Outline

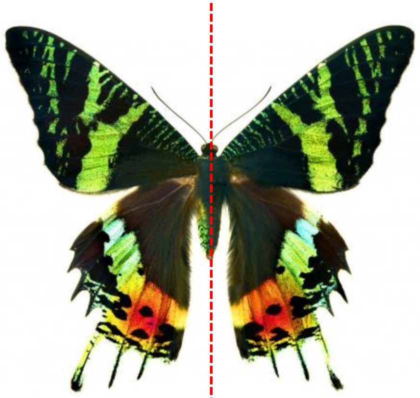
- **Chapter 1.1** Periodic Array of Atoms (原子的周期性排列)
- **Chapter 1.2** Symmetry of Crystals (晶体的对称性)
- **Chapter 1.3** Typical Crystal Structures (典型晶体结构)
- **Chapter 1.4** Reciprocal Lattice (倒易点阵)

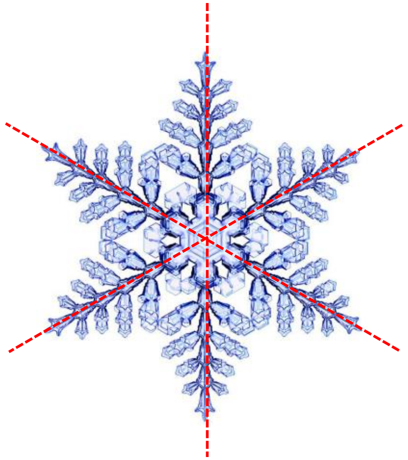
Objectives

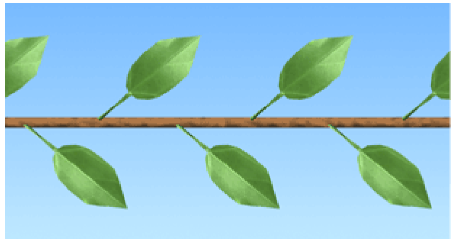
- To learn the classification of **crystal symmetries**;
- To understand the **macroscopic symmetry of crystals and its properties;**
- To learn the microscopic symmetry of crystals.

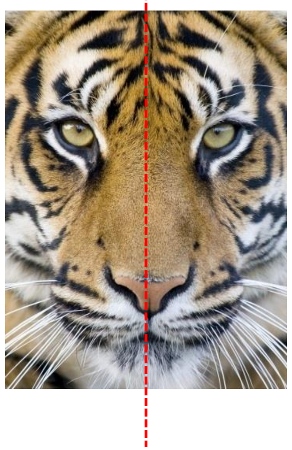
Symmetry

- Symmetry is the exact correspondence in position of parts of an object with respect to a dividing plane, line, or point.









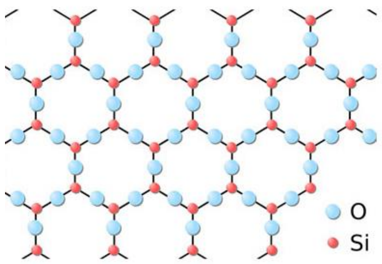
➢ Symmetry of Crystals

Symmetry of Crystals

- Macroscopic (宏观)

  - ❖ Symmetry of a crystal of **finite size**.
  - ❖ Focused on the **outer shape** of a crystal.
  - ❖ Described by **point group**.

- Microscopic (微观)



  - ❖ Symmetry of crystal lattices of **infinite size**.
  - ❖ Focused on the **inner structure** of a crystal.
  - ❖ Described by **space group**.

- **Symmetry of Crystals**

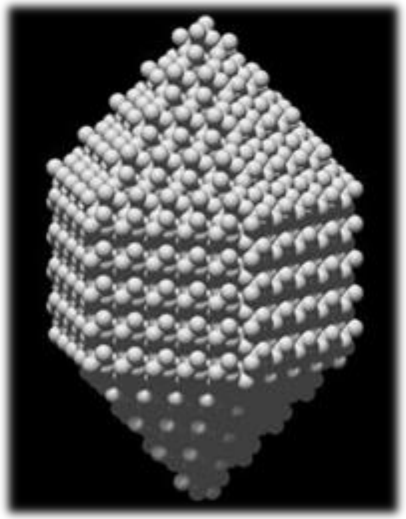
The **macroscopic symmetry** is essentially governed by the **microscopic symmetry**!

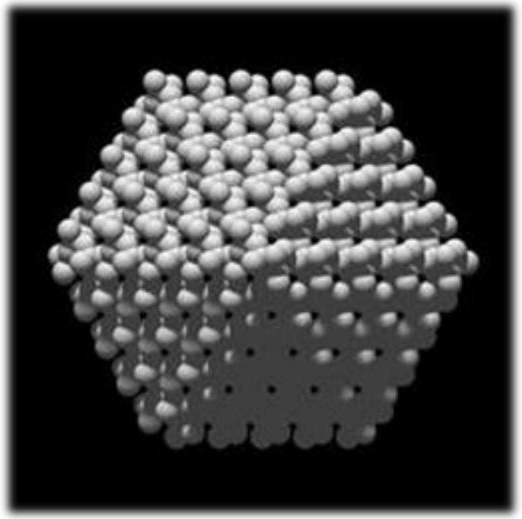
Macroscopic Symmetry of Crystals (晶体的宏观对称性)

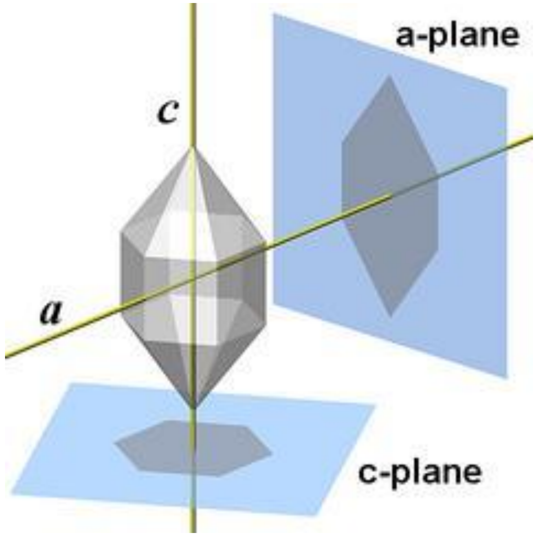
Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➢ Macroscopic Symmetry of Crystals (晶体的宏观对称性)

❖ The macroscopic symmetry of crystals is the symmetry associated with the outer shape of a crystal.







