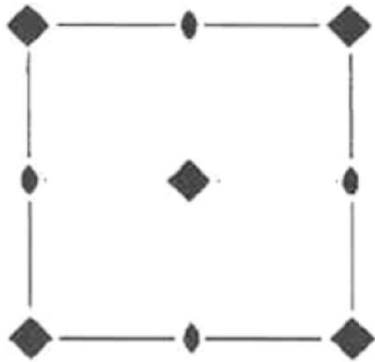
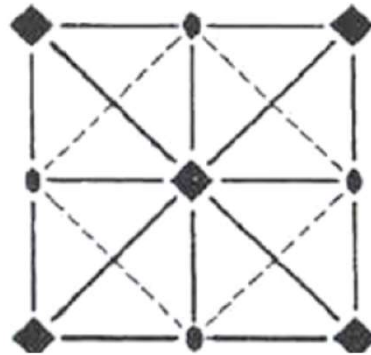


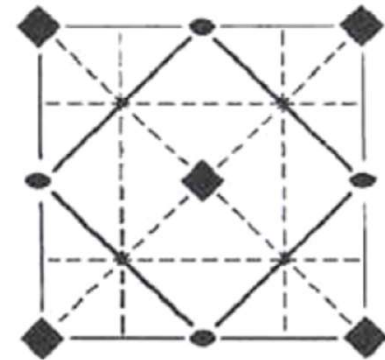
# Plane groups from square cell



**p4**



**p4mm**



**p4gm**



**4**

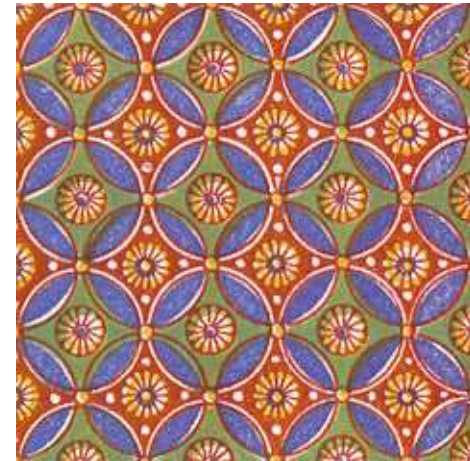
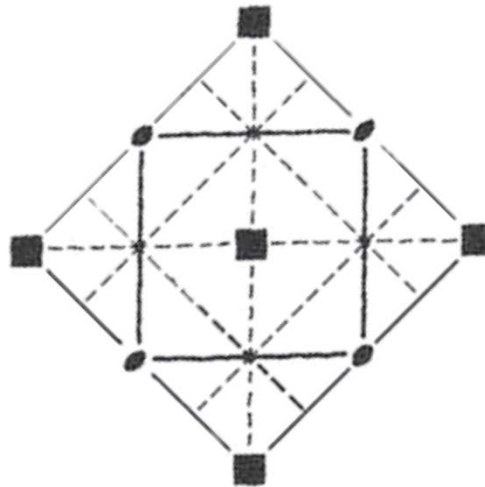


