VE320 – Summer 2022

Introduction to Semiconductor Devices

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Chapter 1 Crystalline structure of solids

Outline

1.1 Semiconductor materials

1.2 Type of Solids

1.3 Space lattices

1.4 The diamond structure

1.5 Atomic bonding

1.6 Imperfections and impurities in solids

Outline

1.1 Semiconductor materials

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1.1 Semiconductor materials

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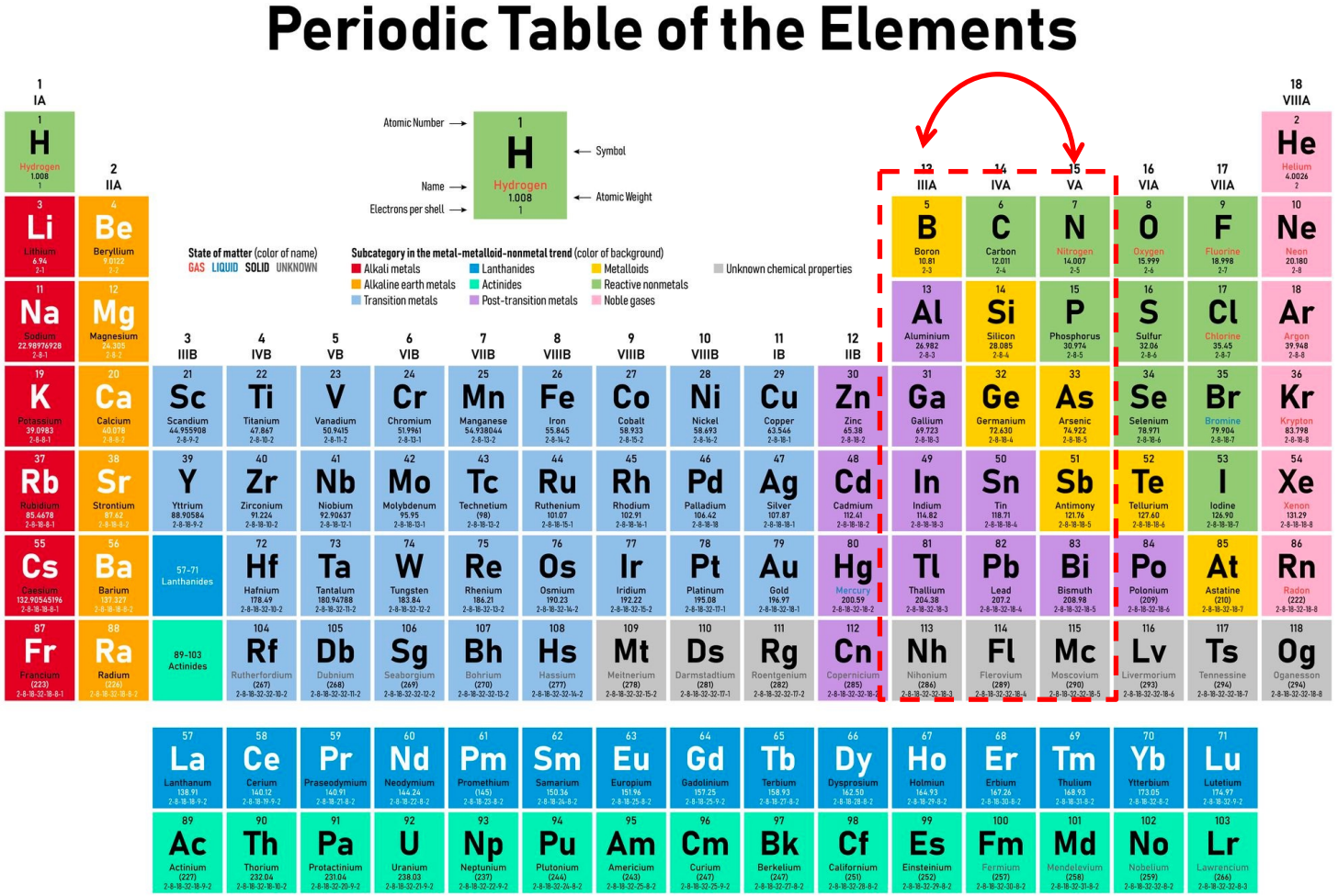
Resistivity:

Conductors	Semiconductors	Insulators
$< 10^{-3}$ Ω•cm	$10^{-3} – 10^{9}$ Ω•cm	$> 10^{9}$ Ω•cm
Metals (Au, Al, Cu, Hg…)	Si, Ge, GaAs, InP…	SiO_2, HfO_2 …
Solids, liquids (Hg)	Solids	Solids, liquids gases

1.1 Semiconductor materials



1.1 Semiconductor materials

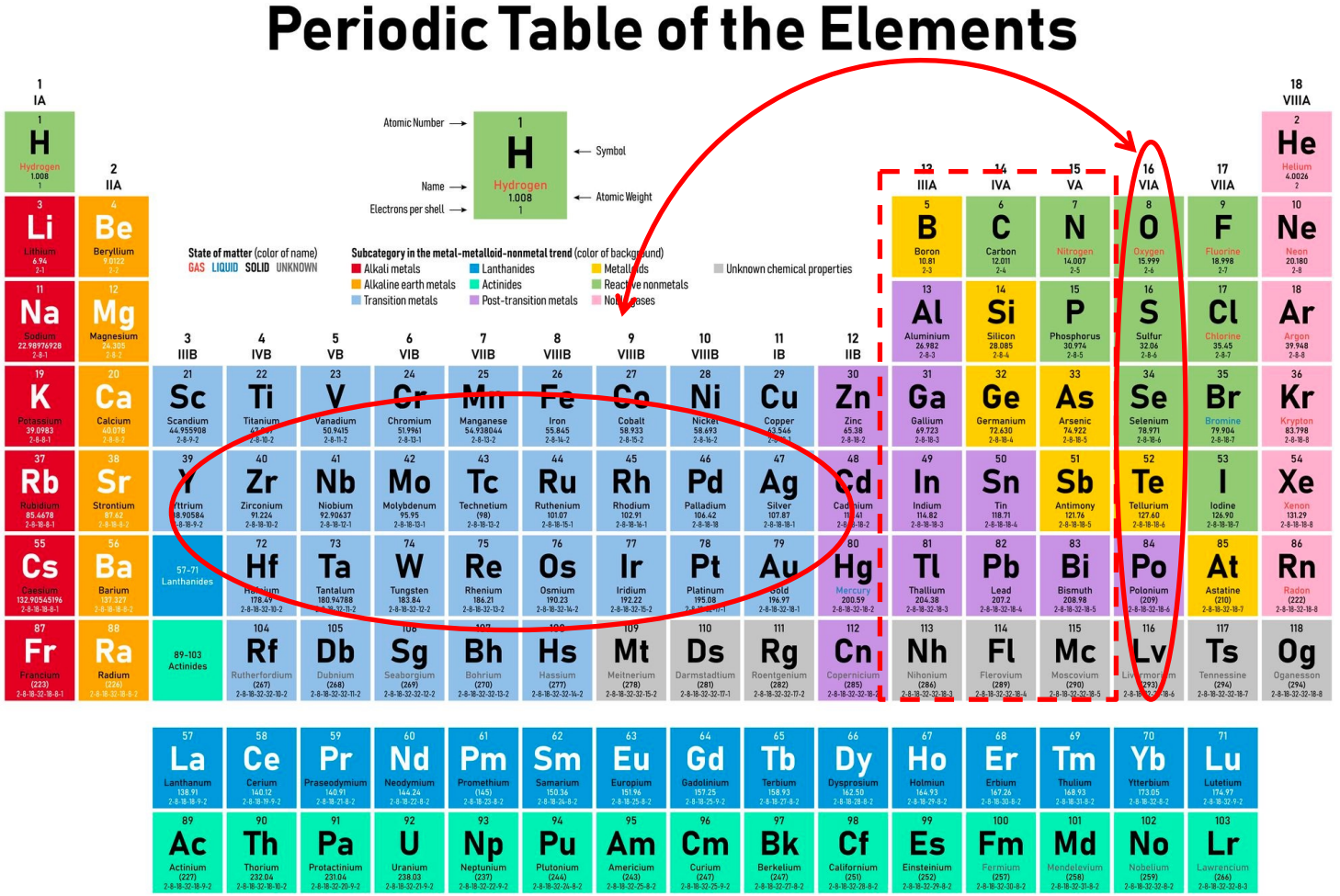
Table 1.1 | A portion of the periodic table

III	IV	V
5 **B** Boron	6 **C** Carbon	
13 **Al** Aluminum	14 **Si** Silicon	15 **P** Phosphorus
31 **Ga** Gallium	32 **Ge** Germanium	33 **As** Arsenic
49 **In** Indium		51 **Sb** Antimony

Table 1.2 | A list of some semiconductor materials

Elemental semiconductors	
Si	Silicon
Ge	Germanium
Compound semiconductors	
AlP	Aluminum phosphide
AlAs	Aluminum arsenide
GaP	Gallium phosphide
GaAs	Gallium arsenide
InP	Indium phosphide

1.1 Semiconductor materials



1.1 Semiconductor materials

Conductivity of semiconductors:

- ❑ Tunable by static electric field
  - MOSFET: metal oxide semiconductor field effect transistors
- ❑ Susceptible to impurities
  - Intrinsic silicon: 214000 Ω•cm at 300K
  - Doped with phosphorus (1ppm): 0.2 Ω•cm at 300K
- ❑ Sensitive to light illumination

1.1 Semiconductor materials

Semiconductors are the materials that have resistivities between 10^{-3} – 10^{9} Ω•cm depending on light illumination, temperature, electric field, magnetic field and impurities.

Outline

1.1 Semiconductor materials

1.2 Type of Solids

1.3 Space lattices

1.4 The diamond structure

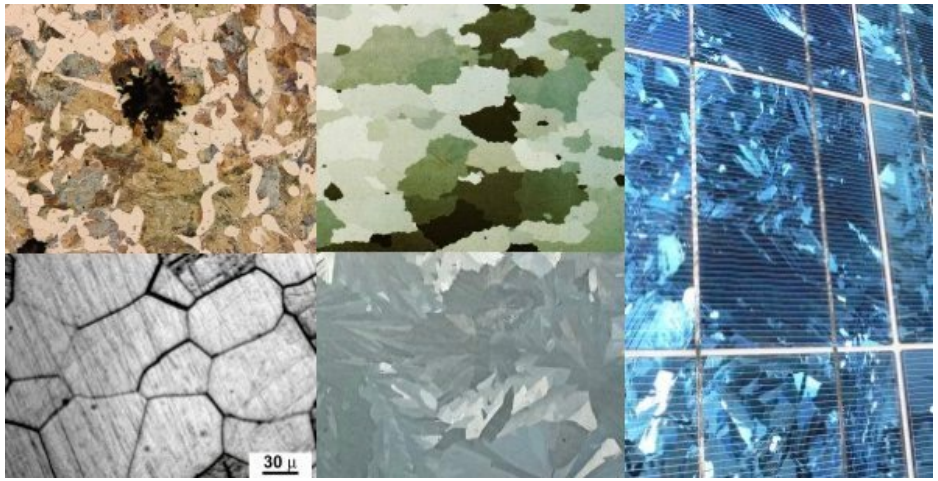
1.5 Atomic bonding

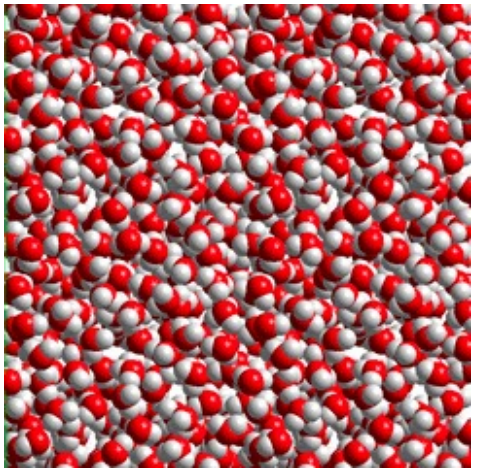
1.6 Imperfections and impurities in solids

1.2 Type of Solids

Solids:

- Single crystals
- Polycrystals
- Amorphous

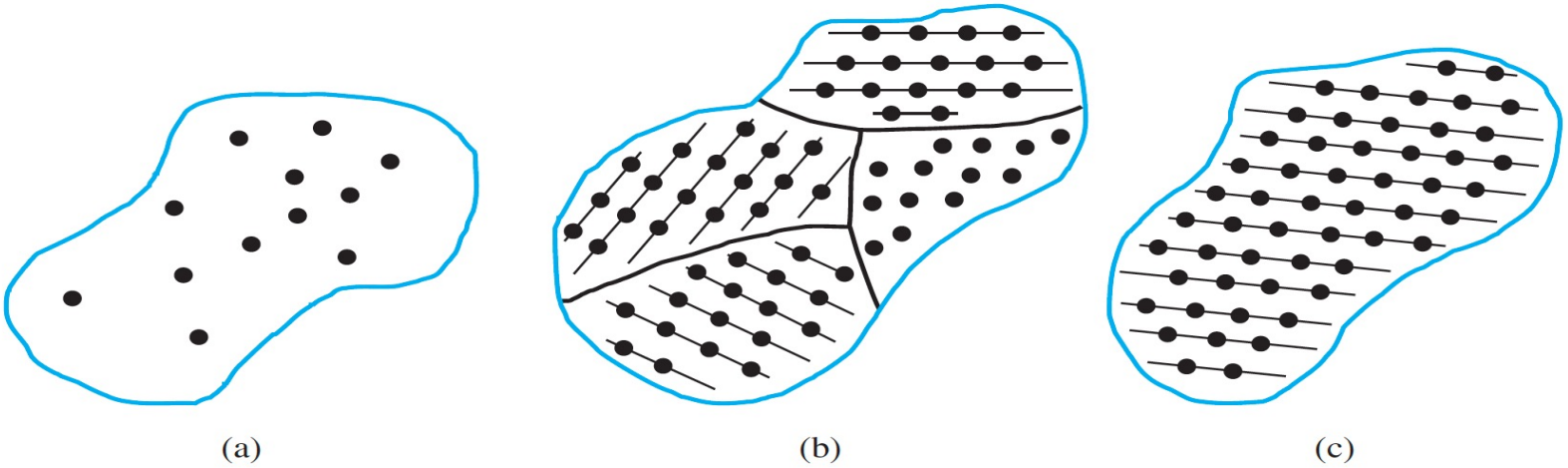




1.2 Type of Solids

Solids :

- Amorphous
- Polycrystals
- Single crystals



(a) (b) (c)

All atoms or ions are periodically ranged in a short range (a few atoms)

Multiple crystalline grains randomly packed

All atoms or ions are periodically ranged in a long range (μm scale)

1.2 Type of Solids

Characteristics of Crystals

- Specific shape and fixed melting point
- Atoms or ions periodically arranged in a relatively large scale (μm)

All semiconductors covered in this course are assumed to be single crystalline.

Outline

1.1 Semiconductor materials

1.2 Type of Solids

1.3 Space lattices

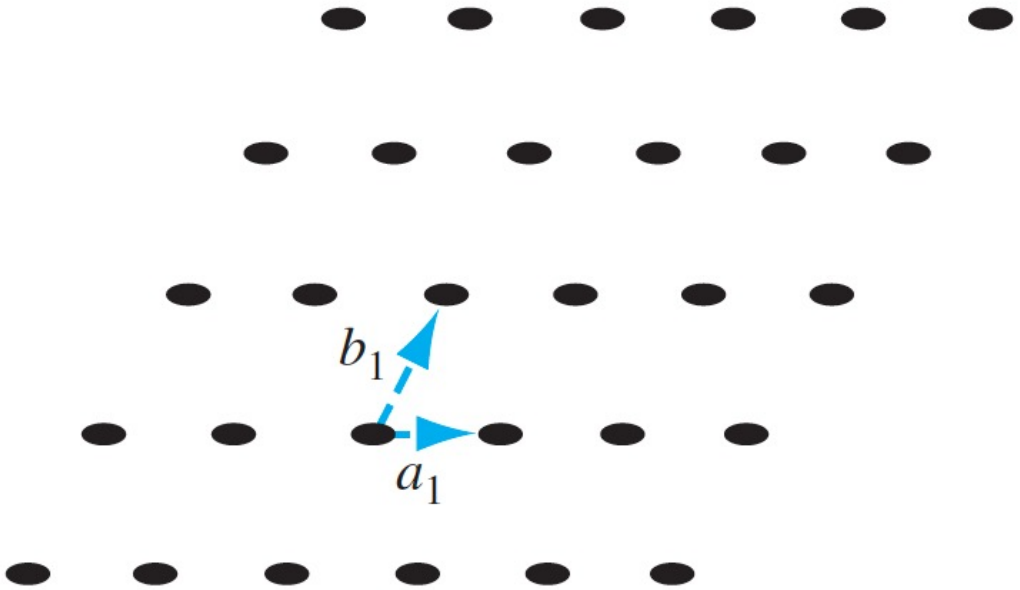
1.4 The diamond structure

1.5 Atomic bonding

1.6 Imperfections and impurities in solids

1.3 Space lattice

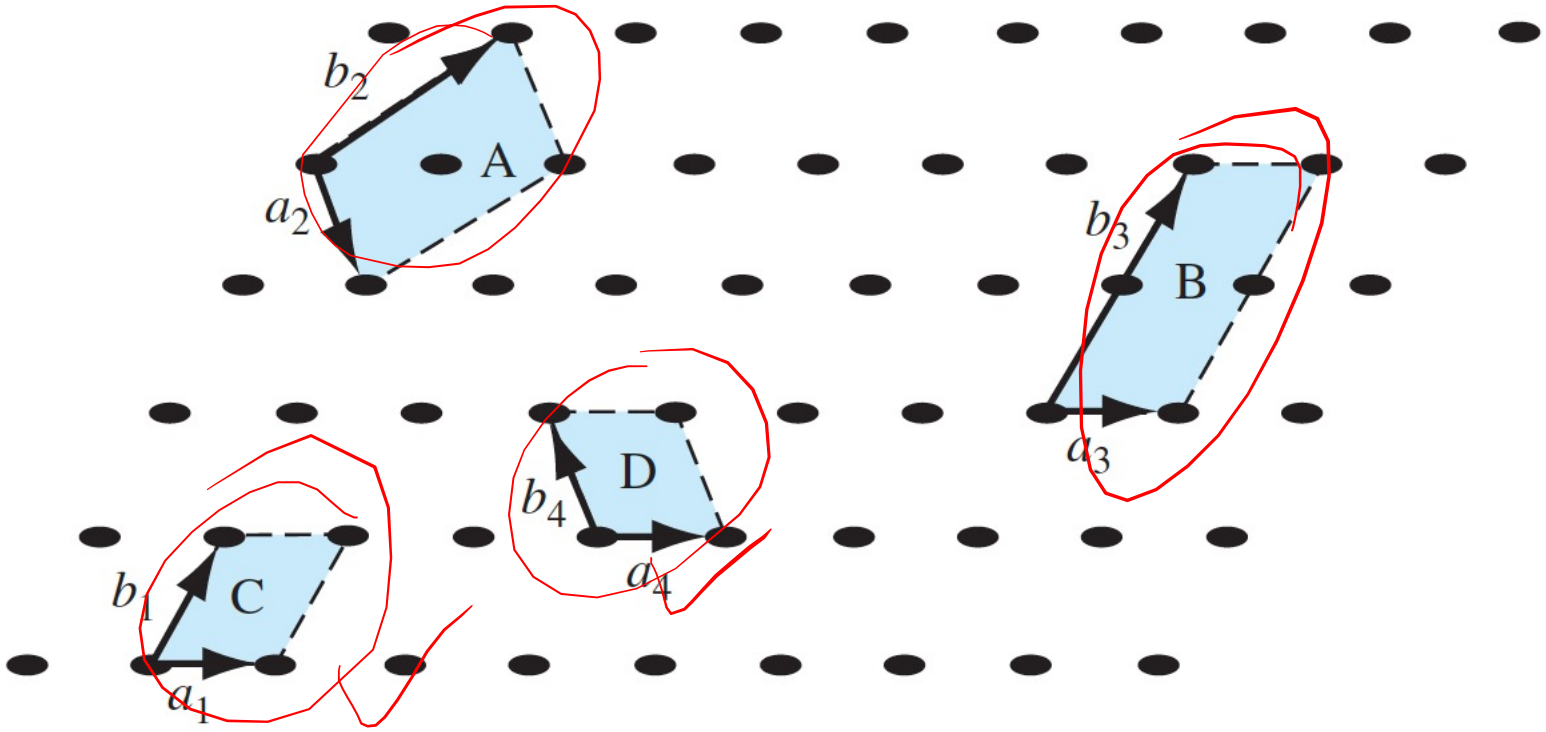
Primitive and Unit Cell



Unit cell: any small volume of crystal to reproduce the entire crystal.
Primitive cell: smallest unit cell

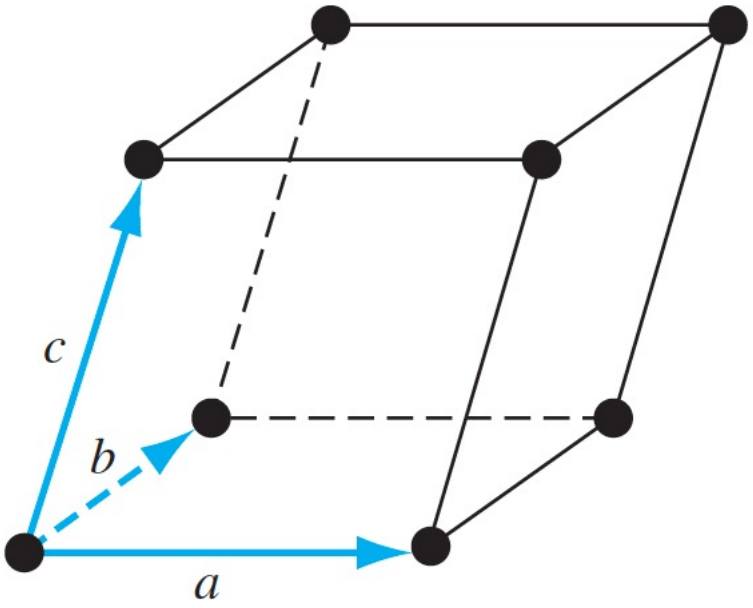
1.3 Space lattice

Primitive and Unit Cell



1.3 Space lattice

Primitive and Unit Cell



$$\bar{r} = p\bar{a} + q\bar{b} + s\bar{c}$$

A generalized primitive unit cell

1.3 Space lattice

Basic Crystal Structures

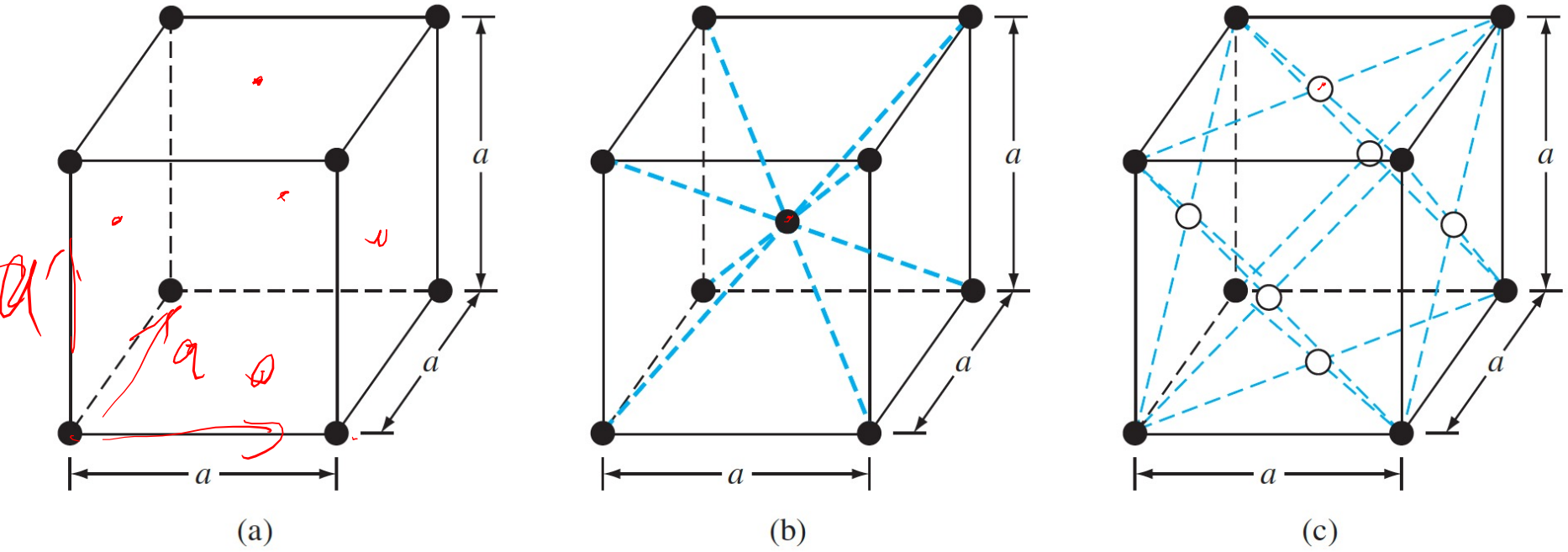


Figure 1.5 | Three lattice types: (a) simple cubic, (b) body-centered cubic, (c) face-centered cubic.

