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Advanced Electromagnetics:
21st Century Electromagnetics

Introduction to Periodic Structures

Lecture Outline

- Periodic structures in electromagnetics
- Classifying periodic structures

Periodic Structures in Electromagnetics

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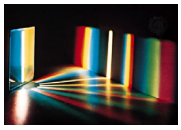
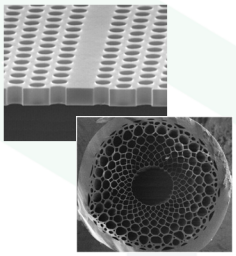
Examples of Periodic Electromagnetic Devices

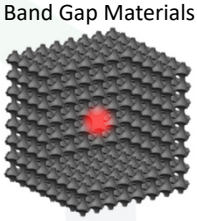
Diffraction Gratings



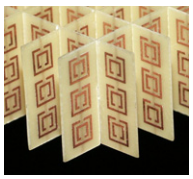
Waveguides



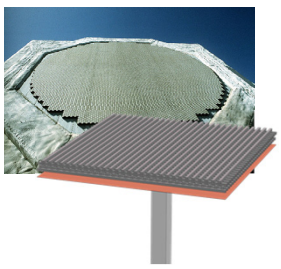
Band Gap Materials



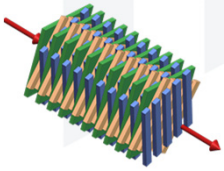
Metamaterials



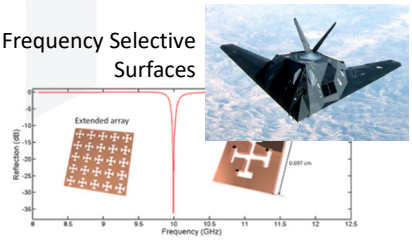
Antennas



Slow Wave Devices



Frequency Selective Surfaces



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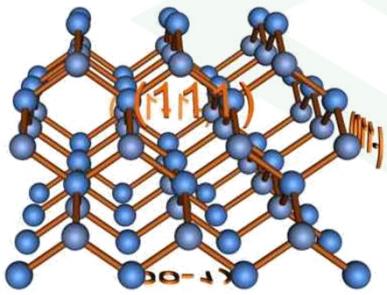
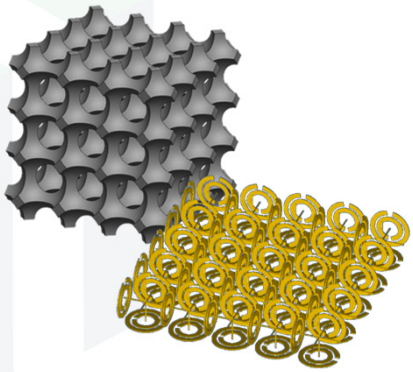
What is a Periodic Structure?

Periodicity at the Atomic Scale



Larger-Scale Periodicity



Materials are periodic at the atomic scale.
Metamaterials and photonic crystals are periodic at a much larger scale, but smaller than a wavelength.
The math describing how things are periodic is the same for both atomic scale and larger scale.

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Classifying Periodic Structures

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Describing Periodic Structures

- There is an infinite number of ways that structures can be periodic.
- Despite this, a methodical way to describe and classify periodic lattices is needed. To do this, generalizations must be made.
- We classify periodic structures into:
  - 230 space groups
  - 32 crystal classes
  - 14 Bravais lattices
  - 7 crystal systems

Less specific.
More generalizations.

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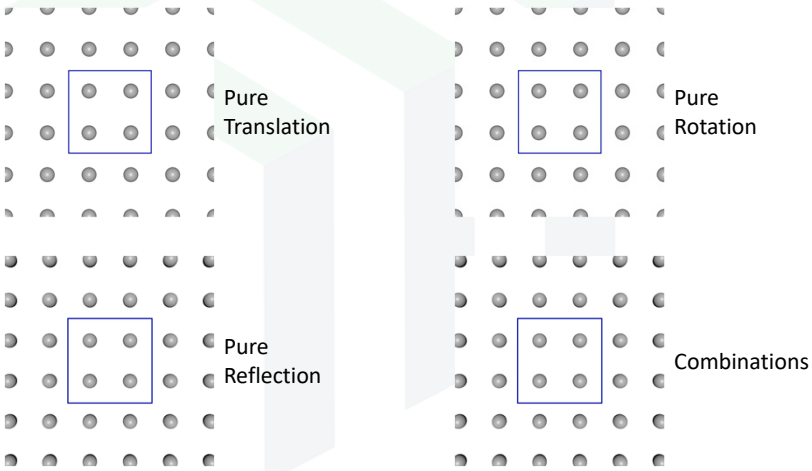
Symmetry Operations *(Animated)*

