PHYSICS 565 – Solid State Physics
SPRING 2012 (TR 9.30-10.30 AM @ Neckers 410)

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Text Book: *Solid State Physics – ASHCROFT/MERMIN*

Other References: Introduction to Solid State Physics C. Kittel
Condensed Matter Physics M. P. Marder
Elementary Solid State Physics M. A. Omar
Electronic Structure Richard Martin

Solid State Physics:

Study of the properties of materials in an atomistic view

Grading: Homework & Quizzes --- 20%

Exam 1 --- 20 %

Exam 2 --- 20 %

Final Exam --- 20%

Term Paper (Written and Oral Presentations) --- 20%

Total = 100%

Grade Policy:

A	**85% -100%**
B	75 % - 84 %
C	60 % - 74 %
D	50 % - 59.9 %
F	**Less Than 50%**

Properties of Materials

The macroscopic properties of materials are a result of the microscopic structure

Sometimes materials can be found in crystalline order. Why materials stay in a crystalline order? That is a hard question to answer. Why the lowest energy is crystalline? It may be due to the fact that each atoms would like to come to the same environment. So the environment is repeating to make a crystalline state.

Also it depends on the way the material is made.

Equilibrium structure can be a function of temperature and pressure. Some materials change to several crystalline structures before it melts.

Some materials have few types of crystalline states at a given temperature and pressure (Allotropes)

In Nature however, materials occur in
crystals with defects/ impurities.

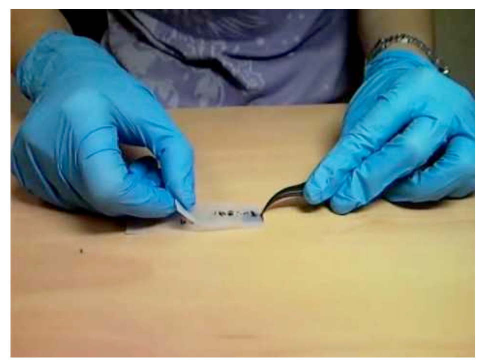
If we learn the properties of a perfect crystals, it would be then possible to learn the properties of the same materials with defects/impurities treated as perturbations

Properties of Materials

Graphite

Diamond

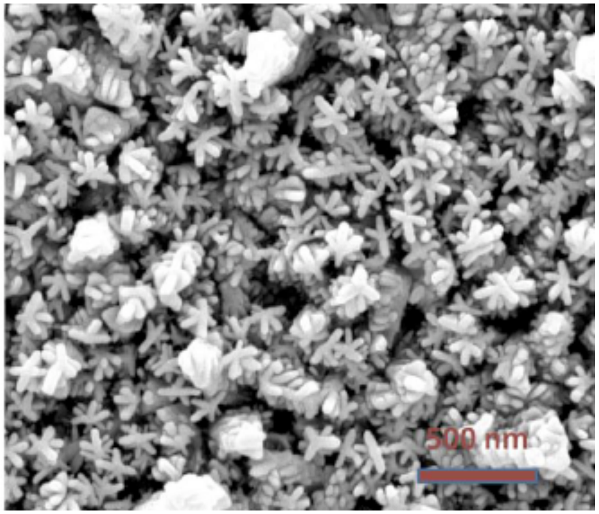
Coal

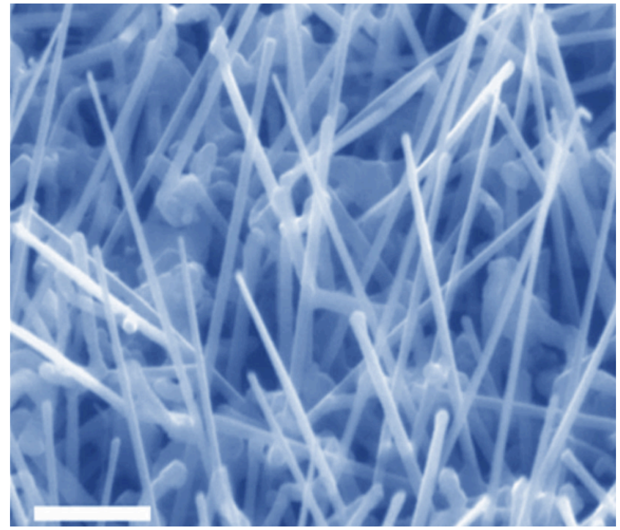


Graphene

Same Material: Here it is Carbon.
Different Atomic arrangements. Drastically different properties

Properties of Materials





Some times, the materials come in different arrangements in the nature,
Some times we make them in different arrangements,

Either way, we need to understand their properties, How do they conduct current, how much they get heated as you pass current, How strong they are? What is their reaction to light etc etc….

Mainly, How can we use these creatures to improve our lives

The goal of the class is thus set to:

Study the Macroscopic properties of materials from atomistic point of view.

