SOLID STATE PHYSICS

REFERENCES

Core book:

Elementary Solid state physics,
M. A. Omar, Second edition

Other books at a similar level:

Solid state physics, Charles Kittel
Oxford Solid state Baiscs, Steven H. Simon

More advanced:

Solid state physics, Ashcroft and Mermin

Chapter 1.
Crystal Structure

Crystalline Solids

- We will deal with crystalline solids, that is solids with an atomic structure based on a regular repeated pattern.

- Many important solids are crystalline.

- More progress has been made in understanding the behaviour of crystalline solids than that of non-crystalline materials since the calculation are easier in crystalline materials.

CHAPTER 1. CRYSTAL STRUCTURE

- ❖ **Elementary Crystallography**

Solid materials (crystalline, polycrystalline, amorphous)
Crystallography
Crystal Lattice
Crystal Structure
Types of Lattices
Unit Cell
Directions-Planes-Miller Indices in Cubic Unit Cell

- ❖ **Typical Crystal Structures**

(3D– 14 Bravais Lattices and the Seven Crystal System)
Elements of Symmetry

Objectives

By the end of this section you should:

- be able to **identify a unit cell** in a symmetrical pattern
- know that there are 7 possible unit cell shapes
- be able to define cubic, tetragonal, orthorhombic and hexagonal unit cell shapes

Crystal

- **Solids consist of atoms or molecules *executing thermal motion* about an equilibrium position *fixed at a point* in space.**
- **Solids can take the form of crystalline, polycrstalline, or amorphous materials.**
- **Solids (at a given temperature, pressure, and volume) have stronger bonds between molecules and atoms than liquids.**
- **Solids require more energy to *break the bonds.***

ELEMENTARY CRYSTALLOGRAPHY

- SOLID MATERIALS
  - CRYSTALLINE
    - Single Crystal
  - POLYCRYSTALLINE
  - AMORPHOUS (NON-CRYSTALLINE)

Types of Solids

- **Single crystal, polycrystalline, and amorphous, are the three general types of solids.**

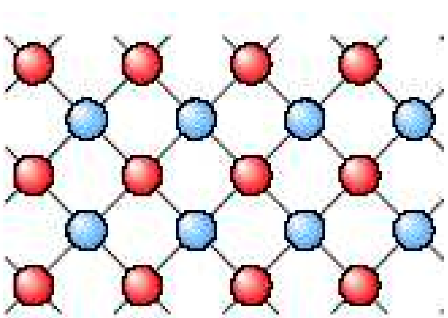
- **Each type is characterized by the size of ordered region within the material.**

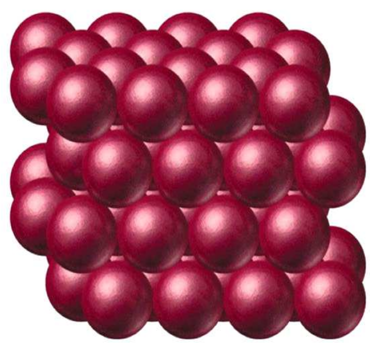
- **An ordered region is a spatial volume in which atoms or molecules have a regular geometric arrangement or periodicity.**

Crystalline Solid

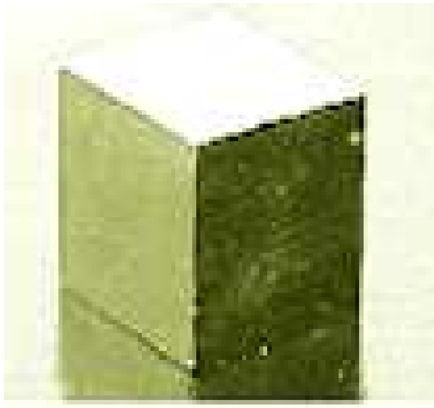
- **<u>Crystalline Solid</u> is the solid form of a substance in which the *atoms or molecules* are arranged in a definite, repeating pattern in three dimension.**

