Al-Mustansiriyah University

College of Sciences

Physics Department

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Year 4 – Semester 1

Solid State Physics

Lecture #1

Introduction & Overview

Assistant Professor

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This course will include:

This subject integrates theory of Solid State Physics with experimental demonstrations in the Research Physics Lab. The subject will provide a valuable theoretical introduction and an overview of the fundamental applications of the physics of solids. This subject includes theoretical description of crystal and electronic structure, lattice dynamics, and optical properties of different materials, based on the classical and quantum physics principles. Several advanced experiments of X-ray diffraction

Course Intended Outcomes

At the end of the course, students are expected to learn:

- Physical structure, Lattice dynamics
- X-ray Diffraction methods and Brags Low
- The phonon spectra , specific heat
- Thermal conductivity for electrons and the electrical conductivity.

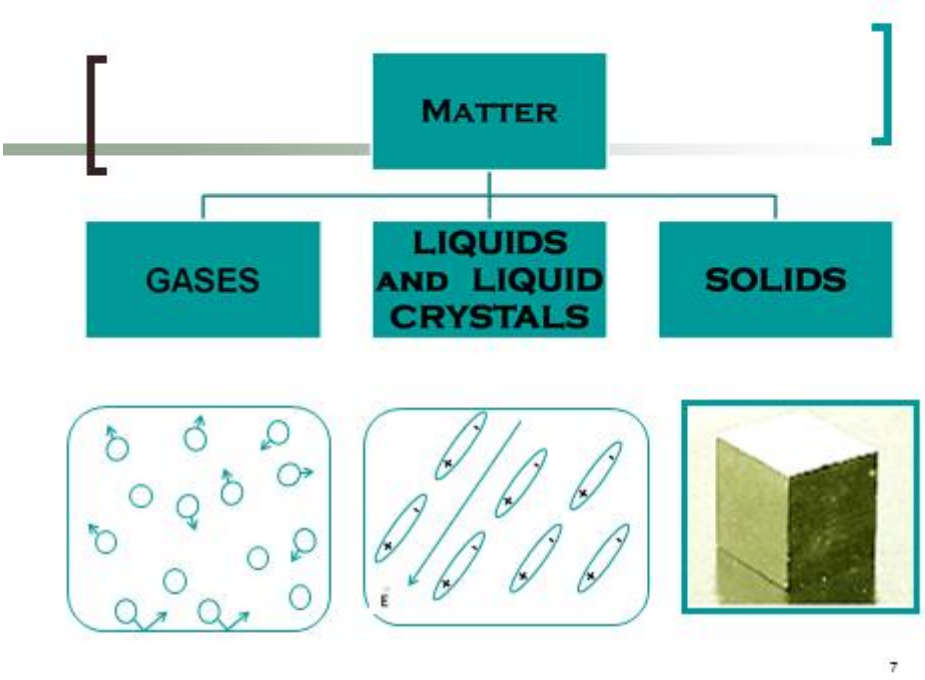
Lecture No.	**Subjects**
1	Introduction in solid state physics, Overview
2	Lattice symmetry operation
3	Crystal systems
4	Miller Indices
5	Miller Indices: Directions
6	Crystal diffraction
7	Experimental methods of X-ray diffraction
8	Reciprocal lattice
9	Lattice vibration and phonons.
10	Thermal properties of solids (introduction).
11	Classical model of lattice energy.
12	The Einstein s model for specific heat.
13	Debye model for specific heat.
14	Free electron energy (introduction).
15	Classical theory of free electrons.
16	Thermal conductivity for electrons.

References:

1. J. S. Blakemore, "Solid State Physics", Third Edition, Cambridge University Press, 1985
2. مؤيد جبرائيل (فيزياء الحاله الصلبة الجزء الاول
3. H. Ibach, H. Lüth, "Solid-State Physics.An Introduction to Principles of Materials Science", Springer, 2003.
4. P. Yu and M. Cardona, "Fundamentals of semiconductors"
5. N. W. Ashcroft and N. D. Mermin, "Solid State Physics"
6. Elementary solid state physics : Principle and Applications, M. A. OMAR.

Introductions and overview:

In general matter divided in to solid, liquid, gas ,



And fourth state of matter (Plasma) in which the matter separated in to ions under special condition (heat and pressure).

Our interest will focus on solid states physics.

