

## Inorganic Chemistry-Sem-V Course No.502

### □ Paper-II Unit-IV. Some Selected Topics

- Chemistry of Non-Aqueous Solvents
- Comparative Chemistry of group 16 and 17 elements
- Chemistry of Interhalogens

# Paper Pattern

- **Main Theory Papers**

- Physical

- Inorganic

- Organic

- Analytical

- **Applied component – Drugs and Dyes**

- Each paper-100mark

- Unit-I (25) +Unit-II(25) +Unit-IV(25)=100

- Total Five Questions-Each Q of 20marks

- Unit-1+2+3+4+5<sup>th</sup> Q(1+2+3+4)

# What is Inorganic Chemistry?

- Inorganic chemistry involves the study of metals and non-metals

## Metals...



Lead



Tin



Nickel



GOLD



PLATINUM



COPPER

## Non-Metals...



CARBON



Carbon

Phosphorus

Sulfur

# Periodic Table

Group →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
↓ Period																		
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
		*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
		**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

# The Periodic Table of the Elements, in Pictures

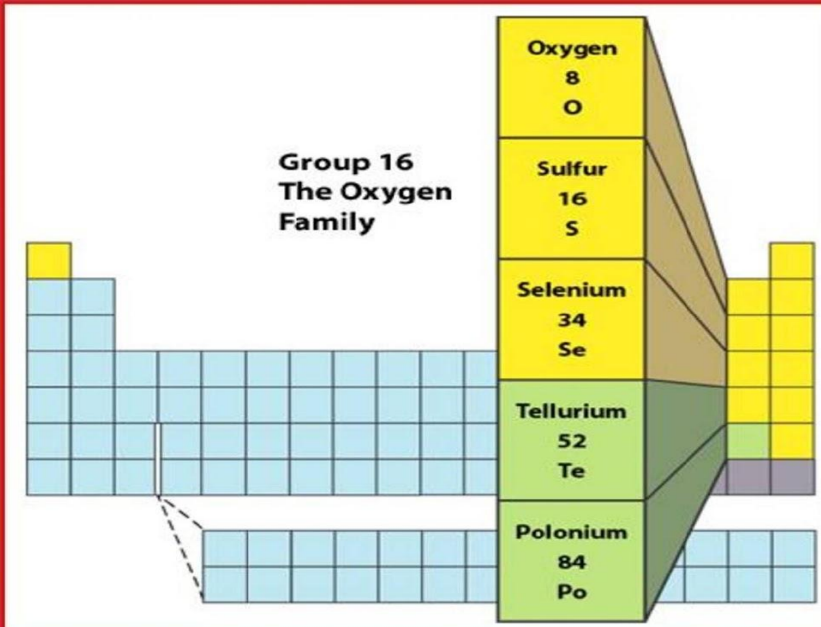
Periods	↓	1	Alkali Metals Group 1		Alkali Earth Metals Group 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Noble Gases Group 18															
			2	3																			4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1			H Hydrogen Sun and Stars																			He Helium Balloons															
2			Li Lithium Batteries		Be Beryllium Emeralds																	Ne Neon Advertising Signs															
3			Na Sodium Salt		Mg Magnesium Chlorophyll																	Ar Argon Light Bulbs															
4			K Potassium Fruits and Vegetables		Ca Calcium Shells and Bones		Sc Scandium Bicycles		Ti Titanium Aerospace		V Vanadium Springs		Cr Chromium Stainless Steel		Mn Manganese Earthmovers		Fe Iron Steel Structures		Co Cobalt Magnets		Ni Nickel Coins		Cu Copper Electric Wires		Zn Zinc Brass Instruments		Ga Gallium Light-Emitting Diodes (LEDs)		Ge Germanium Semiconductor Electronics		As Arsenic Poison		Se Selenium Copiers		Br Bromine Photography Film		Kr Krypton Flashlights
5			Rb Rubidium Global Navigation		Sr Strontium Fireworks		Y Yttrium Lasers		Zr Zirconium Chemical Pipelines		Nb Niobium Mag Lev Trains		Mo Molybdenum Cutting Tools		Tc Technetium Radioactive Diagnosis		Ru Ruthenium Electric Switches		Rh Rhodium Searchlight Reflectors		Pd Palladium Pollution Control		Ag Silver Jewelry		Cd Cadmium Paint		In Indium Liquid Crystal Displays (LCDs)		Sn Tin Plated Food Cans		Sb Antimony Car Batteries		Te Tellurium Thermoelectric Coolers		I Iodine Disinfectant		Xe Xenon High-Intensity Lamps