- **Single crystals, ideally have a high degree of order, or regular geometric periodicity, throughout the *entire volume of the material*.**



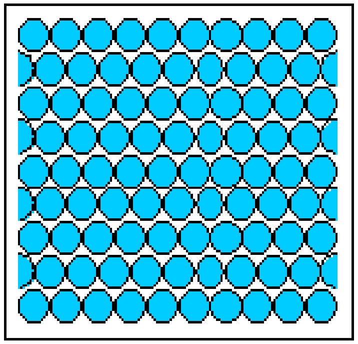


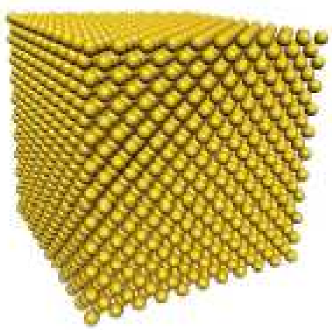
(a) Crystalline solid

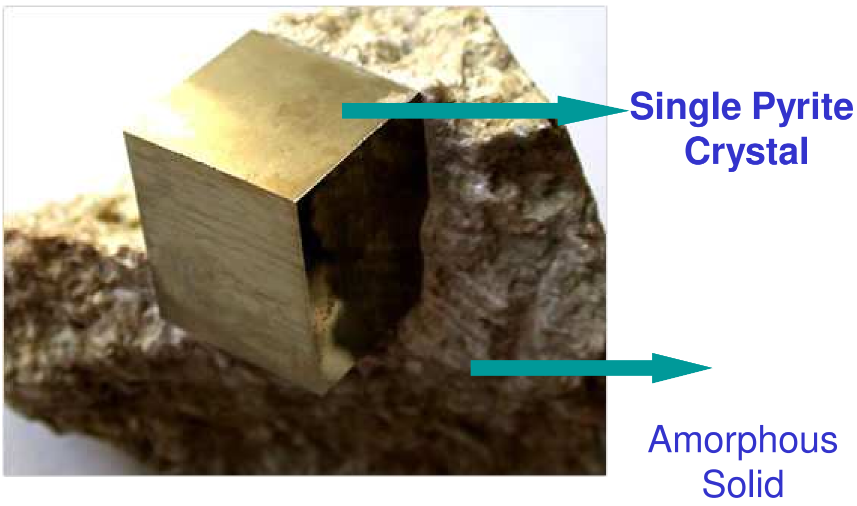


Crystalline Solid

Single crystal has an atomic structure that repeats periodically across its whole volume. Even at infinite length scales, each atom is related to every other equivalent atom in the structure by translational symmetry

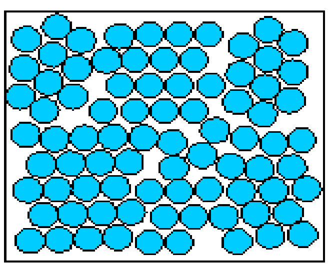




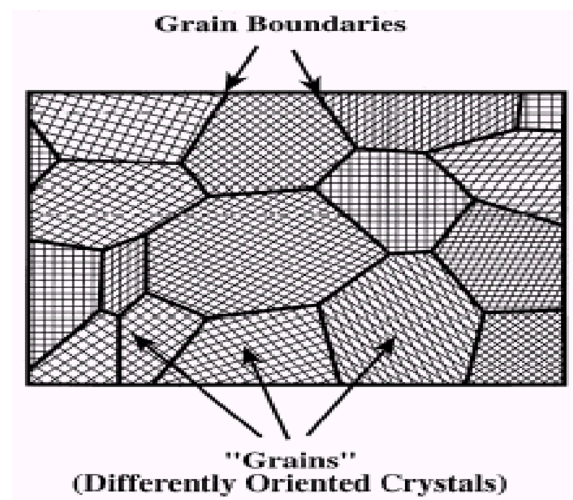


Polycrystalline Solid

- Polycrystal is a material made up of an aggregate of *many small single crystals* (also called crystallites or grains).
- Polycrystalline material have a high degree of order over many atomic or molecular dimensions.
- These *ordered regions,* or single crytal regions, vary in size and orientation wrt one another.
- These regions are called as *grains (domain)* and are separated from one another by *grain boundaries. The atomic order can vary from one domain to the next.*
- The grains are usually *100 nm - 100 microns in diameter*. Polycrystals with grains that are <10 nm in diameter are called nanocrystalline