Matter can be classified according to their properties such as electrical , magnetic, binding energy, thermal, etc.

Electrical properties

⇩

Conductors—semiconductors—insulator

Magnetic properties

⇩

Paramagnetic—Diamagnetic—ferromagnetic

⇩

binding energy

Ionic—valance—vanderval—metallic

Thermal Properties

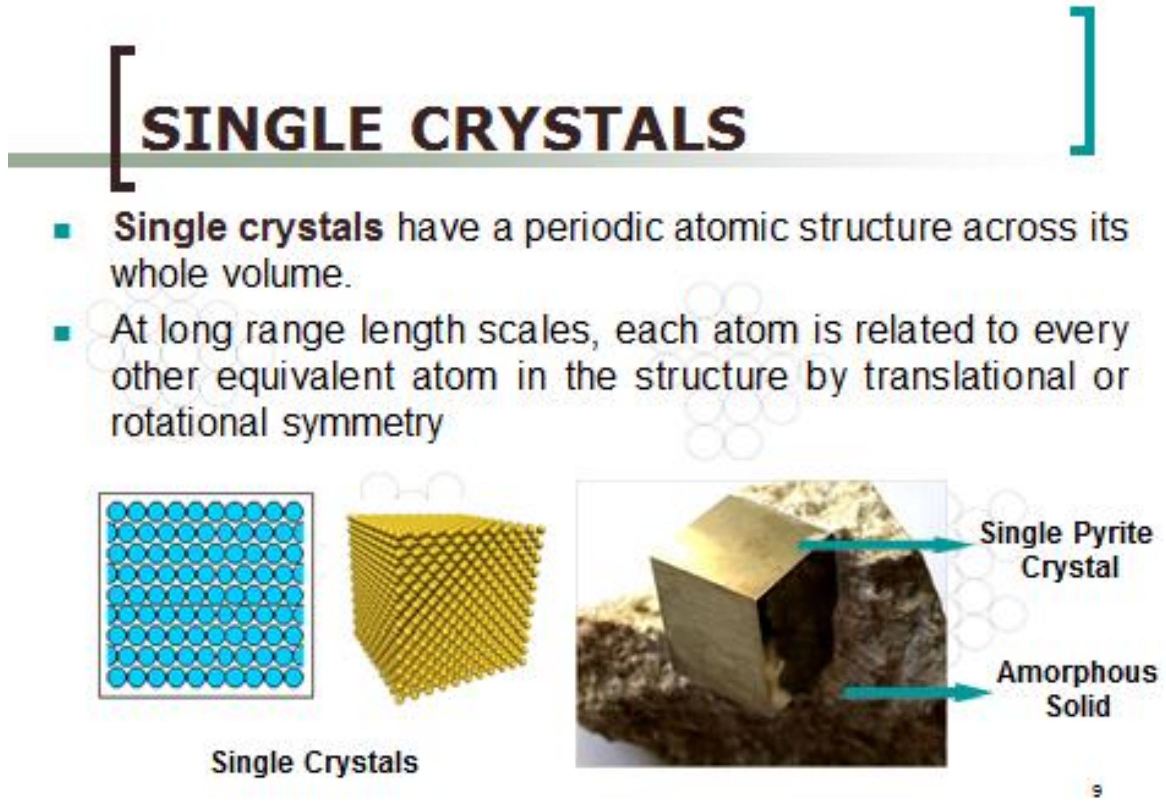
⇩

Thermal conductor—thermal insulator