Chapter 1.2: Symmetry of Crystals (晶体的对称性)

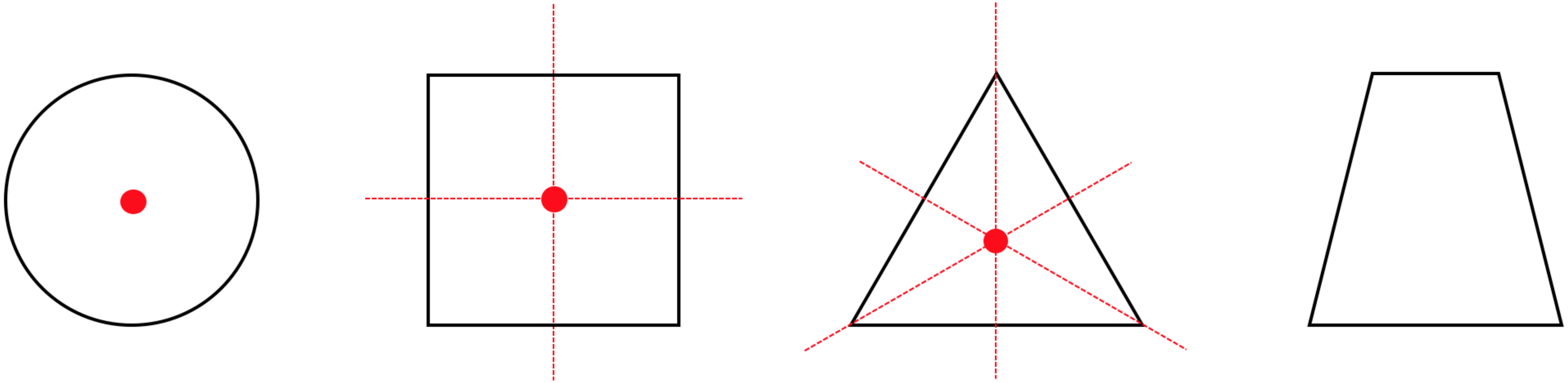
➢ **Macroscopic Symmetry of Crystals (晶体的宏观对称性)**

The macroscopic symmetry of crystals can be described in terms of certain **symmetry elements** and their associated **symmetry operations**.

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➢ Symmetry Operations (对称操作)

❖ Symmetry operation is **an action of rearranging atoms** such that the crystal is transformed into a state indistinguishable from the starting state.



Examples of symmetry operation (rotation) performed to some simple geometry shapes.

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➢ Symmetry Operations (对称操作)

❖ The **physical properties** of crystals are **invariant** with respect to symmetry operations.

❖ Mathematically, a symmetry operation is an **orthogonal transformation (正交变换)** that keeps the crystal unchanged.

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \bullet \begin{pmatrix} x \\ y \\ z \end{pmatrix} \qquad A_{ij} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

Coordinates
After transformation

Coordinates
Before Transformation

Orthogonal Matrix
(正交矩阵)

Symmetry Operations (对称操作)

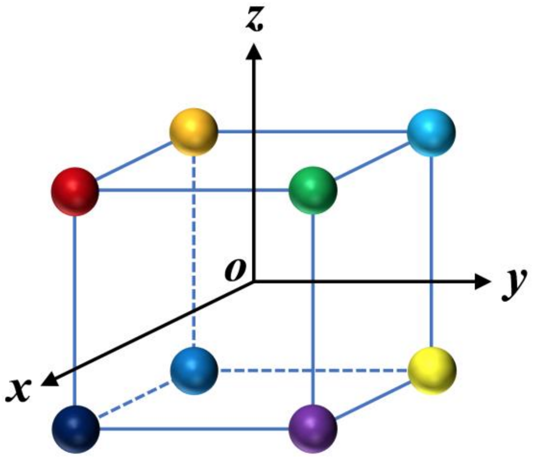
- The symmetry operations regarding to macroscopic symmetry include:

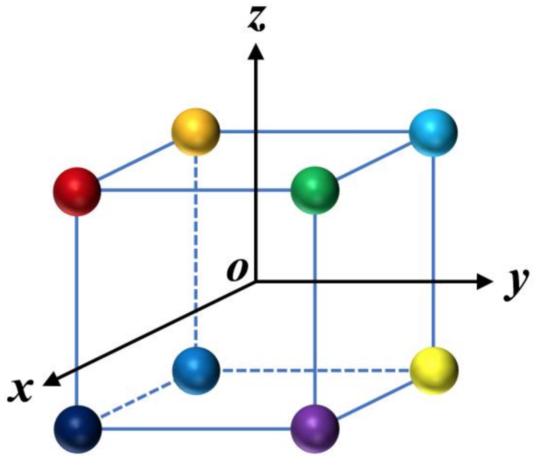
1) **Identity (恒等)**
2) **Inversion (反演)**
3) **Reflection (反映)**
4) **Proper Rotation (旋转)**
5) **Improper Rotation (瑕旋转)**

Symmetry Operations (对称操作)

1) Identity (恒等)

- The identity operation is ***doing nothing***!





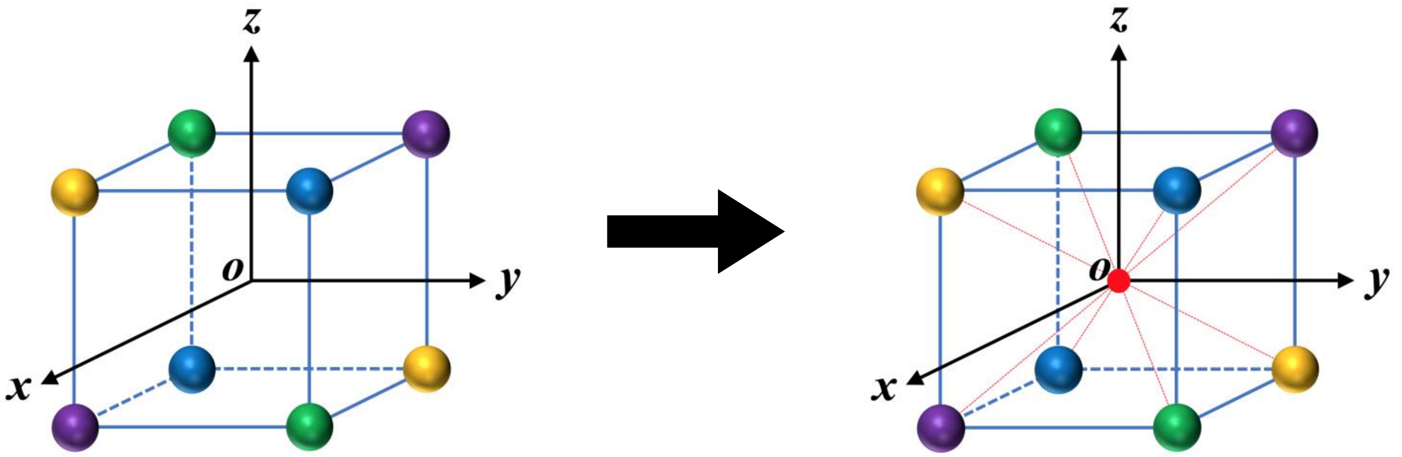
$$A_{ij} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$x \quad y \quad z \quad \rightarrow \quad x \quad y \quad z$$