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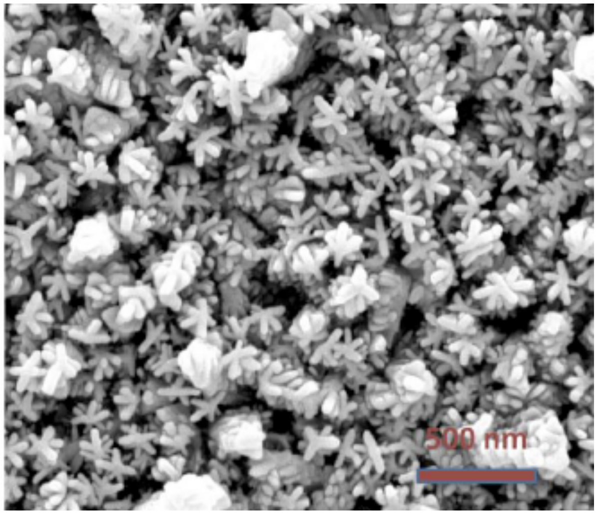
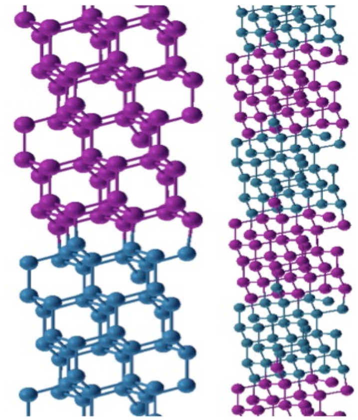
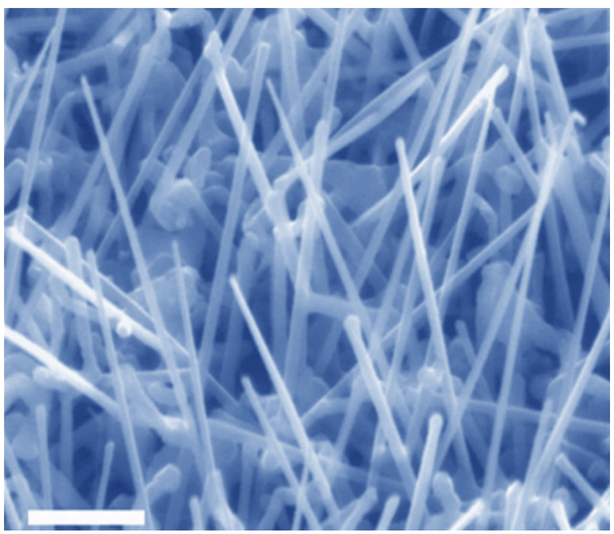
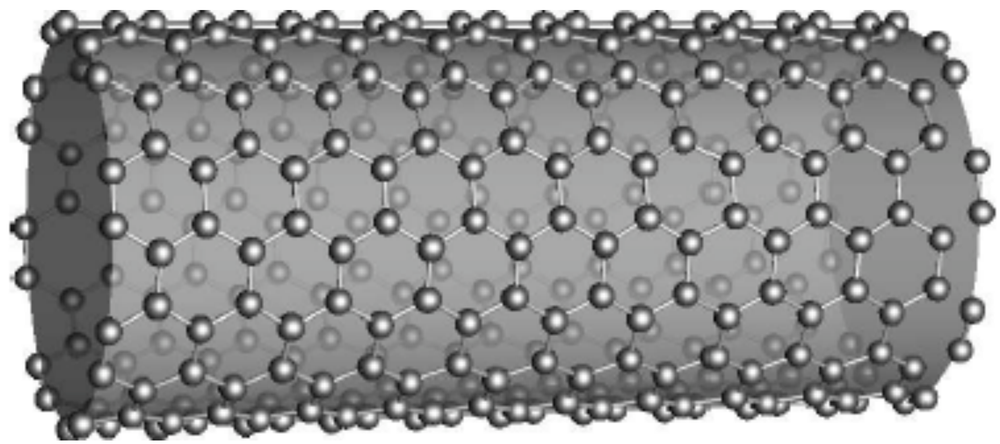








Course Content

ATOMIC STRUCTURE:

The ideal of crystals
Introduction to crystals -2-D crystal structures and their symmetries
Three Dimensional Crystal Structures
Experimental Determination of Crystal Structures – Introduction to Reciprocal Lattice
Surfaces and Interfaces
Complex Structures (Alloys, Glasses, Polymers etc)

ELECTRONIC STRUCTURE:

The single electron model
The Schrodinger Equation and Symmetry – Bloch's Theorem
Nearly Free Electrons and Tight Binding Model
Electron-Electron Interactions : Introduction to Advanced Methods for Electronic Structure Calculations
Calculation of Electron Band Structures - Metals, Semiconductors and Insulators

MECHANICAL PROPOERTIES:

Introduction to Lattice Vibrations and their Applications

SPECIAL TOPICS:

Quantum Confined Structures (Semiconductors, Graphene etc)
Electron Transport Properties
Optical Properties
Magnetism