Also mater can be classified according to internal building of atoms

⇩

Single crystalline -- polycrystalline – Amorphous



SINGLE CRYSTALS

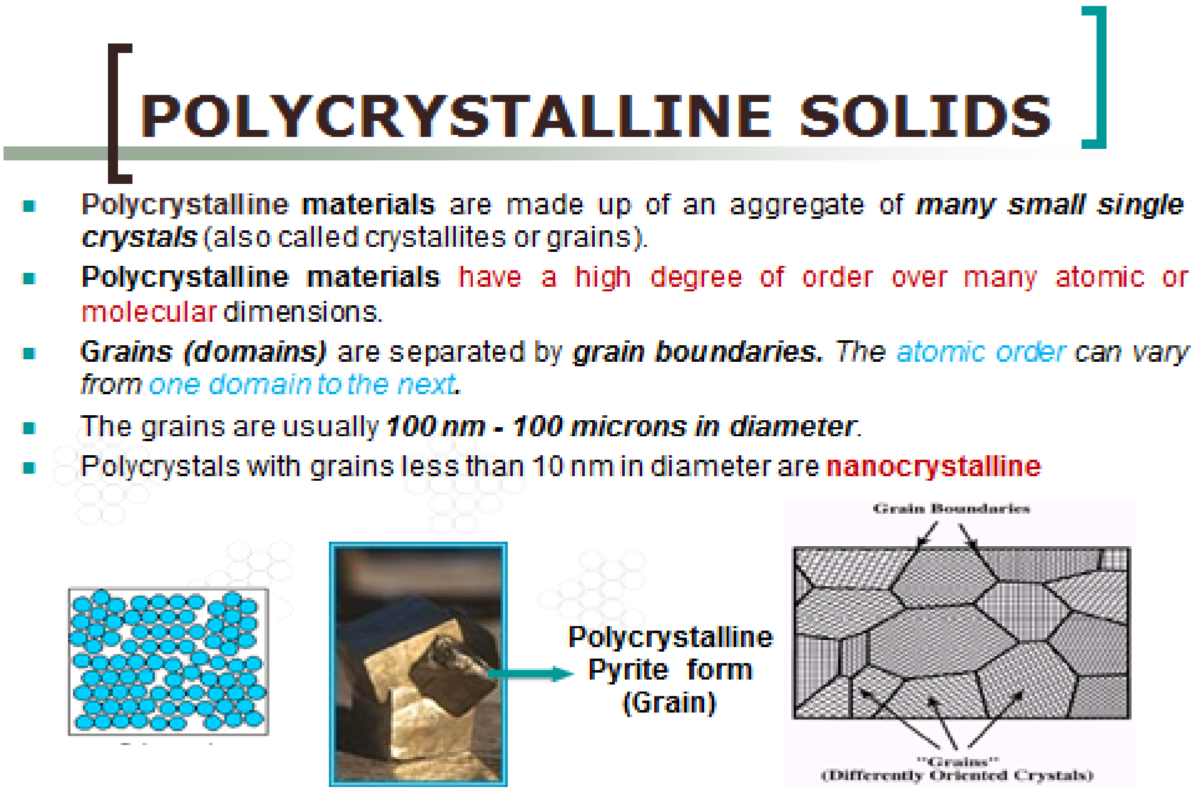
- **Single crystals** have a periodic atomic structure across its whole volume.
- At long range length scales, each atom is related to every other equivalent atom in the structure by translational or rotational symmetry