- **Symmetry Operations (对称操作)**

2) Inversion (反演)

- The inversion operation occurs through a single point (**inversion center**).



$$A_{ij} = \begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

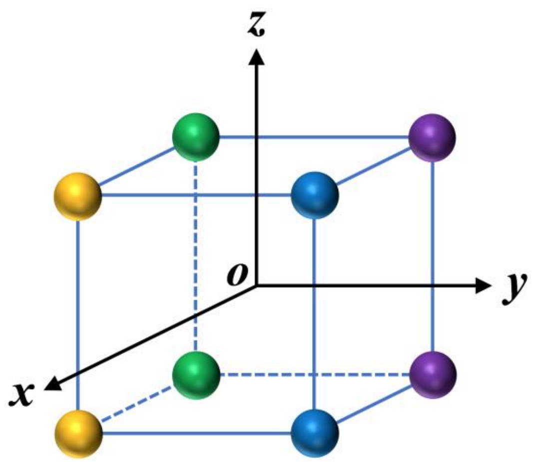
$$x \quad y \quad z \quad \rightarrow \quad -x \quad -y \quad -z$$

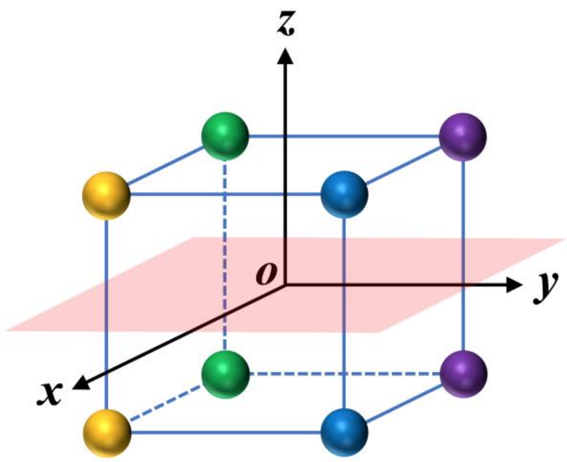
(Here, the inversion center is at o)

➢ Symmetry Operations (对称操作)

3) Reflection (反映)

❖ The reflection operation occurs through a plane (**symmetry plane**) dividing the object.





$$A_{ij} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

$$x \quad y \quad z \quad \rightarrow \quad x \quad y \quad -z$$

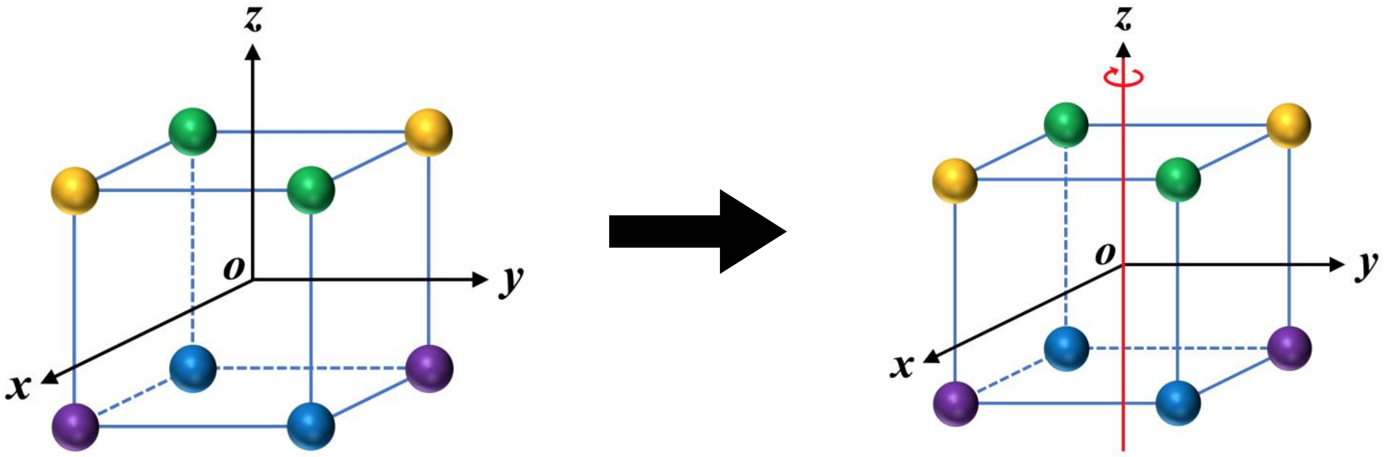
(Here, the symmetry plane is the one with z = 0)

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➢ Symmetry Operations (对称操作)

4) Proper Rotation (旋转)

- The proper rotation operation occurs w.r.t. a line (**proper axis**) that the object rotates.
- The proper axis is ***n*-fold** (*n*次旋转轴) when rotation by $2\pi/n$.



$$A_{ij} = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$x \quad y \quad z \quad \rightarrow \quad x' \quad y' \quad z$$

(Here, the proper axis is the z axis)

$$x' = x\cos\theta - y\sin\theta$$

$$y' = x\sin\theta + y\cos\theta$$

➢ Symmetry Operations (对称操作)

5) Improper Rotation (瑕旋转)

- The improper rotation operation is a **combination of rotation and reflection/inversion**.
- It is also called **rotoreflection** (**映转**) or **rotoinversion** (**倒转**).

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

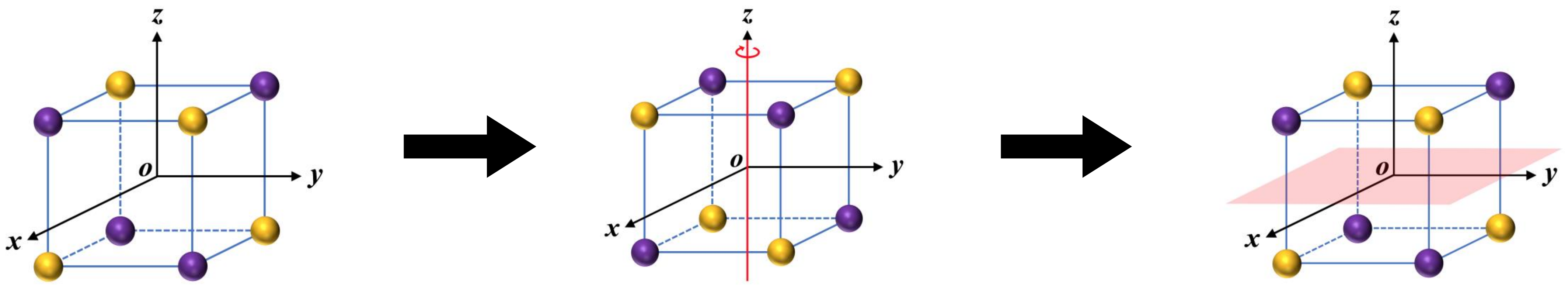
➢ Symmetry Operations (对称操作)

5) Improper Rotation (瑕旋转)

❖ Rotoreflection (映转):

1) rotation by $2\pi/n$;

2) reflection through a plane perpendicular to the axis.