Infinite crystals are invariant under certain symmetry operations that involve:



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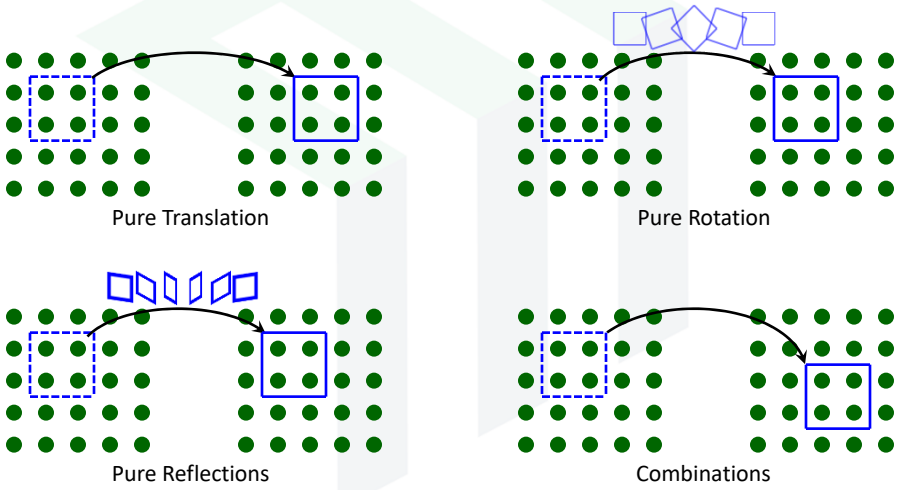
Symmetry Operations *(Static)*

Infinite crystals are invariant under certain symmetry operations that involve:



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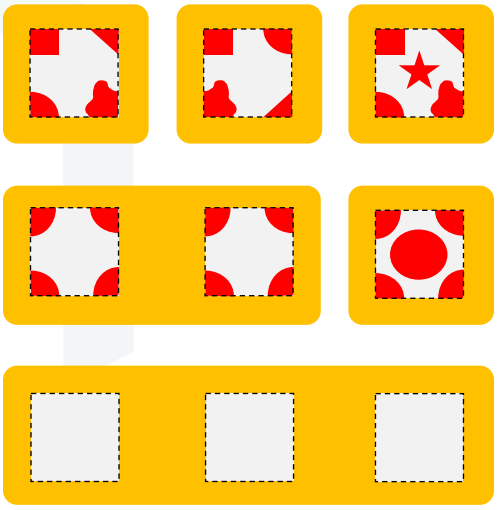
Definition of Symmetry Categories

- Space Groups
  - Set of all possible combinations of symmetry operations that restore the crystal to itself.
  - 230 space groups
- Bravais Lattices
  - Set of all possible ways a lattice can be periodic if composed of identical spheres placed at the lattice points.
  - 14 Bravais lattices
- Crystal Systems
  - Set of all Bravais lattices that have the same holohedry (shape of the conventional unit cell)
  - 7 crystal systems



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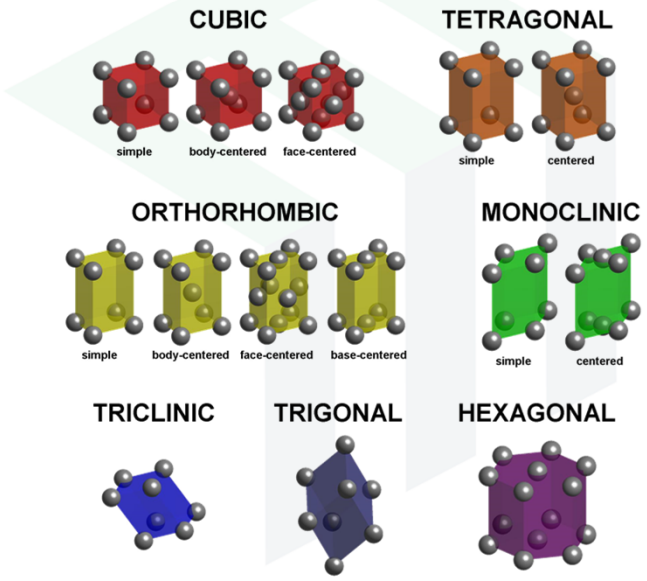
The 14 Bravais Lattices and the Seven Crystal Systems