Single Crystals

Single Pyrite Crystal

Amorphous Solid

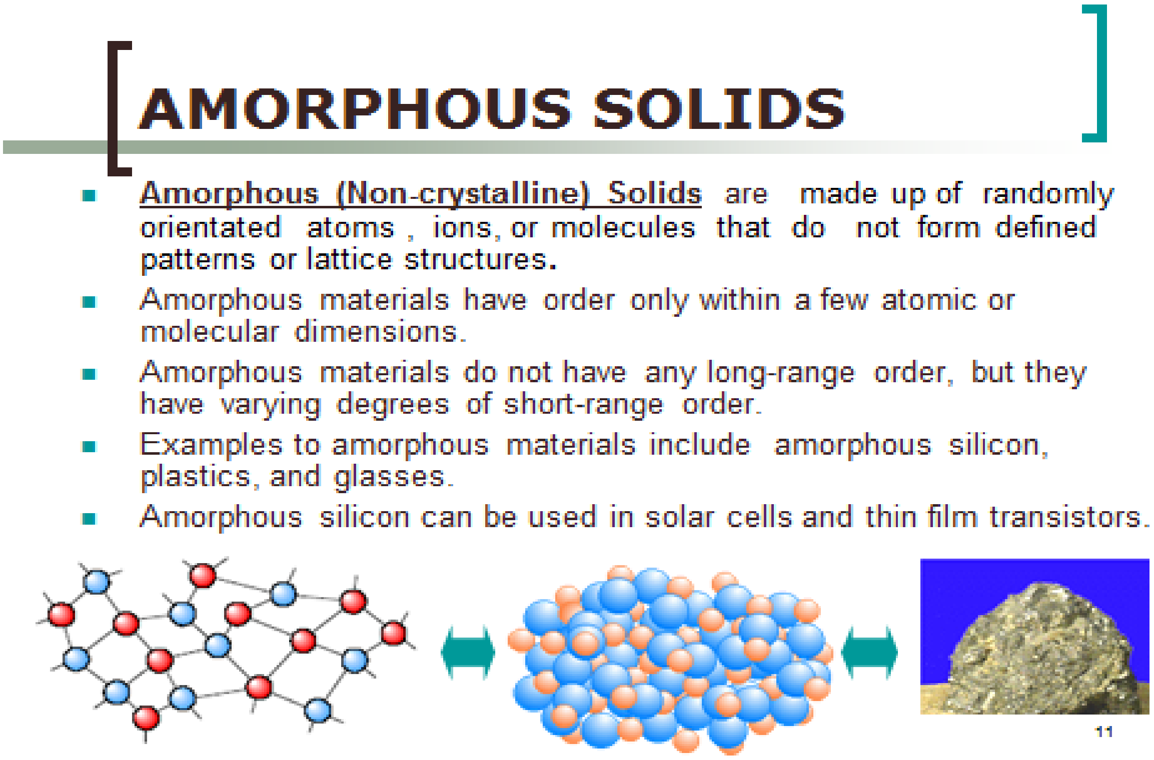
9



POLYCRYSTALLINE SOLIDS

- **Polycrystalline materials** are made up of an aggregate of ***many small single crystals*** (also called crystallites or grains).
- **Polycrystalline materials** have a high degree of order over many atomic or molecular dimensions.
- ***Grains (domains)*** are separated 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 less than 10 nm in diameter are **nanocrystalline**

Polycrystalline Pyrite form (Grain)

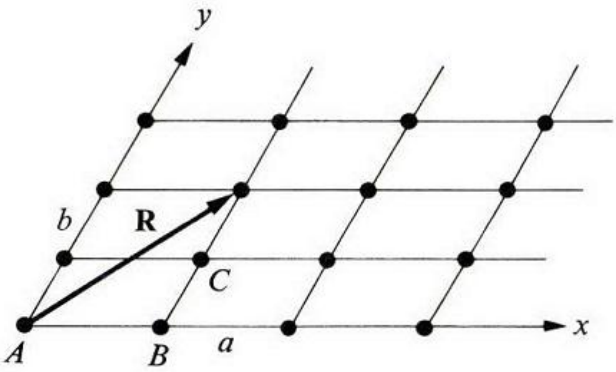


AMORPHOUS SOLIDS

- **Amorphous (Non-crystalline) Solids** are made up 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.

THE CRYSTALLINE STATE

A solid is said to be a crystal if the atoms are arranged in such a way that their positions are exactly periodic. Figure below illustrates the concept. The distance between any two nearest neighbors along the x direction is a, and along the y direction is D (the x and axes are not necessarily orthogonal). A perfect crystal maintains this periodicity (or repetitivity) in both the x and y directions from -∞ to ∞. It follows from the periodicity that the atoms A, B, C, etc., are Equivalent. In other words, to an observer located at any of these atomic sites, the crystal appears exactly the same.