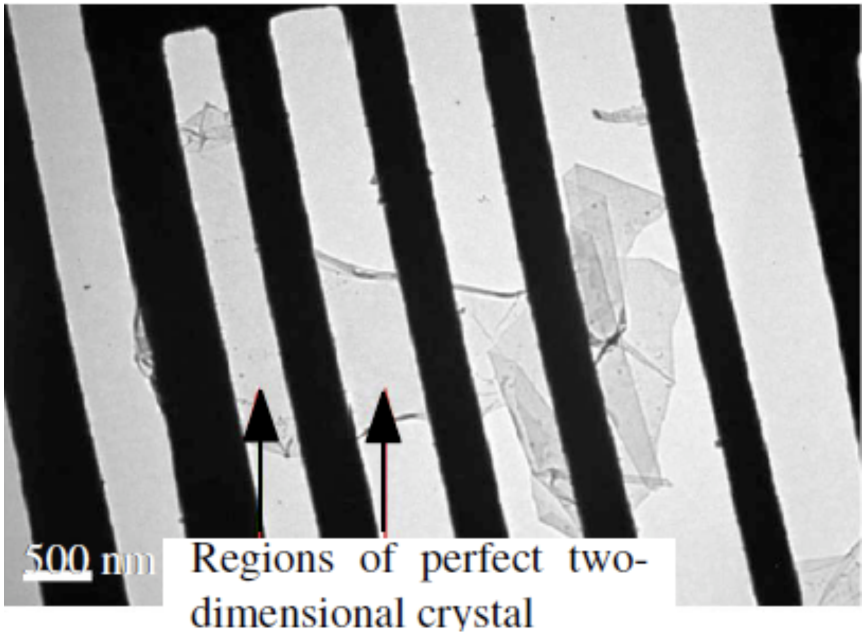
We need to understand the terminology:

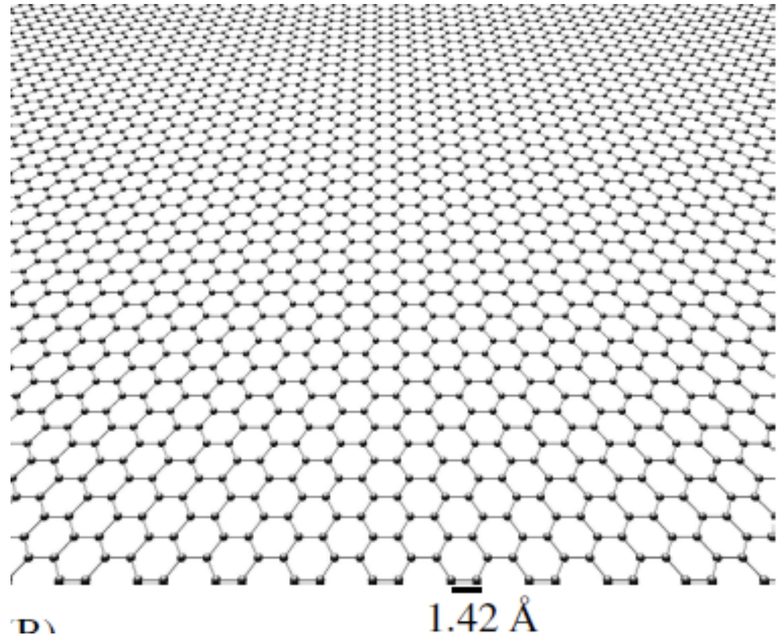
CRYSTAL: A solid is a crystal if the atoms are arranged in such a way that their positions are exactly periodic. (Long Range Ordered Materials)

Bravais Lattices: A collection of points in which the neighborhood of each atom is identical to each other.

Let's start with a two dimensional crystals to refresh what we know about the lattices.

Two-Dimensional Lattices



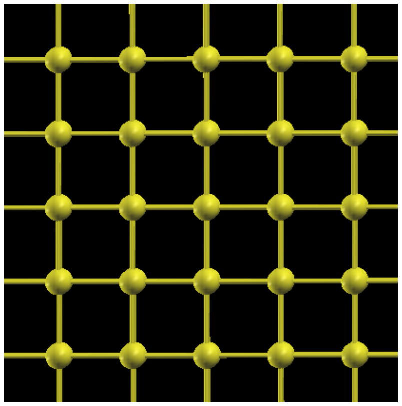


There are five Bravais Lattices in 2D.

There are five Bravais Lattices in 2D.

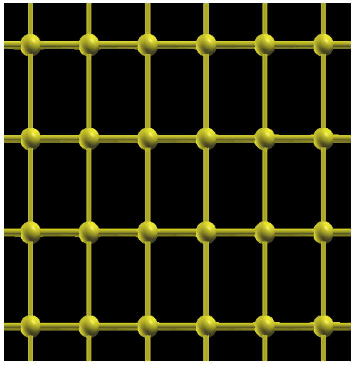
- Square Lattice
- Rectangular Lattice
- Hexagonal Lattice
- Centered Lattice
- Oblique Lattice

Square Lattice



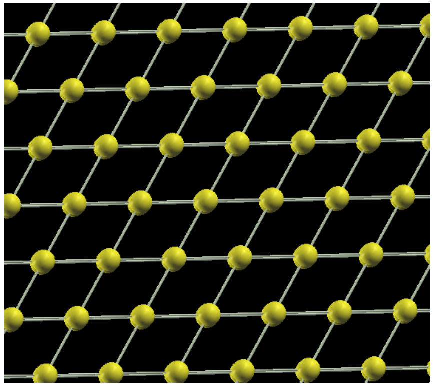
Symmetric under reflection about both x and y
90 degree Rotational symmetry