1.3 Space lattice

Basic Crystal Structures: volume density of atoms

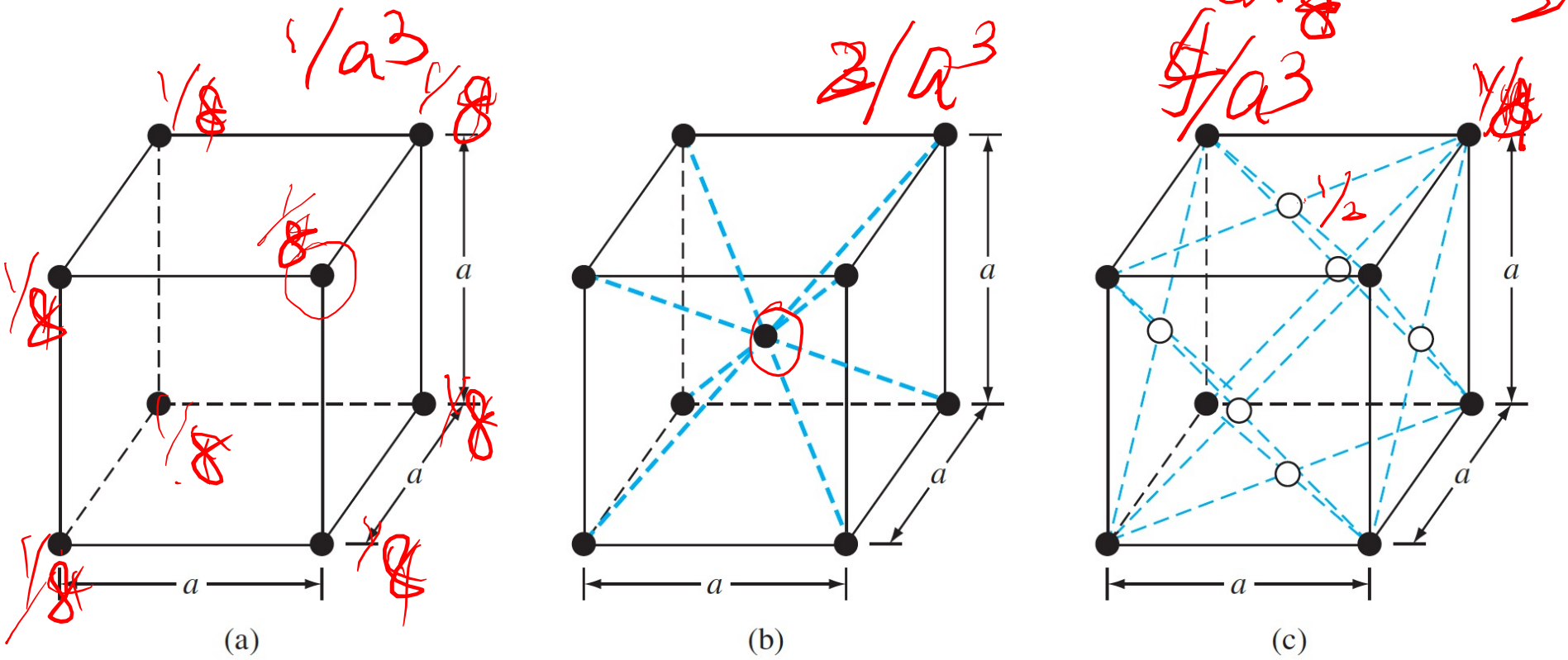
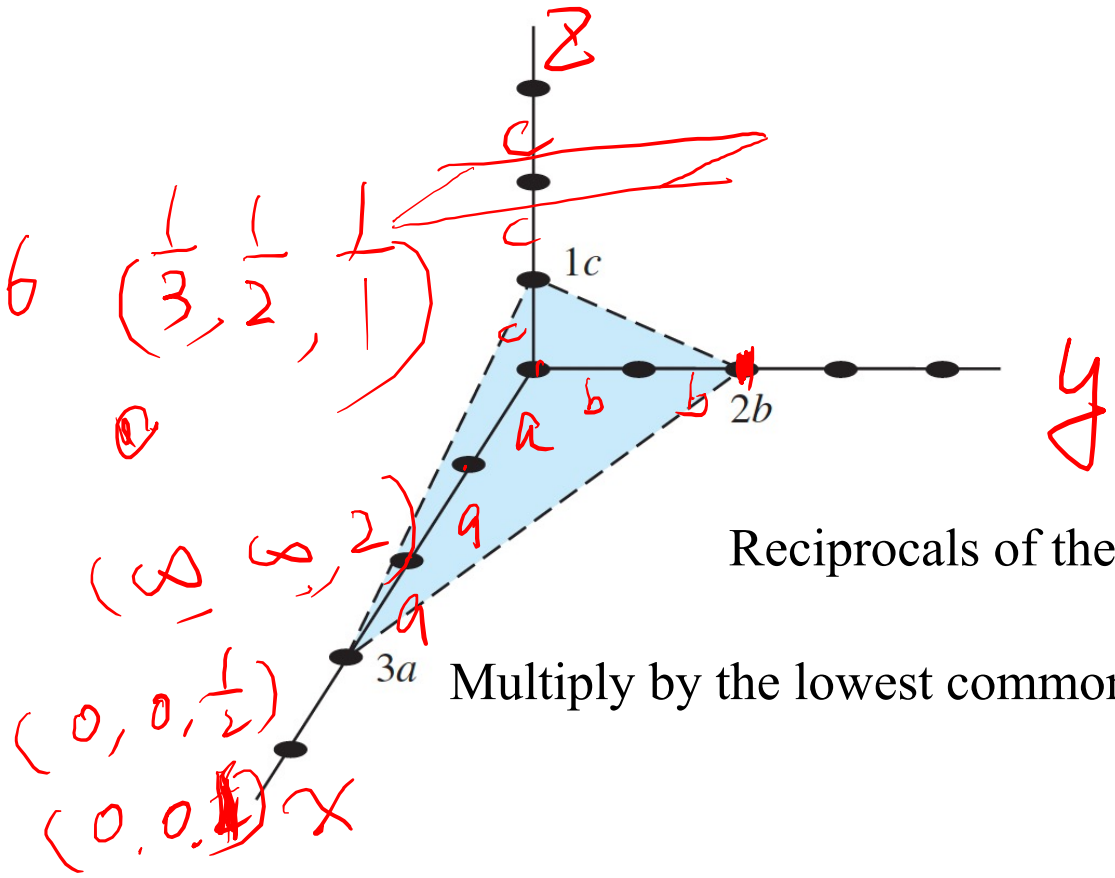


Figure 1.5 | Three lattice types: (a) simple cubic, (b) body-centered cubic, (c) face-centered cubic.

1.3 Space lattice

Crystalline Plane and Miller Index

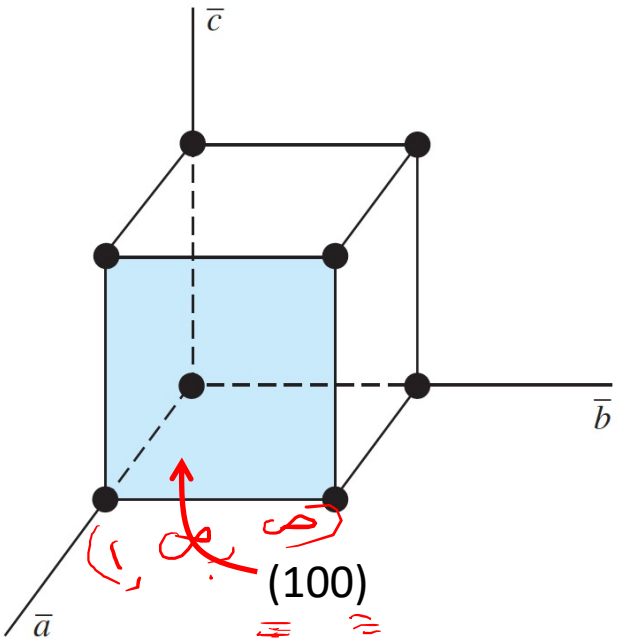


Reciprocals of the intercepts: (1/3, ½, 1)

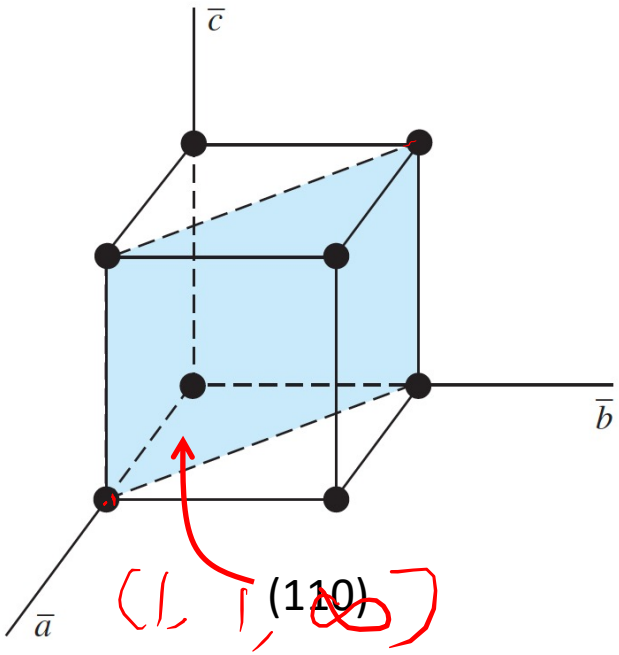
Multiply by the lowest common denominator: (2,3,6)

1.3 Space lattice

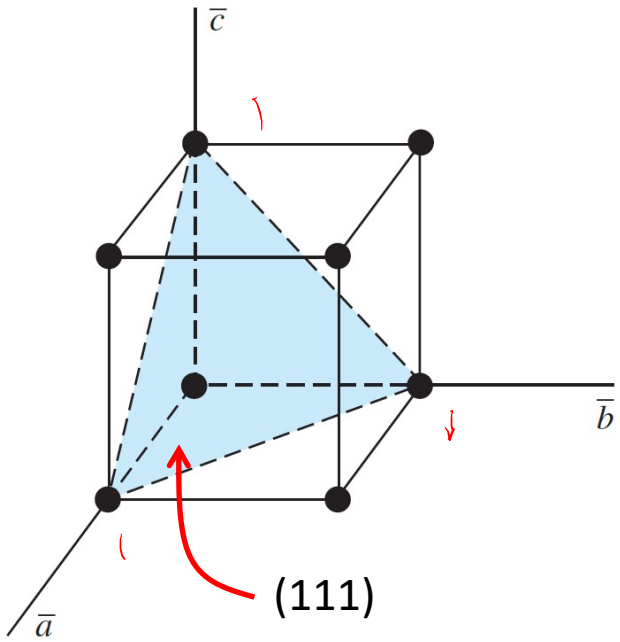
Crystalline Plane and Miller Index



(a)



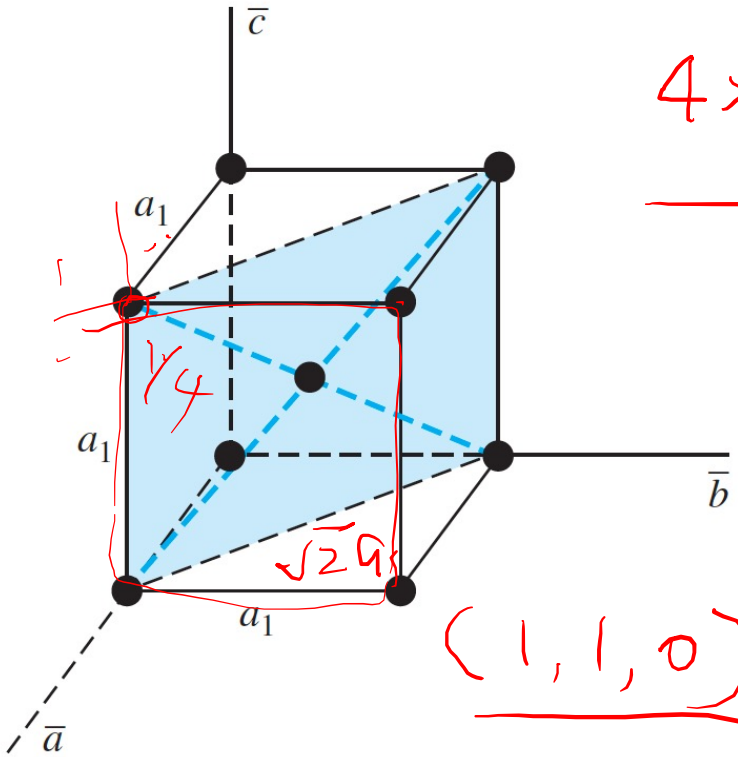
(b)



