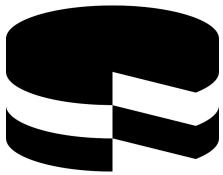
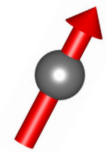
Symmetry as the guiding principle

polarimetry and birefringence



quasicrystals

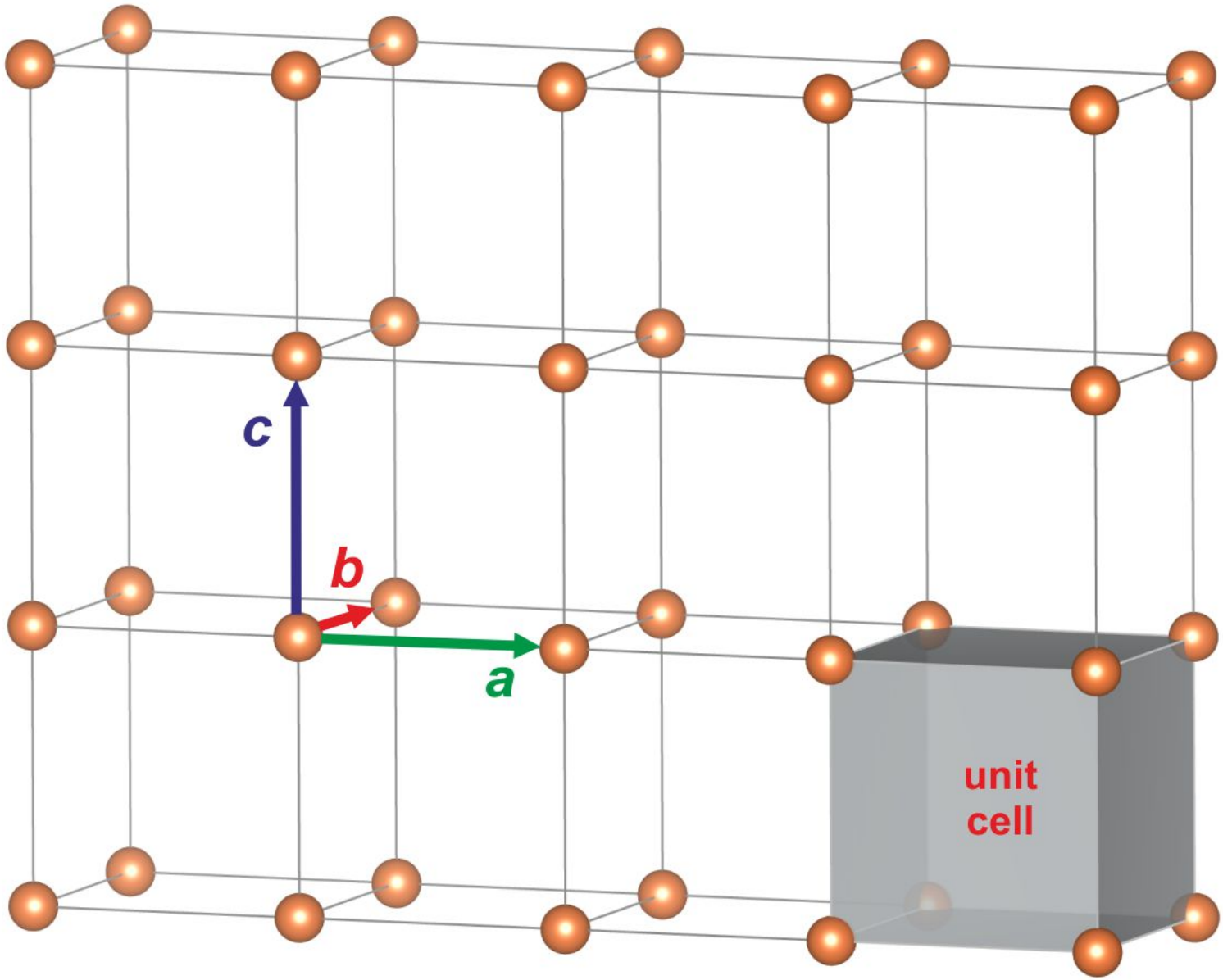
Dan Shechtman



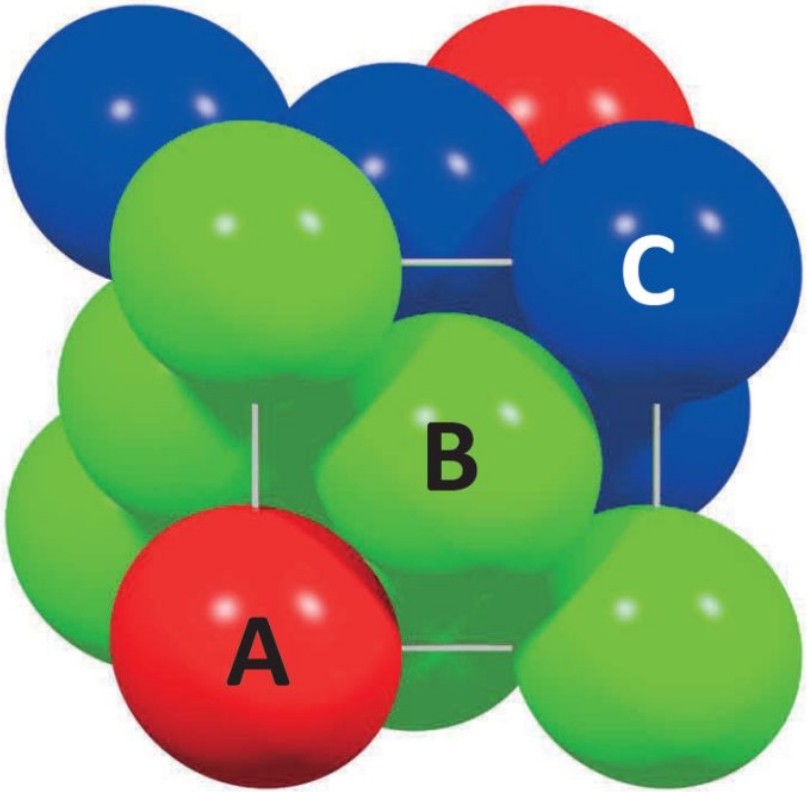
by Alexander Tsirlin, Leipzig University