Rectangular Lattice

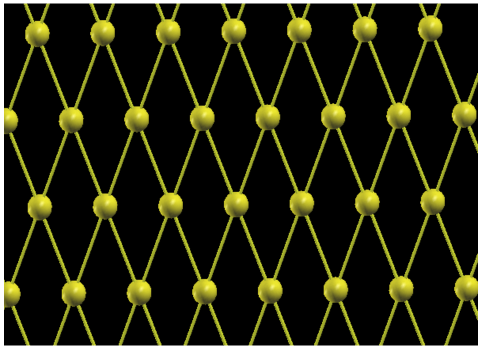


Symmetric under reflection about both x and y
90 degree Rotational symmetry is lost

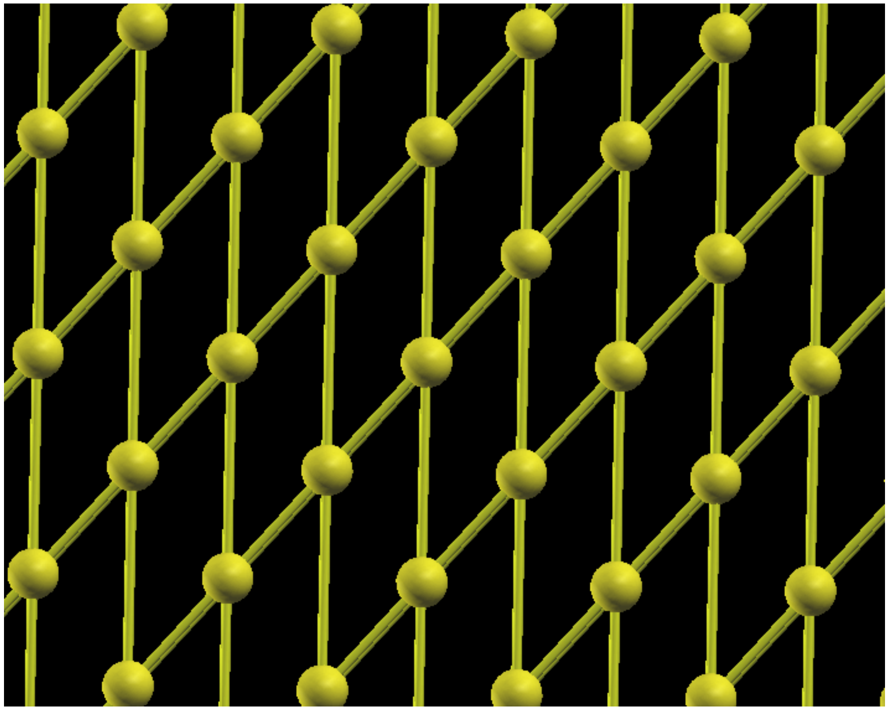
Hexagonal Lattice



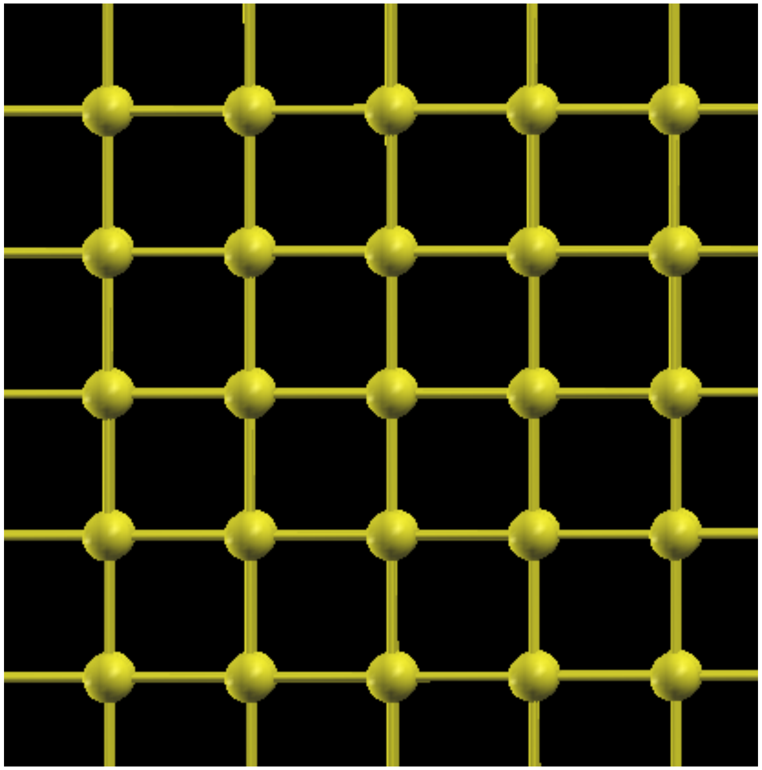
Centered Rectangular Lattice



Oblique Lattice



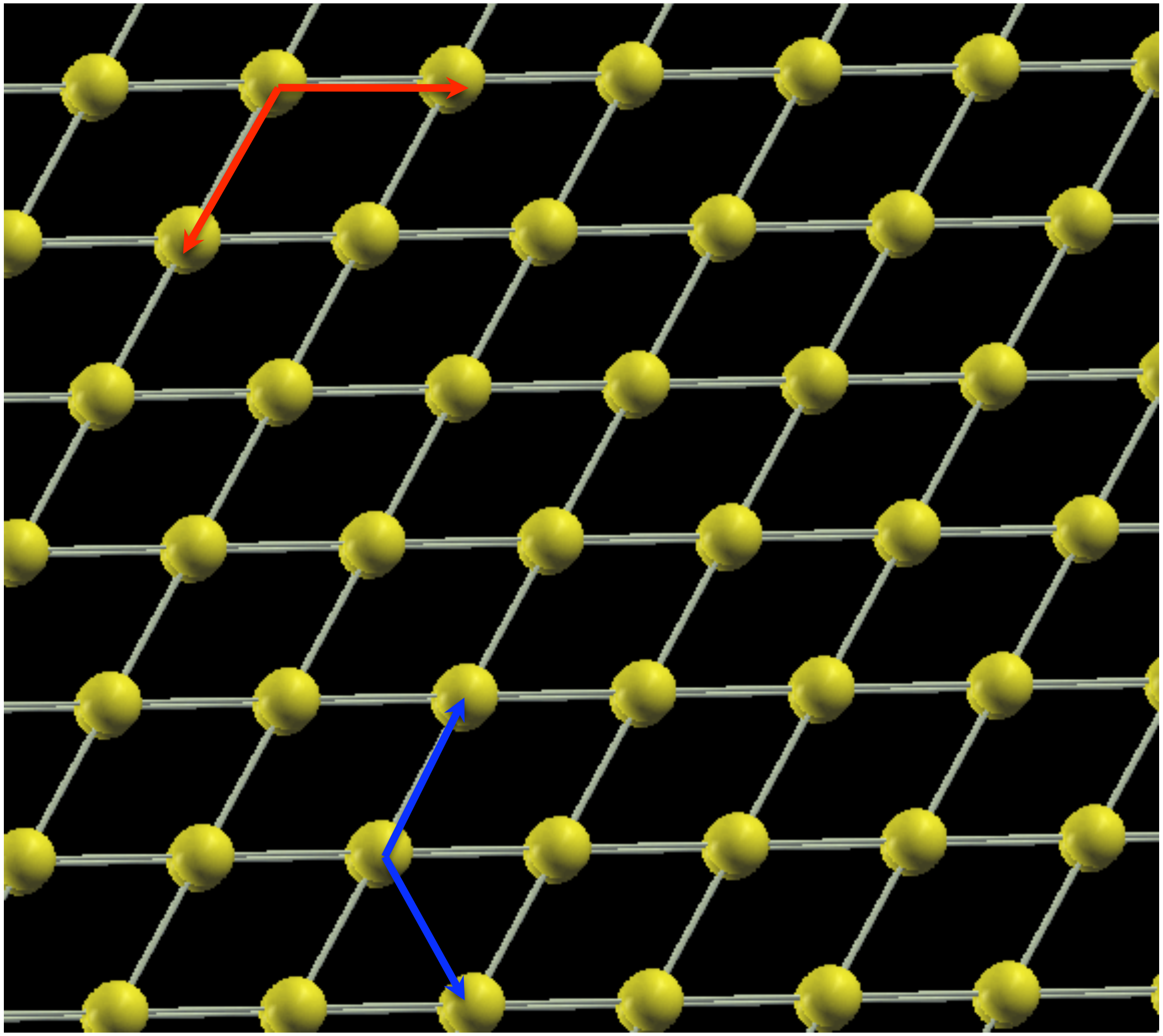
Square Lattice



The location of every point can be described as: $R = n1\ \mathbf{a1} + n2\ \mathbf{a2}$

a1 & **a2** are primitive vectors

