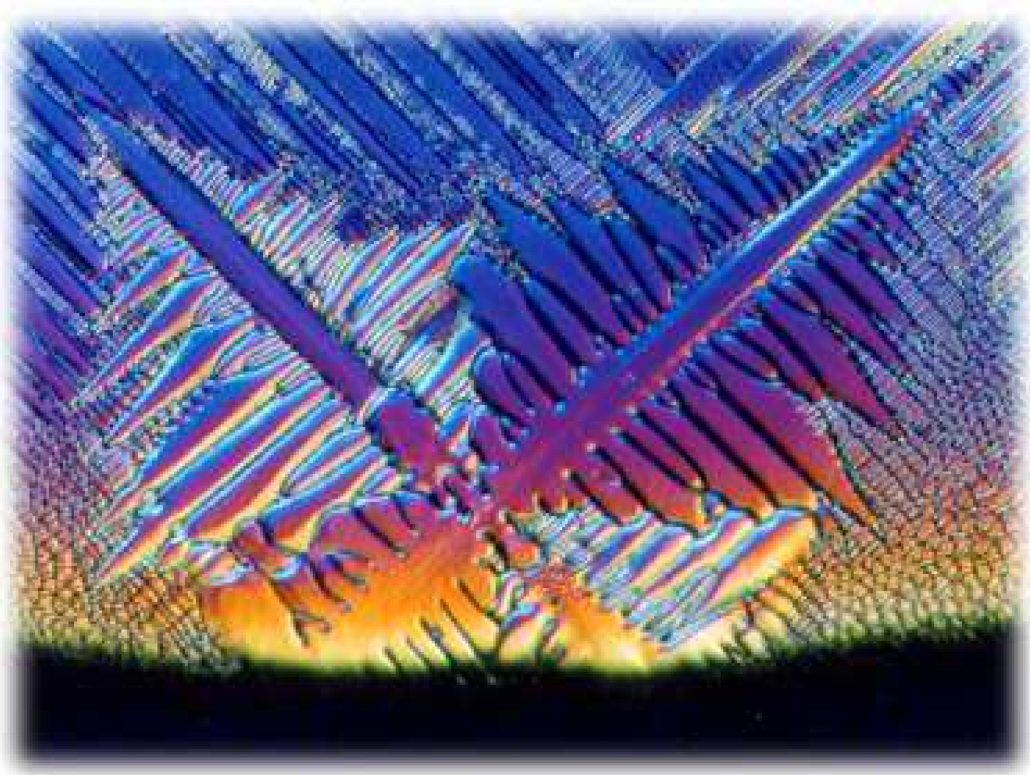
Condensed Matter Physics

- Largest subfield of physics
- Link between atoms and everyday world.
- Unity obscured by tremendous variety of topics.



Dividing the field

Historical Roots

- Atomic Structure
- Electronic Structure
- Mechanical Properties
- Electron Transport
- Optical Properties
- Magnetism

Concepts

- Self–organization
- Form and Function
- Scaling and Symmetry
- Precision Measurement
- Fabrication
- Computation

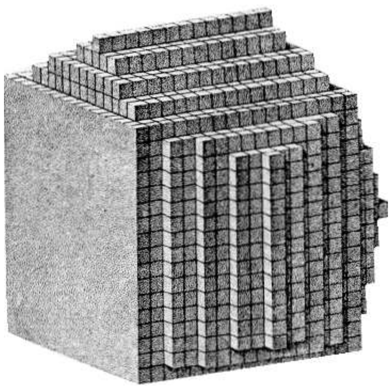
Atomic Structure

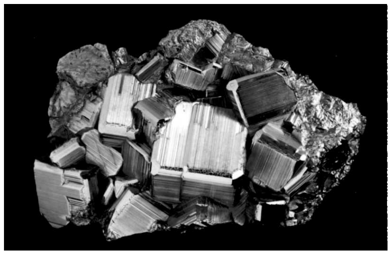
Questions:

- What is the basic structure of matter?
- How do atoms spontaneously organize?

Basic Answer:

- Scaling theory relates atom–scale units to macroscopic solids.
- Atoms form crystalline arrays.
- Idea comes from special class of solids: minerals.