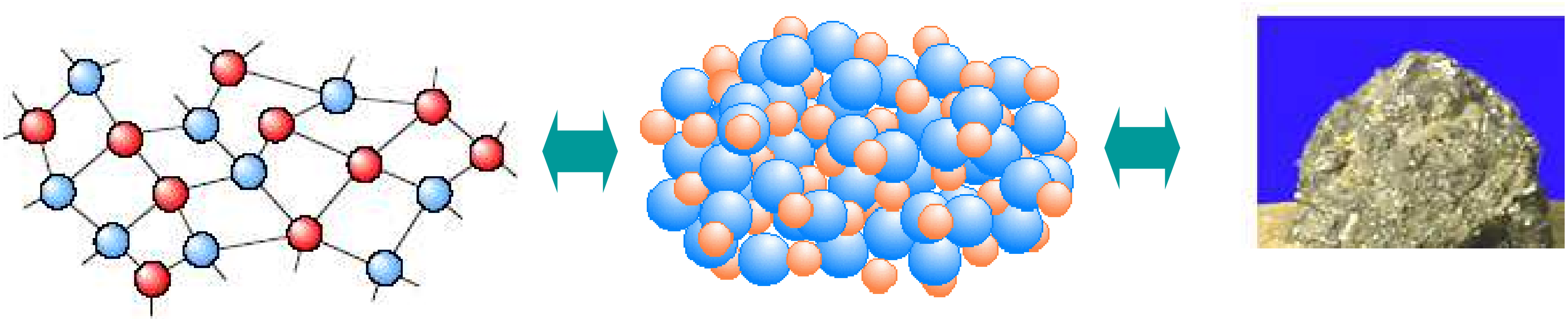


Polycrystalline Pyrite form (Grain)



Amorphous Solid

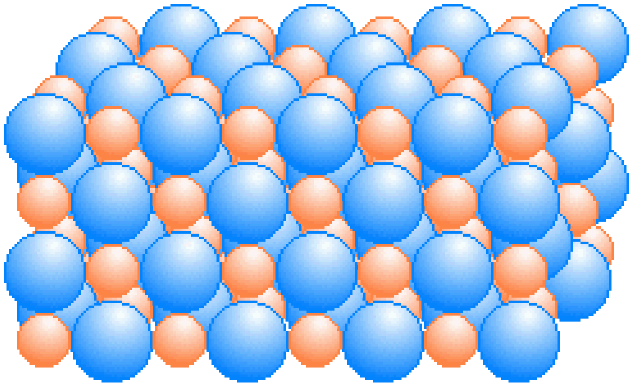
- Amorphous (Non-crystalline) Solid is composed of randomly orientated atoms, ions, or molecules that do not form defined patterns or lattice structures.
- Amorphous materials have order only within a few atomic or molecular dimensions.
- Amorphous materials do not have any long-range order, but they have varying degrees of short-range order.
- Examples to amorphous materials include amorphous silicon, plastics, and glasses.
- Amorphous silicon can be used in solar cells and thin film transistors.



Departure From Perfect Crystal

- Strictly speaking, one cannot prepare a perfect crystal. For example, even the surface of a crystal is a kind of imperfection because the periodicity is interrupted there.

- Another example concerns the thermal vibrations of the atoms around their equilibrium positions for any temperature T>0°K.