Primitive Vectors are not unique



a1 = (1 ,0)
a2 = (1/2 ,√3/ 2)

a1 = (1/2 , √3/ 2)
a2 = (-1/2 ,√3/ 2)

Both vectors are OK. The vectors need to be independent.

Lattice with Bases

Let's remind that:

The neighborhood of all particles must be identical in order for a lattice to be qualiioed for a Bravais Lattice.

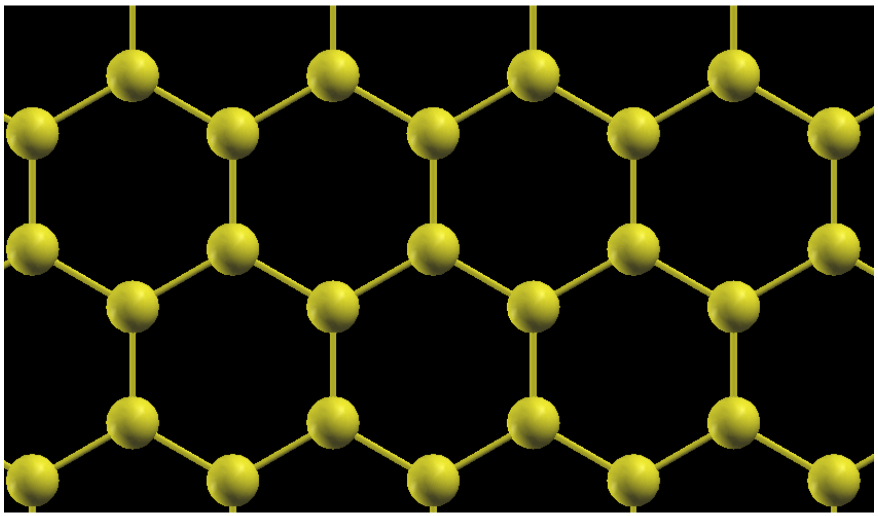
Most Lattices in nature are not however Bravais Lattices. Some times these are called non-Bravais lattices.