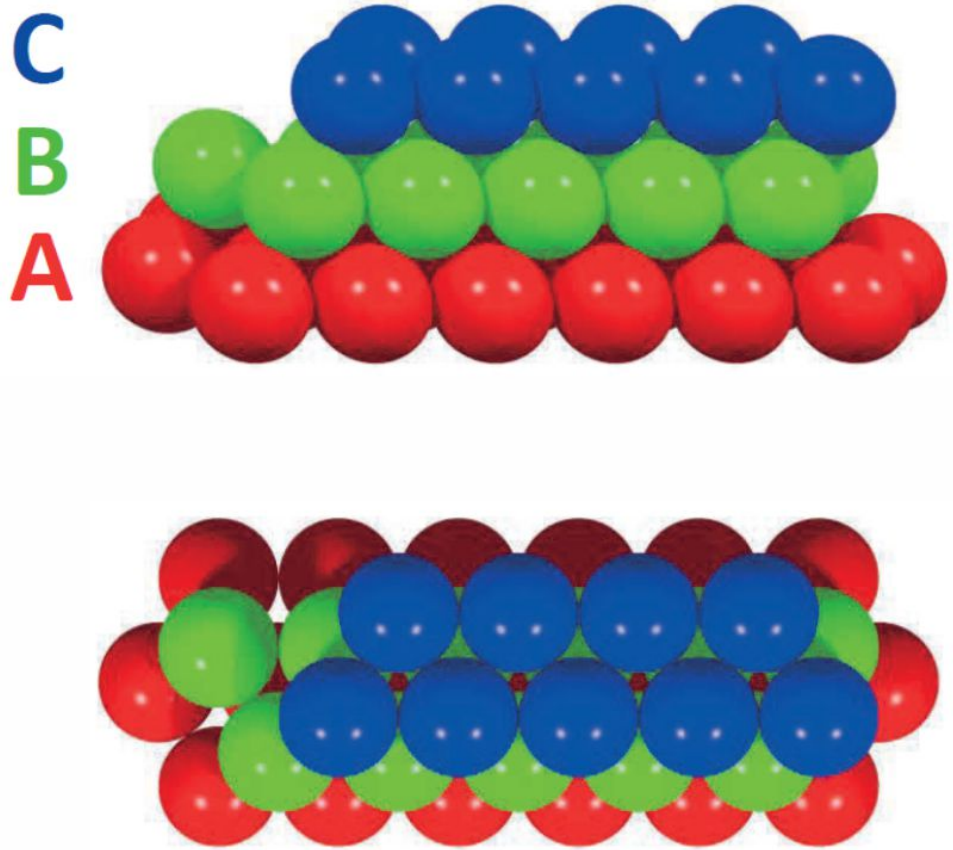
Lecture 2: October 12, 2023

Simple cubic lattice



Close packing: ABCABC



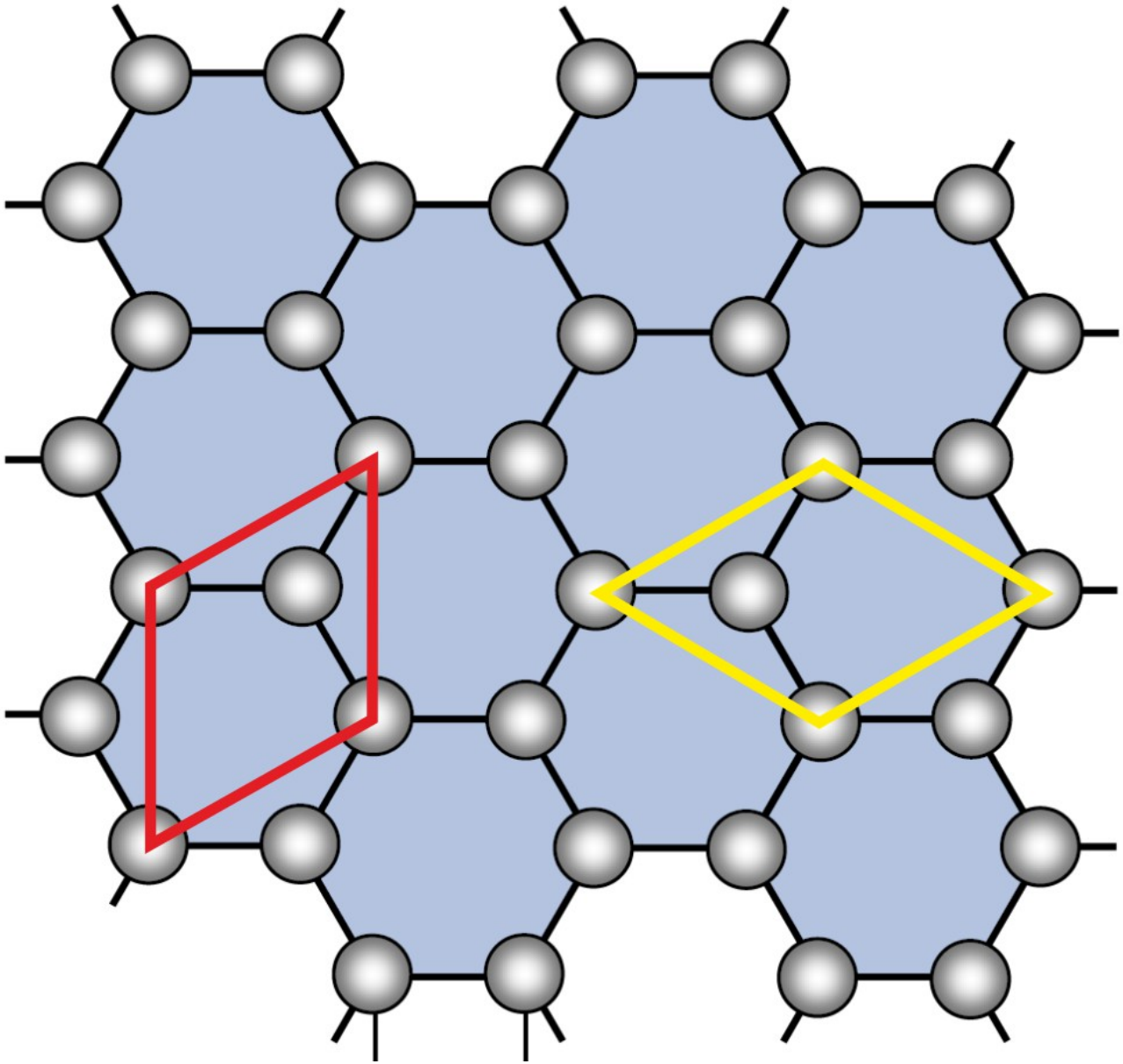


fcc (face-centered cubic) structure

entails additional translations along half of the face diagonal

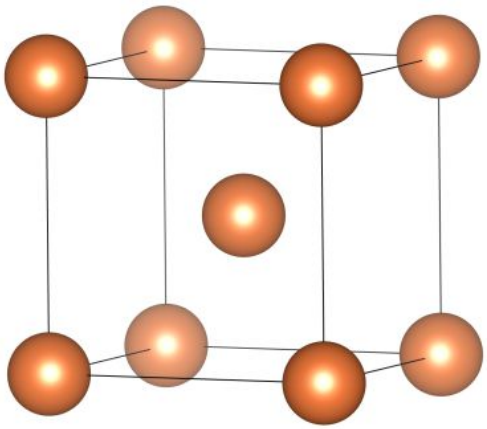
Image from Gross and Marx, Festkörperphysik

Honeycomb lattice again

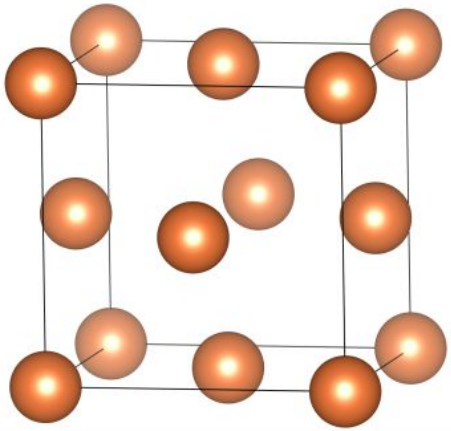


60° **rotation**

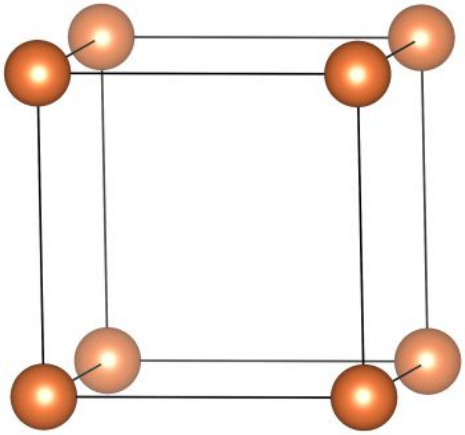
Image credit: Thomas Bresson (CC-BY-SA) and S. Hunklinger, Festkörperphysik



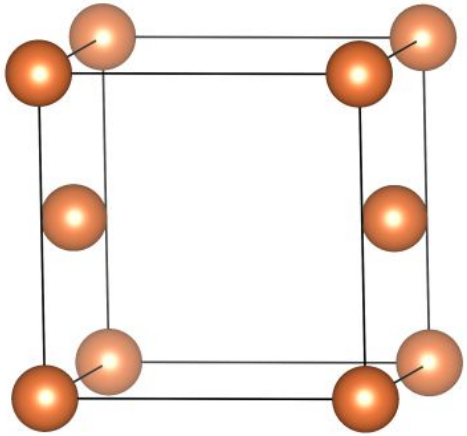
Body-centering (I)



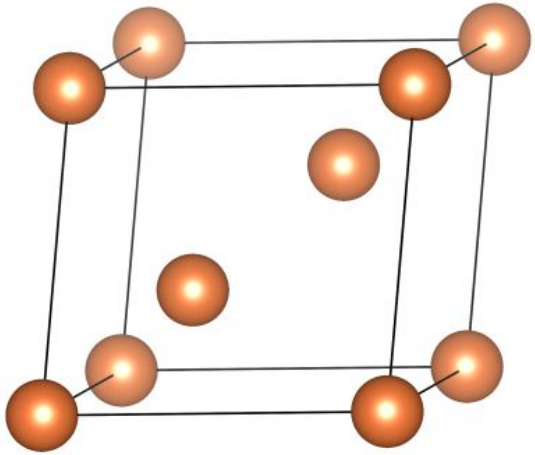
Face-centering (F)



Primitive (P)

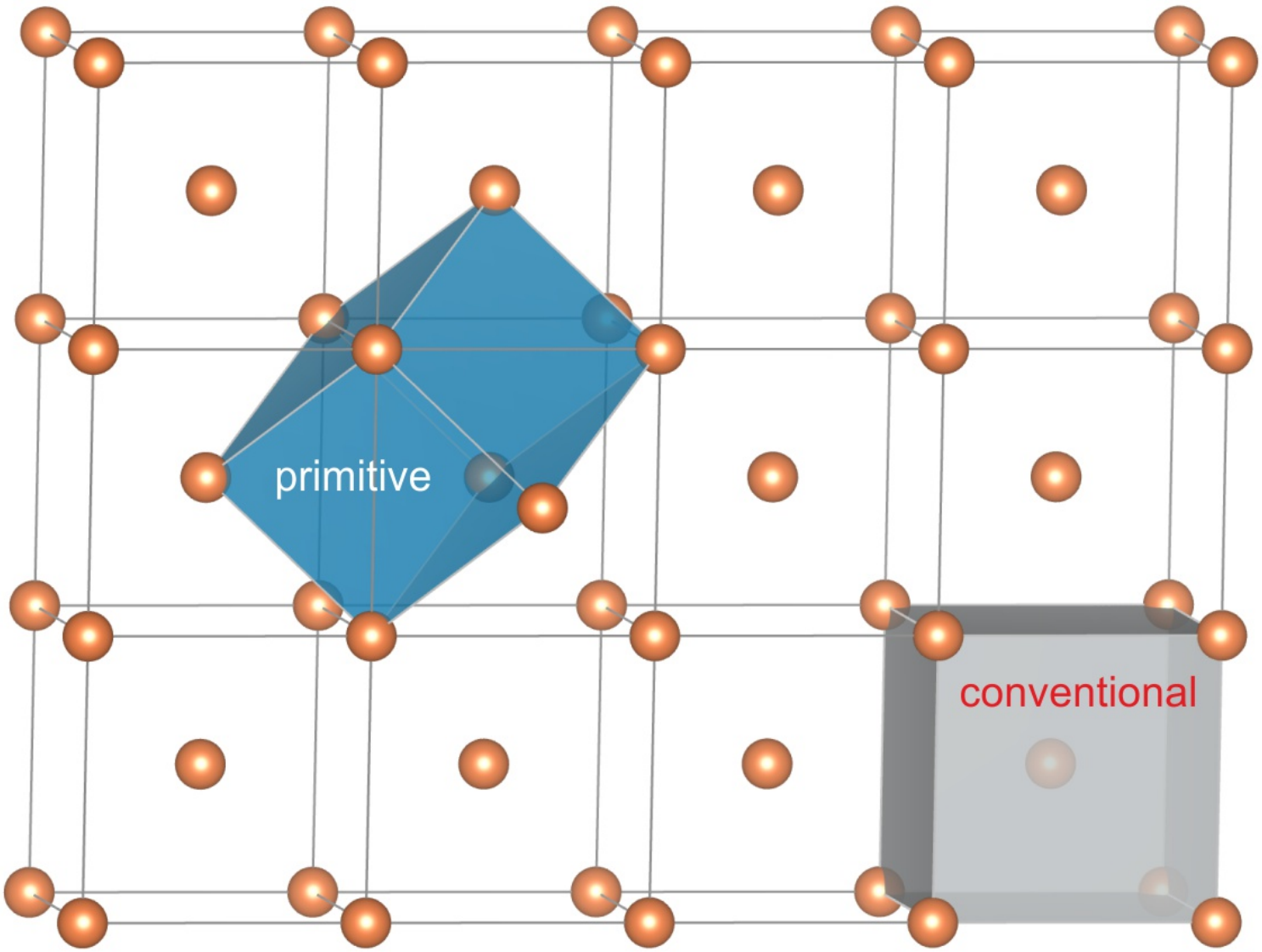


Base-centering (A, B, C)



Rhombohedral (R)