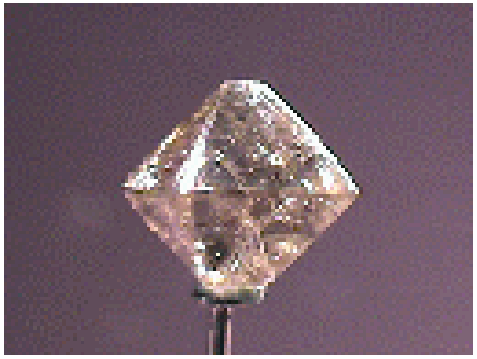


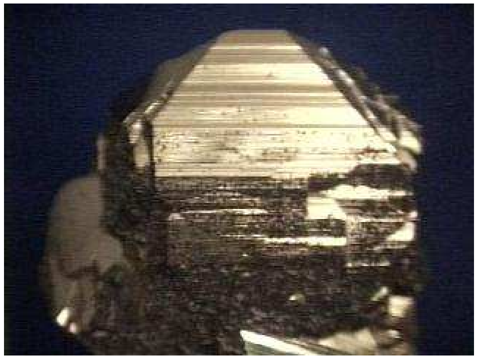
As a third example, actual crystal always contains some foreign atoms, i.e., impurities. These impurities spoils the perfect crystal structure.

CRYSTALLOGRAPHY

What is crystallography?

The branch of science that deals with the geometric description of crystals and their internal arrangement.





CRYSTALLOGRAPHY

Crystallography is essential for solid state physics

- ✓ **Symmetry of a crystal can have a profound influence on its properties.**
- ✓ **Any crystal structure should be specified completely, concisely and unambiguously.**
- ✓ **Structures should be classified into different types according to the symmetries they possess.**

ELEMENTARY CRYSTALLOGRAPHY

- A basic knowledge of crystallography is essential for solid state physicists;

- to specify any crystal structure and
- to classify the solids into different types according to the symmetries they possess.

- Symmetry of a crystal can have a profound influence on its properties.

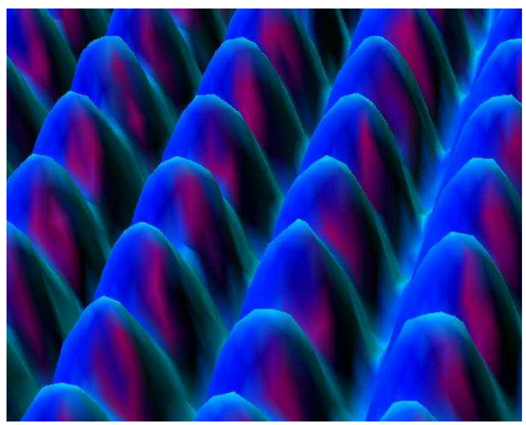
- We will concern in this course with solids with simple structures.

CRYSTAL LATTICE

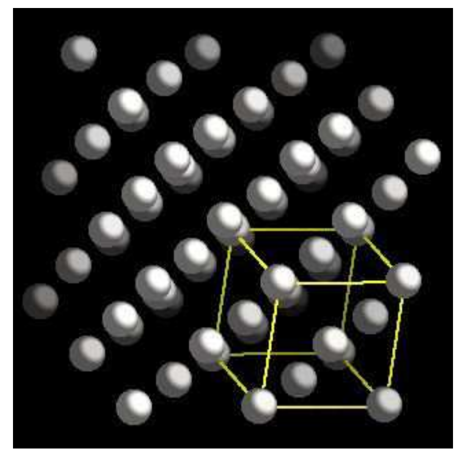
What is crystal (space) lattice?

In crystallography, only the geometrical properties of the crystal are of interest, therefore one replaces each atom by a geometrical point located at the equilibrium position of that atom.