Those non-Bravais lattices can be described by a Bravais lattice with a basis.

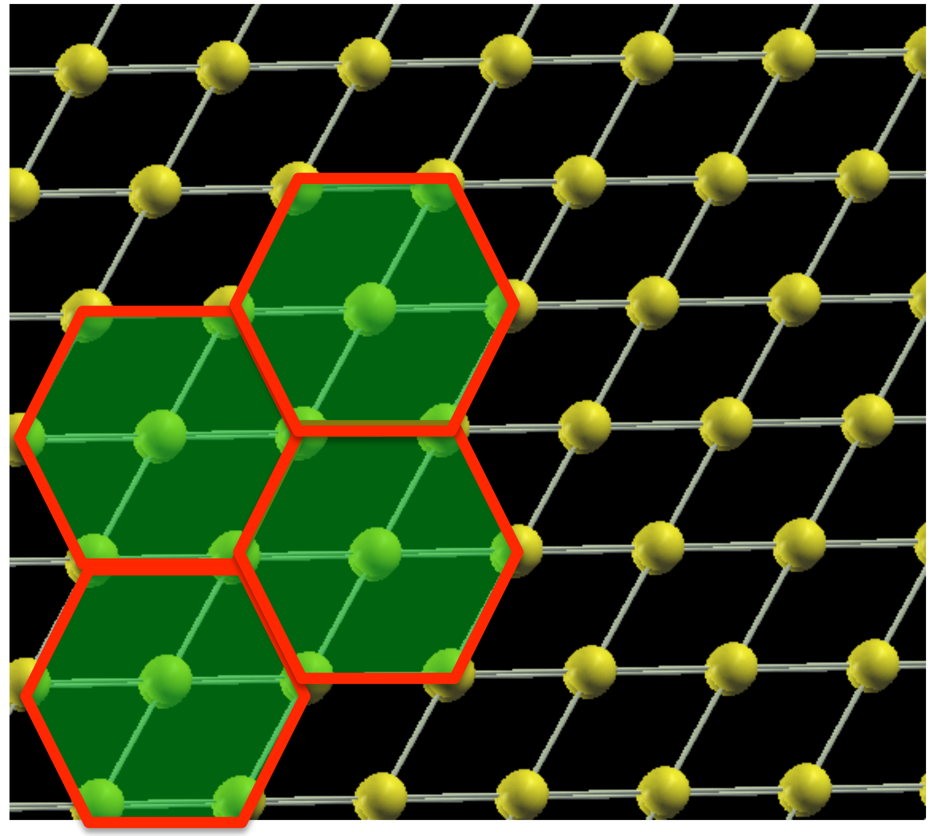
Lattice with a Basis --- We begin with a Bravais lattice. Each lattice point is replaced by a collection of an identical assembly of particles.