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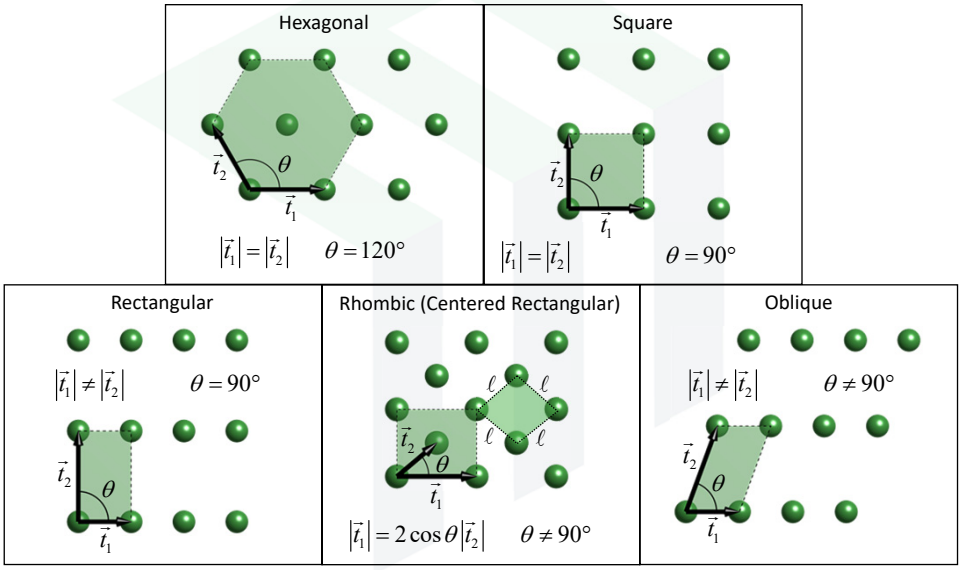
Five Bravais Lattices in Two Dimensions



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Axis vectors = translation vectors for 2D lattices

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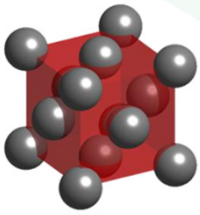
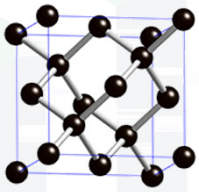
Hybrid Symmetries

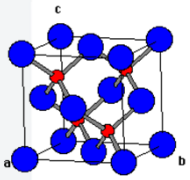
FCC Symmetry



Diamond = FCC + FCC



Zinc Blend



* GaAs

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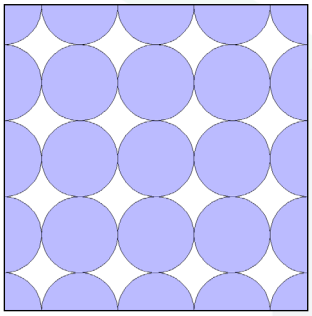
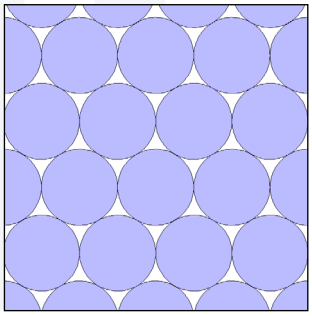
Hexagonal Symmetry Has Optimal Packing Density in 2D

Electromagnetic behavior from hexagonal arrays tends to be at lower frequencies than compared to square arrays. This means feature sizes can be larger than they would be for square arrays. This is important at high frequencies and photonics where small features may be more difficult to realize.



$$f_{sq} = \pi\left(\frac{r}{a}\right)^2$$



$$f_{hex} = \frac{2\pi}{\sqrt{3}}\left(\frac{r}{a}\right)^2$$

$$\frac{f_{hex}}{f_{sq}} = \frac{2}{\sqrt{3}} = 1.1547$$

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