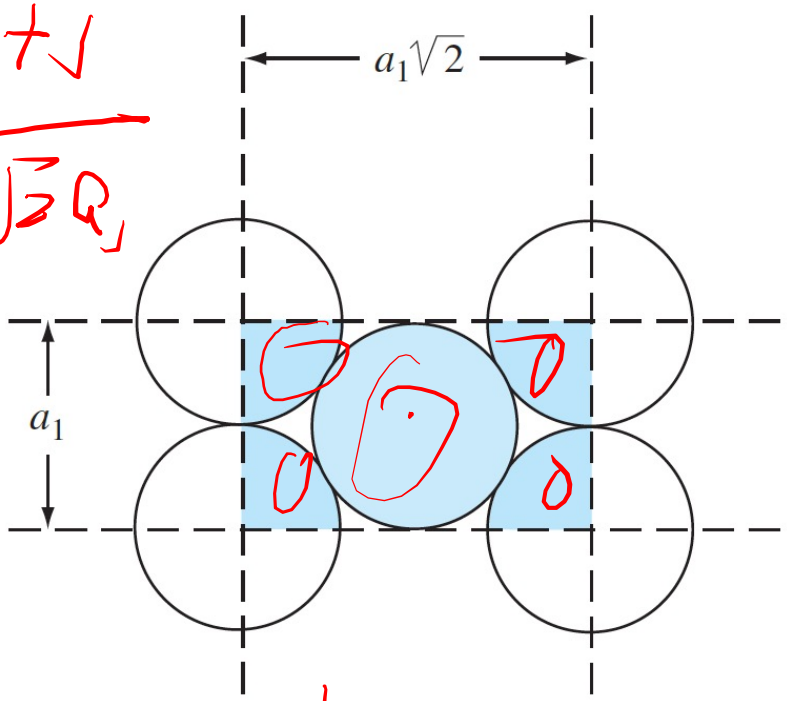
(c)

1.3 Space lattice

Crystalline Plane and Miller Index: surface density of atoms



(a)



(b)

$4 \times \frac{1}{4}$ + √

$a_1 \times \sqrt{2} a_1$

(1, 1, 0)

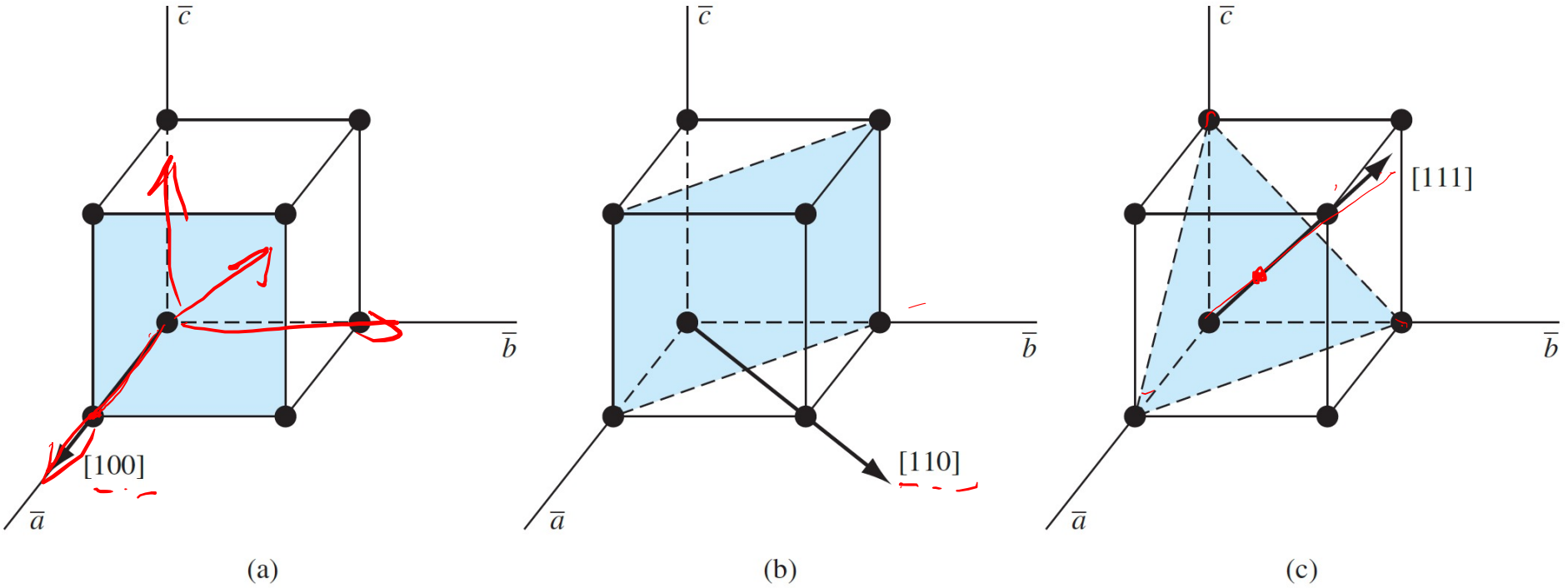
$4 \times \frac{1}{4}$

(1, 0, 0)

a_1^2

1.3 Space lattice

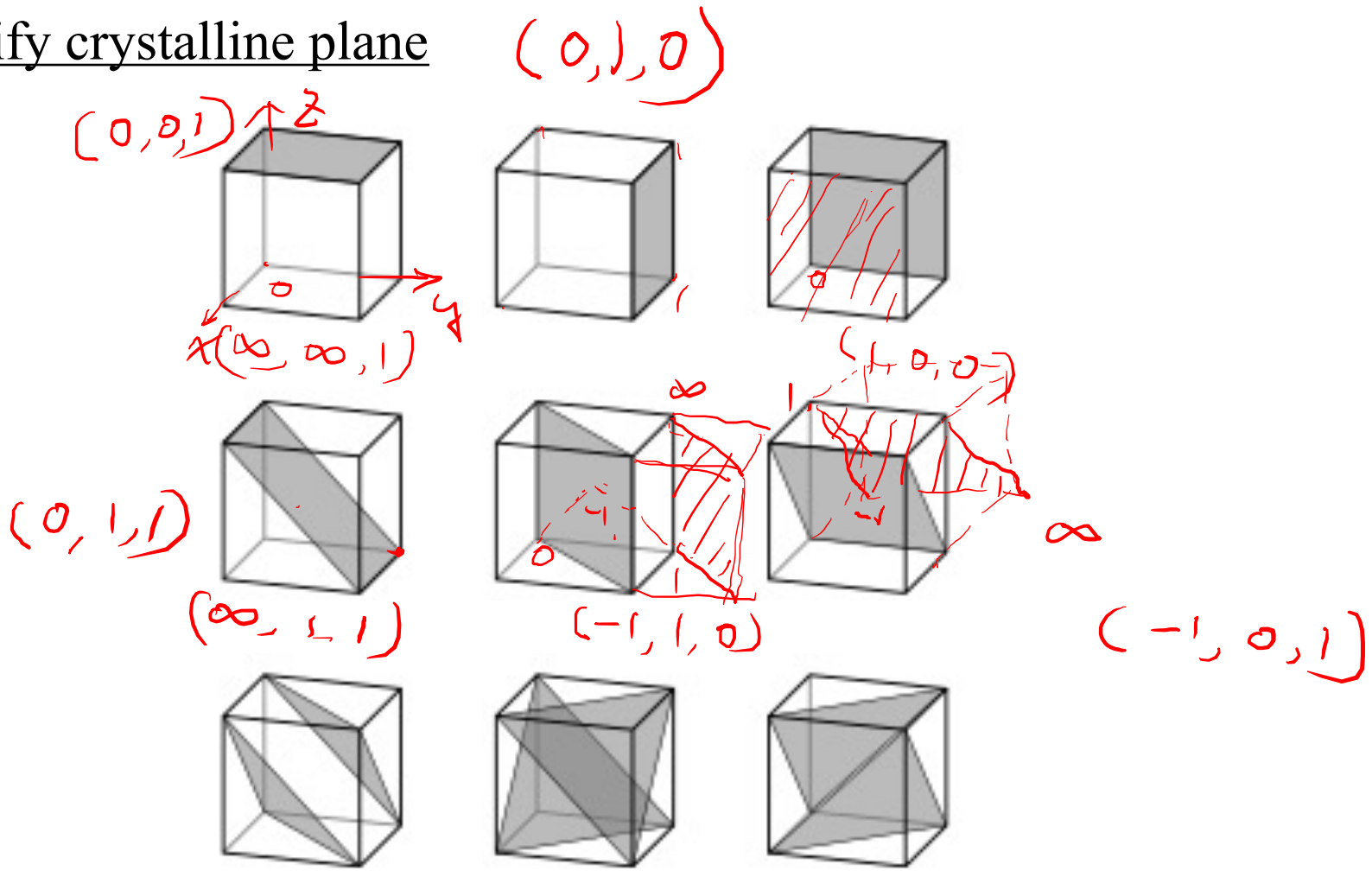
Directions in Crystals



In cubic lattice: [hkl] direction is perpendicular to the (hkl) plane

Check your understanding

Identify crystalline plane



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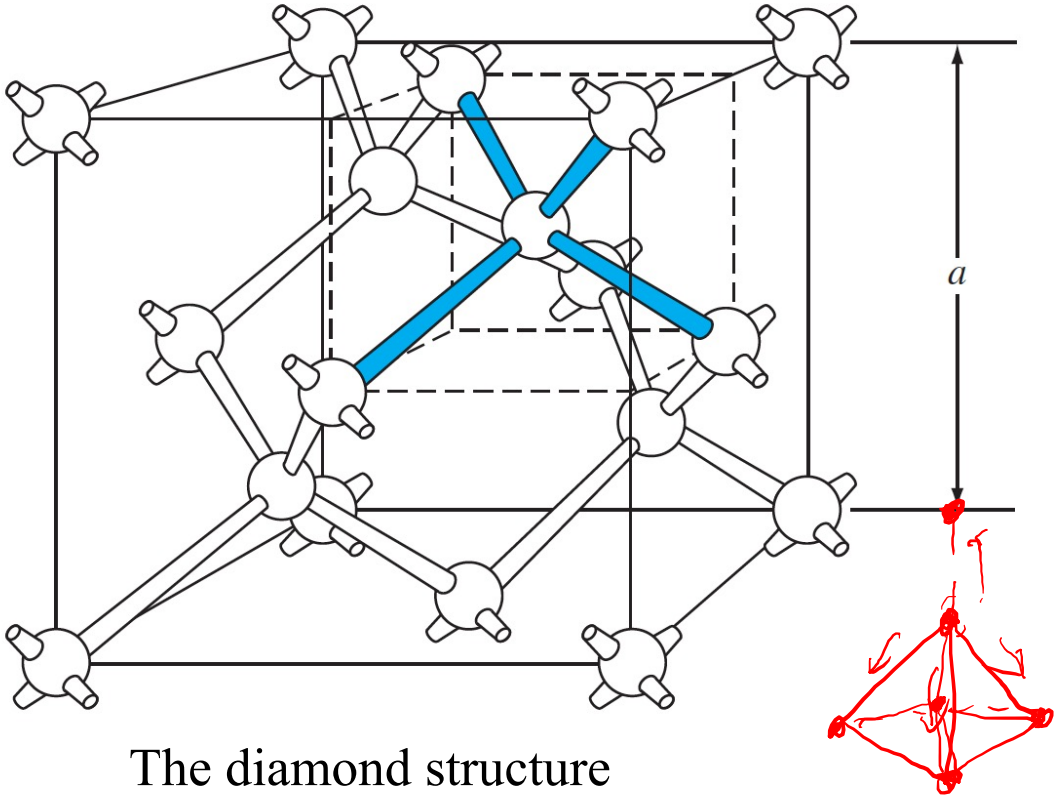
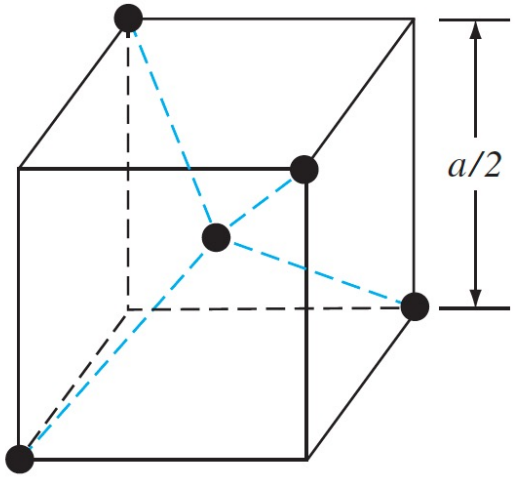
1.6 Imperfections and impurities in solids