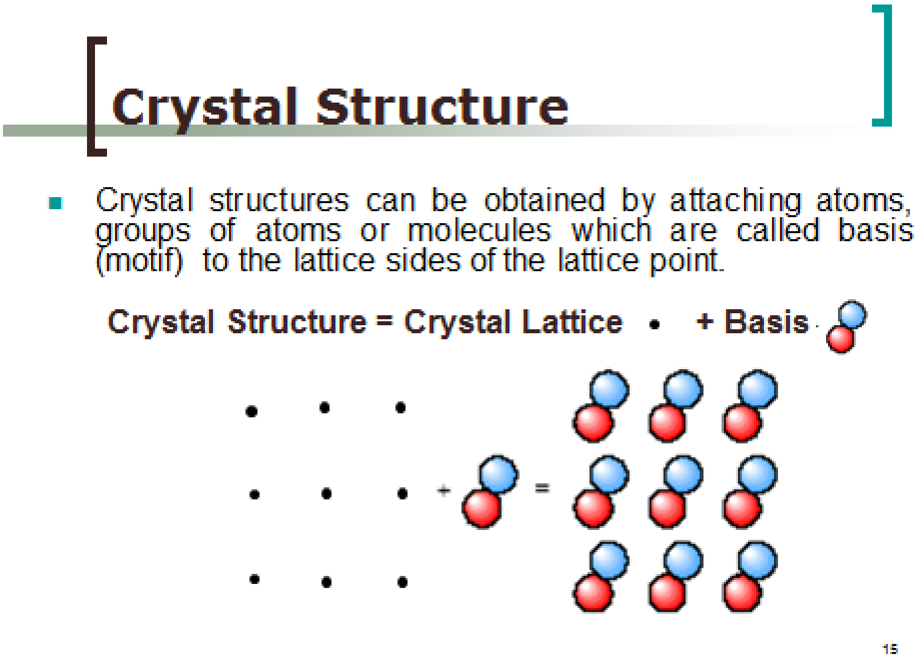


A crystalline solid. All the atoms are arranged periodically.

The same idea is often expressed by saying that a crystal possesses a translational symmetry, meaning that if the crystal is translated by any vector.

Joining two atoms, say R, the crystal appears exactly the same as it did before the translation. In other words, the crystal remains invariant under any such translation The consequences of this translational symmetry or invariance are many, and a great portion of this book will be concerned with them 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. The atoms near the surface see an environment different from the environment seen by atoms deep within the crystal, and as a result behave differently. Another example concerns the thermal vibrations of the atoms around their equilibrium positions for any temperature T > 0"K. Because of these vibrations, the crystal is always distorted, to a lesser or greater degree, depending on T. As a third example, note that an actual crystal always contains some foreign atoms, i.e., impurities Even with the best crystal-growing techniques,

In summery :



Crystal Structure

- Crystal structures 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

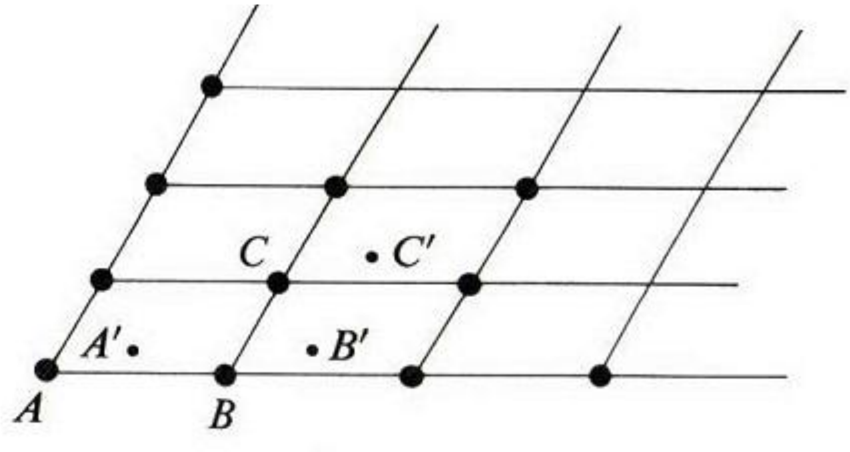
Lattice

In order to talk precisely about crystal structures, we must introduce here a few of the basic definitions which serve as a kind of crystallographic language. These definitions are such that they apply to one-, two-, or three-dimensional crystals Although most of our illustrative examples will be two-dimensional, the results will be restated later for the 3-D case