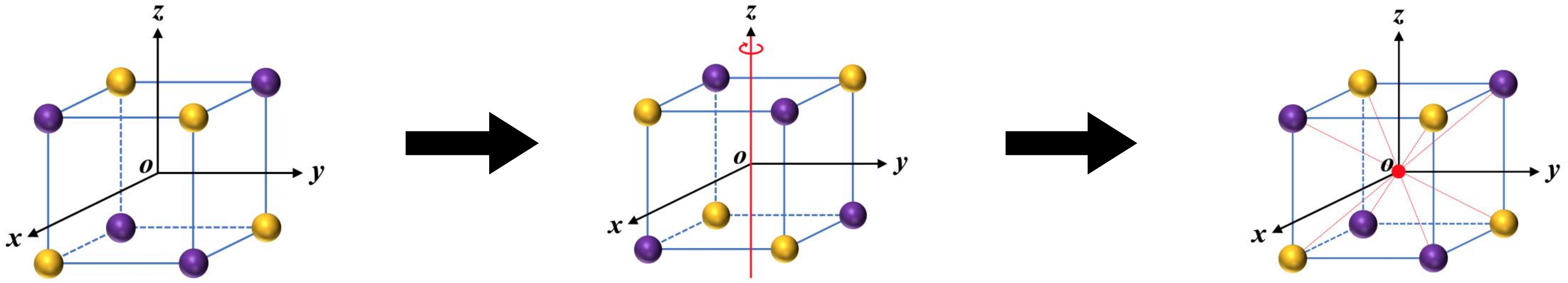
- **Symmetry Operations (对称操作)**

5) Improper Rotation (瑕旋转)

❖ Rotoinversion (倒转):

1) rotation by $2\pi/n'$;

2) inversion through a inversion center on the axis.



Symmetry Operations (对称操作)

5) Improper Rotation (瑕旋转)

- The rotoreflection and rotoinversion are **essentially equivalent!**
- They are only different in rotation with an angle of π.

Rotoreflection: $$A_{ij} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} \cos\theta' & -\sin\theta' & 0 \\ \sin\theta' & \cos\theta' & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$x \quad y \quad z \quad \rightarrow \quad x' \quad y' \quad -z$$
$$x' = x\cos\theta' - y\sin\theta'$$
$$y' = x\sin\theta' + y\cos\theta'$$

Rotoinversion: $$A_{ij} = \begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} \cos\theta'' & -\sin\theta'' & 0 \\ \sin\theta'' & \cos\theta'' & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$x \quad y \quad z \quad \rightarrow \quad x'' \quad y'' \quad -z$$
$$x'' = x\cos\theta'' - y\sin\theta''$$
$$y'' = x\sin\theta'' + y\cos\theta''$$

$$x'' = -x'$$
$$y'' = -y'$$
$$\rightarrow \quad \boxed{\theta'' = \theta' \pm \pi}$$

➢ Symmetry Operations (对称操作)

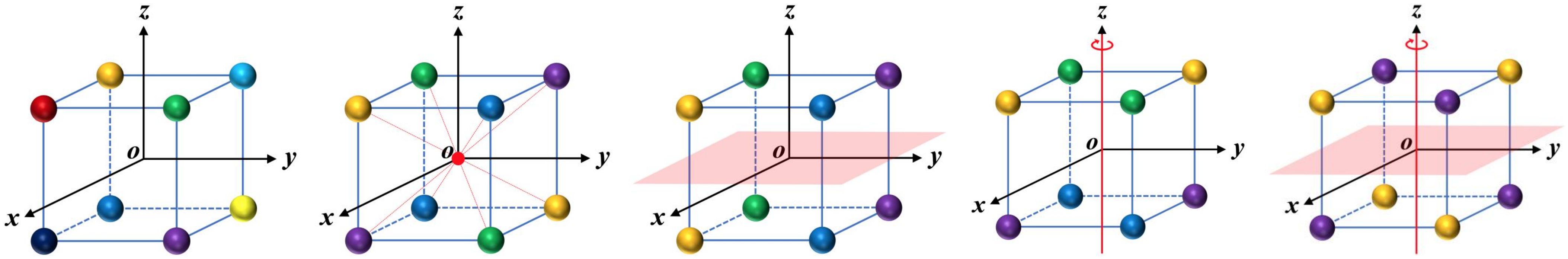
2019级崇新学堂同学“科学可视化”作品

杨天池，靳明昊，胡欣然
李宁萍，刘姿含，郭美婧

➢ Symmetry Elements (对称元素)

❖ A symmetry element is a **point of reference** about which symmetry operations can take place.

In particular, symmetry elements include:



Identity (恒等)	**Inversion Center (对称中心)**	**Symmetry Plane (对称面)**	**Proper Axis (旋转轴)**	**Improper Axis (反轴)**

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➤ **Symmetry Elements (对称元素)**

Symmetry Operations 对称操作	**Symmetry Elements 对称元素**	**Notation 符号**	
		International Notation 国际符号	**Schoenflies Notation 熊夫利符号**
Identity 恒等	Identity **恒等**	**1**	**E**
Inversion 反演	Inversion Center **对称中心**/反演中心	$\bar{1}$	**i**
Reflection 反映	Symmetry Plane **对称面**/反映面	**m**	**σ**
Proper Rotation 旋转	Proper Axis **旋转轴**	**1, 2, 3, 4, 6**	C_1, C_2, C_3, C_4, C_6
Improper Rotation 瑕旋转/映转/倒转	Improper Axis **反轴**/映转轴/倒转轴	$\bar{3}$, $\bar{4}$, $\bar{6}$	C_{3i}, S_4, C_{3h}

➢ Symmetry Elements (对称元素)