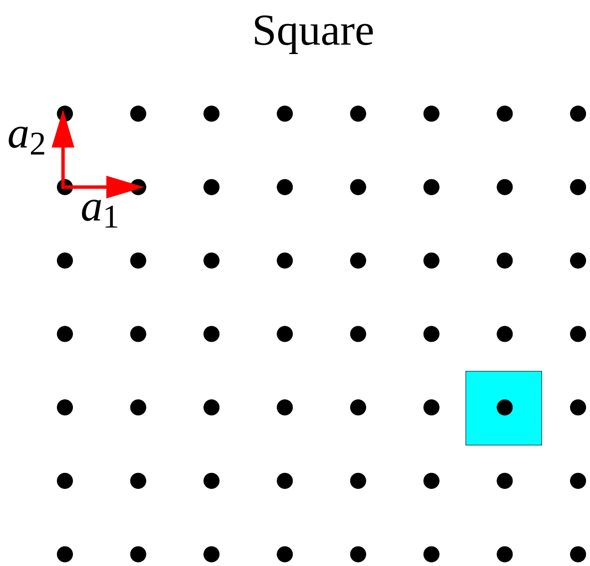
See vast numbers of minerals at `http://webmineral.com/`

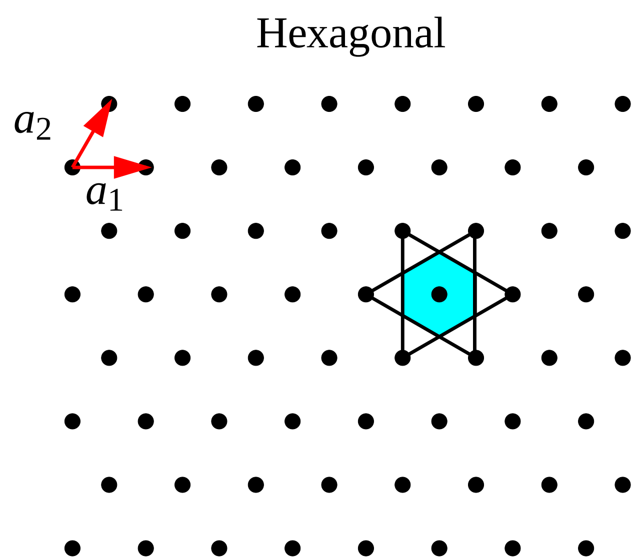
Two–Dimensional Lattices

Definitions:

- ☞ Bravais lattice
- ☞ primitive vector
- ☞ basis vector
- ☞ unit cell (primitive or not)
- ☞ Wigner–Seitz cell (Voronoi polyhedron)
- ☞ translation, space, and point groups