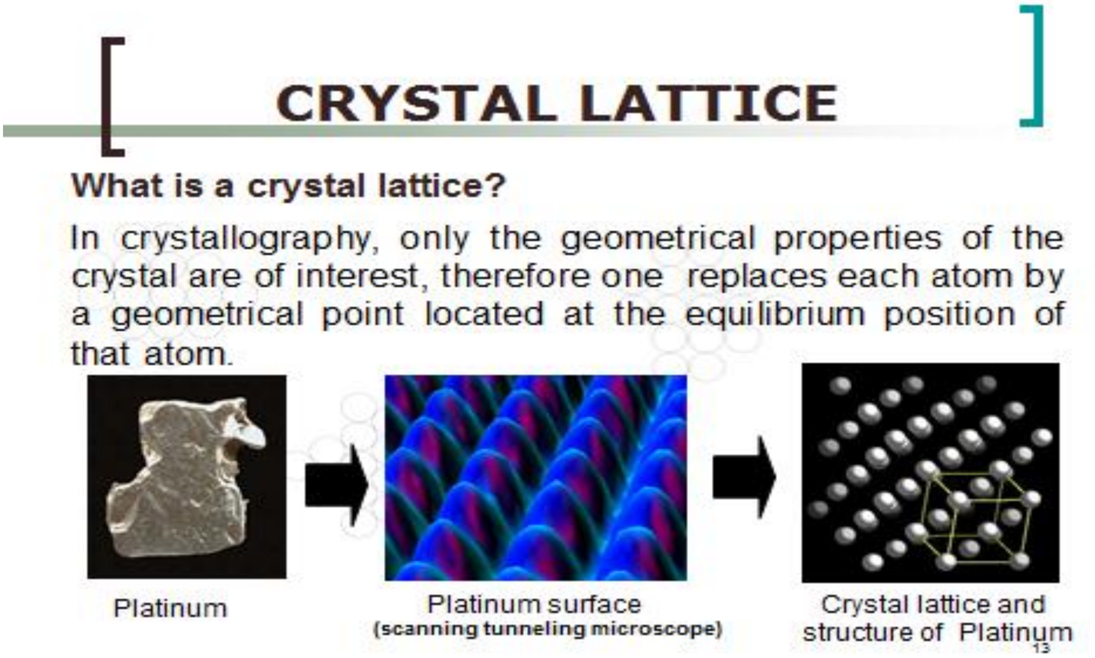
The crystal lattice In crystallography, only the geometrical properties of the crystal are of interest rather than those arising from the particular atoms constituting the crystal Therefore one replaces each atom by a geometrical point located at the equilibrium position of that atom. The result is a pattern of points having the same geometrical properties as the crystal, but which is devoi&of any physical contents. This geometrical pattern is the crystal lattice, or simply the lattice; all the atomic sites have been replaced by lattice sites

There are two classes of lattices: the Brauais and the non-Brauais. In a Bravais Iattice, all lattice points are equivalent, and hence by necessity all atoms in the crystal are of the same kind. On the other hand, in a non-Bravais lattice, some of the lattice points are nonequivalent. Figure 1.2 shows this clearly. Here the lattice sites A, B, C are equivalent to each other, and so are the sites A', B', C among themselves, but the two sites A and z4' are not equivalent to each other as can be seen by the fact that the lattice is not invariant under a translation by AA'. This is so whether the atoms A and A'are of the same kind (for example, two H atoms) or of different kinds (for example, H and Cl atoms).

A non-Bravais lattice is sometimes referred to as a lattice with a basis, the basis referring to the set of atoms stationed near each site of a Bravais lattice. Thus, in Fig. below



In summary:



CRYSTAL LATTICE

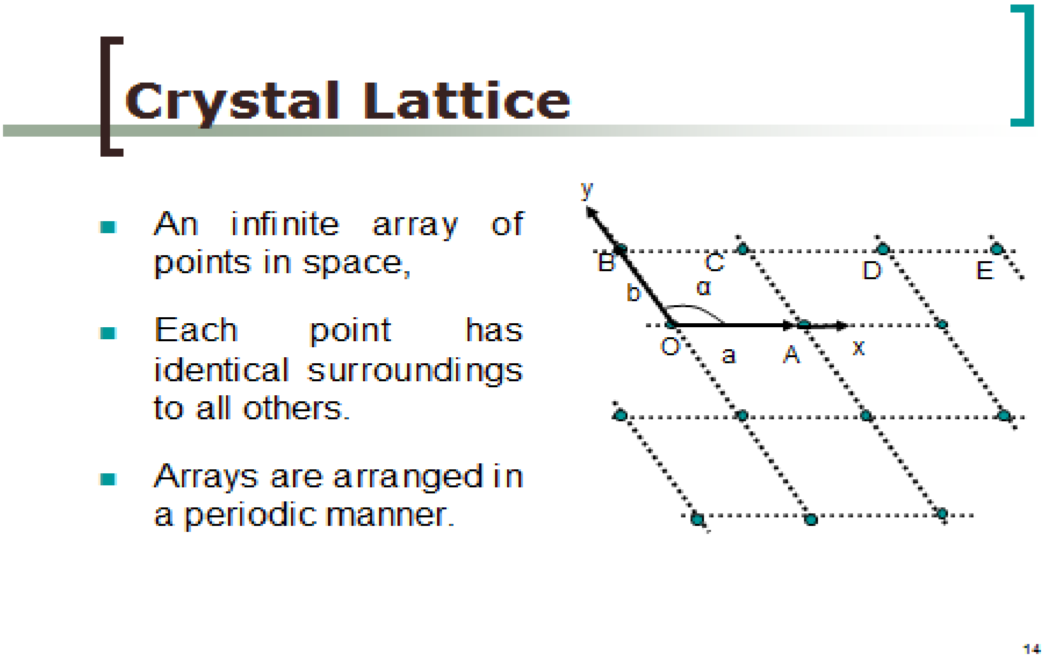
What is a crystal lattice?