Primitive vs. conventional unit cell



Structures of simple metals

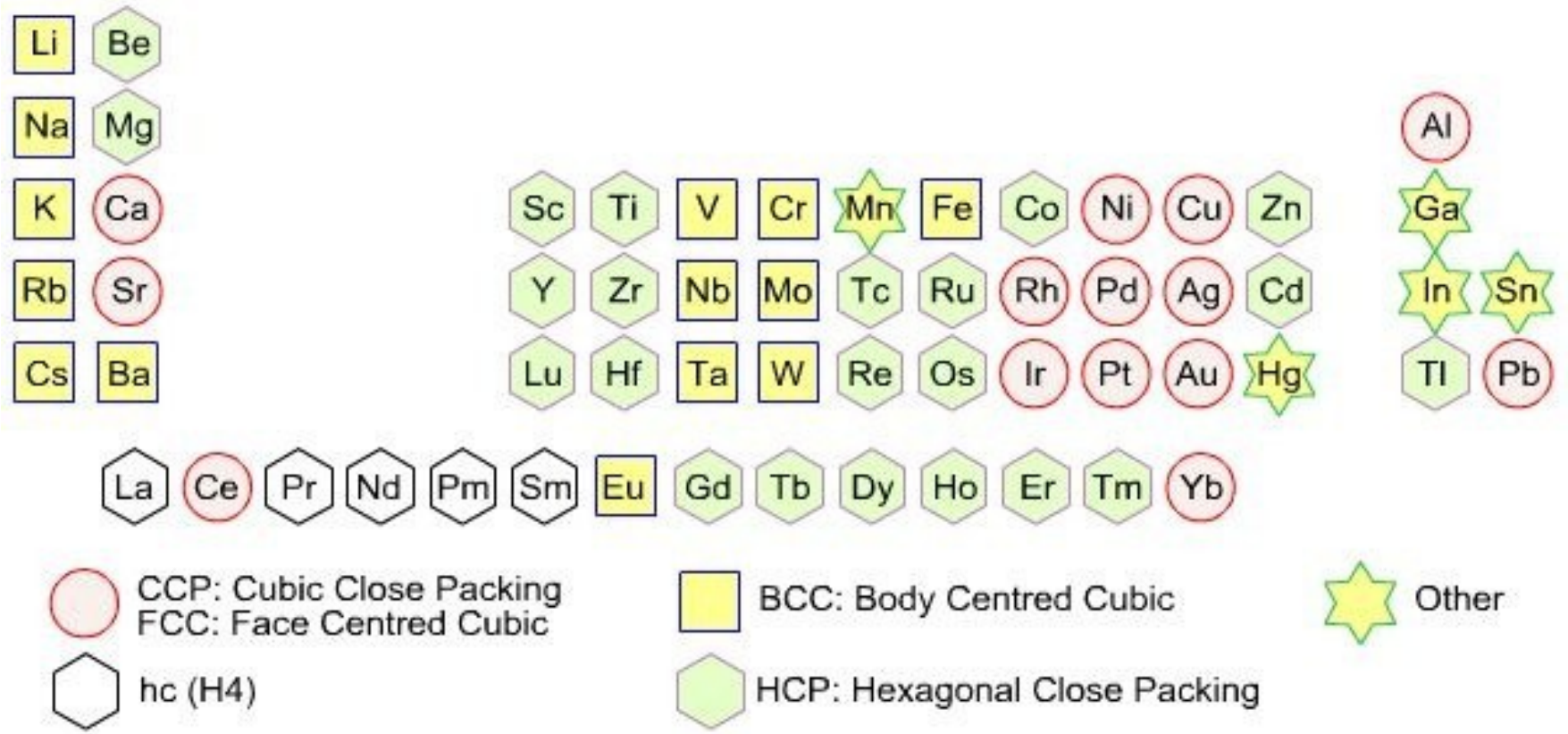
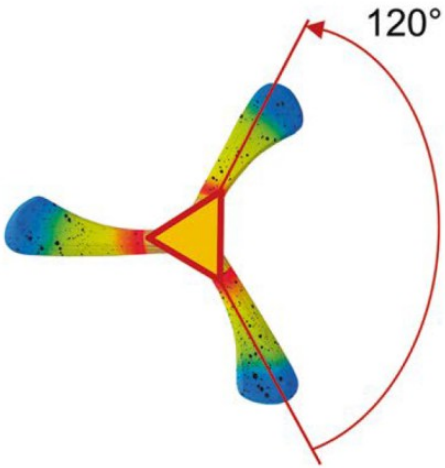
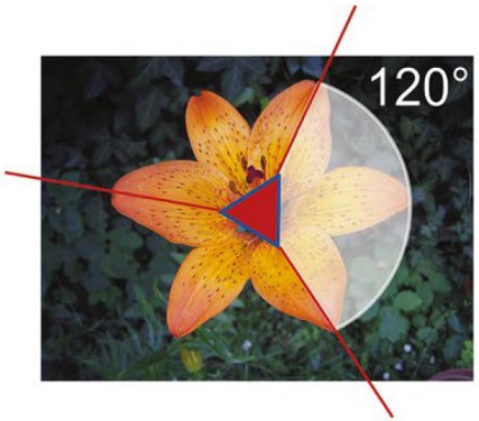


Image by Jeanne Paquette (fair use)



3-fold rotation axis

3



3-fold rotation axis

3

5-fold rotation axis

5

∞-fold rotation axis

Schönflies notation: $C_2,\ C_3,\ C_4,\ C_6$

Hermann-Mauguin notation: 2, 3, 4, 6

Example $(2 \parallel b)$: $x, y, z \longrightarrow \bar{x}, y, \bar{z}$

Image credit: F. Hoffmann, Faszination Kristalle und Symmetrie

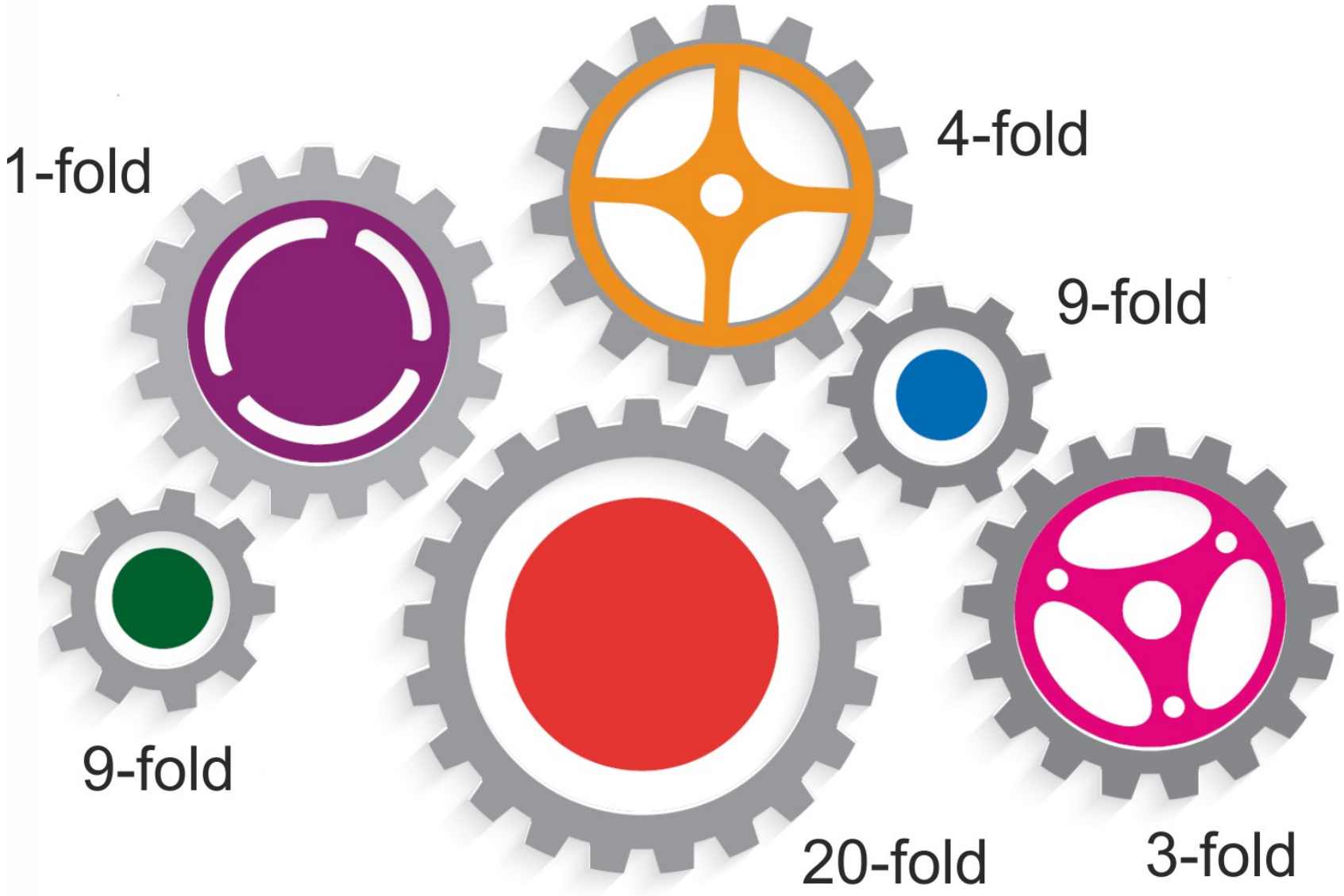
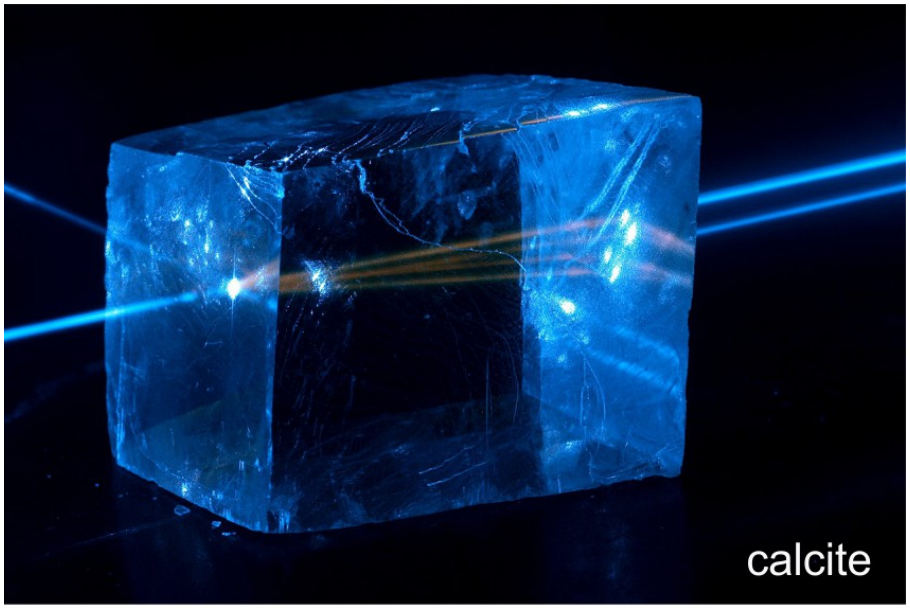


Image credit: F. Hoffmann, Faszination Kristalle und Symmetrie

Experimental technique

polarimetry and birefringence

Birefringence



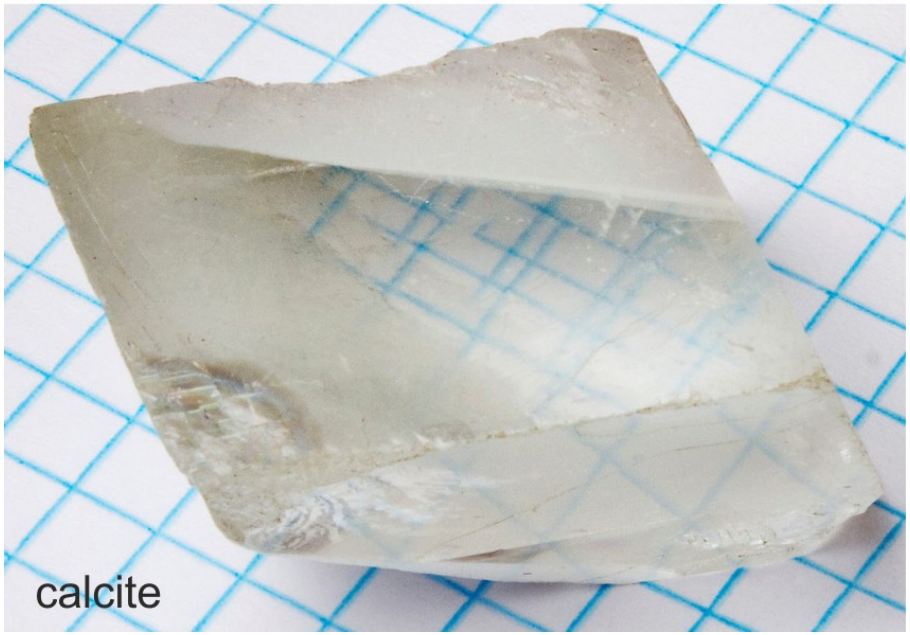
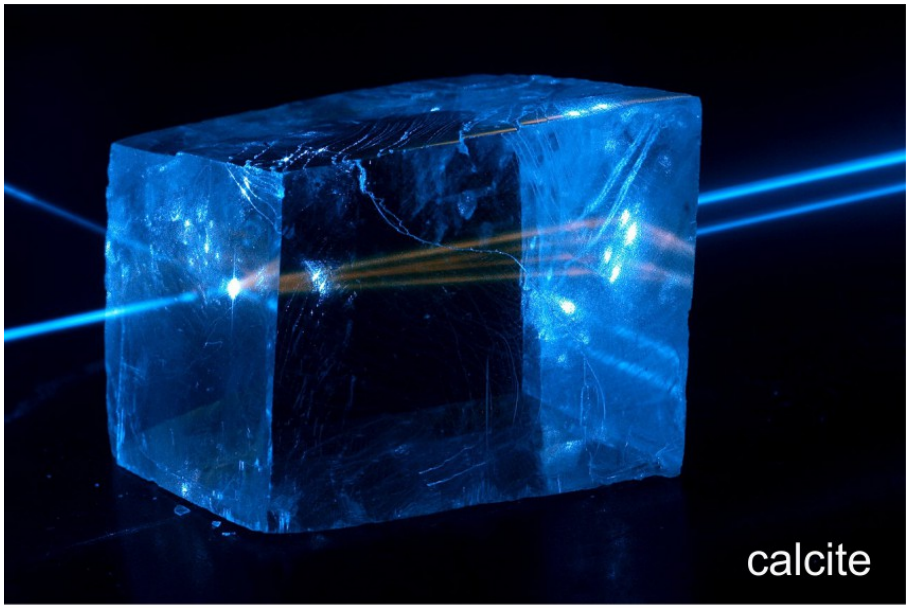
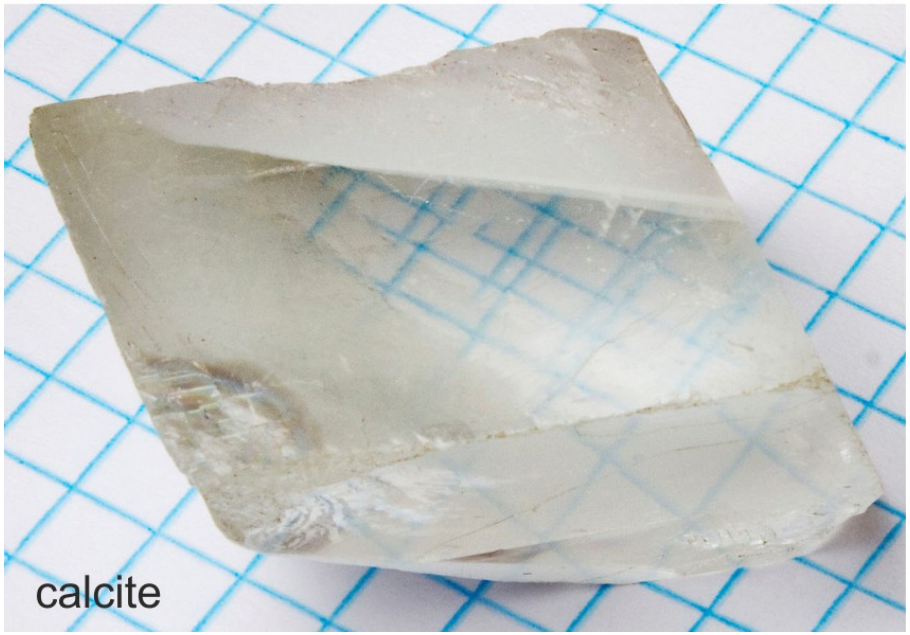