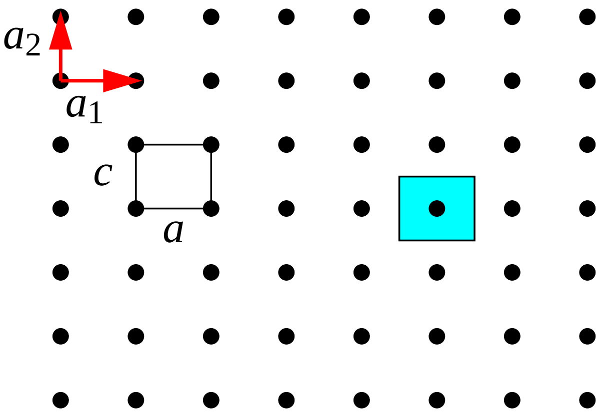
Bravais Lattices



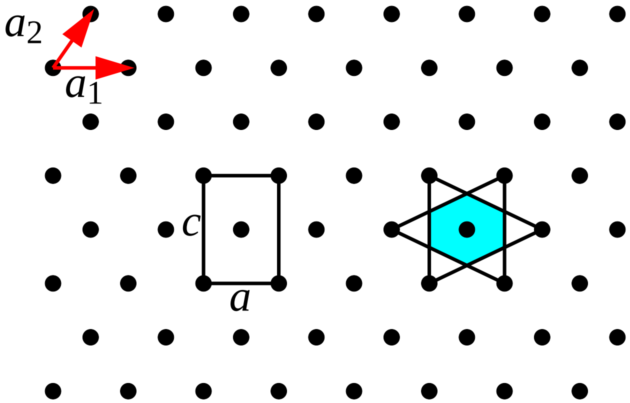


Bravais Lattices

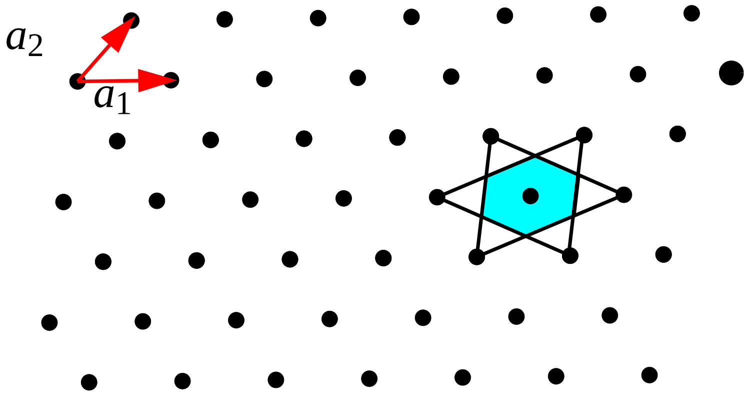
Rectangular



Centered Rectangular



Oblique



Question

Q: Are primitive vectors unique?

A: No..for hexagonal lattice

$$\vec{a}_1 = a(1 \;\; 0) \tag{L1a}$$

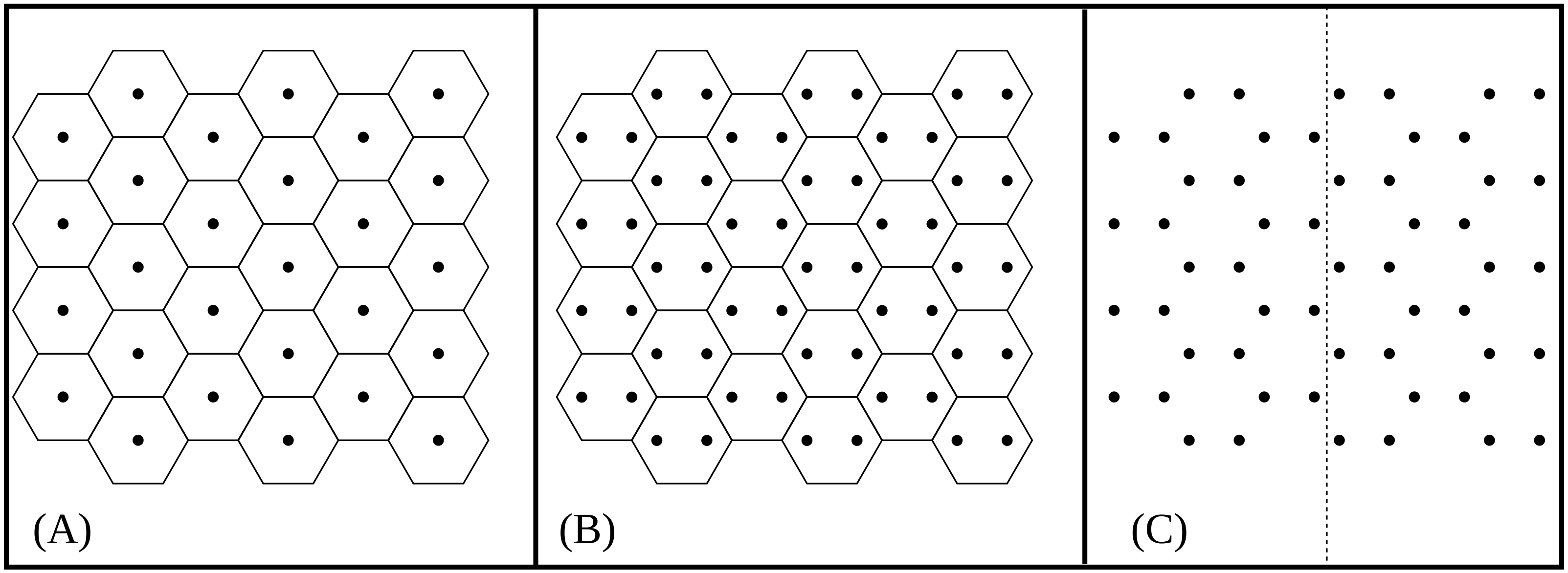
$$\vec{a}_2 = a\left(\frac{1}{2} \;\; \frac{\sqrt{3}}{2}\right). \tag{L1b}$$