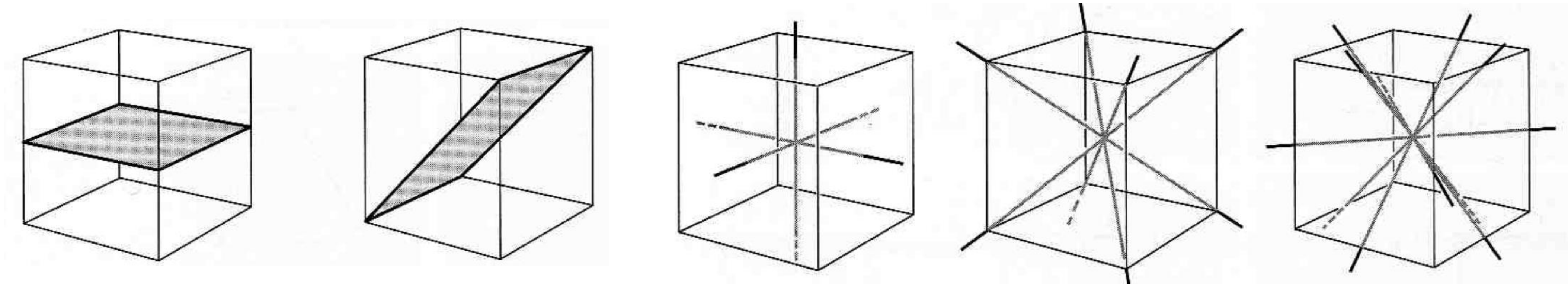
❖ In periodic crystals, there are only **8 independent symmetry elements**:

$$\boxed{1, 2, 3, 4, 6, \mathrm{i}, \mathrm{m}, \bar{4}}$$

(**Note**: $\bar{1} = \mathrm{i}$, $\bar{2} = \mathrm{m}$, and $\bar{3}$ and $\bar{6}$ are not independent because $\bar{3} = 3 + \mathrm{i}$; $\bar{6} = 3 + \mathrm{m}$)

➢ Symmetry Elements (对称元素)

❖ In practice, for simplicity, only the symmetry elements (instead of the symmetry operations) are listed in order to describe the symmetry properties of a crystal.



The symmetry elements of a cube.

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➢ Crystallographic Restriction Theorem (晶体学限制定理)

❖ The rotational symmetries of a crystal are limited to only 1-fold, 2-fold, 3-fold, 4-fold, and 6-fold, i.e., the **symmetry elements of 1, 2, 3, 4, and 6**. We cannot find a lattice that goes into itself under other rotations, such 5-fold, 7-fold, …

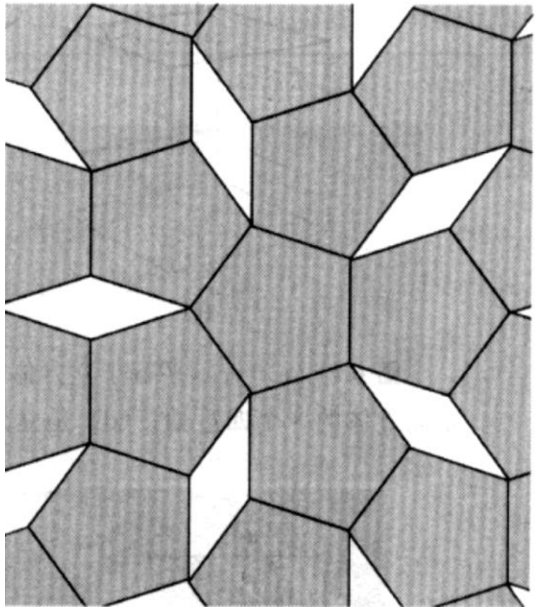
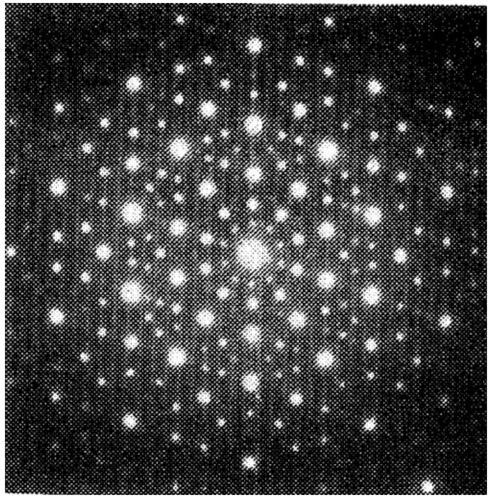


Figure 5 A fivefold axis of symmetry cannot exist in a periodic lattice because it is not possible to fill the area of a plane with a connected array of pentagons. We can, however, fill all the area of a plane with just two distinct designs of “tiles” or elementary polygons.

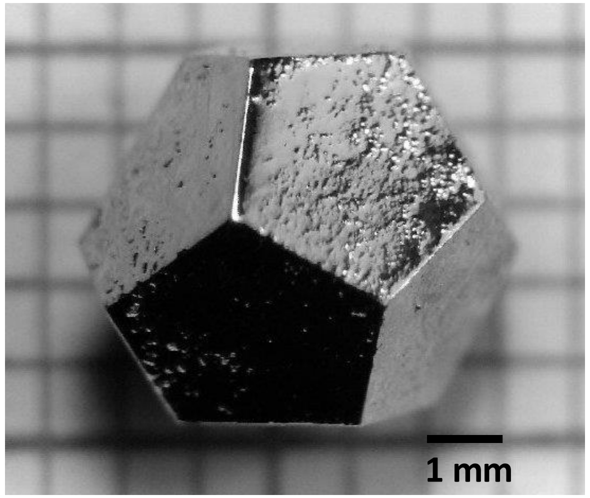
(基泰尔书, page 5)

➢ Quasicrystal (准晶)

❖ The discovery of **quasicrystal (准晶)** in 1984 broke the crystallographic restriction theorem and proved that **there exists 5-fold rotation symmetry in real crystals**.

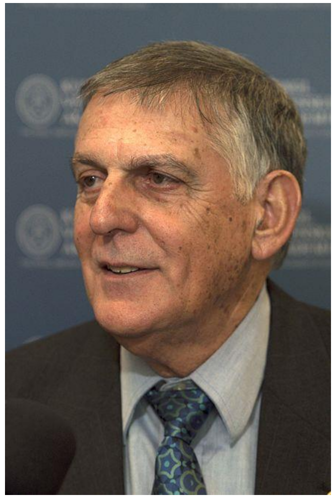


Electron Diffraction Pattern of AlMn Quasicrystal



A Sample of $Ho_{8.7}Mg_{34.6}Zn_{56.8}$ Quasicrystal

Nobel Prize in Chemistry 2011



Dan Shechtman
(1941-)
Israeli Material Scientist

D. Shechtman, I. Blech, D. Gratias, and J. W. Cahn, ***Phys. Rev. Lett.*** **53, 1951 (1984).**

Quasicrystal (准晶)

- The discovery of **quasicrystal (准晶)** in 1984 broke the crystallographic restriction theorem and proved that **there exists 5-fold rotation symmetry in real crystals**.