6			Cs Cesium Atomic Clocks		Ba Barium X-Ray Diagnosis		La Lanthanum Rare Earth Metals		Hf Hafnium Nuclear Submarines		Ta Tantalum Mobile Phones		W Tungsten Lamp Filaments		Re Rhenium Rocket Engines		Os Osmium Pen Points		Ir Iridium Spark Plugs		Pt Platinum Labware		Au Gold Jewelry		Hg Mercury Thermometers		Tl Thallium Low-Temperature Thermometers		Pb Lead Weights		Bi Bismuth Fire Sprinklers		Po Polonium Anti-Static Brushes		At Astatine Radioactive Medicine		Rn Radon Surgical Implants
7			Fr Francium Laser Atom Traps		Ra Radium Luminous Watches		Ac Actinium Actinide Metals		Rf Rutherfordium		Db Dubnium		Sg Seaborgium		Bh Bohrium		Hs Hassium		Mt Meitnerium		Ds Darmstadtium		Rg Roentgenium		Cn Copernicium		Nh Nihonium		Fl Flerovium		Mc Moscovium		Lv Livermorium		Ts Tennessine		Og Oganesson
8			119		120		121...																														
			Rare Earth Metals																																		
			La Lanthanum Telescope Lenses		Ce Cerium Lighter Flints		Pr Praseodymium Torchworkers' Eyeglasses		Nd Neodymium Electric Motor Magnets		Pm Promethium Luminous Dials		Sm Samarium Electric Motor Magnets		Eu Europium Color Televisions		Gd Gadolinium MRI Diagnosis		Tb Terbium Fluorescent Lamps		Dy Dysprosium Smart Material Actuators		Ho Holmium Laser Surgery		Er Erbium Optical Fiber Communications		Tm Thulium Laser Surgery		Yb Ytterbium Scientific Fiber Lasers		Lu Lutetium Photodynamic Medicine						
			Actinide Metals																																		
			Ac Actinium Radioactive Medicine		Th Thorium Gas Lamp Mantles		Pa Protactinium Radioactive Waste		U Uranium Nuclear Power		Np Neptunium Radioactive Waste		Pu Plutonium Nuclear Weapons		Am Americium Smoke Detectors		Cm Curium Mineral Analyzers		Bk Berkelium Radioactive Waste		Cf Californium Mineral Analyzers		Es Einsteinium		Fm Fermium		Md Mendelevium		No Nobelium		Lr Lawrencium						
			radioactive, never found in nature, no uses except atomic research																																		

# Comparative Study of Group 16 Elements

## Representative Elements

### Group 16—The Oxygen Family

- The first two members of Group 16, oxygen and sulfur, are essential for life.
- The heavier members of the group, tellurium and polonium, are both metalloids.



The diagram shows a portion of the periodic table with a red border. A vertical column of five elements is highlighted in yellow and green. The elements are Oxygen (8, O), Sulfur (16, S), Selenium (34, Se), Tellurium (52, Te), and Polonium (84, Po). The text 'Group 16 The Oxygen Family' is written above the column. The background of the periodic table is light blue.