**4mm**

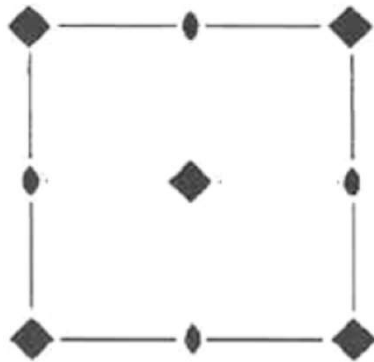




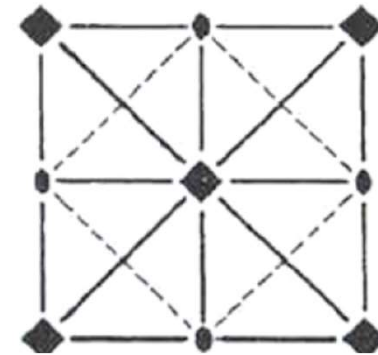
**p4**



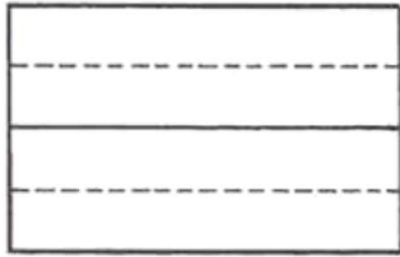
**p4mm**



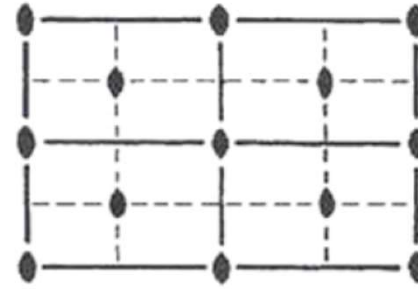
**p4gm**



# Plane groups from centered rectangular cell



cm



cmm2



m



2mm

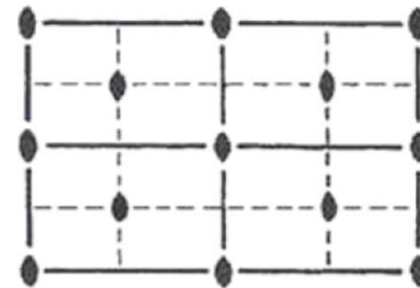
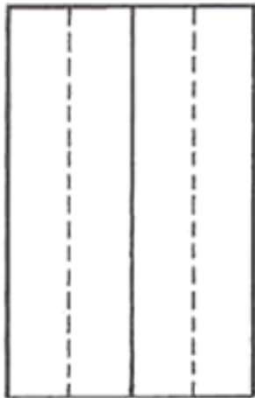




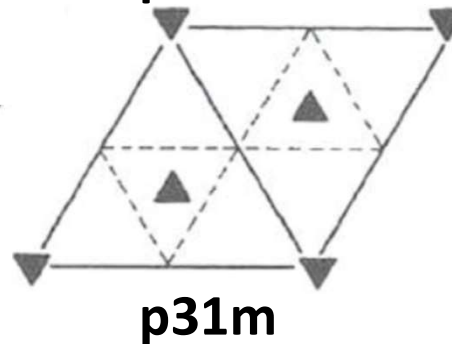
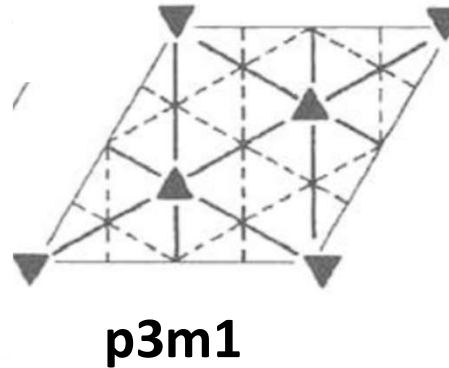
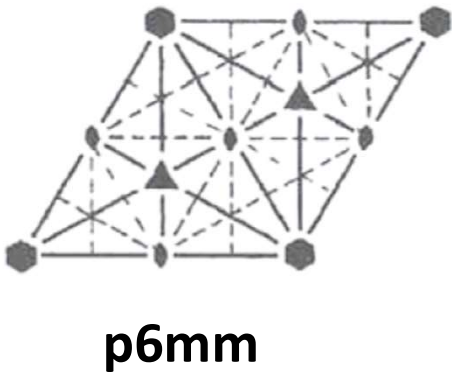
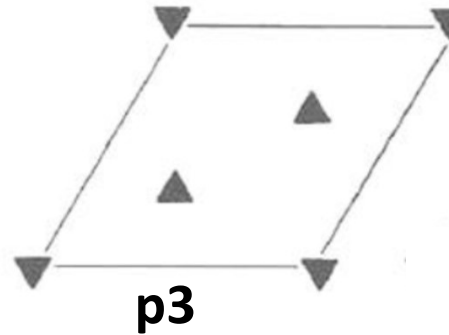
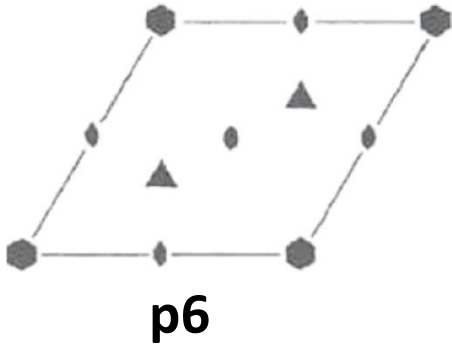
**cm**



