MLL 100
Lec 2 Tuesday 29.07.2025

1. Sahnavavatu
2. The Emperor's New Clothes
3. Curious by Todd Kashdan
4. Acharyat Padmadatte
5. MLL100 Topics
6. Course related Videos (NPTEL)
7. Grading
8. Polyhedra: Platonic and Archemedian

ॐ सह नाववतु।

सह नौ भुनक्तु।

सह वीर्यं करवावहै।

तेजस्वि नावधीतमस्तु मा विद्विषाव है।

ॐ शान्तिः शान्तिः शान्तिः

om sahanā vavatu
saha nau bhunaktu
saha vīryam karavāvahai
tejasvinā vadhītamastu
mā vidvisāvahai
om śānti śānti śāntih

Om Saha Nau Avatu:

"May we both be protected."

Saha Nau Bhunaktu:

"May we both be nourished."

Saha Veeryam Karavaavahai: "

"May we work together with great energy."

Tejasvi Naavdhitamastu: '

"May our studies be filled with brilliance

Maa Vidvishavahai:

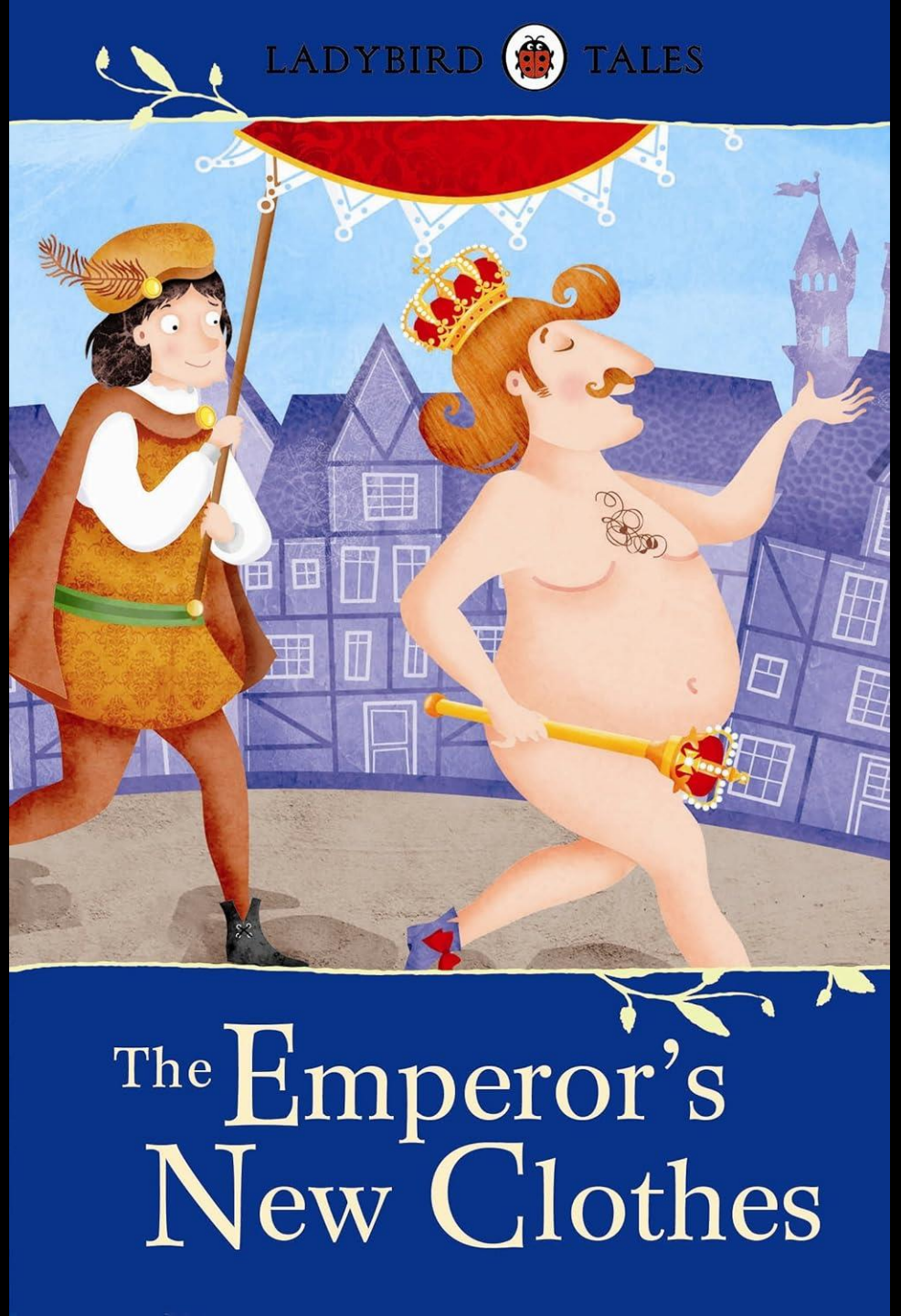
"May there be no animosity between us

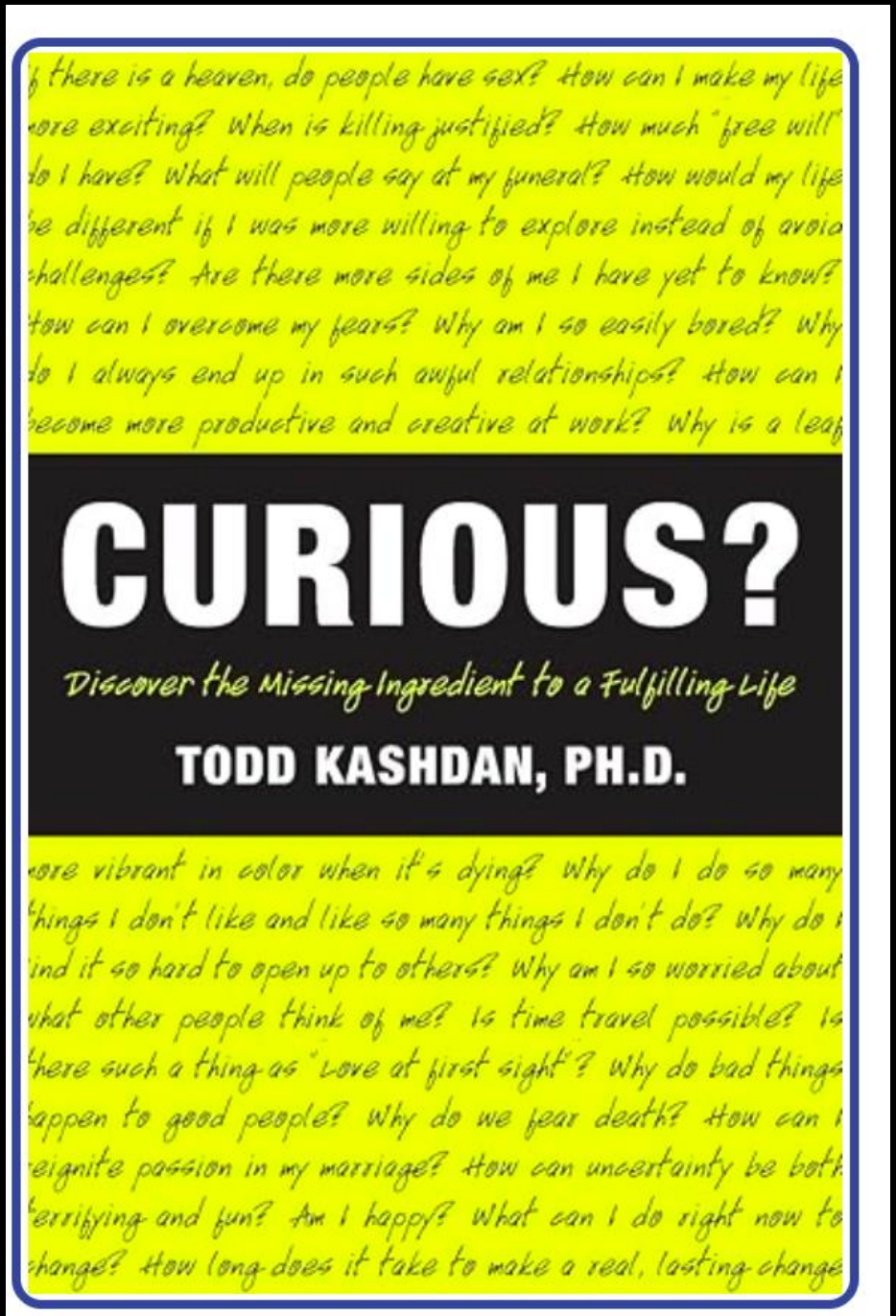
May our studies be filled with brilliance.

What is best method to study?

What is best method to teach?

ANS: To ask question.


LADYBIRD TALES
The Emperor's New Clothes



Q: What is the central ingredient to creating a fulfilling life?

A: Curiosity.

Teacher
1/4

Self-study
1/4

आचार्यात् पादमादत्ते पादं शिष्यः स्वमेधया ।
सब्रह्मचारिभ्यः पादं पादं कालक्रमेण च ॥

Co-students
1/4

Time and
experience
1/4

तेजस्वि नावधीतमस्तु

May there be no animosity between us

तेजस्वि नावधीतमस्तु

May there be no animosity between us

Rajesh Prasad

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MLL100

Introduction to Materials Science and Engineering

3-0-2

APL102: Introduction to Materials Science and Engineering 3-0-2

Lectures:	3 hours/wk
Lab	2 hours/wk

	Topics	*Approximate No. of Lectures*
1.	Introduction	1
2.	Crystallography and x-ray diffraction	5
3.	Structure of solids (metals, alloys, glasses & polymers)	5
4.	Crystal Imperfections	5
5.	Phase Diagrams	4
6.	Elastic Deformation	2
7.	Plastic Deformation	4
8.	Fracture	3
9.	Diffusion	3
10.	Phase Transformations	4
11	Electronic and magnetic materials	5
12.	Revision and Discussion	1

