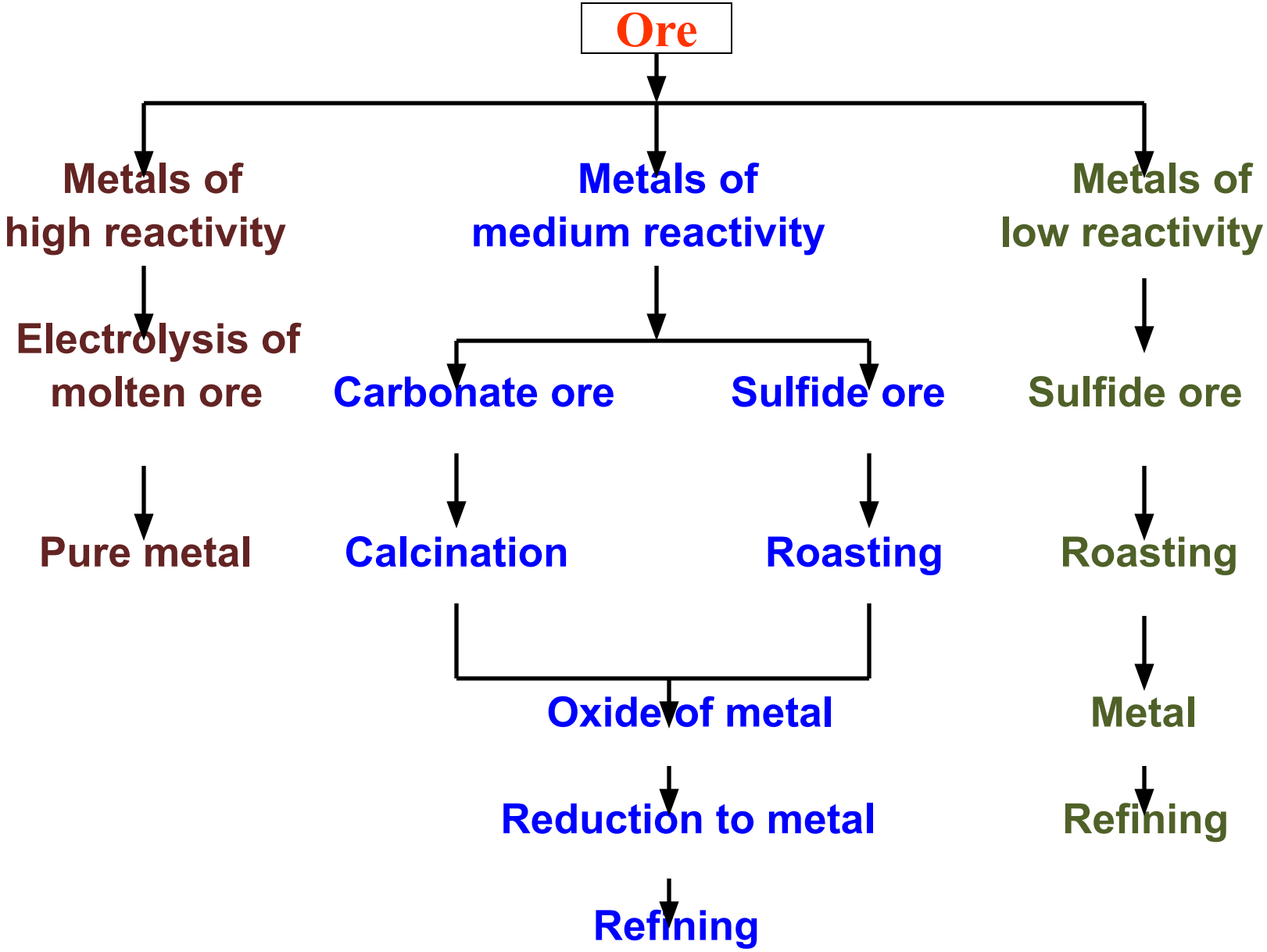
- Zinc Zn
- Iron Fe
- Tin Sn
- Lead Pb
- Copper Cu

Extraction by reduction of oxides using carbon

- Mercury Hg
- Silver Ag
- Gold Au
- Platinum Pt

Roasting ore by heating alone

Steps involved in the extraction of metals from their ores



Using of Metals

Metal used in manufacturing are usually alloys, which are composed of two or more elements, with at least one being metallic element.

Metals can be divided into two basic categories:

a) **Ferrous**

b) **Non ferrous**

Alloys are stronger and harder than pure metals and they also can with stand corrosion better. Pure metals are relatively a little softer (but they are still hard) and they have a low resistance to corrosion as they are affected by air and water easily. Hence alloys are used more often instead of pure metals. Nowadays, complex alloys have been made with specific desired properties. Usually, transition metals are used in the production of alloys.

- **Ferrous Metals (black):**

Ferrous metals are based on iron: the group includes steel and cast iron. Pure iron has limited commercial use, but when alloyed with carbon. Iron has more uses and greater commercial value than any other metal.

- **Non ferrous (colored):**

They include the other metallic elements and their alloys. They include metals and alloys of aluminum, copper, gold, silver and other metals.

METALS ALLOYS

An alloy is a homogeneous mixture of a metal with other metals or non metal:

- **Steel and cast iron – iron, carbon**
- **Stainless steel – iron, carbon, cobalt, nickel**
- **Brass – copper, zinc**
- **Bronze – copper, tin**
- **Solder – Lead, tin (used for welding electrical wires together)**
- **If one of the metals in an alloy is mercury, it is called an amalgam.**

Four main reasons for making alloys

To improve the strength and hardness of metals.

To lower the melting point of the metal.

To improve the appearance of the metal.

To improve the resistance of metals against corrosion and rusting.

*Summary

1. The reactivity series is a list of the metals in order of their drive to form **positive ions** (therefore a stable outer shell). The more easily its atoms give up electrons, the more reactive the metal is.

2. A metal will react with a compound of a less reactive metal (an oxide, an aqueous salt) by pushing the less reactive metal out of the compound and taking it's place.

3. The **more reactive** the metal, the **more stable** its compounds are. They do not break down.

4. The more reactive the metal, the more difficult it is to extract from its ores (they are stable). For the most reactive metals you need the toughest method of extraction - electrolysis!

5. The less reactive the metal, the less it likes to form compounds. This is why copper, silver, and gold are found as elements and not potassium, sodium, or calcium. These elements are always found as compounds.

*Extraction of metals

How do you extract a metal from it's ore?

* The most unreactive metals (Ag and Au) occur in their ores as elements. All you need to do is separate the metal from sand and other impurities - it does NOT involve chemical reactions.
* The ores of all other metals are compounds - they have to be reduced to get the metal.
* The compounds of more reactive metals are very stable so electrolysis is needed.
* The compounds of less reactive metals are less stable so a reducing agent can be used.

Potassium (K)
Sodium (Na)
Calcium (Ca)
Magnesium (Mg)
Aluminium (Al)

electrolysis

(Carbon)
Zinc (Zn)
Iron (Fe)
Lead (Pb)

Heating with reducing agent - ex Carbon

Silver (Ag)
Gold (Au)
Platinum (Pt)

Occur naturally as elements - no chemical reaction needed

Which method is more expensive?