Group 16 The Oxygen Family	
Oxygen	8 O
Sulfur	16 S
Selenium	34 Se
Tellurium	52 Te
Polonium	84 Po

## Electronic Configuration of Group 16 Elements

Element	Symbol	Atomic No.	Electronic Configuration	Abundance In Earth's Crust (in ppm)
Oxygen	O	8	[He] $2s^2 2p^4$	$4.66 \times 10^5$
Sulphur	S	16	[Ne] $3s^2 3p^4$	$5.20 \times 10^2$
Selenium	Se	34	[Ar] $3d^{10} 4s^2 4p^4$	$9.0 \times 10^{-2}$
Tellurium	Te	52	[Kr] $4d^{10} 5s^2 5p^4$	$9.0 \times 10^{-2}$
Polonium			[Xe] $4f^{14} 5d^{10} 6s^2 6p^4$	$2 \times 10^{-3}$

# Oxidation State

## GROUP 16 ELEMENTS (OXYGEN FAMILY)

mtg

### Group 16 Elements ( $ns^2np^4$ )

Element	At. No.	Electronic Configuration	Oxidation State
Oxygen (O)	8	[He] $2s^2 2p^4$	-2, -1, +1, +2
Sulphur (S)	16	[Ne] $3s^2 3p^4$	-2, +2, +4, +6
Selenium (Se)	34	[Ar] $3d^{10} 4s^2 4p^4$	-2, +2, +4, +6
Tellurium (Te)	52	[Kr] $4d^{10} 5s^2 5p^4$	-2, +2, +4, +6
Polonium (Po)	84	[Xe] $4f^{14} 5d^{10} 6s^2 6p^4$	+2, +4, +6
Livermorium (Lv)	116	[Rn] $5f^{14} 6d^{10} 7s^2 7p^4$	—

# Trends in Physical Properties

- Atomic Size, Atomic Volume and Density
- Ionisation Energy, Electropositive and Electronegative Character
- Non metallic and Metallic Character
- Melting and Boiling Point
- Conductivity
- Oxidation State
- Catenation
- Tendency towards formation of hydrogen bond
- Molecular Structure
- Allotropy

Property	Oxygen	Sulfur	Selenium	Tellurium	Polonium
atomic symbol	O	S	Se	Te	Po
atomic number	8	16	34	52	84
atomic mass (amu)	16.00	32.07	78.96	127.60	209
valence electron configuration*	$2s^2 2p^4$	$3s^2 3p^4$	$4s^2 4p^4$	$5s^2 5p^4$	$6s^2 6p^4$
melting point/boiling point (°C)	-219/-183	115/ 445	221/685	450/988	254/962
density (g/cm <sup>3</sup> ) at 25°C	1.31 (g/L)	2.07	4.81	6.24	9.20
atomic radius (pm)	48	88	103	123	135
first ionization energy (kJ/mol)	1314	1000	941	869	812
normal oxidation state(s)	-2	+6, +4, -2	+6, +4, -2	+6, +4, -2	+2 (+4)
ionic radius (pm) <sup>†</sup>	140 (-2)	184 (-2), 29 (+6)	198 (-2), 42 (+6)	221 (-2), 56 (+6)	230 (-2), 97 (+4)
electron affinity (kJ/mol)	-141	-200	-195	-190	-180
electronegativity	3.4	2.6	2.6	2.1	2.0

\*The configuration shown does not include filled *d* and *f* subshells.

<sup>†</sup>The values cited for the hexacations are for six-coordinate ions and are only estimated values.

# Electronegativity

- The most electronegative element of the group is oxygen
- Elec. Conf. Is  $1s^2, 2s^2, 2p^4$
- Outer elec. Conf. Has six electrons
- Oxygen elements needs only 2 electrons to complete the stable octet (ie inert gas configuration)
- This can be achieved by gaining 2 electrons
- Hence oxidation state is -2

# Non metallic and metallic character

- Oxygen and Sulphur are stronger non-metallic character
- Selenium and tellurium has weaker non-metallic character
- The polonium is distinctly a metal. It is , however radioactive and short lived.
- Thus from oxygen to polonium, Non-metallic character decreases and metallic increases.