Platinum



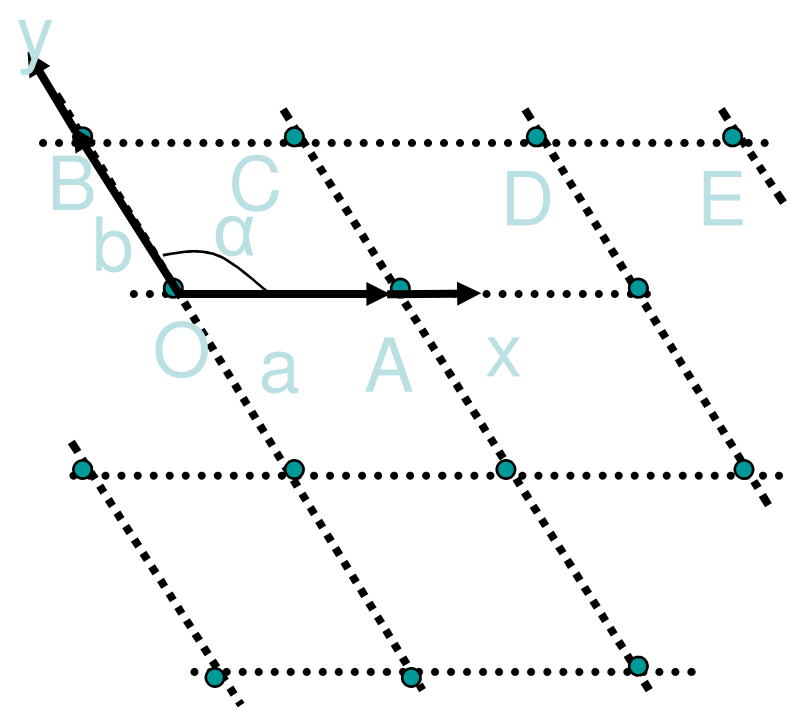
Platinum surface
scanning tunneling microscope)



Crystal lattice and
structure of Platinum

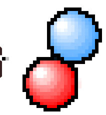
Crystal Lattice

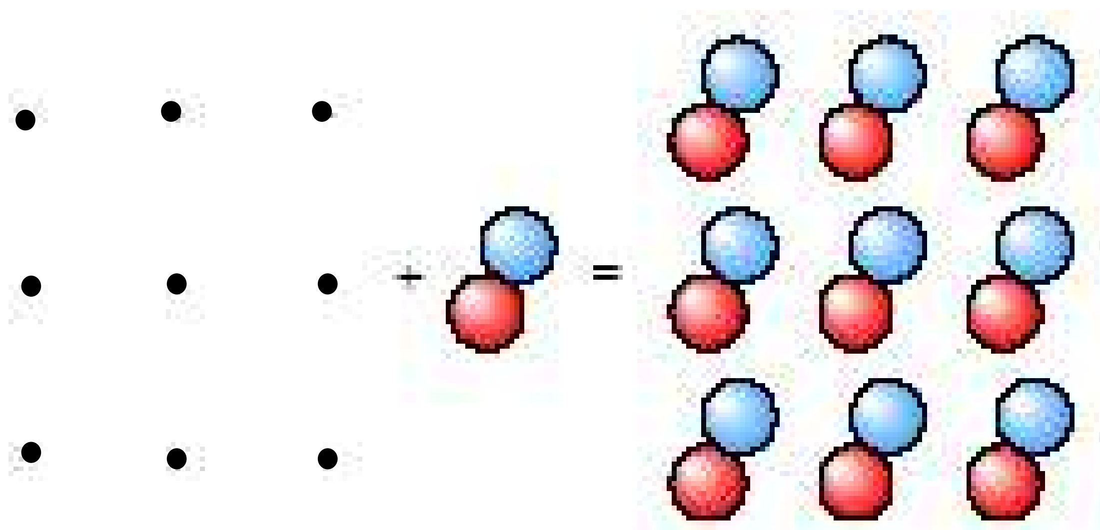
- An infinite array of points in space,
- Each point has identical surroundings to all others.
- Arrays are arranged exactly in a periodic manner.