Example : Honeycomb Lattice

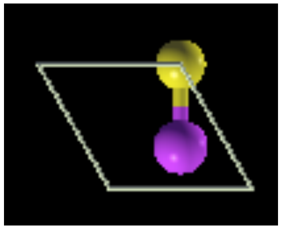
Honeycomb Lattice

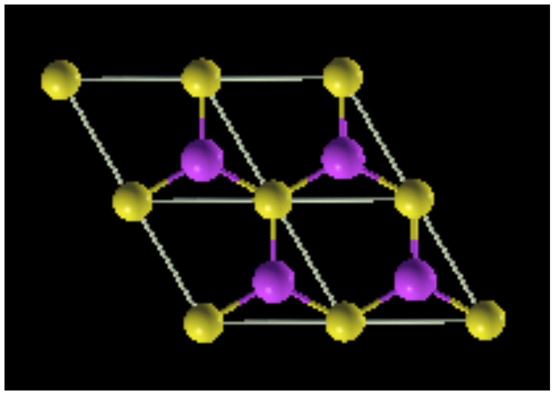


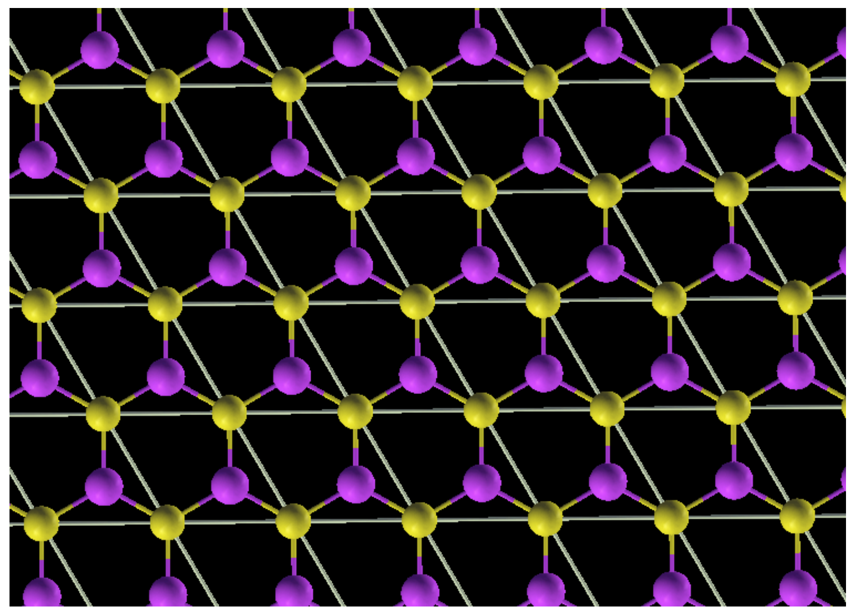
Hexagonal Lattice



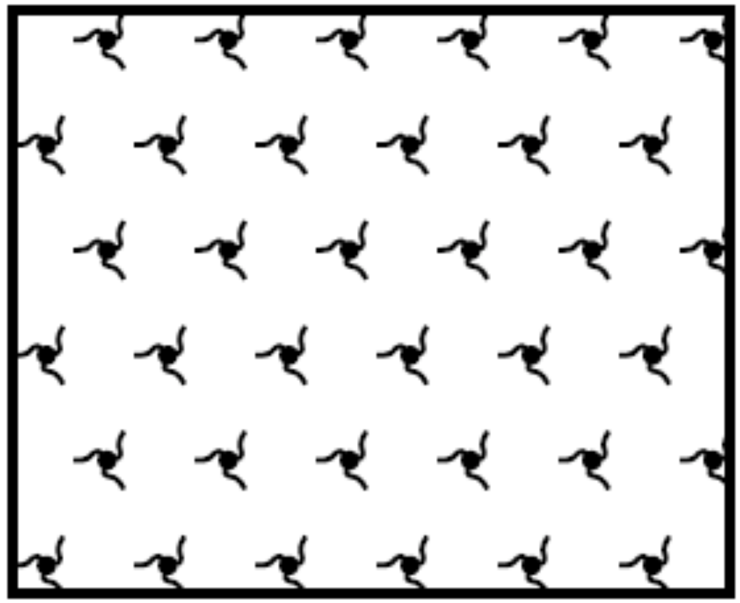
Honeycomb Lattice – Hexagonal Lattice with a Lattice 2-atomic Basis







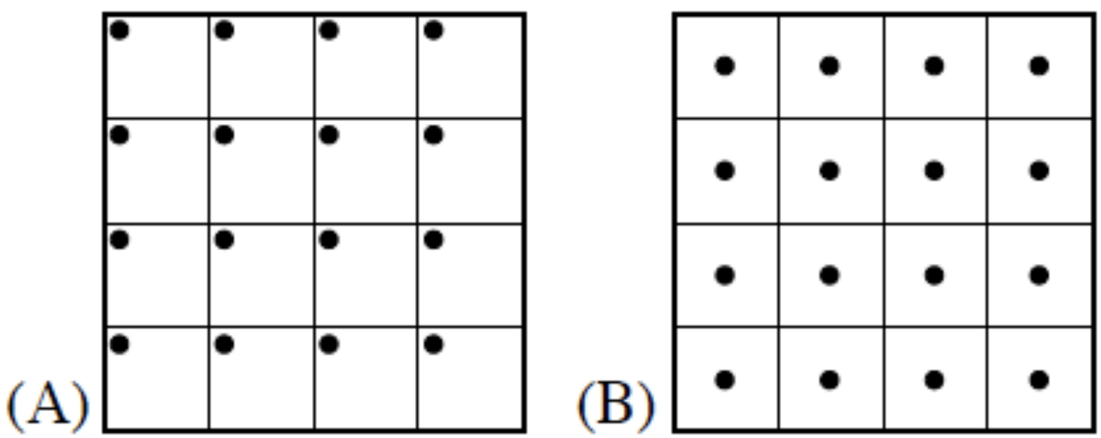
Another Lattice with a basis



A hexagonal lattice decorated with chiral molecules

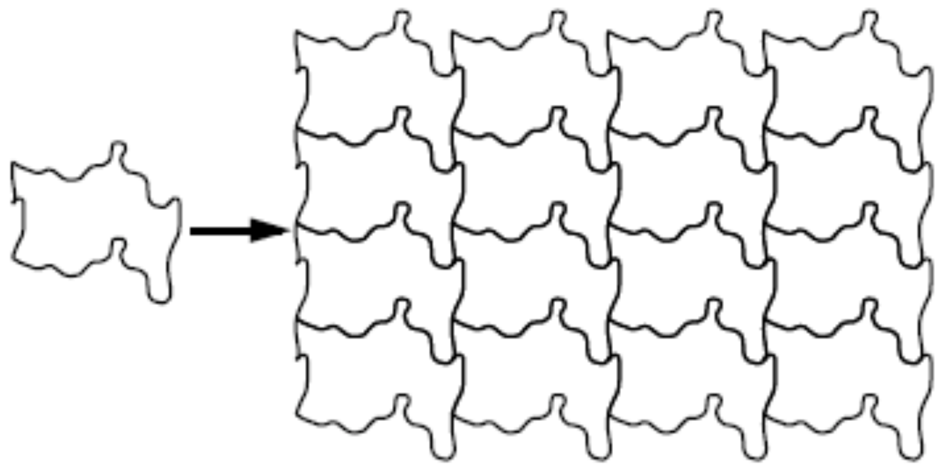
Primitive Cell:

The smallest unit which represents the whole lattice. It contains only one lattice point.
It is the minimum volume cell. But it is not unique. It is defined by primitive translation vectors.