**cmm2**



# Plane groups from rhombic cell





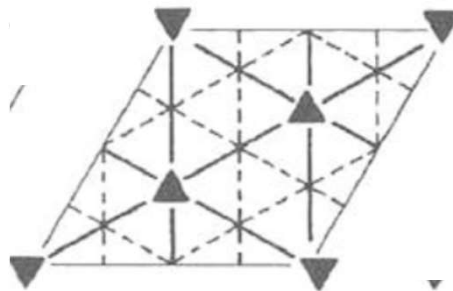
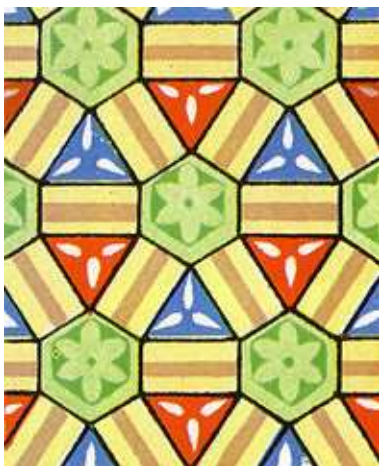
**p3**



**p31m**



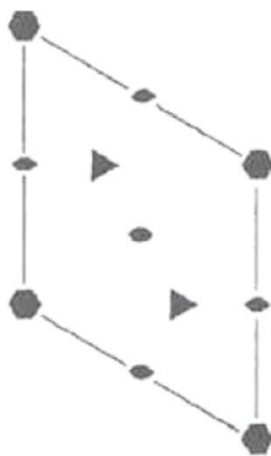
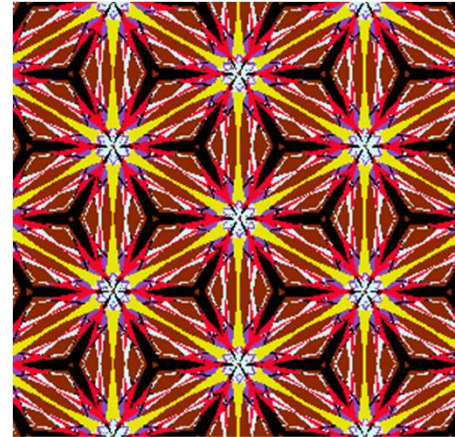
**p3m1**