Image credits: Jan Pavelka, APN MJM, Mikael Häggström (CC-BY-SA)

Birefringence





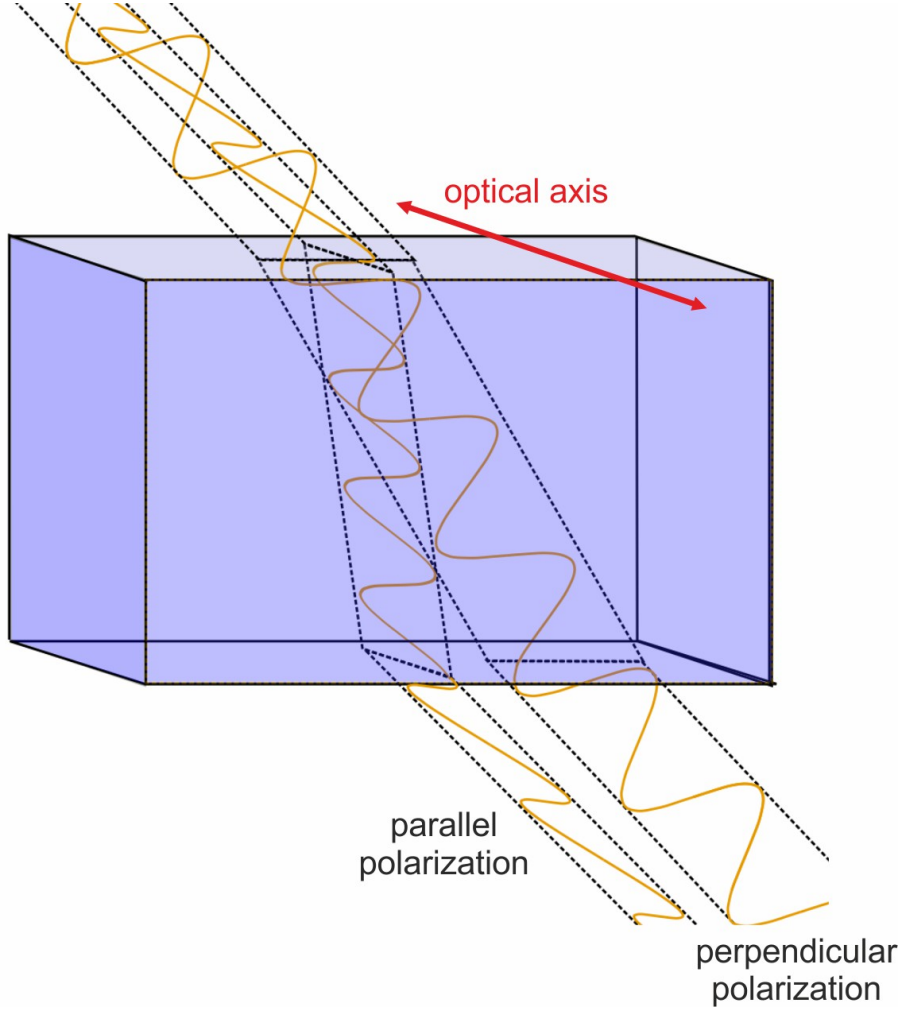
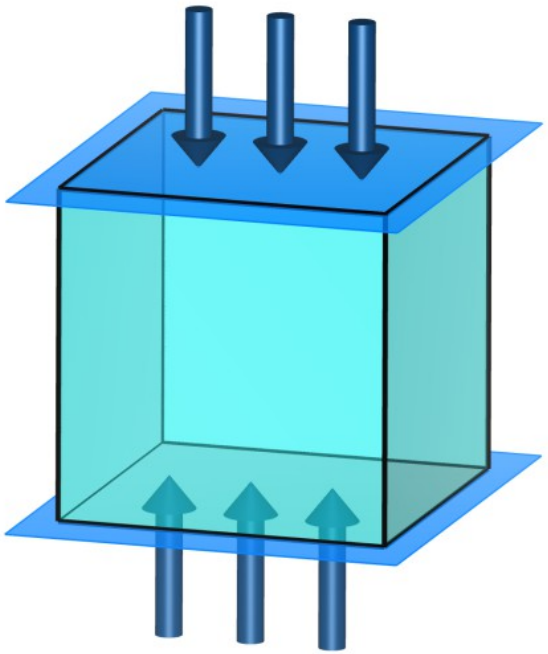


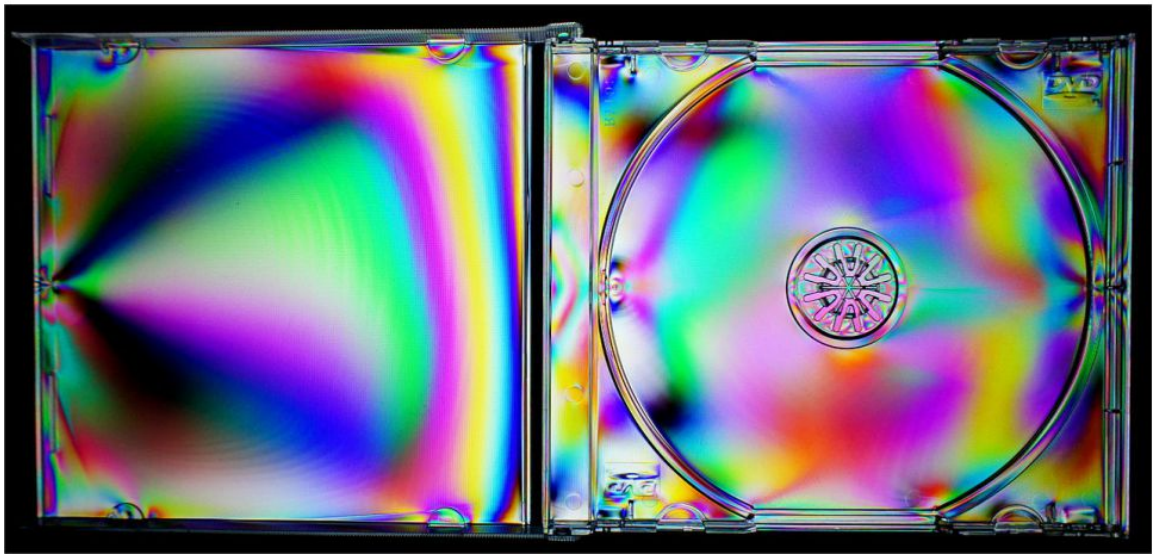
Image credits: Jan Pavelka, APN MJM, Mikael Häggström (CC-BY-SA)

Material	Crystal system	n_o	n_e	Δn
barium borate BaB_2O_4	Trigonal	1.6776	1.5534	−0.1242
beryl $Be_3Al_2(SiO_3)_6$	Hexagonal	1.602	1.557	−0.045
calcite $CaCO_3$	Trigonal	1.658	1.486	−0.172
ice H_2O	Hexagonal	1.3090	1.3104	+0.0014[12]
lithium niobate $LiNbO_3$	Trigonal	2.272	2.187	−0.085
magnesium fluoride MgF_2	Tetragonal	1.380	1.385	+0.006
quartz SiO_2	Trigonal	1.544	1.553	+0.009
ruby Al_2O_3	Trigonal	1.770	1.762	−0.008
rutile TiO_2	Tetragonal	2.616	2.903	+0.287
sapphire Al_2O_3	Trigonal	1.768	1.760	−0.008
silicon carbide SiC	Hexagonal	2.647	2.693	+0.046

Birefringence as a fingerprint of structural anisotropy

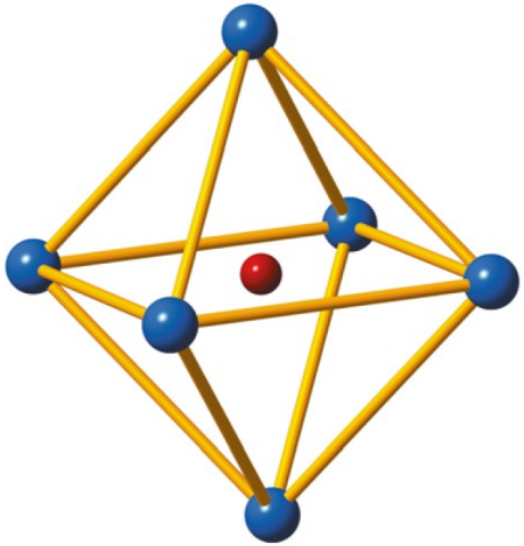
Sources: Wikipedia and Daigger Scientific (fair use)