	Crystals	
Properties	**Periodic Crystals**	**Quasicrystals**
Long-Range Order?	Yes	Yes
Translational Symmetry?	Yes	No
The Crystallographic Restriction Theorem Applies?	Yes	No

➢ Crystallographic Point Group (晶体学点群)

❖ Mathematically, a **group (群)** is a set (e.g., G) consisting of a group of elements.

$$G = \{E, A, B, C, D, \ldots\ldots\}$$

❖ All elements in the group G satisfy:

1. Closure (闭合性): If $A, B \in G$, then $AB = C \in G$

2. Associativity (结合律): $A(BC)=(AB)C$

3. Identity Element (单位元素): There exists E such that all elements meet $AE=A$

4. Inverse Element (逆元素): Each element has an inverse element in the group that $AA^{-1}=E$

➢ Crystallographic Point Group (晶体学点群)

❖ A crystallographic point group, or **point group** (点群) for short, is a set of symmetry operations that leave at least one point fixed during the operations, i.e., **point symmetry operations (点对称操作)**.

$$G = \{1, 2, 3, 4, 6, i, m, \bar{4}\}$$

❖ For a periodic crystal, the point group must be consistent with maintenance of the 3D translational symmetry. (注意: "点对称操作"不包含"平移对称操作").

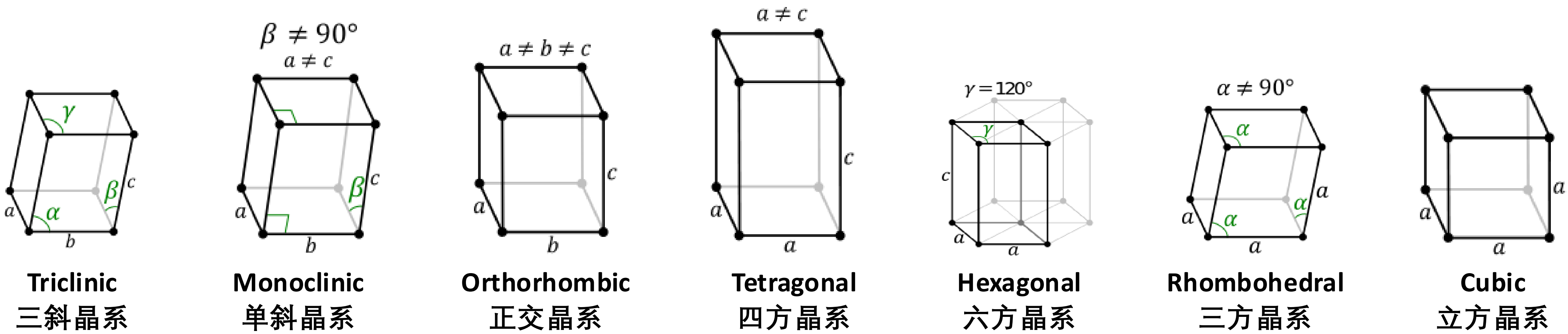
➢ Crystallographic Point Group (晶体学点群)

❖ In periodic crystals, the combination of point symmetry operations lead to **32 point groups**.

符号	符号意义	对称类型	数目
C_n	具有n重旋转对称轴	C_1, C_2, C_3, C_4, C_6	5
C_i	对称中心 (i)	C_i (= S_2)	1
C_s	对称面 (m)	C_s	1
C_{nh}	h代表除n重轴外还有与轴垂直的水平对称面	C_{2h}, C_{3h}, C_{4h}, C_{6h}	4
C_{nv}	v代表除n重轴外还有通过该轴的铅锤对称面	C_{2v}, C_{3v}, C_{4v}, C_{6v}	4
D_n	具有n重轴和n个与之垂直的2重轴	D_2, D_3, D_4, D_6	4
D_{nh}	h意义与前同	D_{2h}, D_{3h}, D_{4h}, D_{6h}	4
D_{nd}	d表示还有1个平分两个2重轴间夹角的对称面	D_{2d}, D_{3d}	2
S_n	经n重旋转后，再经垂直该轴的平面镜像	S_4, S_6	2
T	4个3重轴和3个2重轴 (四面体对称性)	T	1
T_h	h意义与前同	T_h	1
T_d	d意义与前同	T_d	1
O	3个互相垂直的4重轴及6个2重轴和4个3重轴	O, O_h	2
共计			**32**

➢ Crystal Systems (晶系)

❖ Since some symmetry elements may be shared by certain types of crystals, the 32 point groups can be further classified into **7 crystal systems**.



The unit cells characteristic of the 7 crystal systems.

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➢ Crystal Systems (晶系)

❖ All crystals of each crystal system have the same set of **point groups** and **unit cell**.

Crystal System	晶系	对称性特征	晶胞参数	所属点群
Triclinic	三斜	只有C_1或C_i	$a \neq b \neq c$ $\alpha \neq \beta \neq \gamma$	C_1、C_i
Monoclinic	单斜	唯一C_2或C_S	$a \neq b \neq c$ $\alpha = \gamma = 90^o \neq \beta$	C_2、C_S、C_{2h}
Orthorhombic	正交	三个C_2或C_S	$a \neq b \neq c$ $\alpha = \beta = \gamma = 90^o$	D_2、C_{2V}、D_{2h}
Rhombohedral	三方	唯一C_3或S_6	$a=b=c$ $\alpha = \beta = \gamma \neq 90^o$	C_3、S_6、D_3 C_{3V}、D_{3d}
Tetragonal	四方	唯一C_4或S_4	$a=b \neq c$ $\alpha = \beta = \gamma = 90^o$	C_4、S_4、C_{4h}、D_4 C_{4V}、D_{2d}、D_{4h}
Hexagonal	六方	唯一C_6或S_3	$a=b \neq c$ $\alpha = \beta =$ $90^o \gamma = 120^o$	C_6、C_{3h}、C_{6h}、 D_6、C_{6V}、D_{3h}、 D_{6h}
Cubic	立方	四个C_3	$a=b=c$ $\alpha = \beta = \gamma = 90^o$	T、T_h、T_d O、O_h

➢ Bravais Lattices (布拉维格子)

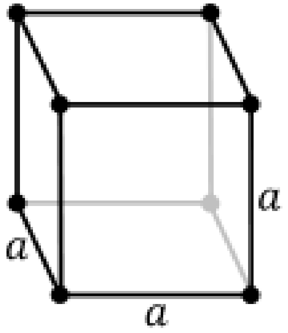
❖ By considering how the lattice sites are located in the unit cells of the 7 crystal systems, it ends up with **14 Bravais lattices** in 3D.