However, one could equally well choose

$$\vec{a}'_1 = a\left(-\frac{1}{2} \;\; \frac{\sqrt{3}}{2}\right) \tag{L2a}$$

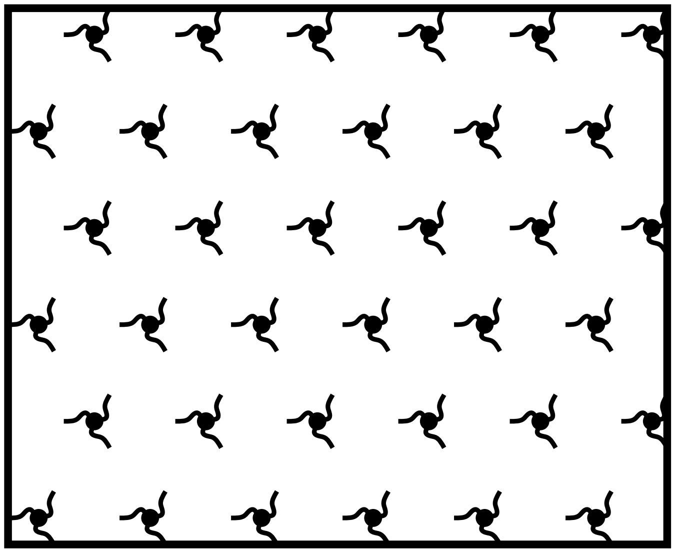
$$\vec{a}'_2 = a\left(\frac{1}{2} \;\; \frac{\sqrt{3}}{2}\right). \tag{L2b}$$

Lattice with Basis



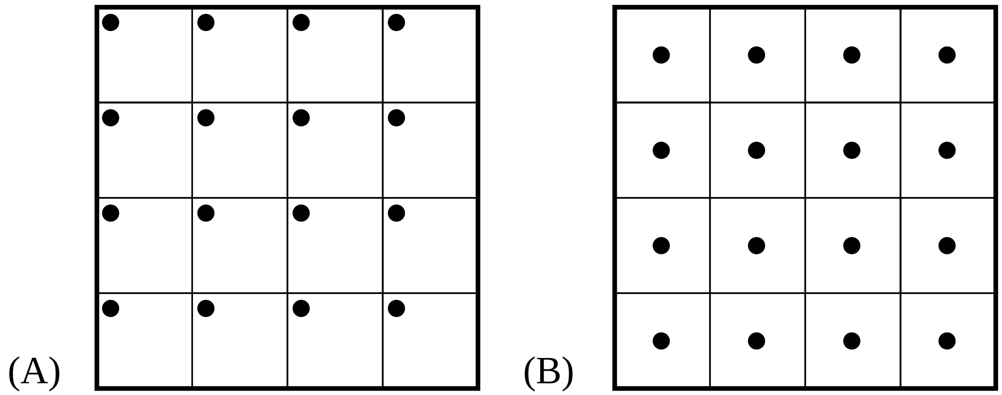
Note presence of glide plane, showing that space group is not the same as the product of translation group and point group.

Some, but not all symmetries of triangular lattice destroyed.

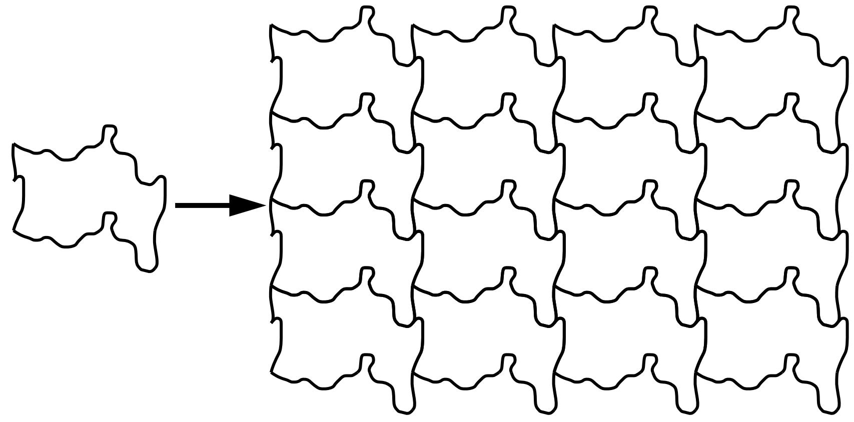


Unit cells

Unit cells are not unique.