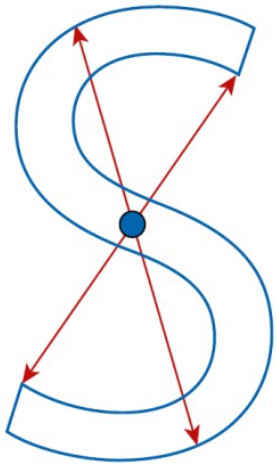


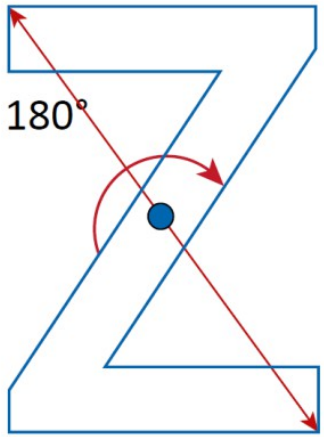


Birefringence due to stress

Image credits: 3465 and Mk2010 (CC-BY-SA)

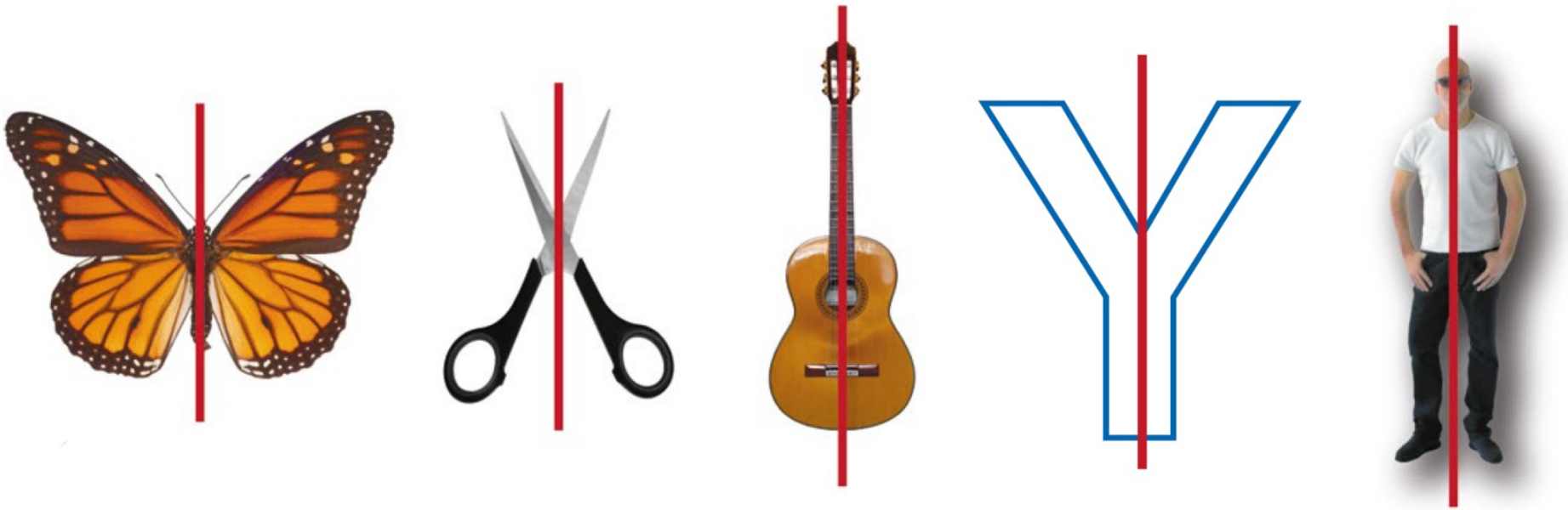






Schönflies notation:	i
Hermann-Mauguin notation:	$\bar{1}$ or -1
Example:	$x, y, z \longrightarrow \bar{x}, \bar{y}, \bar{z}$

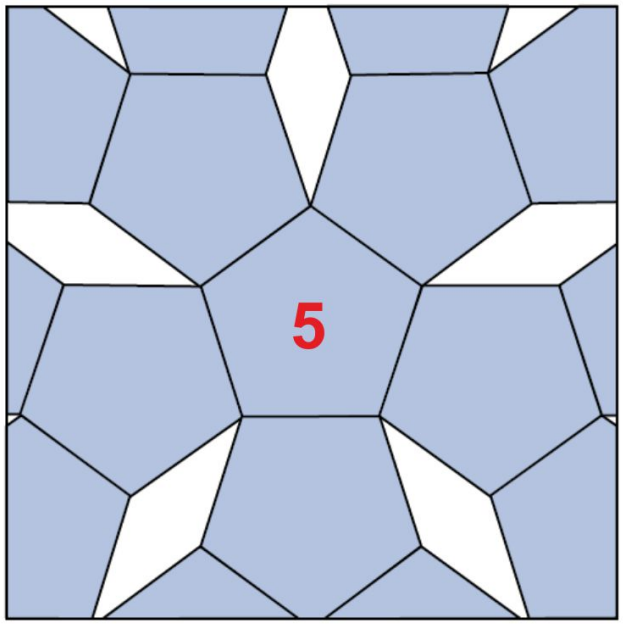
Image credit: F. Hoffmann, Faszination Kristalle und Symmetrie

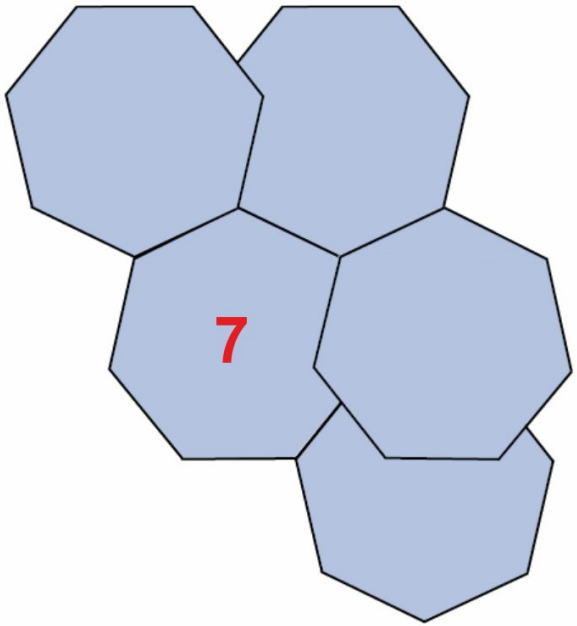


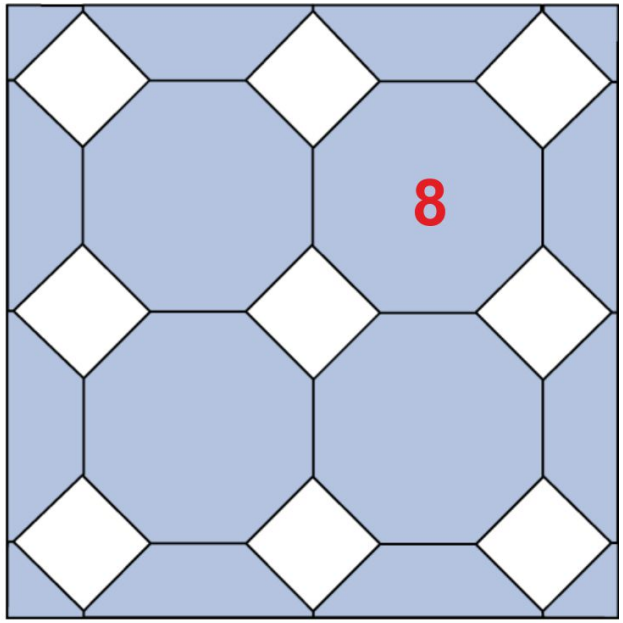
Schönflies notation:	σ_h or σ_v
Hermann-Mauguin notation:	m
Example ($m \perp b$):	$x, y, z \longrightarrow x, \bar{y}, z$

Image credit: F. Hoffmann, Faszination Kristalle und Symmetrie

Forbidden symmetry elements







Only 2, 3, 4, and 6-fold rotations are compatible with periodicity

any other rotations are forbidden in crystals

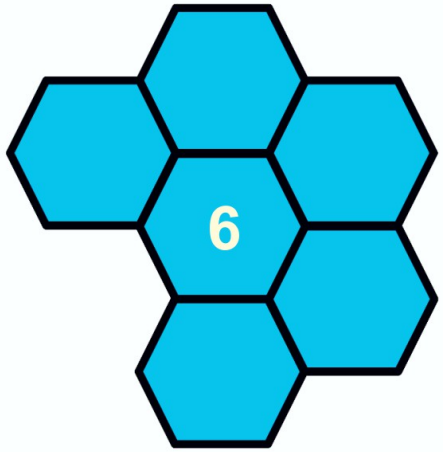
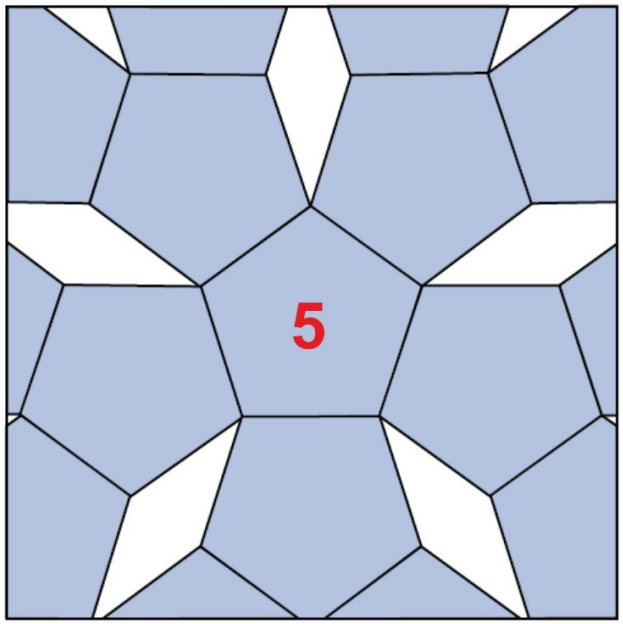
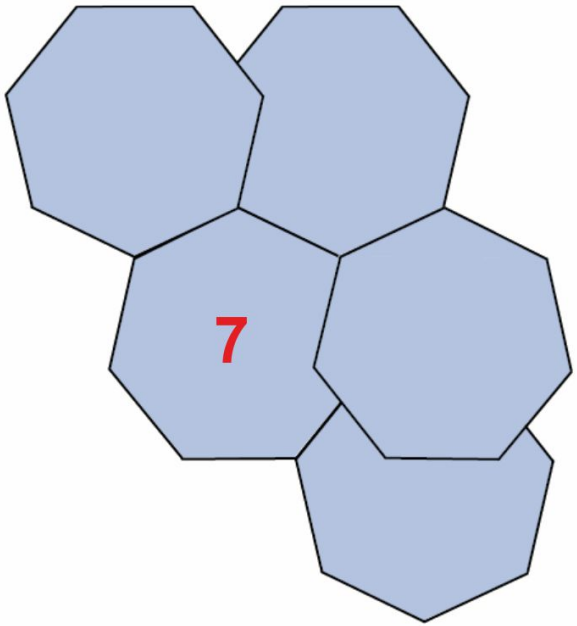
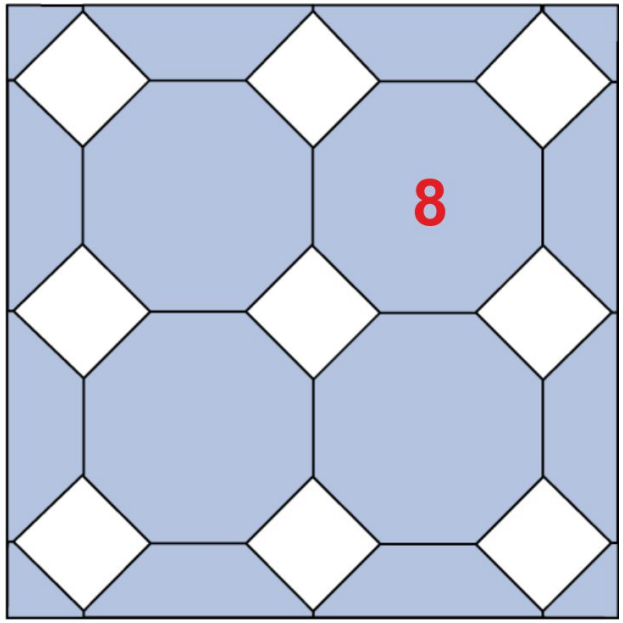