❖ **Any real periodic crystal corresponds to one of the 14 Bravais lattices!**

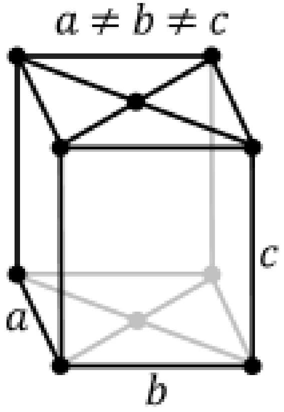
Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➢ Bravais Lattices (布拉维格子)

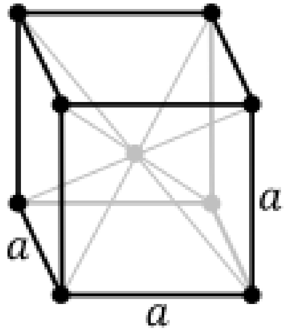
❖ There are **4** centering types identifying the location of the lattice sites in the unit cell:



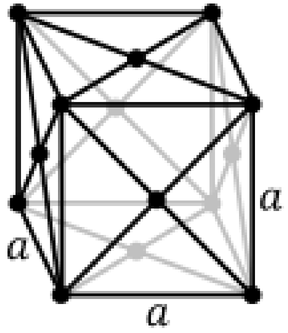
Primitive (P)
原始格子



Base-centered (C)
底心格子



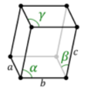
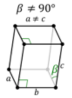
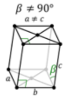
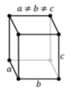
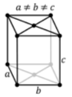
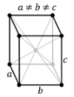
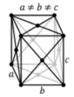
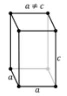
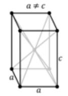
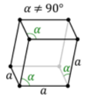
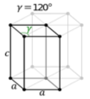
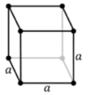
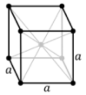
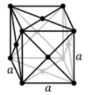
Body-centered (I)
体心格子



Face-centered (F)
面心格子

➢ Bravais Lattices (布拉维格子)

❖ The 14 Bravais lattices in 3D:

晶系	原始格子(P)	底心格子(C)	体心格子(I)	面心格子(F)	合计
三斜		C = I	I = F	F = P	1
单斜			I = F	F = C	2
正交					4
四方		C = P		F = I	2
三方		与本晶系对称不符	I = F	F = P	1
六方		与本晶系对称不符	与空间格子的条件不符	与空间格子的条件不符	1
立方		与本晶系对称不符			3

共计14

Microscopic Symmetry of Crystals (晶体的微观对称性)

- **Microscopic Symmetry of Crystals (晶体的微观对称性)**

Symmetry of Crystals

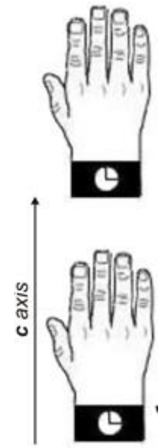
- Macroscopic (宏观)
  - Point Symmetry (Point Groups)
- **Microscopic (微观)**
  - **Point Symmetry + Translational Symmetry (Space Groups)**

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

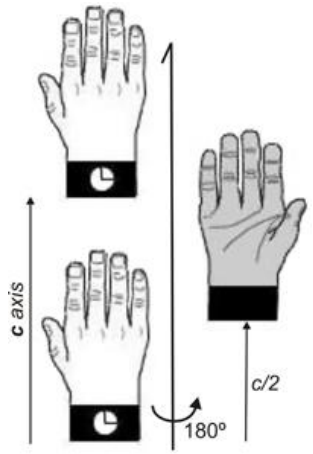
➢ Translational Symmetry (平移对称性)

❖ The translational symmetry can be described in terms of **translational symmetry elements** and the corresponding **translational symmetry operations**.

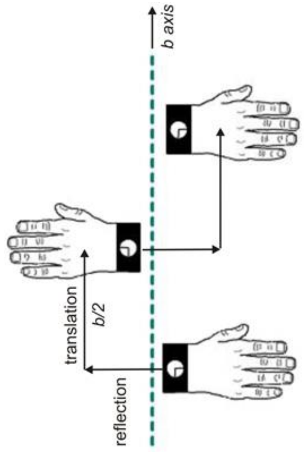
❖ The translational symmetry elements include:



Translation Axis (平移轴)



Screw Axis (螺旋轴)

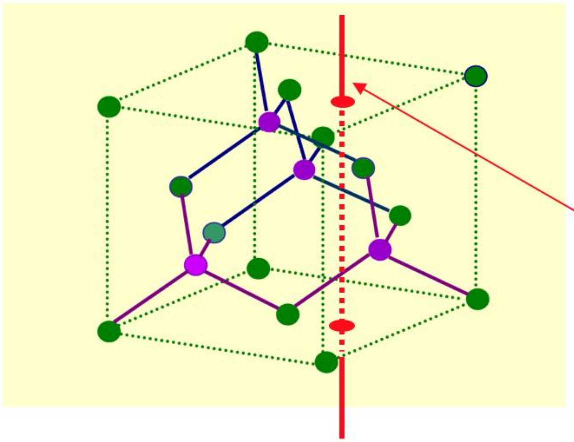


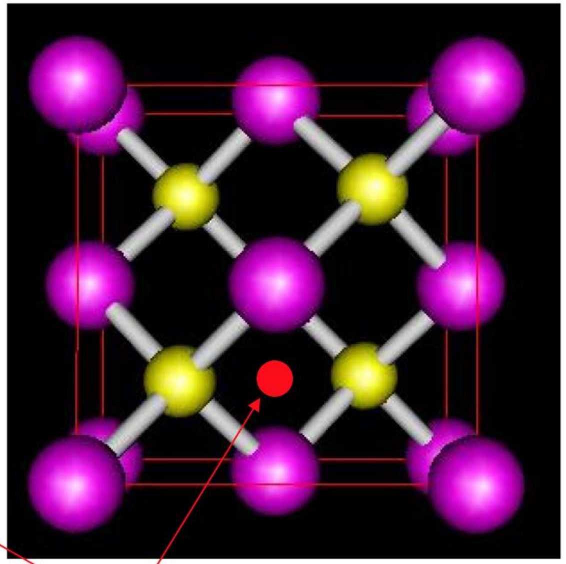
Glide Plane (滑移面)

➢ **Translational Symmetry (平移对称性)**

金刚石结构中的4度螺旋轴

取上下底面心的连线,再沿单胞边长平移$a/4$就是一个4度螺旋轴。晶体绕该轴转90^o后，再沿该轴平移$a/4$，能自身重合。





4度螺旋轴

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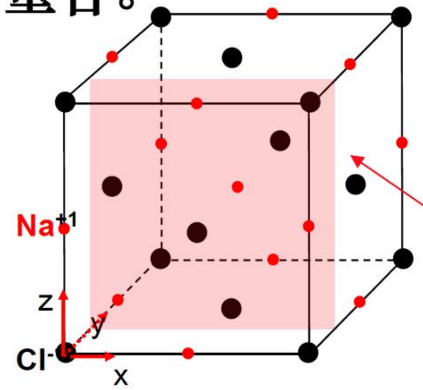
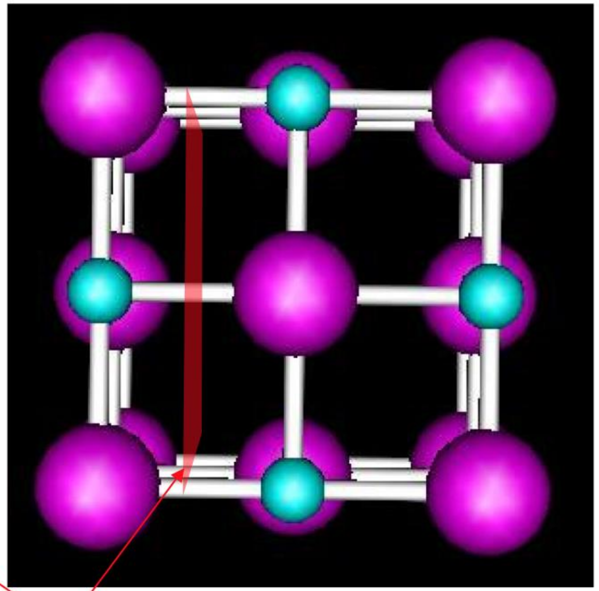
- **Translational Symmetry (平移对称性)**