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 in a periodic manner.

Basis vectors

Consider the lattice shown in figure below Let us choose the origin of coordinates at a certain lattice point, say A. Now the position vector of any lattice point can be written as

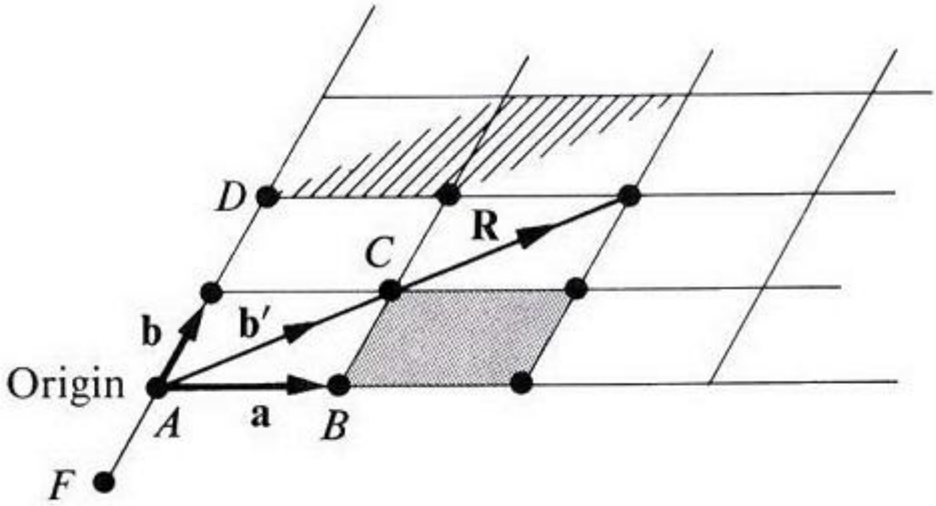
$$\mathbf{R}_n = n_1\mathbf{a} + n_2\mathbf{b}, \qquad \text{---------} \ (1)$$

where a, b are the two vectors shown, and (n1, n2) is a pair of integers whose values depend on the lattice point. Thus for the point D,(n1,n2): (0,2) for B,(n1,n2) : (1,0) and for F,(n1,n2) : (0,-l)

The two vectors a and b (which must be noncolinear) form a set of basis

vectors for the lattice, in terms of which the positions of all lattice points can be

conveniently expressed by the use of The set of all vectors expressed by eq 1



Unit cell

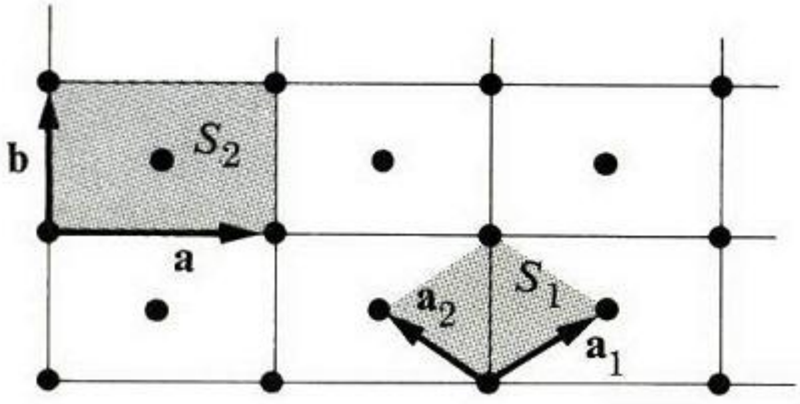
The area of the parallelogram whose sides are the basis vectors a and b is called a unit cell of the lattice (previous figure), in that, if such a cell is translated by all the lattice vectors of (1.1), the area of the whole lattice is covered once and only once. The unit cell is usually the smallest, area which produces this coverage Therefore the lattice may be viewed as composed of a large number of equivalent unit cells placed side by side, like a mosaic pattern The choice of a unit cell for one and the same lattice is not unique, for the same reason that the choice of basis vectors is not unique. The following remarks may be helpful:

i) All unit cells have the same area. Thus the cell formed by **a**, **b** has the area $S = |\mathbf{a} \times \mathbf{b}|$, while that formed by **a**, **b**′ has the area $S' = |\mathbf{a} \times \mathbf{b}'| = |\mathbf{a} \times (\mathbf{a} + \mathbf{b})| = |\mathbf{a} \times \mathbf{b}| = S$, where we used the result $\mathbf{a} \times \mathbf{a} = 0$. Therefore the area of the unit cell is unique, even though the particular shape is not.

ii) If you are interested in how many lattice points belong to a unit cell, refer to Fig. 1.3. The unit cell formed by $\mathbf{a} \times \mathbf{b}$ has four points at its corners, but each of these points is shared by four adjacent cells. Hence each unit cell has only one lattice point.

The unit cell discussed above is called a primitiue cell. It is sometimes more convenient, however, to deal with a unit cell which is larger, and which exhibits the symmetry of the lattice more clearly. The idea is illustrated by the Bravais lattice in Figure below Clearly, the vectors at, az can be chosen as a basis set, in which case the unit cell is the parallelogram S,. However, the lattice may also be regarded as a set of adjacent rectangles, where we take the vectors a and b as basis vectors.

The unit cell is then the area S, formed by these vectors. It has one lattice point at its center, in addition to the points at the corner. This cell is anon primitive unit cell**.**



Area S_1 is a primitive unit cell; area S_2 is a nonprimitive unit cell.

Three dimensions

All the previous statements can be extended to three dimensions in a straight forward manner. when we do so, the lattice vectors become three-dimensional, and are expressed by

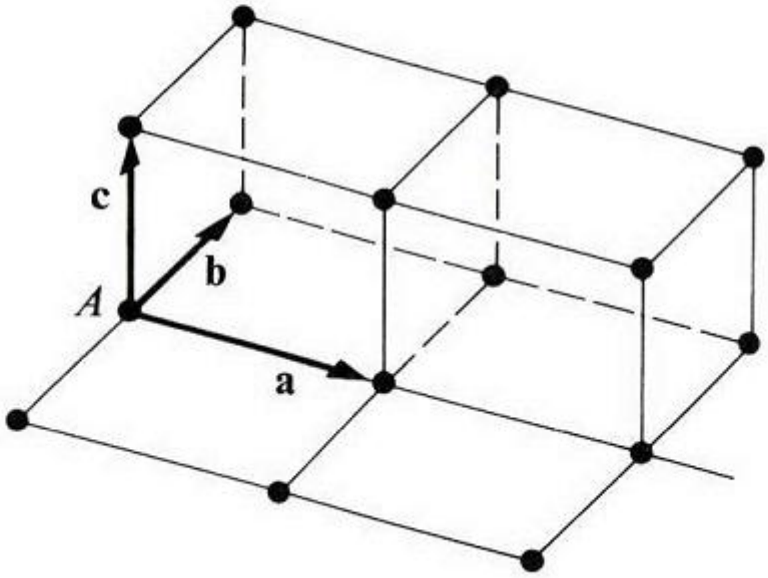
$$\mathbf{R}_n = n_1\mathbf{a} + n_2\mathbf{b} + n_3\mathbf{c} \text{---------(2)}$$

where a, b, and c are three non coplanar vectors joining

the lattice point at the origin to its near neighbors (below and n1, n2, n3 are a triplet of integers 0, 1, 2, etc., whose values depend on the particular lattice point.

The vector triplet a, b, and c.is the basis vector, and the parallepiped whose sides are these vectors is a unit cell.

although all primitive cells have equal volumes. Also, it is sometimes convenient to deal with nonprimitive cells, ones which have additional points either inside the cell or on its surface. Finally, non-Bravais lattices in three dimensions are possible, and are made up of two or more interpenetrating Bravais lattices.



A three-dimensional lattice. Vectors **a**, **b**, **c** are basis vectors.

Q/ How to distinguish between crystalline and and amorphous materials

crystalline	amorphous
X-ray (linear spectrum with peaks	X-ray (continuous spectrum no peaks
It has certain melting point	It take range of heat to melt down
Its show special optical properties such as photoluminses	No special optical properties