Image credit: S. Hunklinger, Festkörperphysik

Forbidden symmetry elements







Only 2, 3, 4, and 6-fold rotations
are compatible with periodicity

any other rotations are forbidden in
conventional crystals

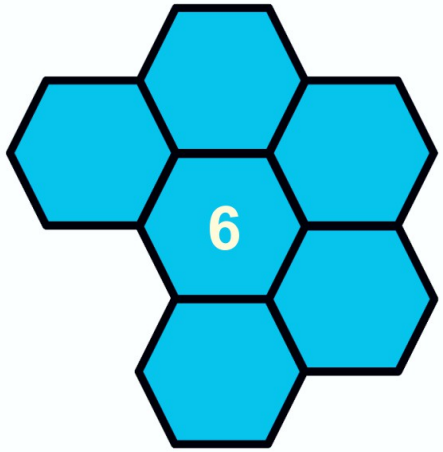
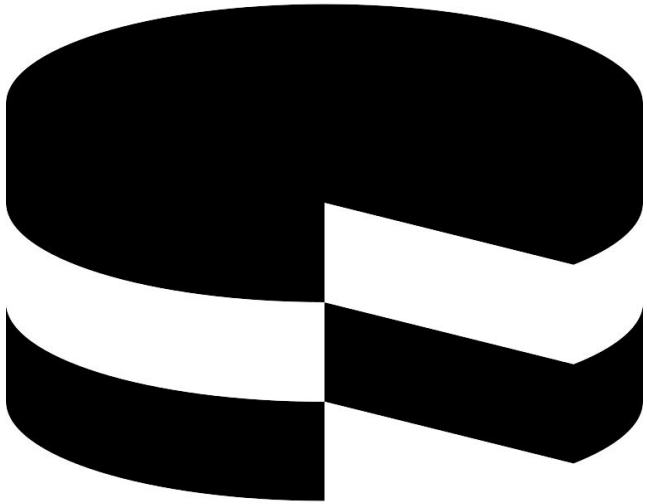


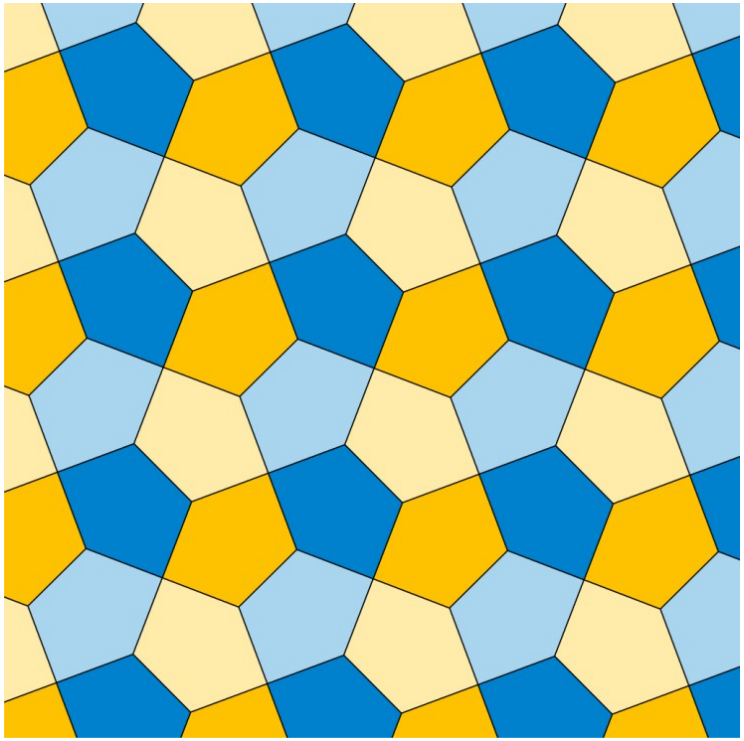
Image credit: S. Hunklinger, Festkörperphysik



Material

Quasicrystals

Pentagonal tilings

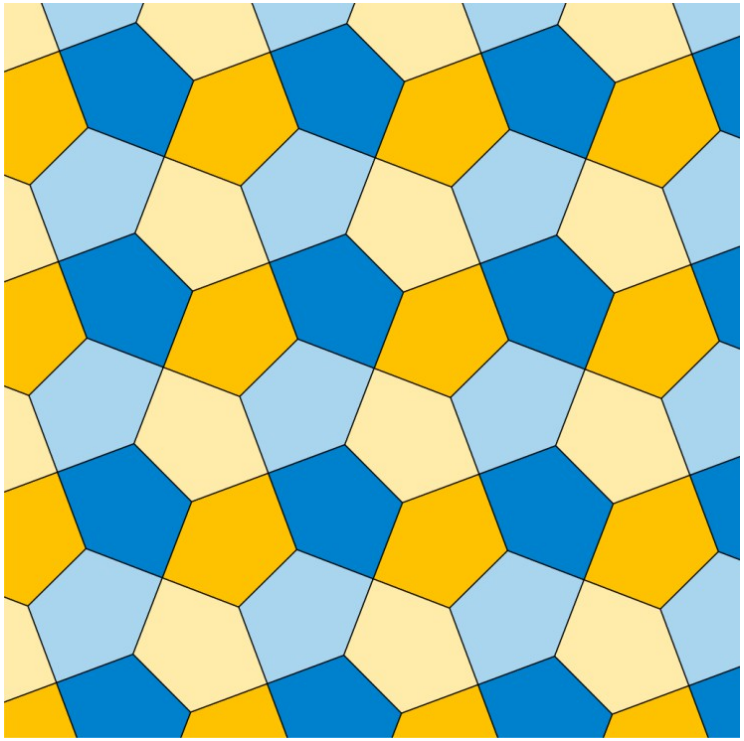


Cairo lattice

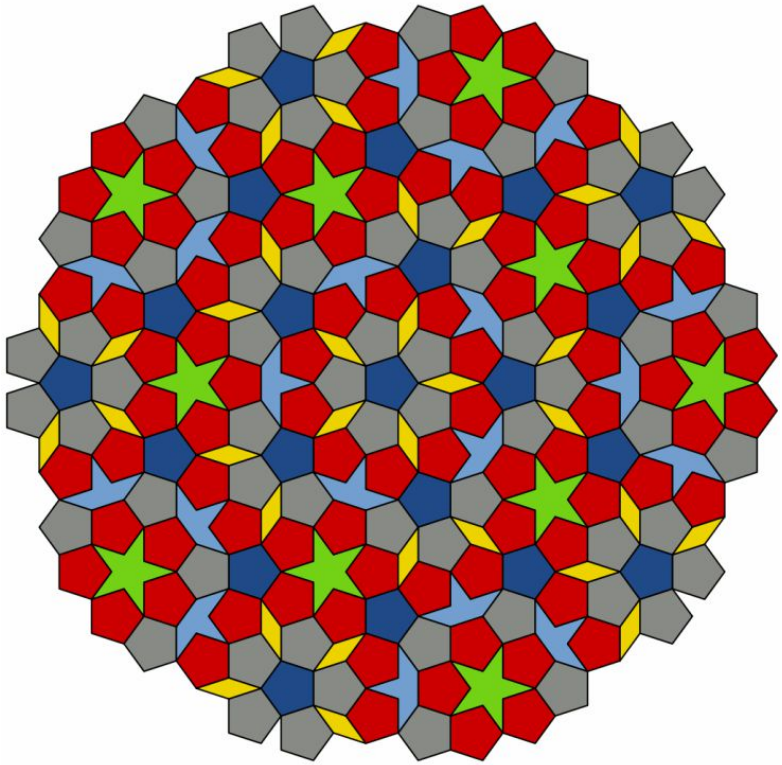
Pentagons must be deformed

Image credits: Inductiveload (CC-zero), David Eppstein (CC-zero), Parabola 52, 1 (2019)

Pentagonal tilings



Cairo lattice

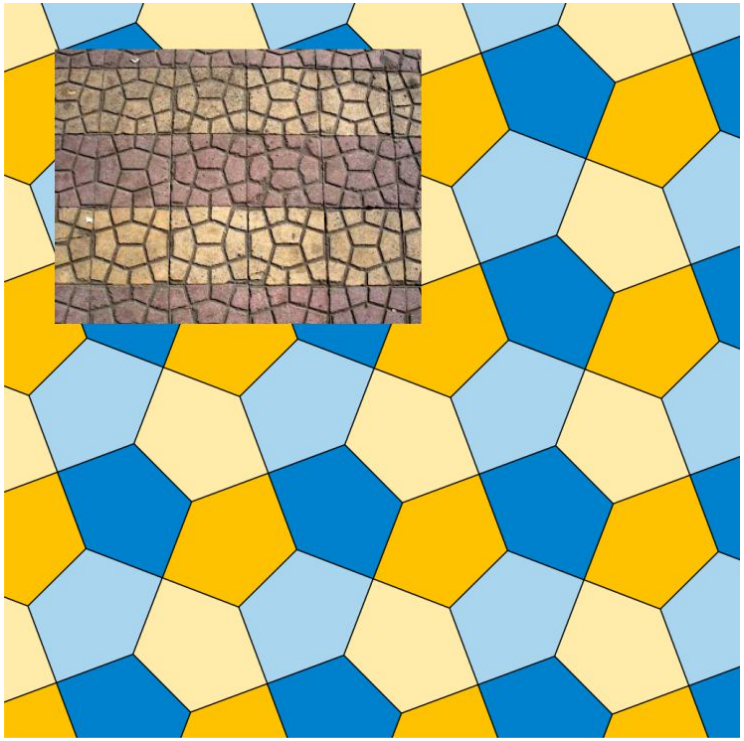


Penrose tiling

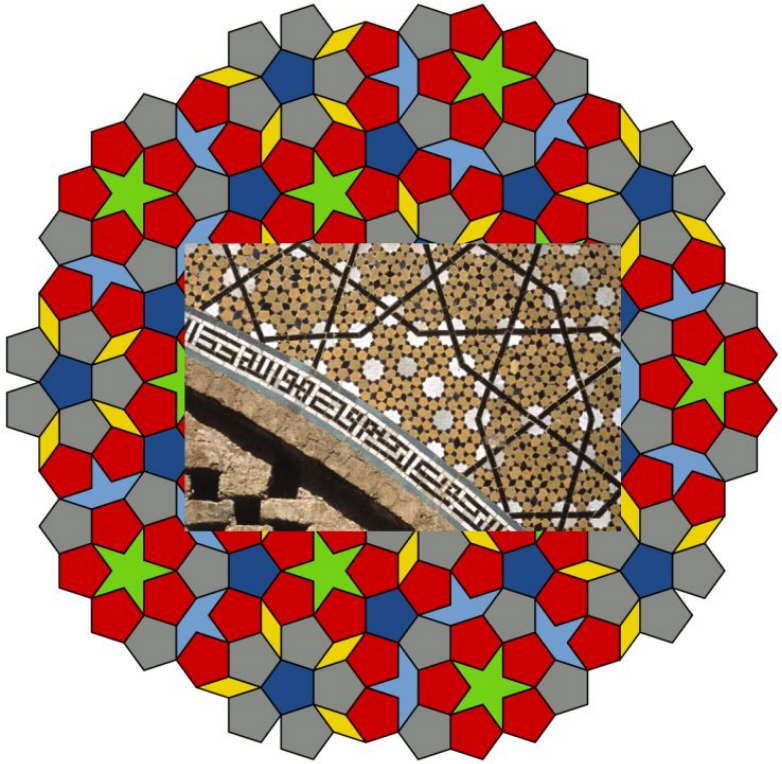
Pentagons must be deformed, or one should **give up the periodicity**