1.4 The diamond structure

The diamond lattice



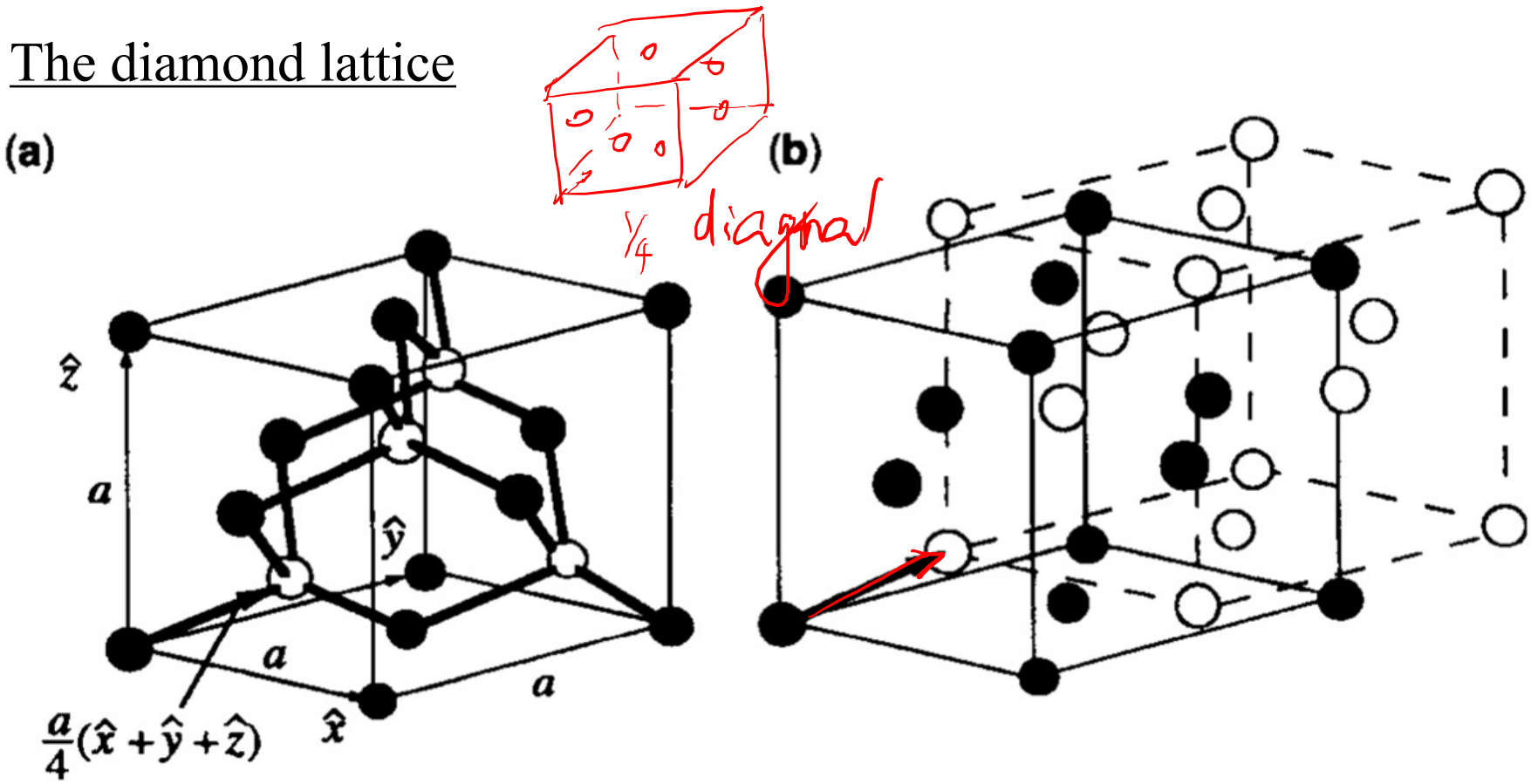
The diamond structure



The tetrahedral structure of closest neighbors in the diamond lattice

1.4 The diamond structure

The diamond lattice

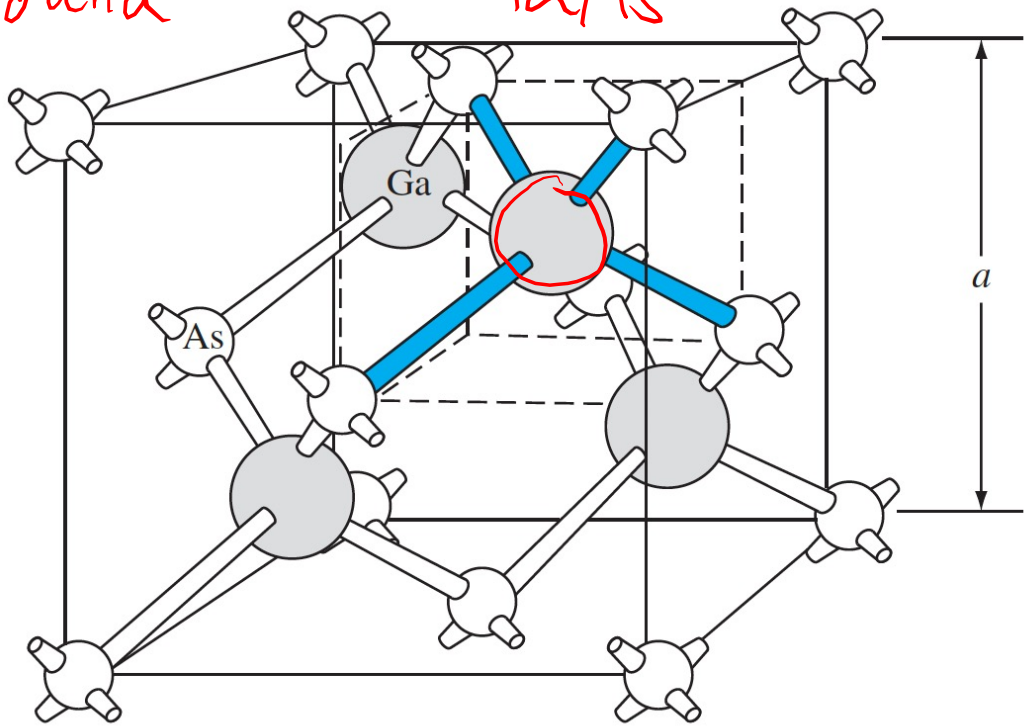


Equivalent to two face-centered cubics sliding ¼ diagonal length along a diagonal

1.4 The diamond structure

The diamond lattice (all atoms are the same)

The zincblende lattice (two different types of atoms in diamond lattice)



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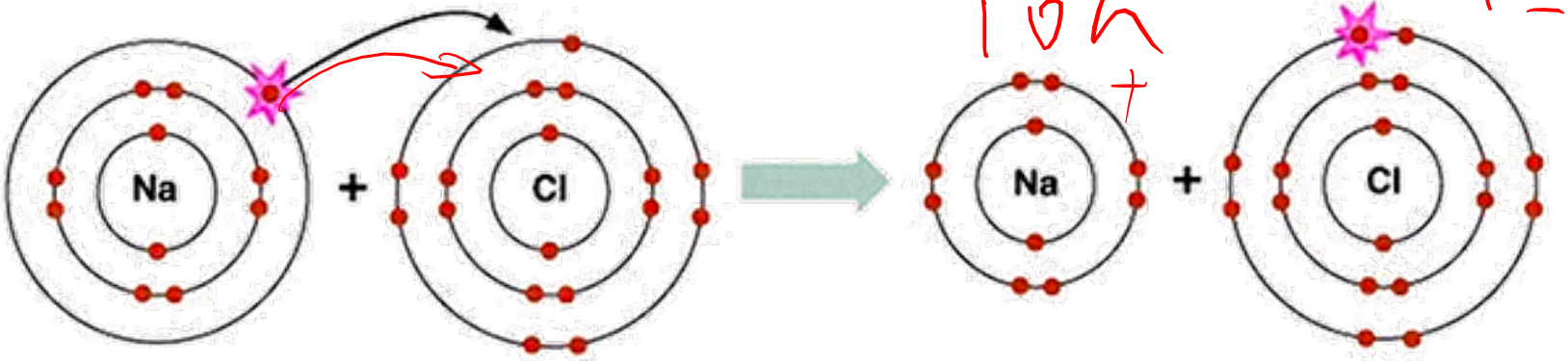
1.5 Chemical bonds

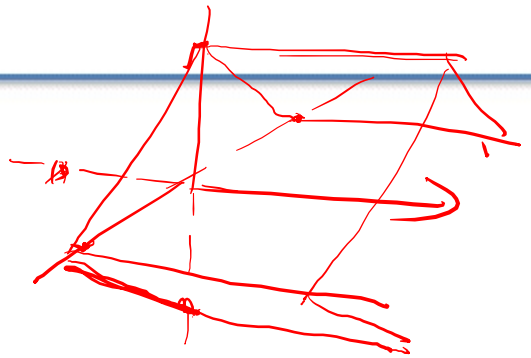
Chemical Bonds: Binding of atoms or ions