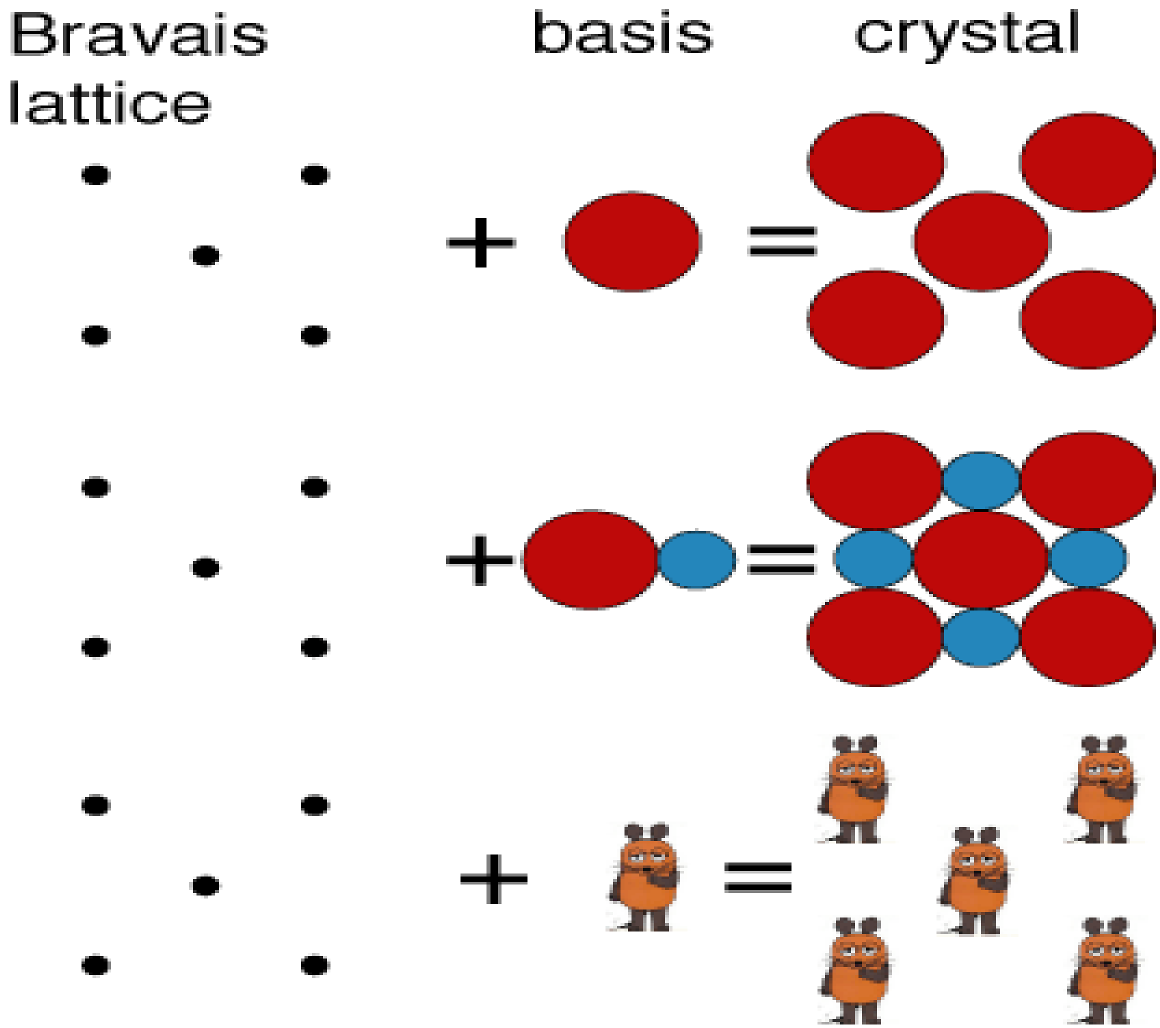
Crystal Structure

Crystal structure can be obtained by attaching atoms, groups of atoms or molecules which are called basis (motif) to the lattice sides of the lattice point.