Image credits: Inductiveload (CC-zero), David Eppstein (CC-zero), Parabola 52, 1 (2019)

Pentagonal tilings



Cairo lattice



Penrose tiling

Pentagons must be deformed, or one should **give up the periodicity**

Image credits: Inductiveload (CC-zero), David Eppstein (CC-zero), Parabola 52, 1 (2019)

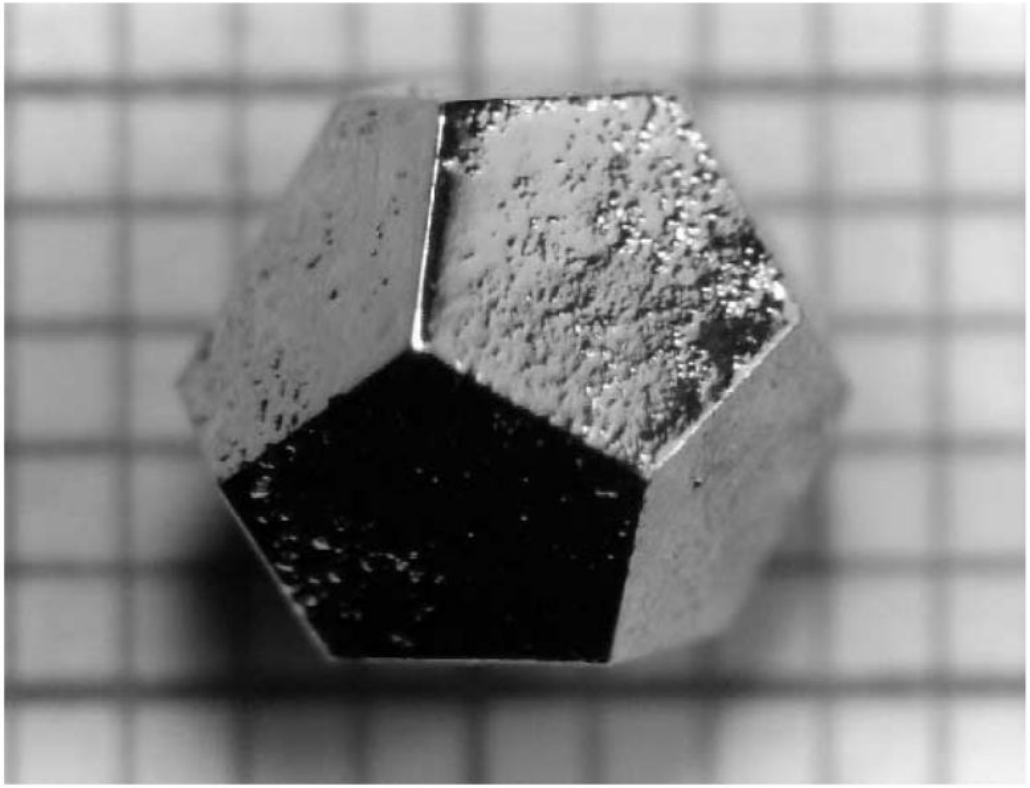
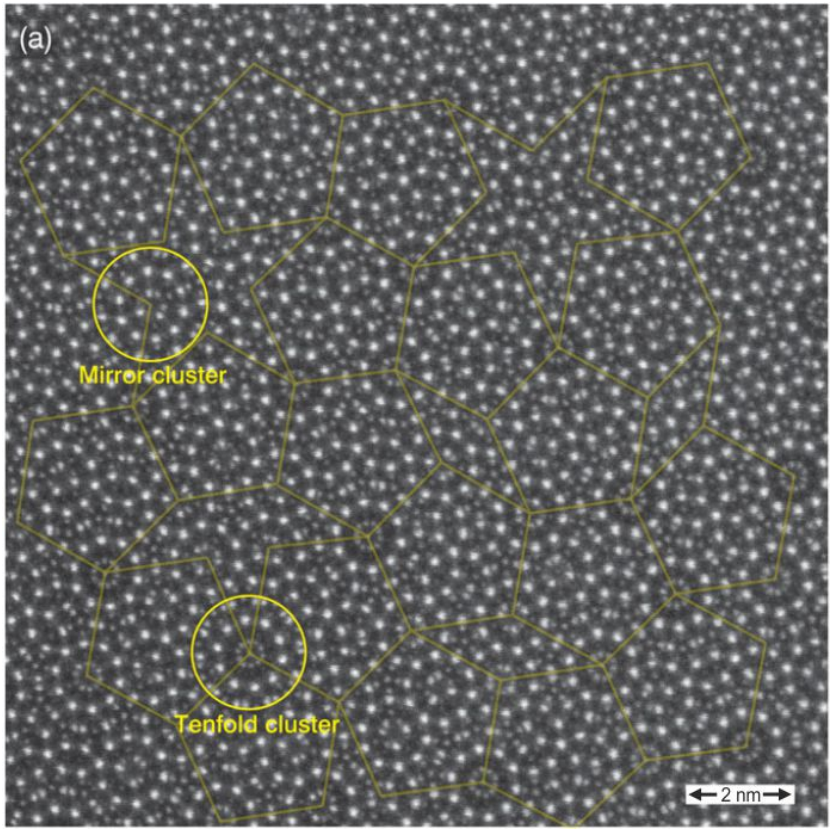


Photo of $Ho_9Mg_{34}Zn_{57}$
on the mm-grid



HAADF-STEM image
of $Al_{58}Cu_{26}Ir_{16}$

Five-fold symmetry and no periodicity, an **aperiodic crystal**

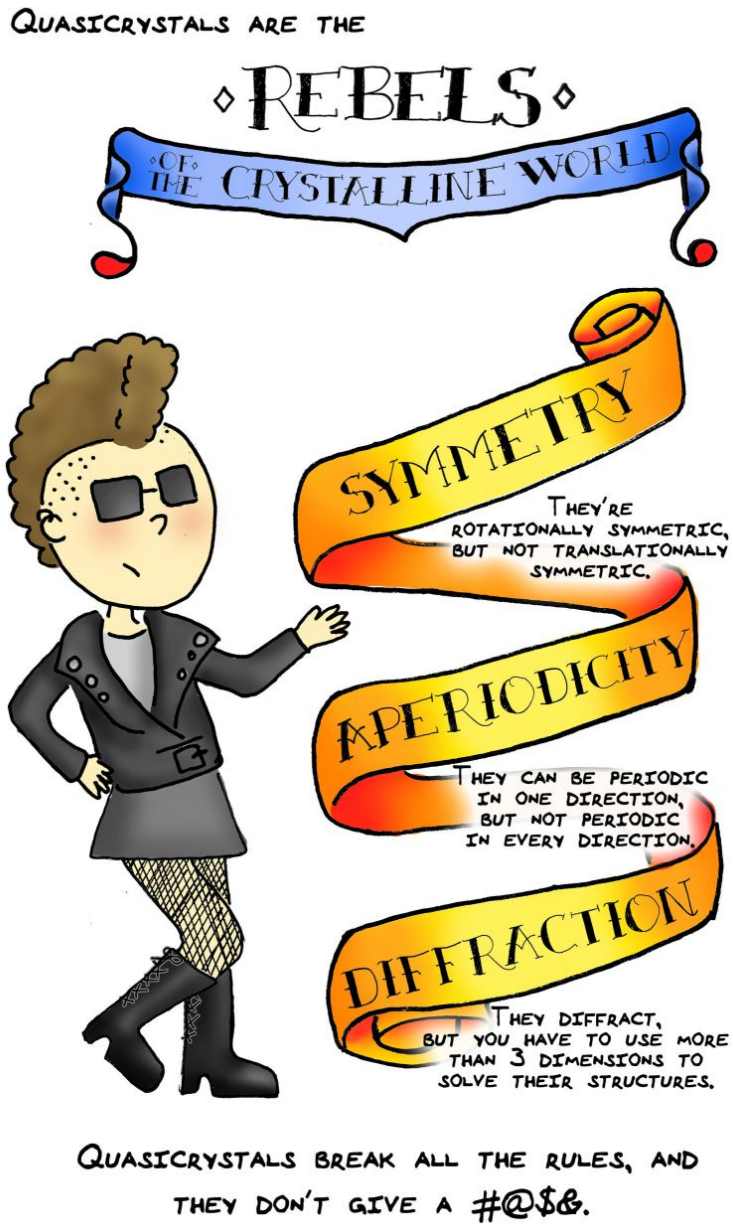
Image credits: J. Cryst. Growth 225, 155 (2001) and Microscopy 64, 341 (2015)

Icosahedrite
(Khatyrka meteorite)
$Al_{63}Cu_{24}Fe_{13}$

Frying pan with
quasicrystalline coating

Image credits: mindat.org and Fundamentals of Friction and Wear (Springer, 2007)

Quasicrystals are rebels



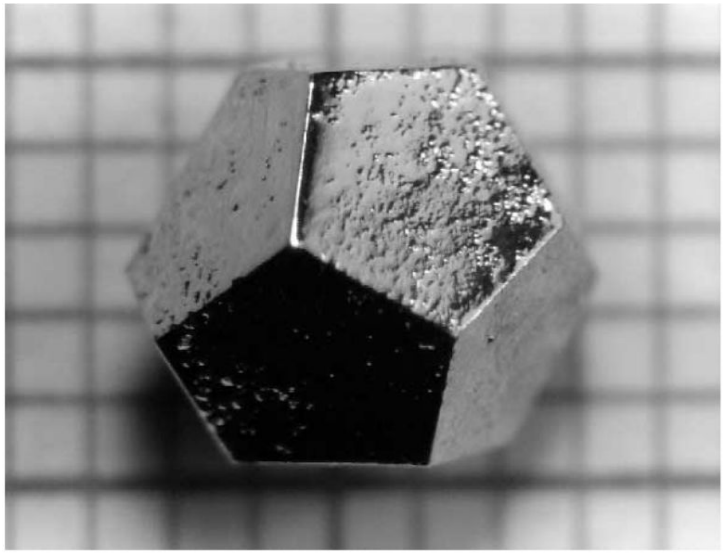


Image credits: Veronica M. Berns, Atomic size matters and J. Cryst. Growth 225, 155 (2001)