Ion bonds, metal bonds, covalent bonds

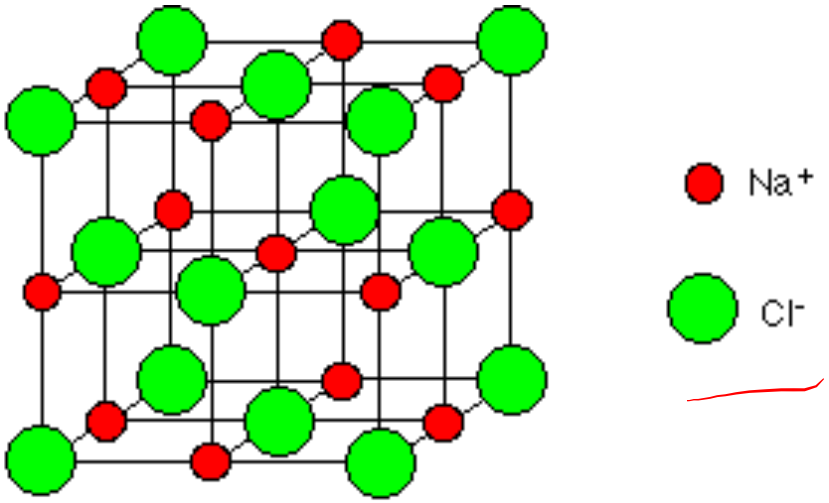


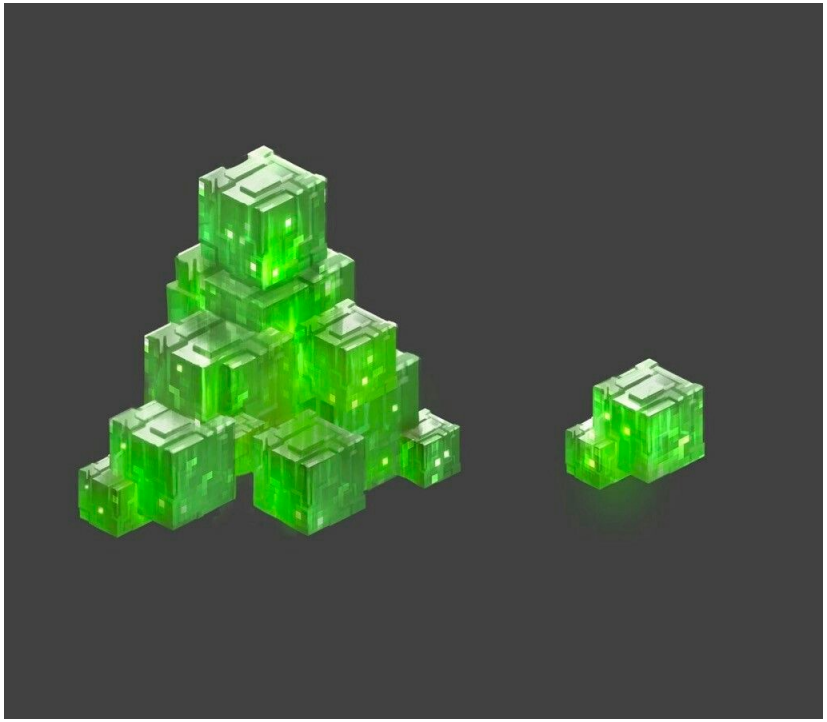
Ion bonds

1.5 Chemical bonds



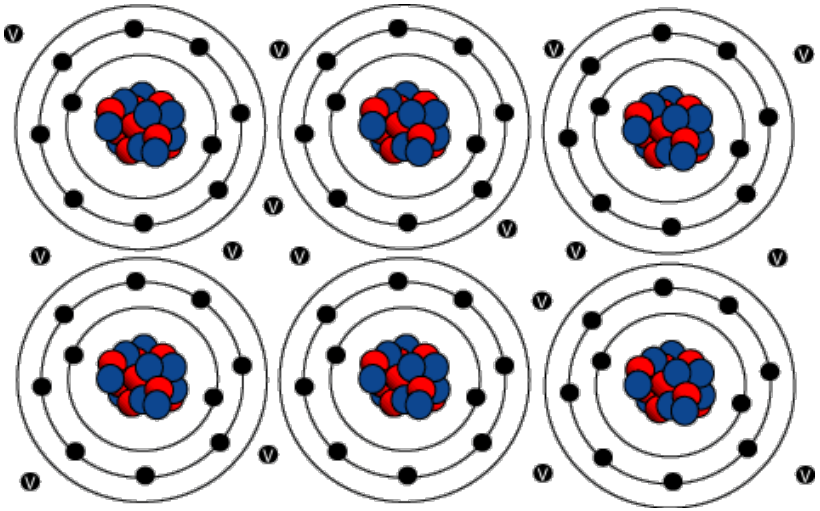
Ion Crystals

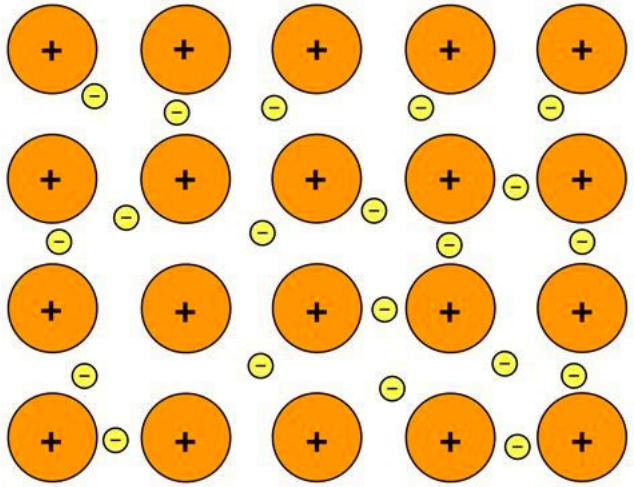




1.5 Chemical bonds

Metal bonds



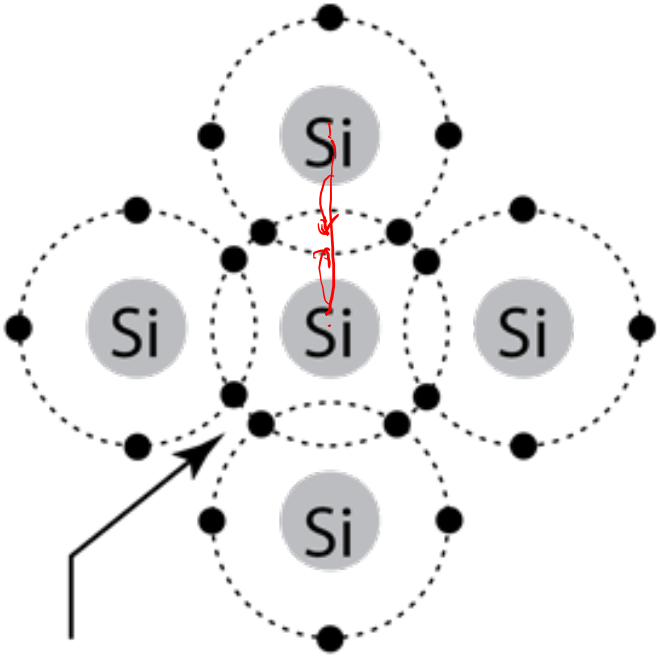


1.5 Chemical bonds

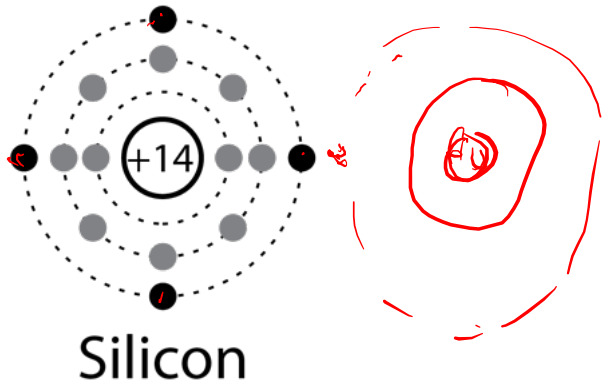
Metal Crystals

1.5 Chemical bonds

Covalent bonds: shared electrons in outer orbitals



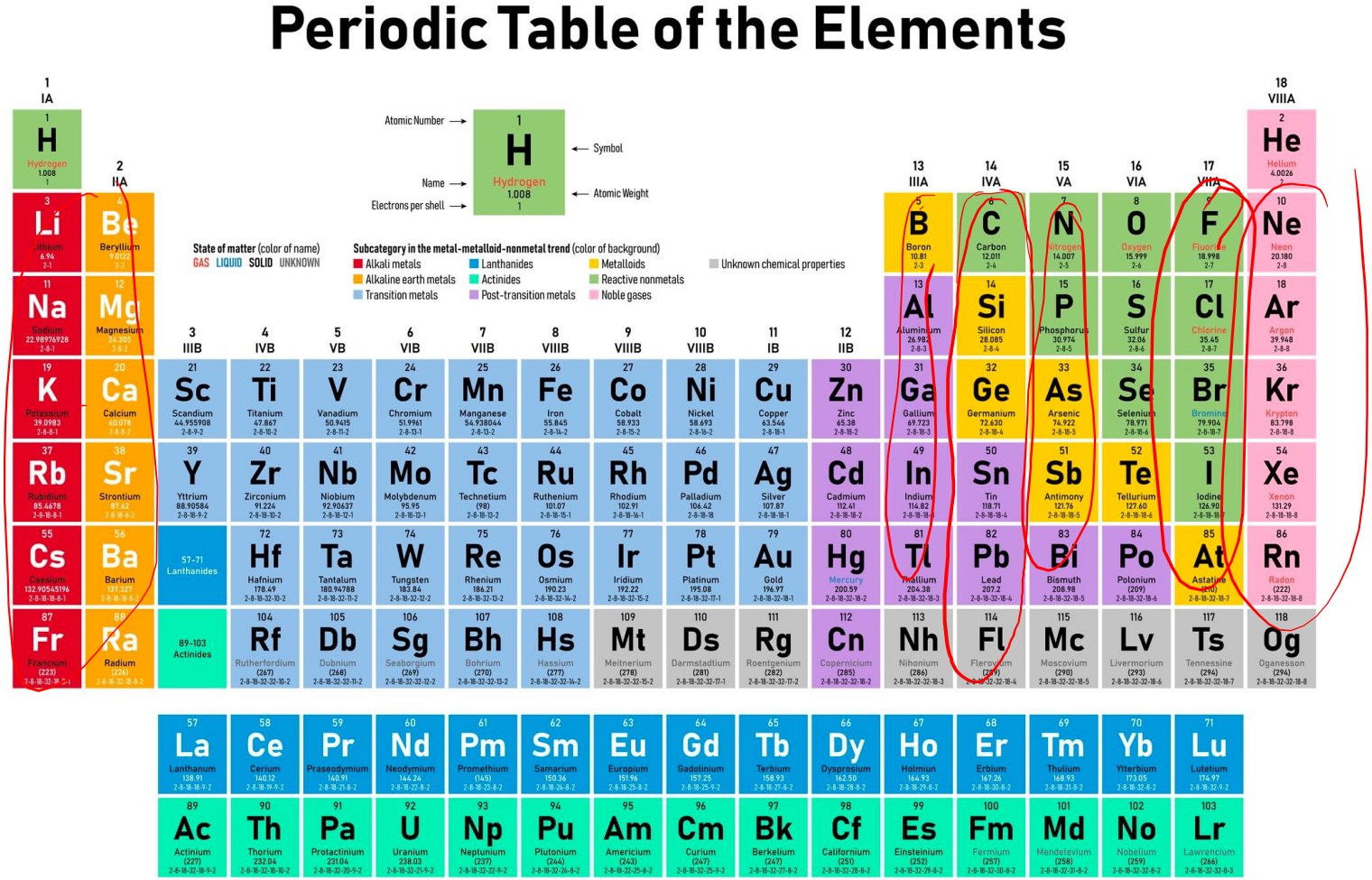
Shared electrons of a covalent bond.



Silicon

Covalent bonds

1.5 Chemical bonds



Outline

1.1 Semiconductor materials

1.2 Type of Solids

1.3 Space lattices

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1.6 Imperfections and impurities in solids

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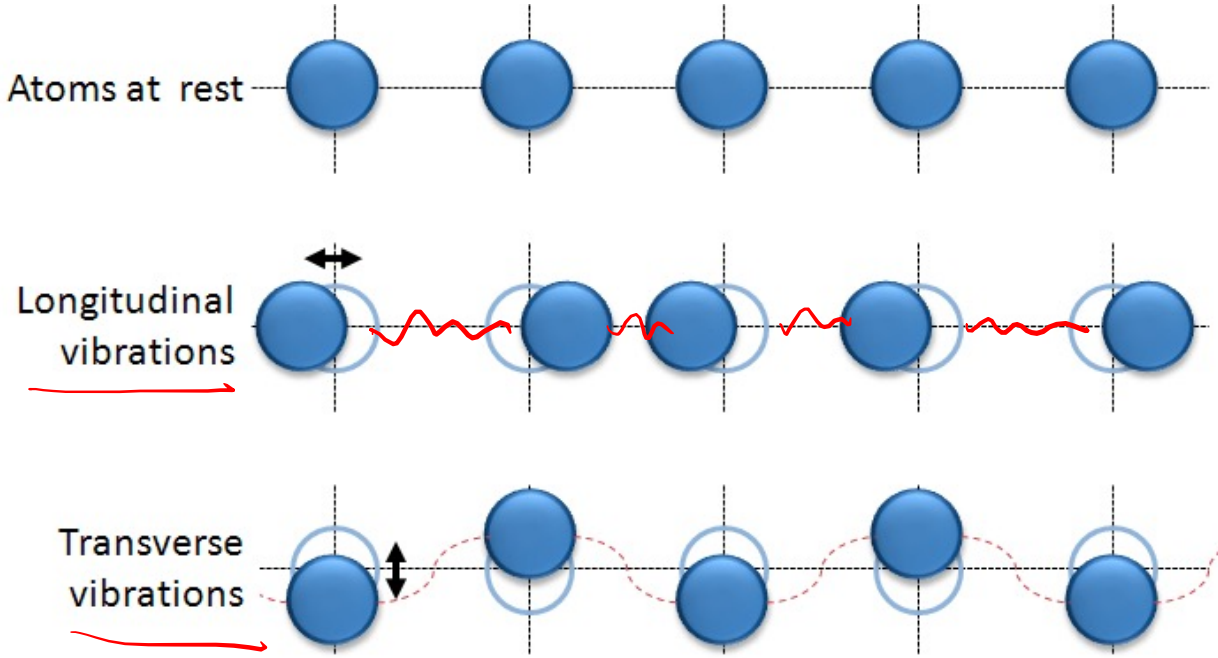
Imperfections in solids

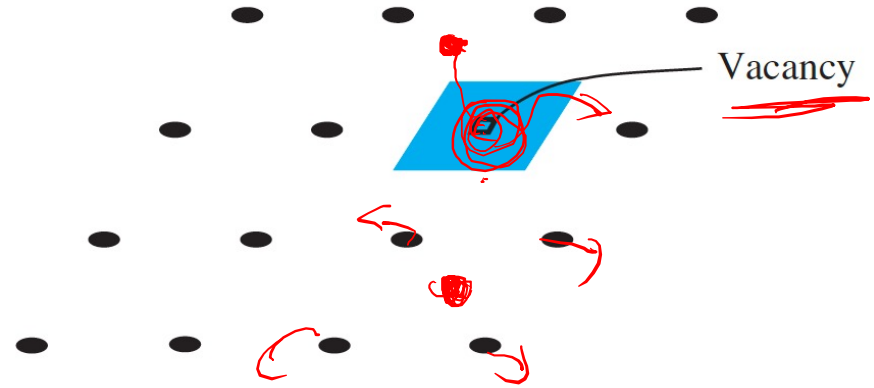
Lattice vibrations: thermal vibration or phonons



1.6 Imperfections and impurities in solids

Imperfections in solids

Lattice vibrations: thermal vibration, or phonons
Point defects: vacancies, interstitial defects, vacancy-interstitial defects



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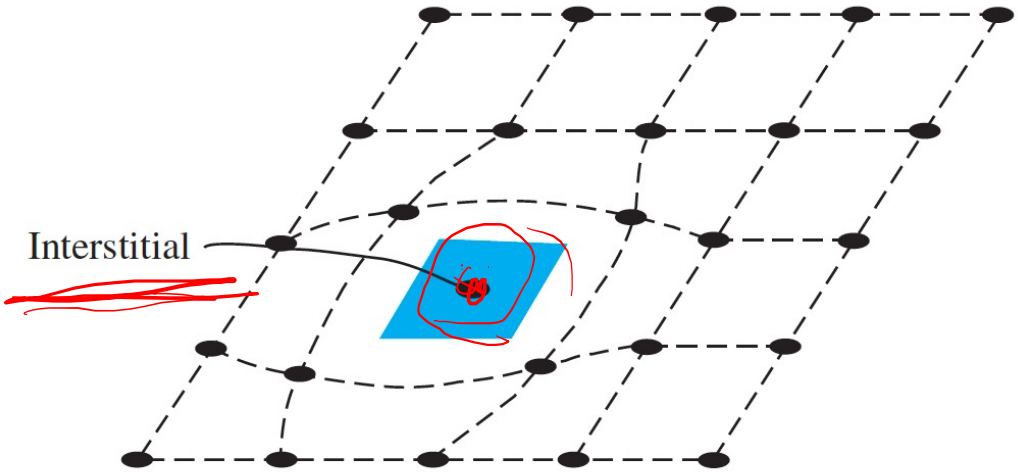