Two primitive cells for the square lattice. One cell has a lattice point at the corer, while the other has a lattice point at the center.

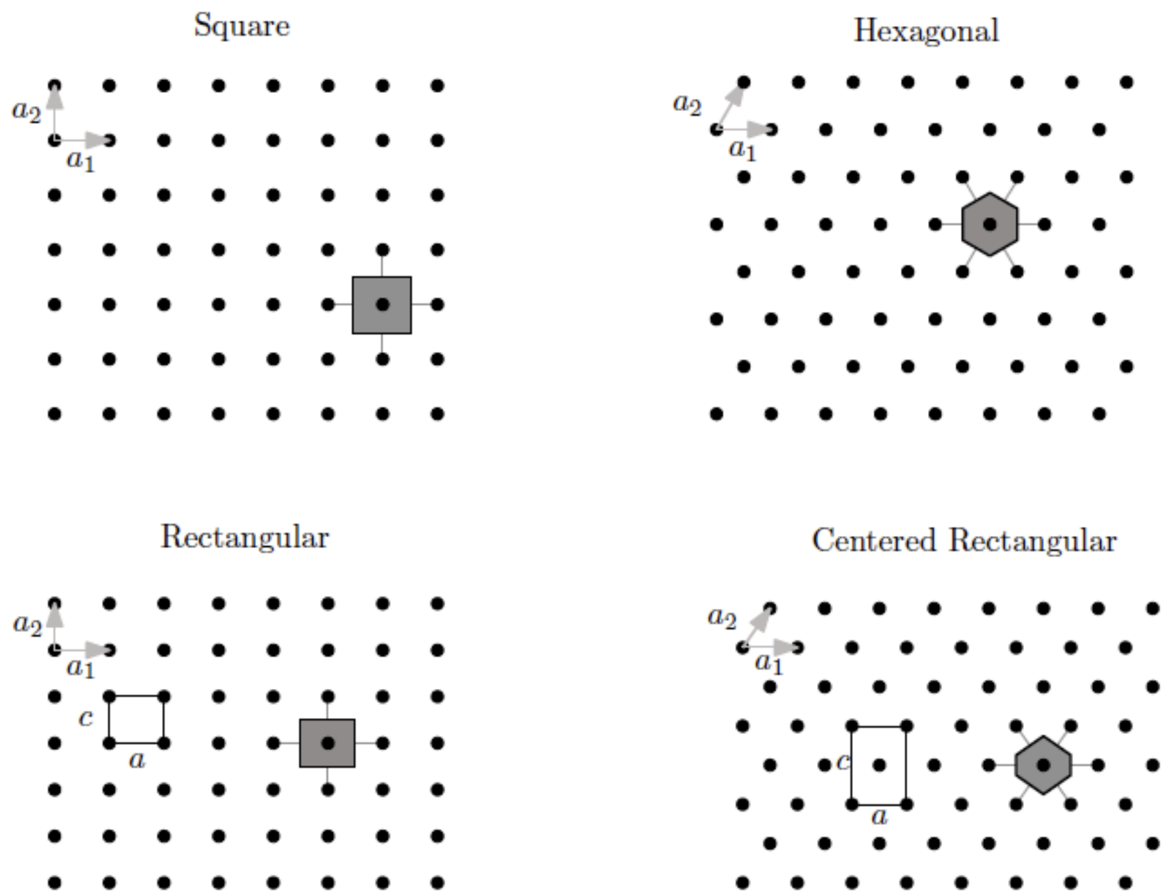
The shape can be any complicated way: as long as it contains only one lattice point.



Wigner-Seitz Unit Cell

It is convenient to have a standard way of constructing the primitive cell
It is important to have a primitive cell which is invariant under all symmetry operations that leave the crystal invariant.

Such a construction is provided by the WIGNER – SEITZ unit cell.



Symmetries

Symmetries of crystals are important:

What we observe in the experiments are related to the symmetries in the crystals
In Theory: Solutions to the Schrodinger equation for electron in a periodic crystal is only possible when we can use the symmetries in the crystals

What is the symmetry?

Imagine you pick the lattice up, move it/ rotate it rigidly, place it back down. Will the lattice be overlap at their original positions.

Problem is to find a complete set of such motions that the crystal in to itself. That complete set is called a space group.

It is a group because it consists of a set of operations with a natural product (performs a first rigid body motion, then another, the resultant is still a rigid body motion.)

We will talk more about symmetries in Three-Dimensional Crystal Structures.