氯化钠结构中的滑移反映面

取氯和钠的中垂面为镜面，再沿平行于该面的原子排列方向平移$a/2$，能自身重合。





滑移反映面

曾长淦，《固体物理讲义》

➢ Crystallographic Space Group (晶体学空间群)

- ❖ The translational symmetry operations give rise to **14 translation groups** (**平移群,** as many as the number of Bravais lattices).

- ❖ In 3D periodic crystals, the combination of **point symmetry operations** and **translational symmetry operations** lead to **230 crystallographic space groups.**

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➢ Crystallographic Space Group (晶体学空间群)

表 2.3 7个晶系，14个布拉维格子和 73个简单空间群

晶系	单胞基矢特性	布拉维格子	空间群
三斜	$a\neq b\neq c$ $\alpha\neq\beta\neq\gamma$	简单三斜(P)	$P1$, $P\bar{1}$
单斜	$a\neq b\neq c$ $\alpha=\beta=90°\neq\gamma$	简单单斜(P) 底心单斜(B 或 A)	$P2$, Pm, $P2/m$ $B2$, Bm, $B2/m$
正交	$a\neq b\neq c$ $\alpha=\beta=\gamma=90°$	简单正交(P) 底心正交(C,A 或 B) 体心正交(I) 面心正交(F)	$P222$, $Pmm2$, $Pmmm$ $C222$, $Cmm2$, $Amm2$, $Cmmm$ $I222$, $Imm2$, $Immm$ $F222$, $Fmm2$, $Fmmm$
四方	$a=b\neq c$ $\alpha=\beta=\gamma=90°$	简单四方(P) 体心四方(I)	$P4$, $P\bar{4}$, $P4/m$, $P422$, $P4mm$, $P\bar{4}2m$, $P\bar{4}m2$, $P4/mmm$。 $I4$, $I\bar{4}$, $I4/m$, $I422$, $I4mm$, $I\bar{4}2m$, $I\bar{4}m2$, $I4/mmm$。
三角	$a=b=c$ $\alpha=\beta=\gamma<120°$ $\neq 90°$	三角(R,P)	$R3$, $R\bar{3}$, $R32$, $R3m$, $R\bar{3}m$ $P3$, $P\bar{3}$, $P312$, $P321$, $P3m1$ $P31m$, $P\bar{3}1m$, $P\bar{3}m1$
六角	$a=b\neq c$ $\alpha=\beta=90°$; $\gamma=120°$	六角(P)	$P6$, $P\bar{6}$, $P6/m$, $P622$, $P6mm$, $P\bar{6}m2$, $P\bar{6}2m$, $P6/mmm$
立方	$a=b=c$ $\alpha=\beta=\gamma=90°$	简单立方(P) 体心立方(I) 面心立方(F)	$P23$, $Pm3$, $P432$, $P\bar{4}3m$, $Pm3m$ $I23$, $Im3$, $I432$, $I\bar{4}3m$, $Im3m$ $F23$, $Fm3$, $F432$, $F\bar{4}3m$, $Fm3m$

❖ Space groups can be used to give **more detailed classifications** of real crystals.

❖ Not all space groups have found examples of real crystals.

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➢ The Case of 3D

❖ In 3D periodic crystals, there exist:

8
Independent Symmetry Elements
(独立对称元素)

Point Symmetry →

32
Crystallographic Point Groups
(点群)

Translational Symmetry →

230
Crystallographic Space Groups
(空间群)

7
Crystal Systems
(晶系)

14
Bravais Lattices
(布拉维格子)

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➢ The Case of 2D

❖ **In 2D periodic crystals, there exist:**

7
Independent Symmetry Elements
(独立对称元素)

Point Symmetry →

10
Crystallographic Point Groups
(点群)

Translational Symmetry →

17
Crystallographic Space Groups
(空间群)

4
Crystal Systems
(晶系)

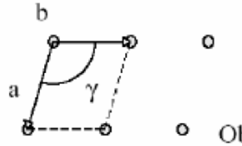
5
Bravais Lattices
(布拉维格子)

Chapter 1.2: Symmetry of Crystals (晶体的对称性)

➢ The Case of 2D

❖ 4 Crystal Systems and 5 Bravais Lattices:

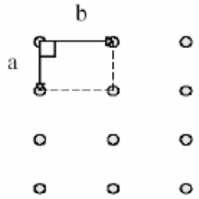
斜方



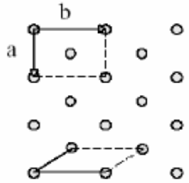
Oblique

$$a \neq b, \gamma \neq 90^{\circ}$$

长方



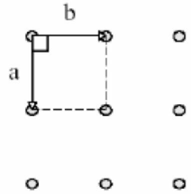
Rectangular



Centered Rectangular

$$a \neq b, \gamma = 90^{\circ}$$

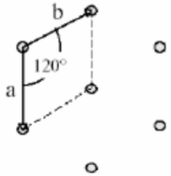
正方



Square

$$a = b, \gamma = 90^{\circ}$$

六角



Hexagonal

$$a = b, \gamma = 120^{\circ}$$

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Summary (总结)

- **Summary (总结)**

  - **Symmetry of Crystals:**

    1) Macroscopic symmetry; 2) Microscopic symmetry

  - **Macroscopic Symmetry:**

    1) Symmetry Operations;

    2) Symmetry Elements;

    3) Point Group;

    4) Crystal Systems;

    5) Bravais Lattices.

  - Microscopic Symmetry.

Chapter 1.2: 课后作业

1. 列出硅(silicon)晶体所属的点群、晶系、布拉维格子等信息，并在单胞中画出可能的点对称元素。

2. 用 Materials Studio 软件画出硅晶体的一个单胞（截图到作业纸上），标出任意一条4度螺旋轴，并熟悉 Materials Studio 软件的使用。

（Materials Studio 下载链接: https://pan.baidu.com/s/1zQ5qVycOEhFmpxZZTpTZWQ?pwd=m8m5 提取码: m8m5）

提交时间：3月3日之前

提交方式：手写（写明姓名学号）后拍照，通过本班课代表统一提交电子版