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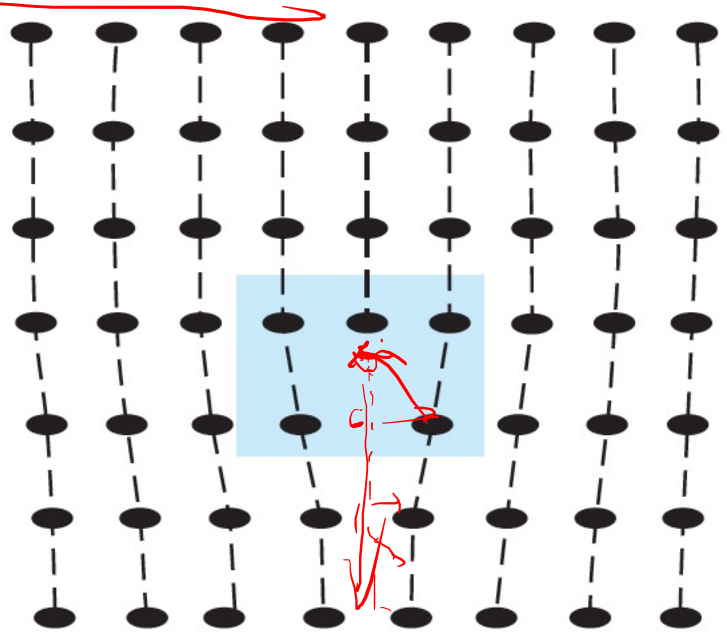
1.6 Imperfections and impurities in solids

Imperfections in solids

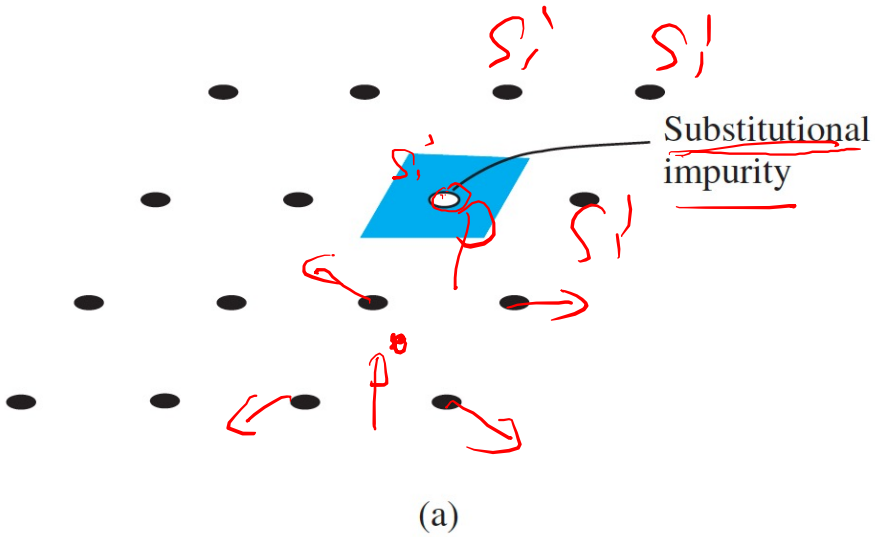
Lattice vibrations: thermal vibration, or phonons
Point defects: vacancies, interstitial defects, vacancy-interstitial defects
Line defects: line dislocation



Line dislocation

1.6 Imperfections and impurities in solids

Impurities in solids: foreign atoms



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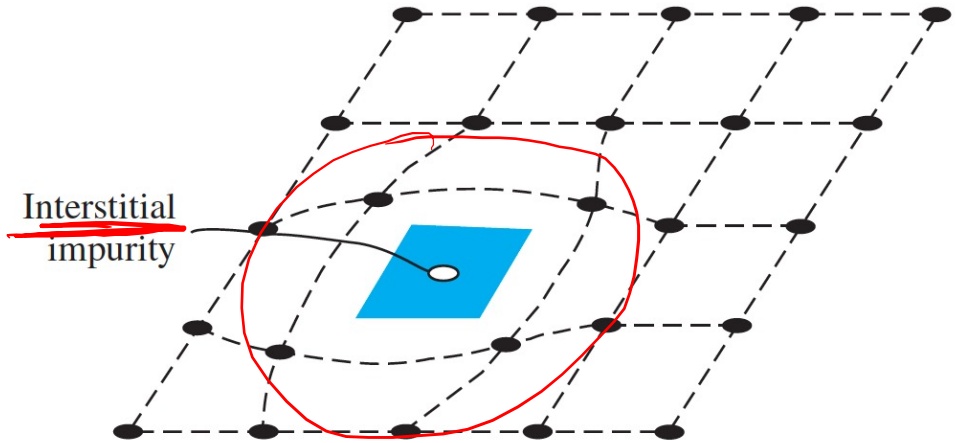
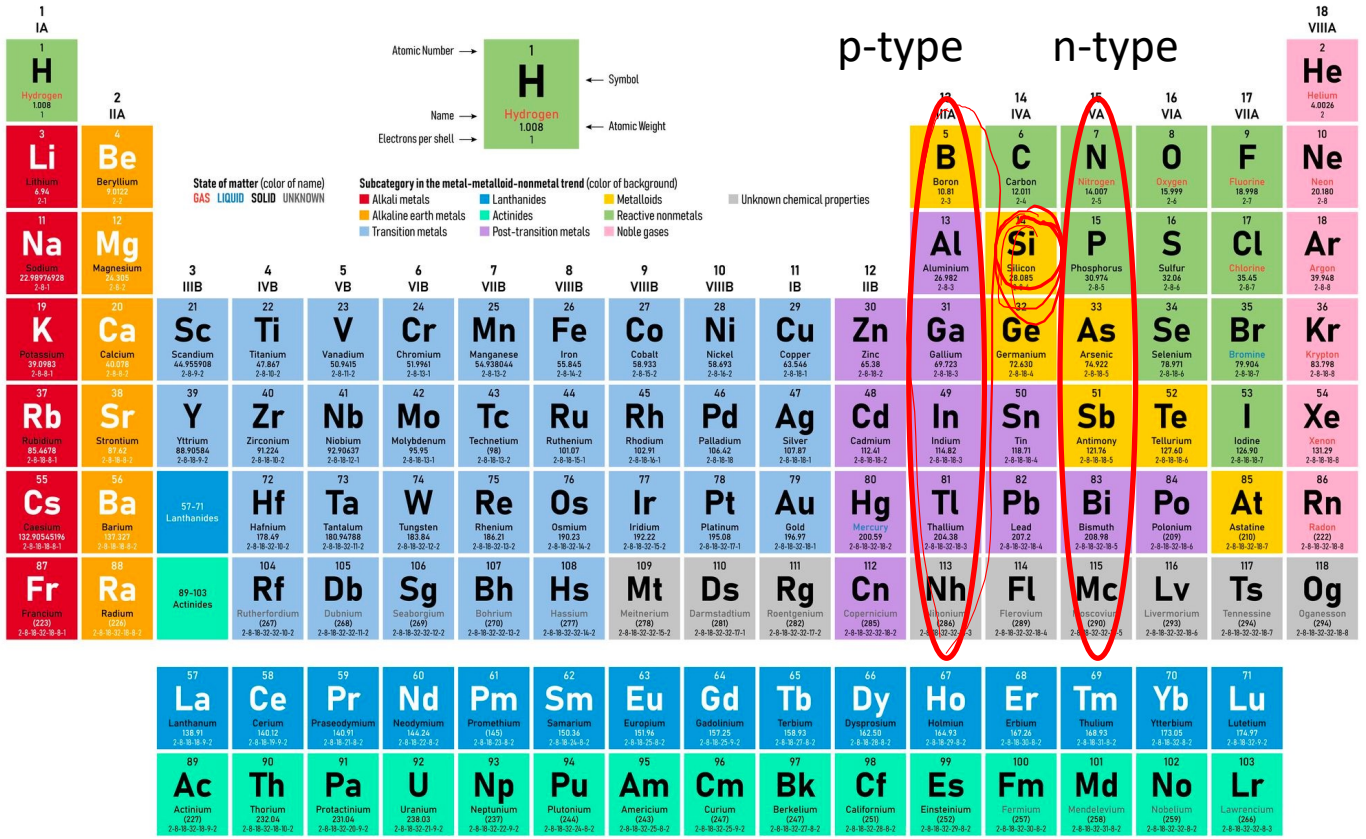


(b)

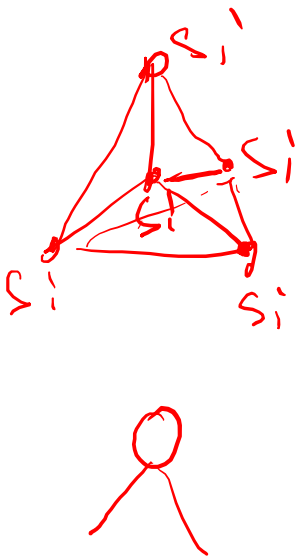
Dopants are special substitutional impurities.

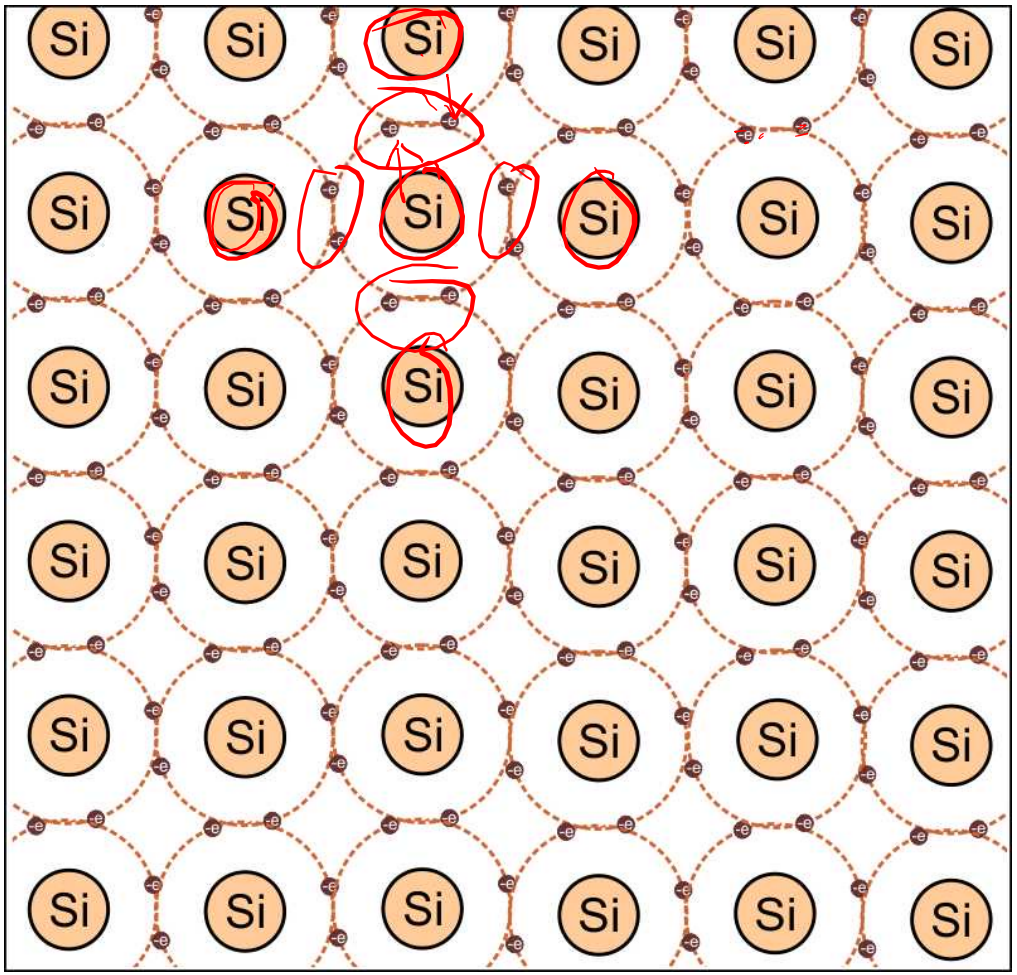
1.6 Imperfections and impurities in solids