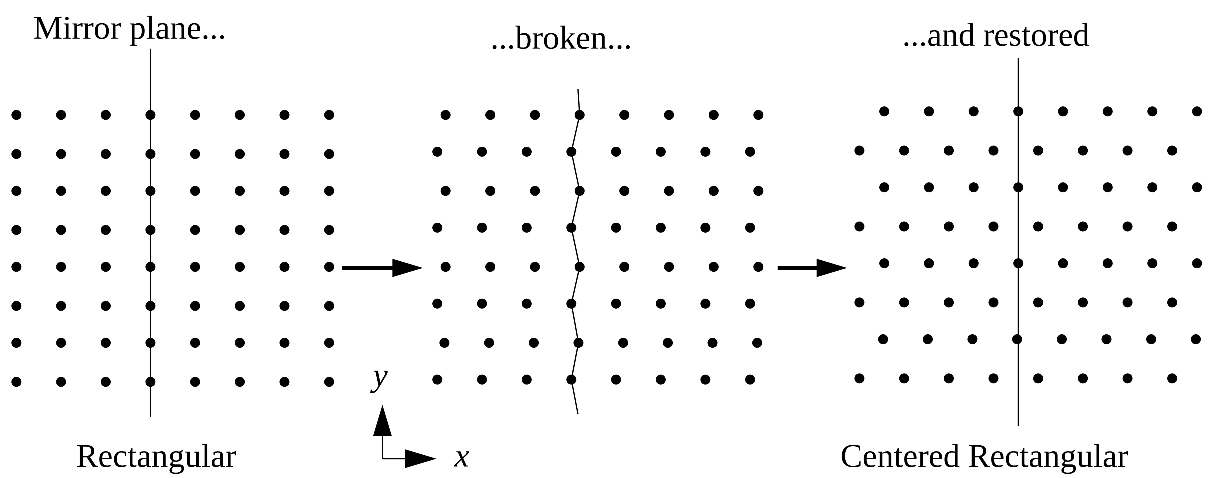


Puzzler: how does one construct bizarre–shaped cells that tile the plane?



Q: What makes lattices the same or different?

A: Two lattices are the same if one can be tranformed continuously into the other without changing any symmetry operations along the way.

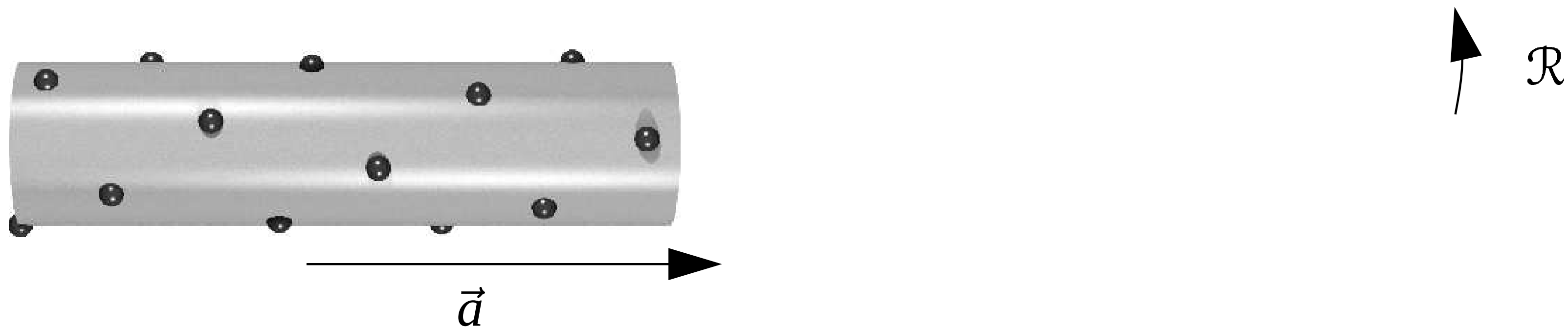


Operations

$$\mathbf{G} = \vec{a} + \mathcal{R}(\hat{n}, \theta). \tag{L3}$$

that leave lattice invariant.

Two important subgroups: translation and point groups. The full space group cannot be formed from these because of glide lines and Screw axes.



$$S\mathcal{R}S^{-1} + S^{-1}\vec{a} = \mathcal{R}' + \vec{a}'. \tag{L4}$$

$$S_t = (1-t) + St, \tag{L5}$$

Questions

Q: How many distinct Bravais lattices are there?

A: Five

Q: How many distinct two-dimensional lattices are there?

A: Seventeen. They are enumerated at `http://www2.spsu.edu/math/tile/index.htm` or `http://www.clarku.edu/~djoyce/wallpaper/`