# Conductivity

- O & S are non-conductors.
- Se And Te are semiconductors.
- Polonium being a metal, shows electrical conductivity

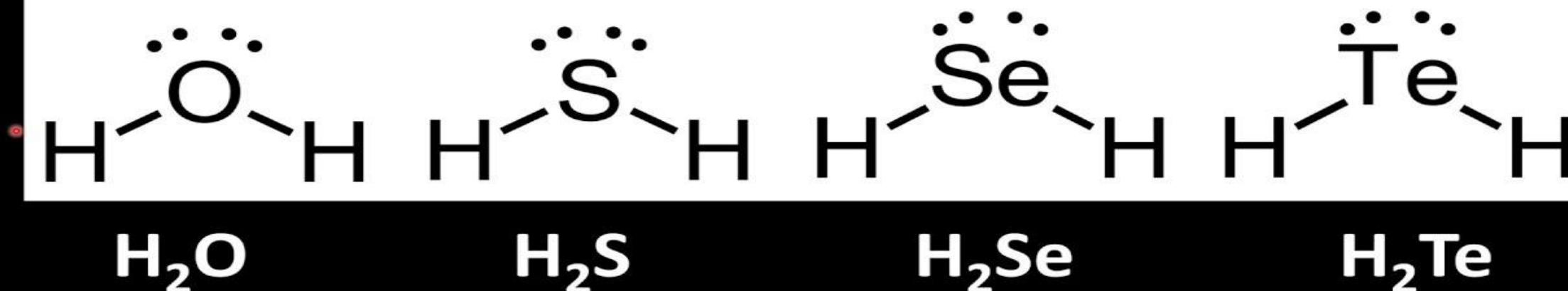
# Oxidation States

- The outer elec. Conf. is  $ns^2 np^4$  hence need 2 electrons to form octet. This is achieved by the following ways
  - By gaining two electrons to form dinegative ions  $O^{2-}, S^{2-}$
  - By sharing two electrons forms hydrides
  - By forming double bonds with another elements  $CO_2, CS_2$  etc
  - By accepting a pair of electron  $(CH_3)_3N \longrightarrow$

Hydrides are formed by sharing of 2 electrons with two hydrogen atoms.

## Group 16 hydrides

The group 16 hydrides are composed of group 16 elements (O, S, Se and Te) bonded to two hydrogen atoms.



# Catenation

- Oxygen and sulphur shows the property of catenation
- H-O-O-H, H-S-S-H, H-S-S-S-S-H

# Tendency to form Hydrogen Bond

Electronegativity of the element.

Difference between the hydrogen and element  
towards formation of hydrogen bond also

Hydrogen bond decreases from O to Se as  
atomic size increases.

Amongst, oxygen forms the strongest bond with

# Molecular structure

- Molecular structure changes from Diatomic linear molecule through rings and chains to a metallic lattice.
  - Oxygen-Diatomic linear molecule
  - Sulphur-Rhombic, puckered S<sub>8</sub> ring
  - Sellenium-Red form has 8-membered ring and grey form has Zig-Zag chain of Se atoms.
  - Tellurium is similar to that of sellenium.
  - Pollonium is dimorphism, alpha has cubic lattice, beta has rhombohedral.

# Anomalous Behaviour of Oxygen

- The main reason for the difference are
  - Smaller atomic size, high electronegativity and absence of d-orbital
- Oxygen is a diatomic gas whereas others are solids.
- It shows negative oxidation states while others show +ve & -ve both.
- It easily forms hydrogen bonding
- Most of the compounds of oxygen are stable & ionic.
- Maximum covalency is 2 while others show 4 & 6.
- In all states, it is paramagnetic. Sulphur is paramagnetic in  $S_2$ , others not paramagnetic.
- Highly stable with 496.6 kJ/mole bond dissociation energy.