Impurities in solids: foreign atoms



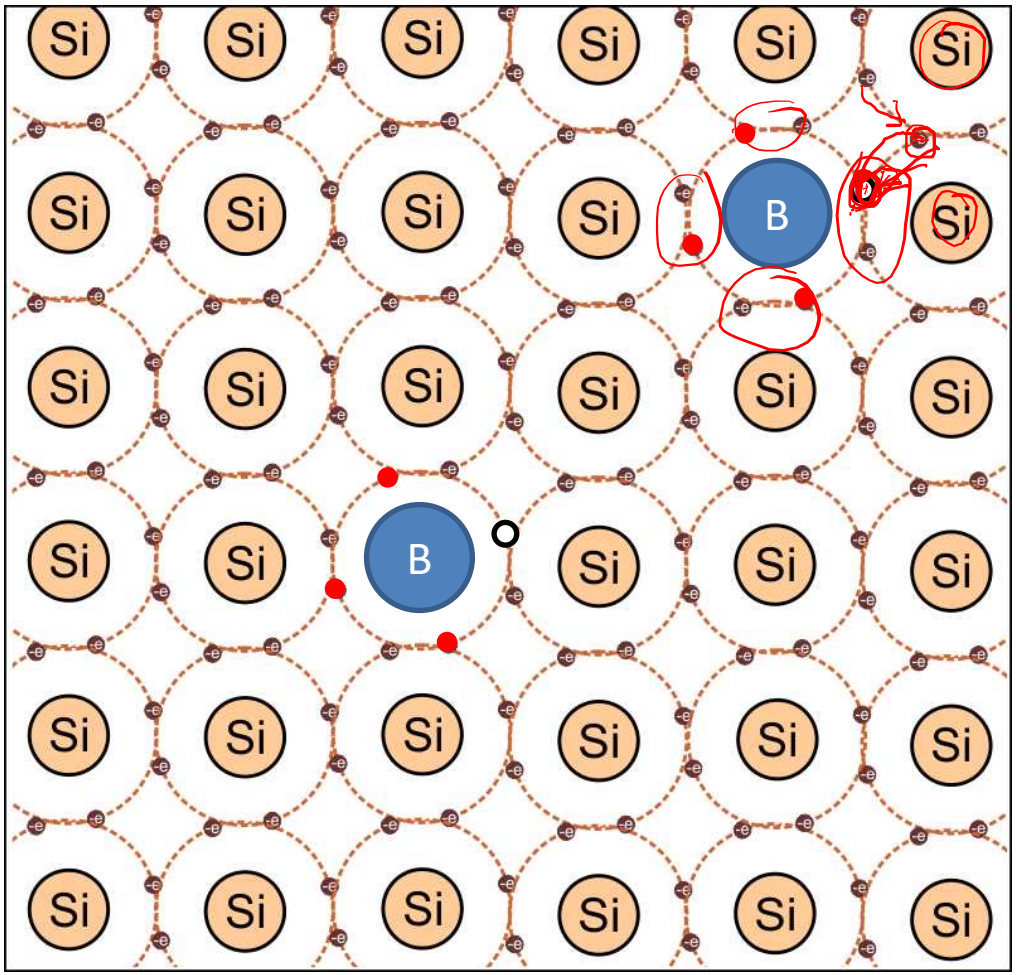
1.6 Imperfections and impurities in solids





1.6 Imperfections and impurities in solids

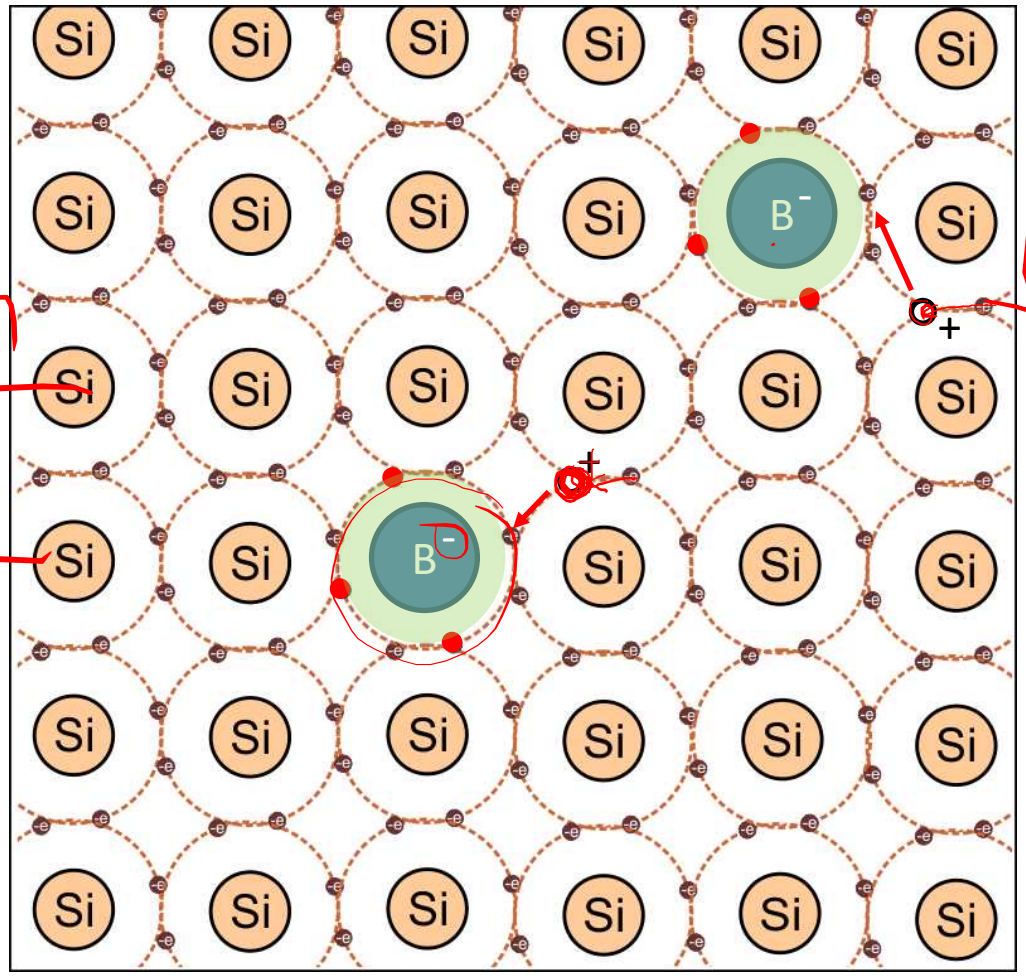
p-type doping



Acceptor-type of doping

1.6 Imperfections and impurities in solids

p-type doping

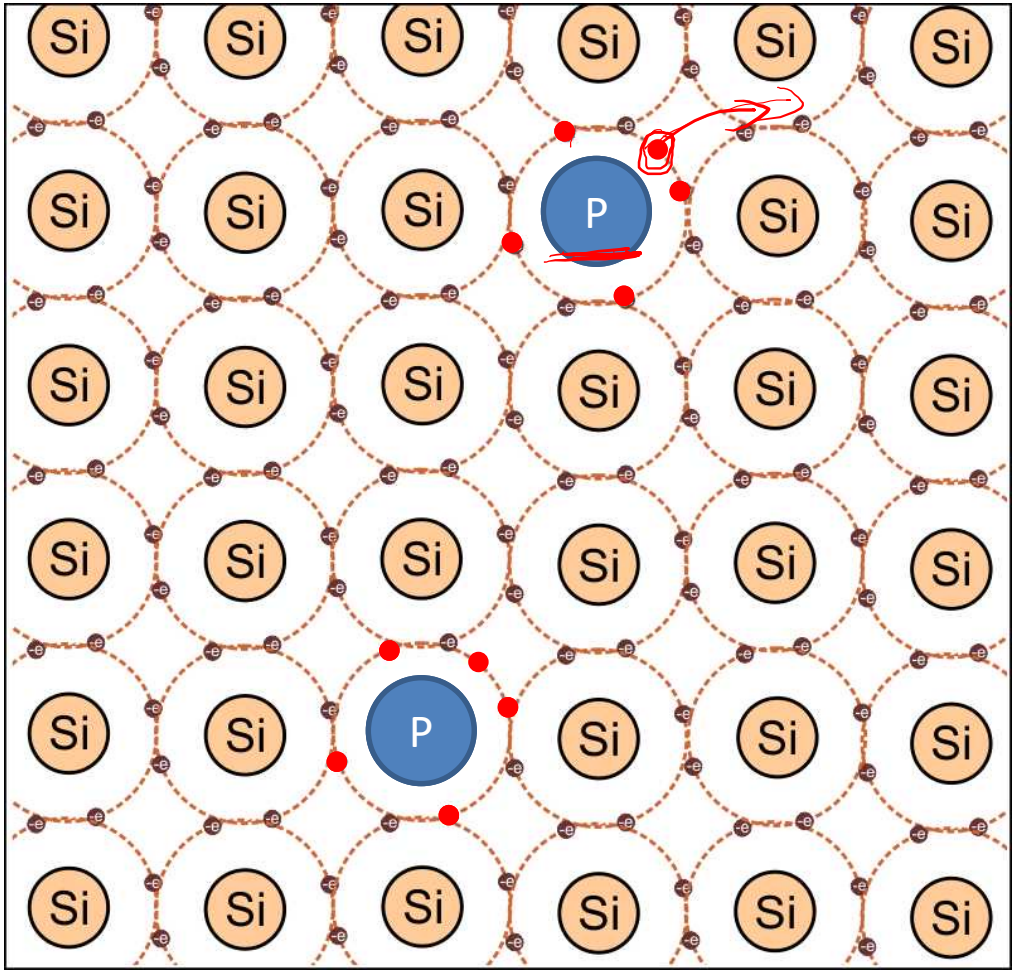


Acceptor-type of doping

1.6 Imperfections and impurities in solids

n-type doping

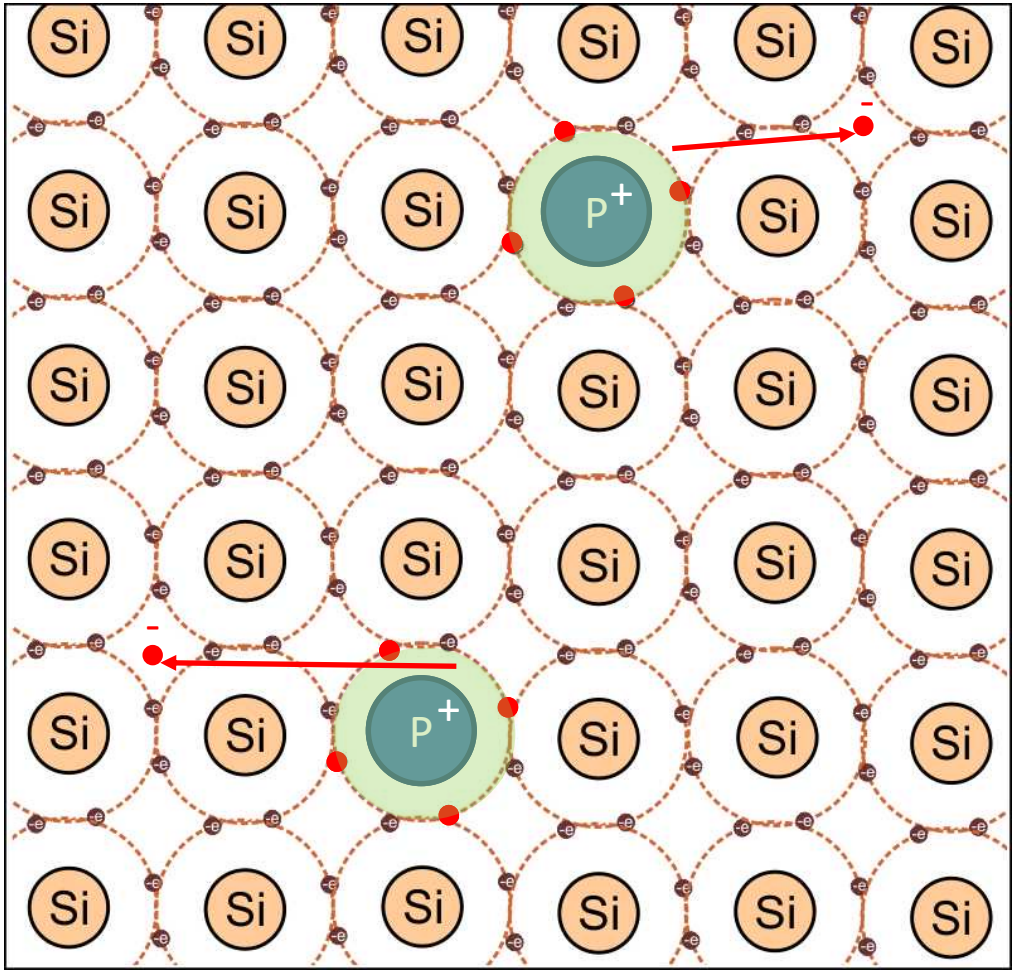
negative



Donor-type of doping

1.6 Imperfections and impurities in solids

n-type doping



Donor-type of doping

Check your understanding

- For Ga, Sn, As, Sb in Si, which forms n-type or p-type doping?
- Will Ge in Si form n-type or p-type doping?