Crystal Structure = Crystal Lattice • + Basis 

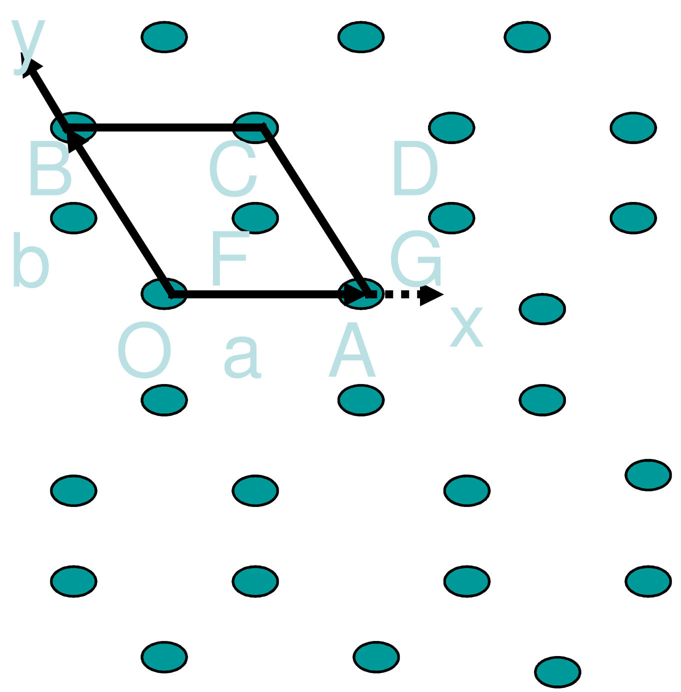


A two-dimensional Bravais lattice with different choices for the basis

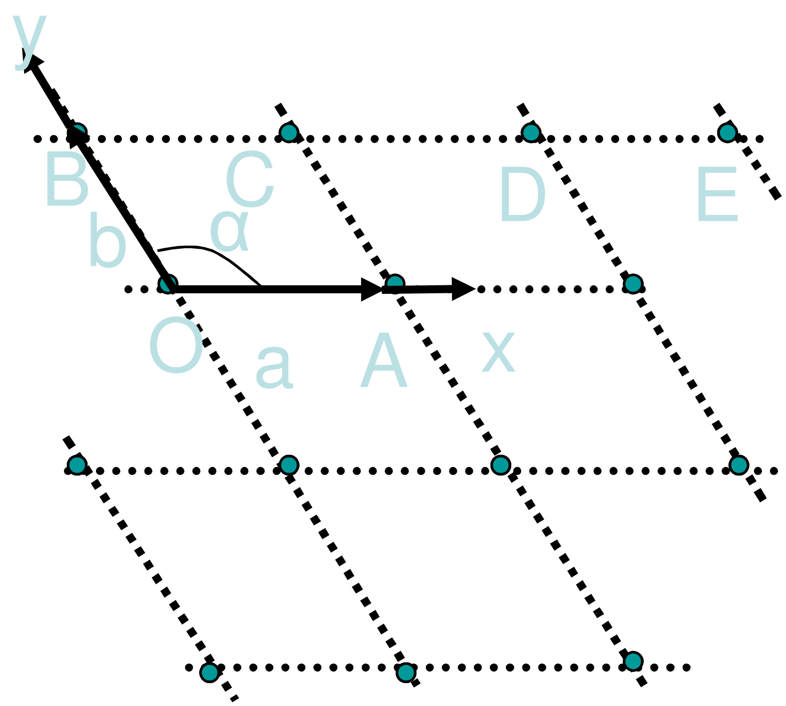


Basis

A group of atoms which describe crystal structure



a) Situation of atoms at the corners of regular hexagons



b) Crystal lattice obtained by identifying all the atoms in (a)