Person

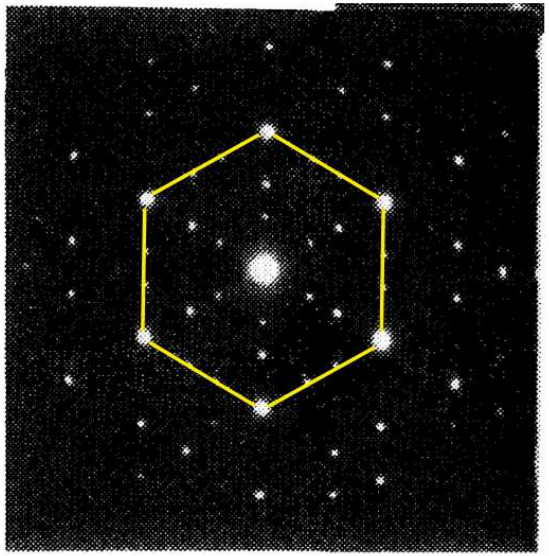
Dan Shechtman

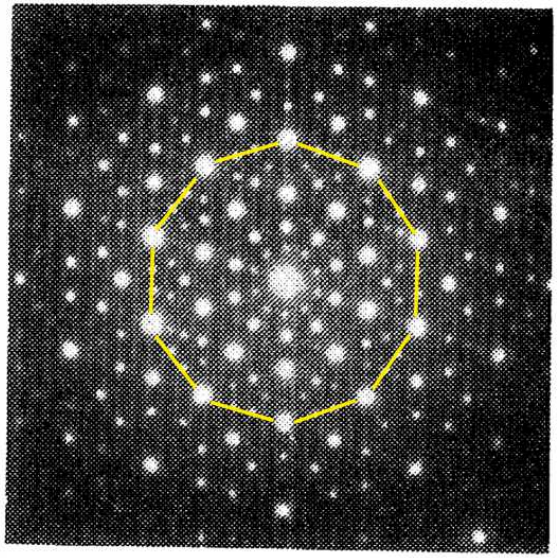
Dan Shechtman

- 1972: PhD in materials engineering, Technion – Israel Institute of Technology
- 1972-75: postdoc on airplane materials, at Aerospace Research Labs, Ohio, US
- from 1975: senior lecturer at Technion
- 1982: discovery of quasicrystals in $MnAl_6$

Dan Shechtman
born 1941

Difficult acceptance





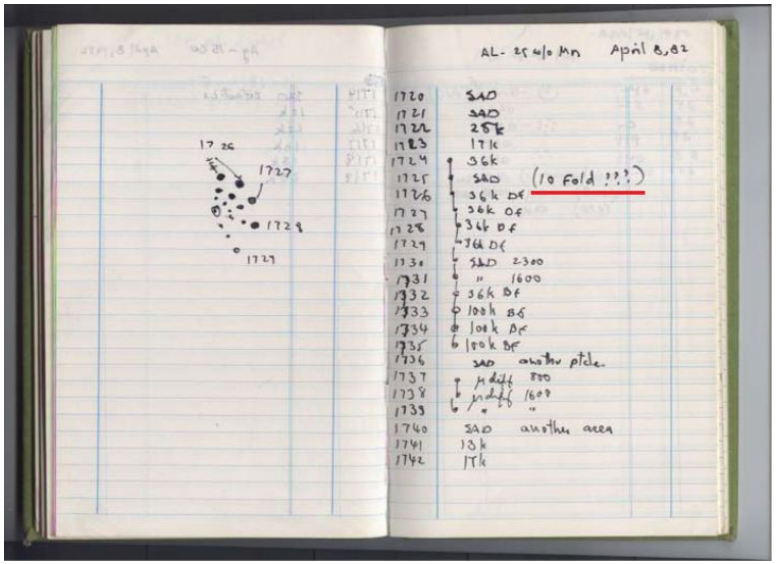
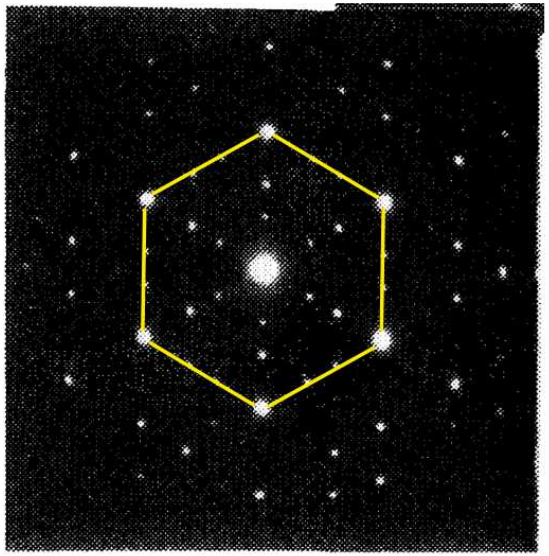
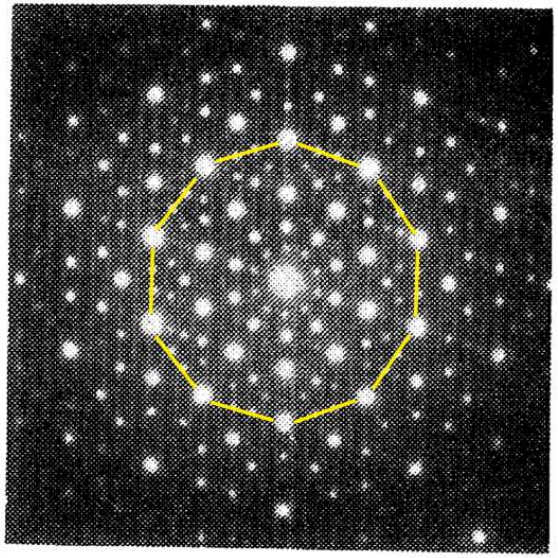


Image credit: Phys. Rev. Lett. 53, 1951 (1984), NIST

Difficult acceptance





Head of the lab gives him
a crystallography textbook,
then fires him for “bringing disgrace”

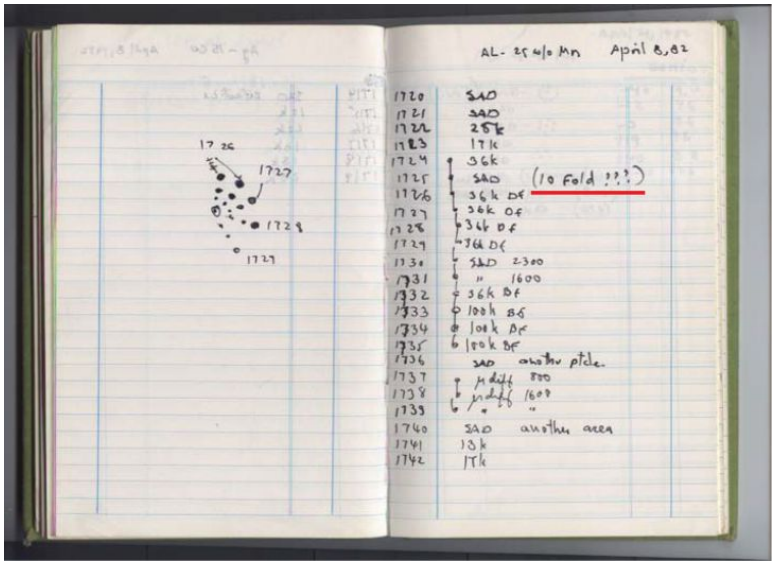
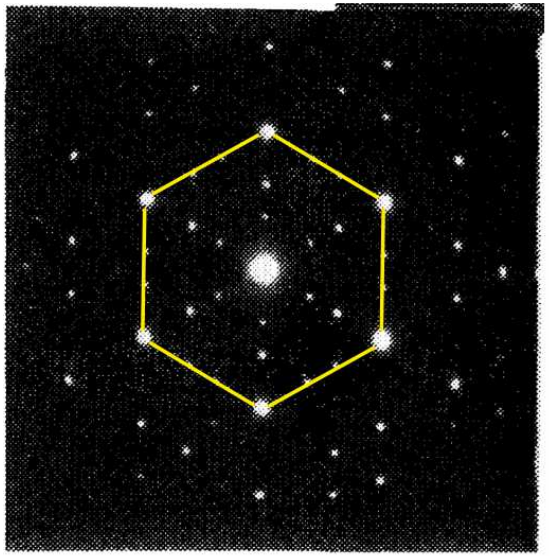
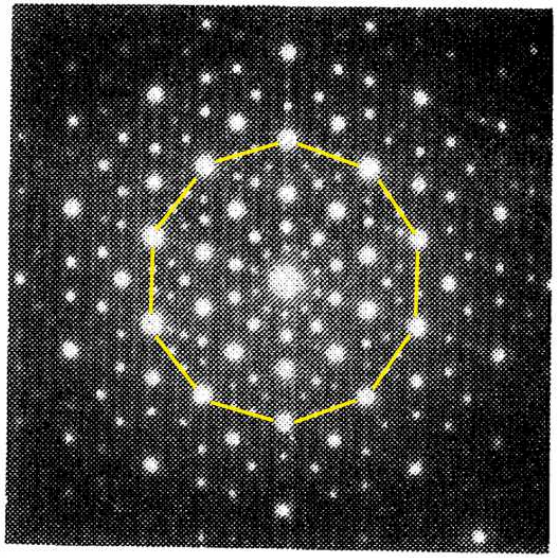
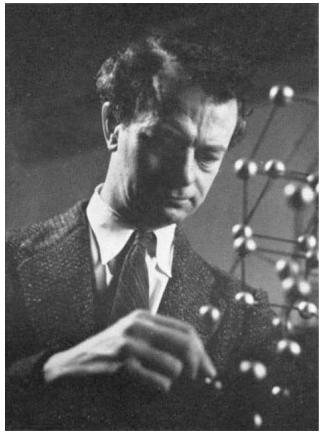


Image credit: Phys. Rev. Lett. 53, 1951 (1984), NIST

Difficult acceptance





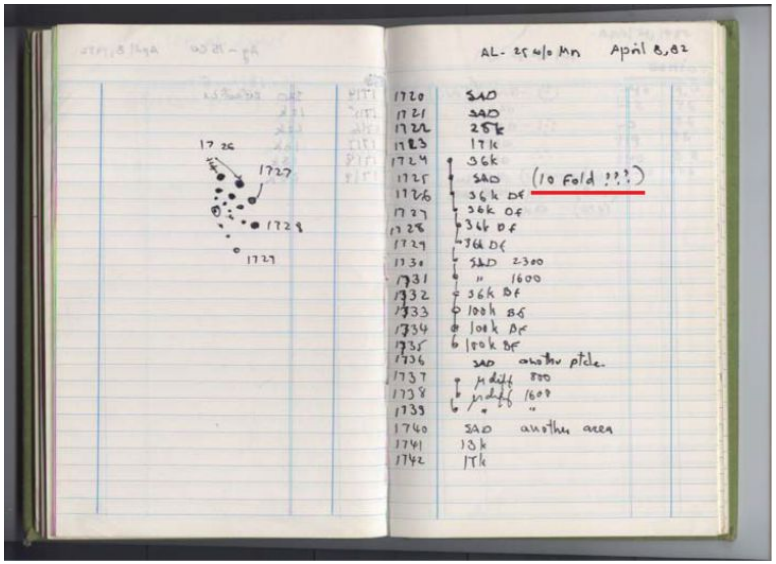


Linus Pauling

Head of the lab gives him
a crystallography textbook,
then fires him for “bringing disgrace”

Linus Pauling (2 Nobel prizes):

...no such things as quasicrystals,
there are only quasi-scientists



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Dan Shechtman

- 1972: PhD in materials engineering, Technion – Israel Institute of Technology
- 1972-75: postdoc on airplane materials, Aerospace Research Labs, Ohio, US
- from 1975: senior lecturer at Technion
- 1982: discovery of quasicrystals in $MnAl_6$
- from 1984: professor at Technion
- 2011: Nobel Prize in Chemistry
- 2014: ran for the President of Israel

Dan Shechtman
born 1941

Source: Technion - Israel Institute of Technology (CC-BY-SA), Wikipedia

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Candidate	Party	First round		Second round	
		Votes	%	Votes	%
Reuven Rivlin	Likud	44	37.6	63	54.3
Meir Sheetrit	Hatnuah	31	26.5	53	45.7
Dalia Itzik	Kadima	28	23.9		
Dalia Dorner	Independent	13	11.1		
Dan Shechtman	Independent	1	0.9		

Dan Shechtman
born 1941

Source: Technion - Israel Institute of Technology (CC-BY-SA), Wikipedia