Sulfuric Acid o

## Group 16: Oxygen Family

### Physical Properties

- Oxygen is a nonmetal gas
  - most abundant element in Earth's crust (1/5 Earth's atmosphere)
- Sulfur is a yellow, nonmetal solid
  - smells like rotten eggs



- Selenium is a nonmetal solid
  - conducts electricity with sunlight
- Te & Po are metalloids

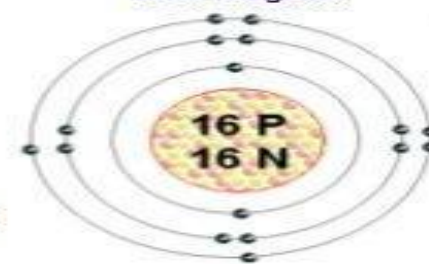
### Chemical Properties

- **have 6 valence electrons**
  - elements vary in reactivity

Lewis Structure



Bohr Diagram



8	O	Oxygen
16	S	Sulfur
34	Se	Selenium
52	Te	Tellurium
84	Po	Polonium

# Allotropy

## DEFINITION OF ALLOTROPES

Two or more than two forms of an element having **different physical properties** but **same chemical properties** are known as **allotropes of an element**. Such condition of elements is known as **Allotropy**.

# Allotropes of oxygen

- The two allotropic form of oxygen are diatomic dioxygen O<sub>2</sub> & triatomic Ozone O<sub>3</sub>.

## □ Diatomic Oxygen O<sub>2</sub>

- It is paramagnetic.
- Bond order 2, suggesting a double bond of which one is sigma ,other is pi.
- Presence of double bond indicates high dissociation energy and two unpaired electrons confirms its para magnetic behaviour.





# Ozone

- It is less stable than  $O_2$ , a powerful oxidising agent, light blue in colour and is diamagnetic.
- It is angular in shape with O-O-O bond angle is  $116.48^\circ$
- Structure is resonance hybrid

## Physical Properties of Group 16 Elements

**Allotropy :** All elements of the group 16 show allotropy. ...

- Oxygen exists as  $O_2$  (dioxygen) and  $O_3$  (ozone). ...
- Sulphur is found to exist in several allotropic forms such as rhombic, monoclinic, plastic and colloidal sulphur.



Oxygen  $O_2$



Ozone  $O_3$

Allotropes of Oxygen



## Chapter 12

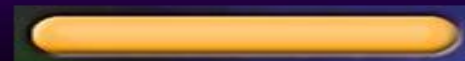
## Section 2 Grouping the Elements

8 <b>O</b> Oxygen
16 <b>S</b> Sulfur
34 <b>Se</b> Selenium
52 <b>Te</b> Tellurium
84 <b>Po</b> Polonium

### Group 16: Oxygen Group

Group 16 properties:

- group contains three nonmetals, one metalloids, and one metal
- 6 electrons in the outer level
- reactive
- solids at room temperature (except for oxygen, which is a gas)



# Allotropes of Sulphur

- Large no of allotropes. Some important allotropic forms are as follows

- Rhombic or alpha sulphur
- Monoclinic or beta sulphur
- Gamma sulphur
- Plastic sulphur