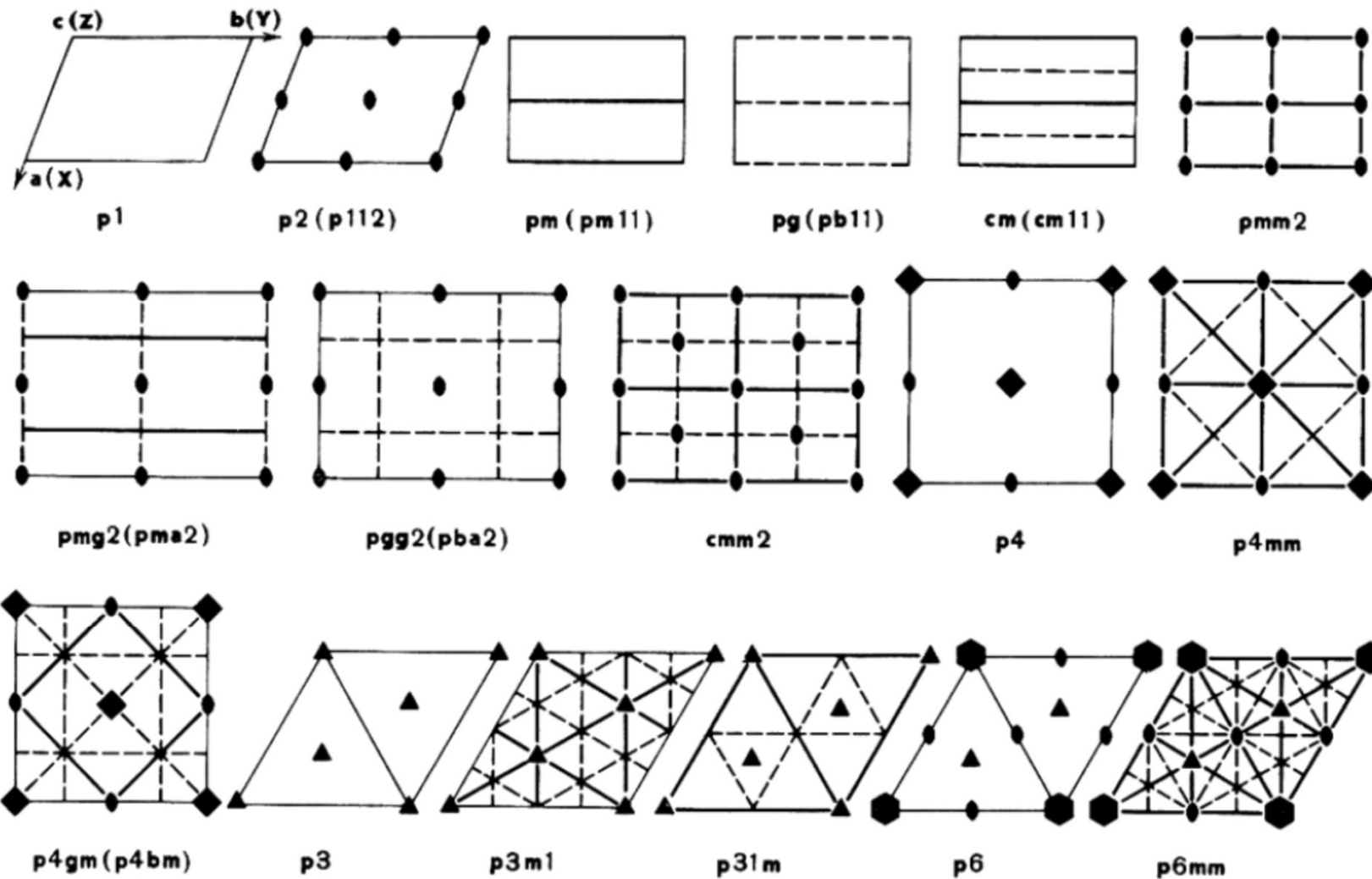


**p6**



**p6mm**









[https://en.wikipedia.org/wiki/Wallpaper\\_group](https://en.wikipedia.org/wiki/Wallpaper_group)

<https://www2.clarku.edu/faculty/djoyce/wallpaper/seventeen.html>



## Tips to identify Plane group

- First look at symmetry of motif
  - 1 or 2 then p1 or p2
  - m or 2mm then pm, pg, pmm2, **pmg2** or **pgg2**
  - it can also be cm or cmm if here is a diamond unit cell
  - 4 or 4mm then p4, p4mm, **p4gm**
  - 3 or 3m then p2, p3m1 or **p31m**
  - 6 or 6mm then p6 or p6mm
- Determine the unit cell and impose symmetry elements
- Glides are confusing


Practice makes a human perfect



## Let us move from 2D to 3D

- Ideally we should look at symmetry elements first
- But perception of 3D comes from 2D
- Our eyes see 2D images and the brain sees 3D
- 3D is stacking of 2D images
- Let us stack our five different 2D lattices



- 
- Stacking of square lattice: Cubic and Tetragonal
  - Stacking of rectangular lattice: Orthorhombic primitive and body centered
  - Stacking of centered rectangular lattice: Orthorhombic base centered and body centered
  - Stacking of hexagonal lattice: Rhombohedral and Hexagonal
  - Stacking of oblique lattice: Monoclinic and Triclinic



# 14 Bravais lattices in 3D

## ➤ 7 crystal classes

Cubic (P, I, F)

Tetragonal (P, I)

Orthorhombic (P, I, B, F)

Rhombohedral (P)

Hexagonal (P)

Monoclinic (P, B)

Triclinic (P)

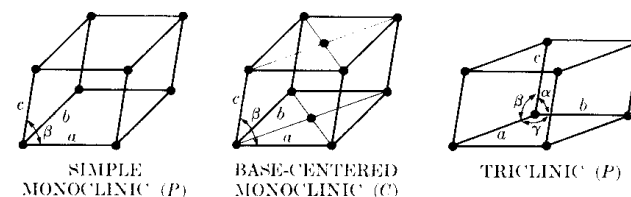
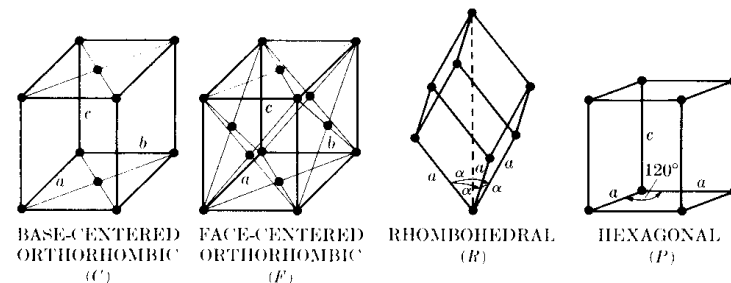
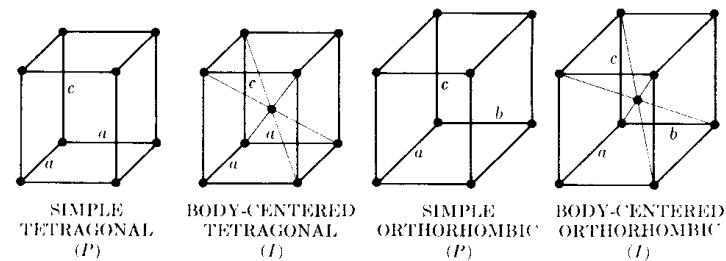
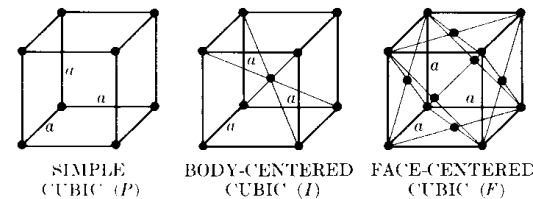
## ➤ 4 type of unite cells

Primitive (P)

Body centered (I)

Base centered (A, B, C)

Face centered (F)





Crystal System	Axial and Angular Relationships	Bravais Lattice*	No. of lattice points/cell
Cubic	$a = b = c$ $\alpha = \beta = \gamma = 90^\circ$	Simple Cubic (P)	1
		Body Centred Cubic (I)	2
		Face Centred Cubic (F)	4
Tetragonal	$a = b \neq c$ $\alpha = \beta = \gamma = 90^\circ$	Simple Tetragonal (P)	1
		Body Centred Tetragonal (I)	2
Orthorhombic	$a \neq b \neq c$ $\alpha = \beta = \gamma = 90^\circ$	Simple Orthorhombic (P)	1
		Body Centred Orthorhombic (I)	2
		Base Centred Orthorhombic (C)	2
		Face Centred Orthorhombic (F)	4
Hexagonal	$a = b \neq c$ $\alpha = \beta = 90^\circ, \gamma = 120^\circ$	Simple Hexagonal (P)	1
Rhombohedral	$a = b = c$ $\alpha = \beta = \gamma \neq 90^\circ$	Simple Rhombohedral (P)	1
Monoclinic	$a \neq b \neq c$ $\alpha = \gamma = 90^\circ \neq \beta$	Simple Monoclinic (P)	1
		Base Centred Monoclinic (C)	2
Triclinic	$a \neq b \neq c$ $\alpha \neq \beta \neq \gamma \neq 90^\circ$	Simple Triclinic (P)	1