# Rhombic Sulphur

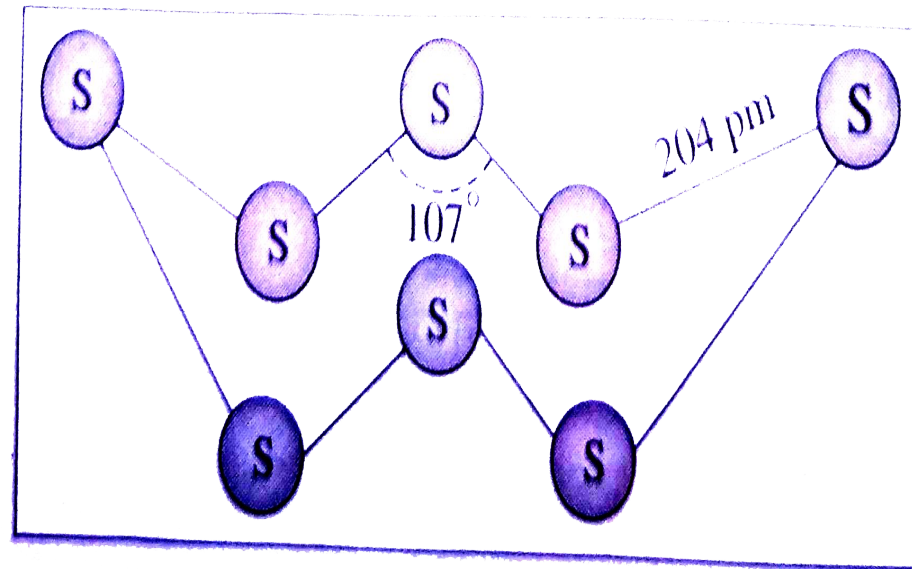
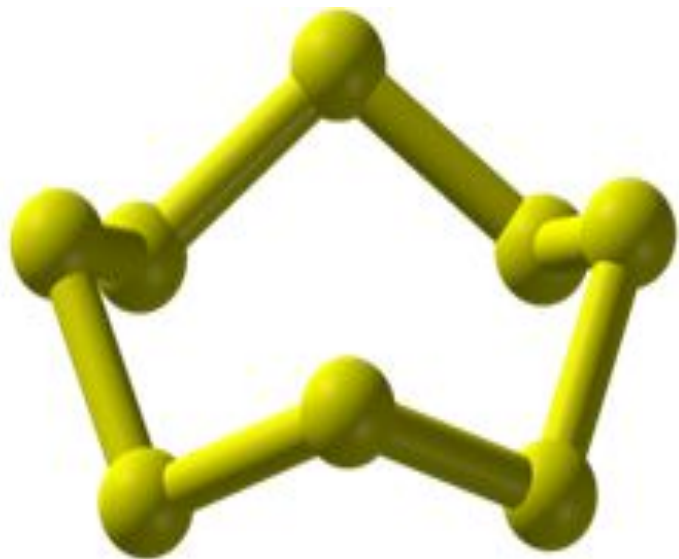
- It is the crystalline form of sulphur occurs in yellow crystals in volcanic areas.

## □ Preparation

- A solution of roll sulphur evaporated slowly in CS<sub>2</sub>
- Its crystal structure has cyclic S<sub>8</sub> rings packed to form rhombic crystal



# Allotropes of Sulphur



# Plastic Sulphur

- Preparations

- When sulphur is heated to about 625K and the molten sulphur is poured into cold water, a soft rubber-like mass is obtained called as plastic sulphur.
- Its specific gravity is 1.95 and is dark coloured
- This sulphur is a mixture of many allotropes of sulphur containing cyclic S<sub>8</sub> ring and long helical or Zig-Zag long chains of S-atoms.



# Structure of plastic Sulphur



# Chemical properties of Group 16 Elements

- Reactivity decreases with increase in atomic number.
- Hence oxygen is most reactive element
- S, Se and Te are moderately reactive.

□ Action of air

□ Action of acids

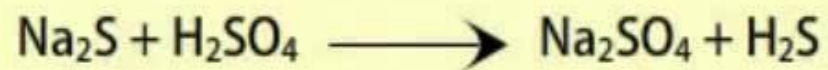
□ Action of alkalies

□ Action of non metals

□ Action of metals

## Chemical Properties of Group 16 Elements

**Hydrides :** These elements form volatile hydrides such as  $\text{H}_2\text{O}$ ,  $\text{H}_2\text{S}$ ,  $\text{H}_2\text{Se}$ ,  $\text{H}_2\text{Te}$  and  $\text{H}_2\text{Po}$ .



- Thermal stability decreases down the group because the size of the atom increases and hence the bond length also increases.
- Acidic character increases down the group.



$\text{H}_2\text{S}$  Molecule