➤ Number of lattice points per unit cell in 2D

Primitive (p): 1

Rectangular centered (c): 2

➤ Number of lattice points per unit cell in 3D

Primitive (P): 1

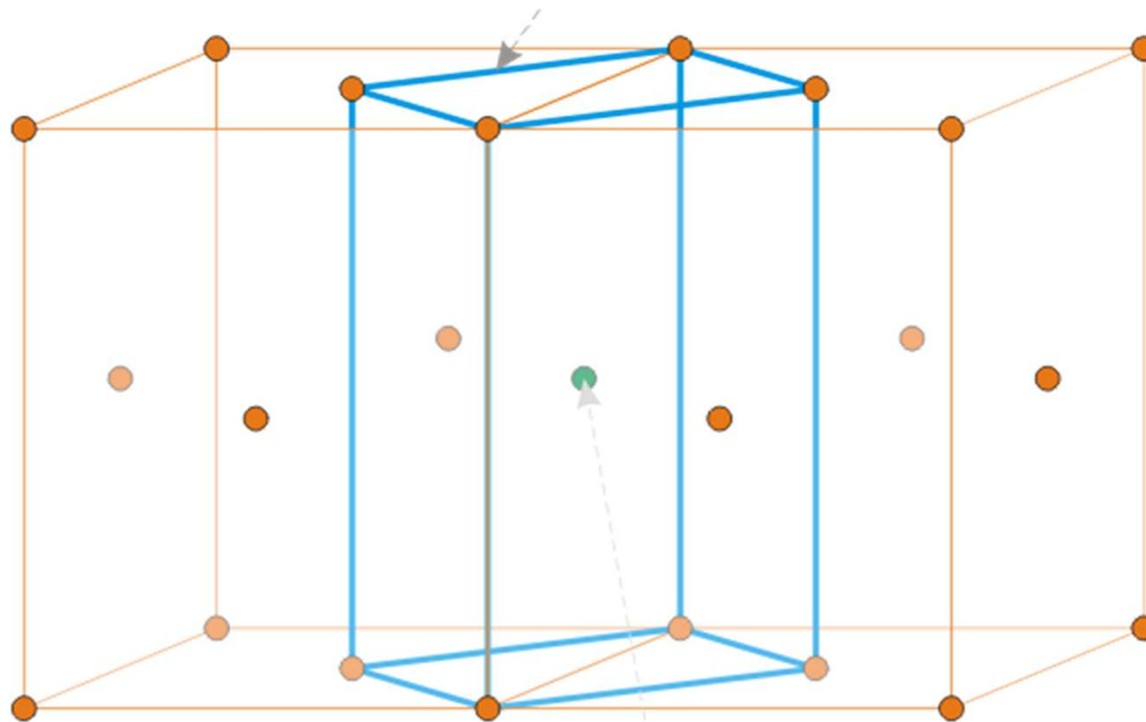
Body centered (I): 2

Base centered (A, B, C): 2

Face centered (F): 4

Prove to your self that only 14 Bravais lattices are possible





Face centered tetragonal = Body Centered Tetragonal



# Minimum Symmetry for Crystal systems

Crystal System:	Minimum Symmetry:	Typical Minerals: (Danish equivalent)
Triclinic	No Symmetry	Plagioclase, Microcline, Kalifeltspar, Kyanite
Monoclinic	1 A2	[Clino]Pyroxene, [Clino]Amphibole, Micas(Glimmerminerale), Sanidine, Orthoclase, Silimanite, Andalusite, Gypsum(Gibs)
Trigonal	1 A3	Quartz, Calcite, Dolomite, Magnesite
Tetragonal	1 A4	Zirconium(Zirkon)
Hexagonal	1 A6	Apatite, Beryllium(Beryl), Tourmaline, Corundum(Korund)
Orthorhombic	3 A2	[Ortho]Pyroxene, [Ortho]Amphibole, Staurolite, Olivine
Cubic	4 A3	Garnet(Granat), Sulphides[Pyrite, Galena, Sphalerite], Fluorite, Magnetite, Hemalite