Introduction to Materials Science and Engineering

Video lectures related to an earlier presentation of the course on NPTEL:

http://www.infocobuild.com/

Introduction to Materials Science and Engineering

Contents

All lab classes would be held in

Materials Science Laboratory, Room LH202

	1.00-3.00 pm	3.00-5:05 pm
Mon	Group **1A**	Group **1B**
Tue	Group **2A**	Group **2B**
Thu	Group **3A**	Group **3B**
Fri	Group **4A**	Group **4B**

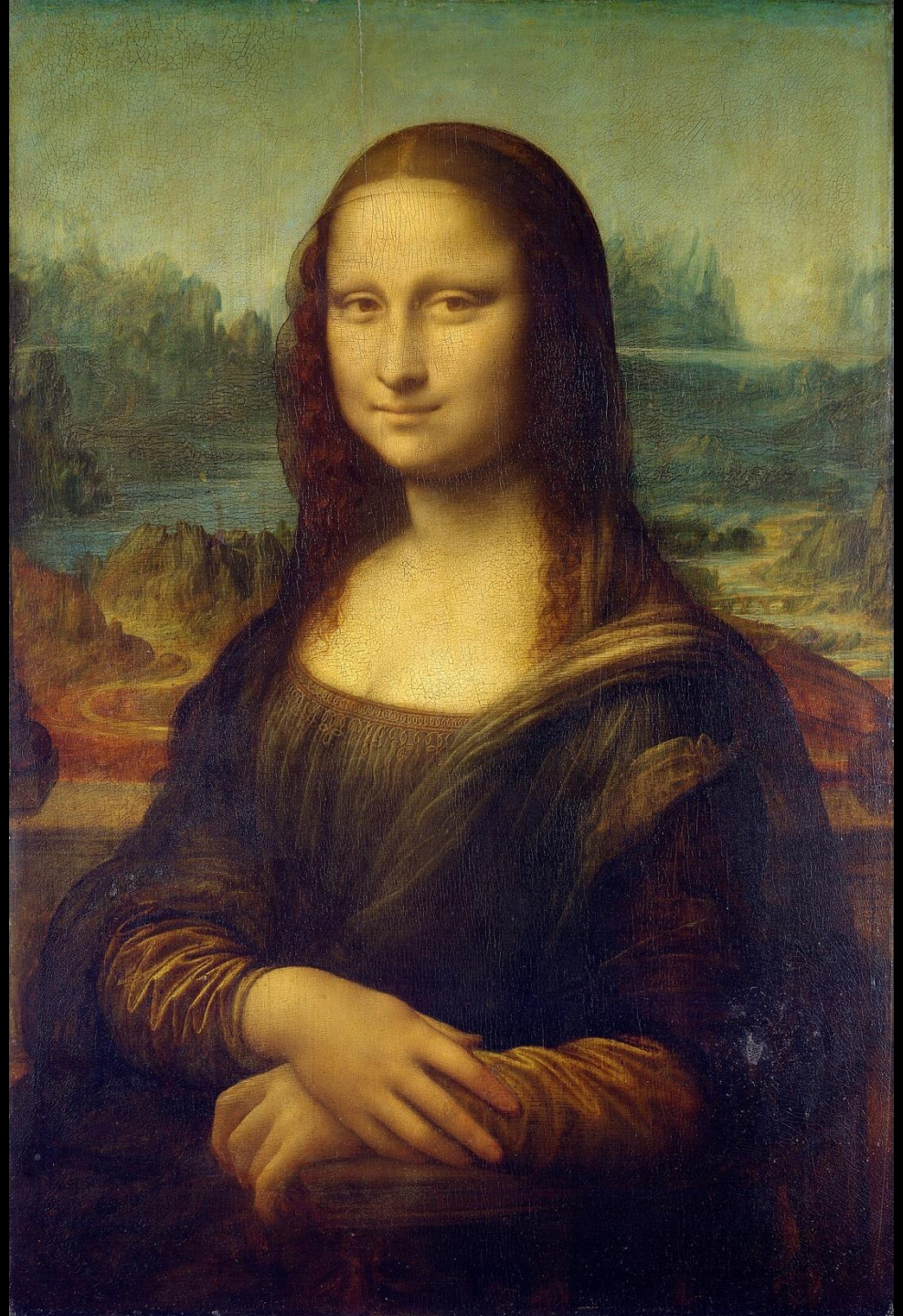
Grading

Mid Term	20
End Term	40
Quizzes I, II	20
Lab	15
Attendance	5
Total	**100**

Quiz I on September 01, 2025, 6-7 pm

Quiz II on November 10, 2025, 6-7 pm

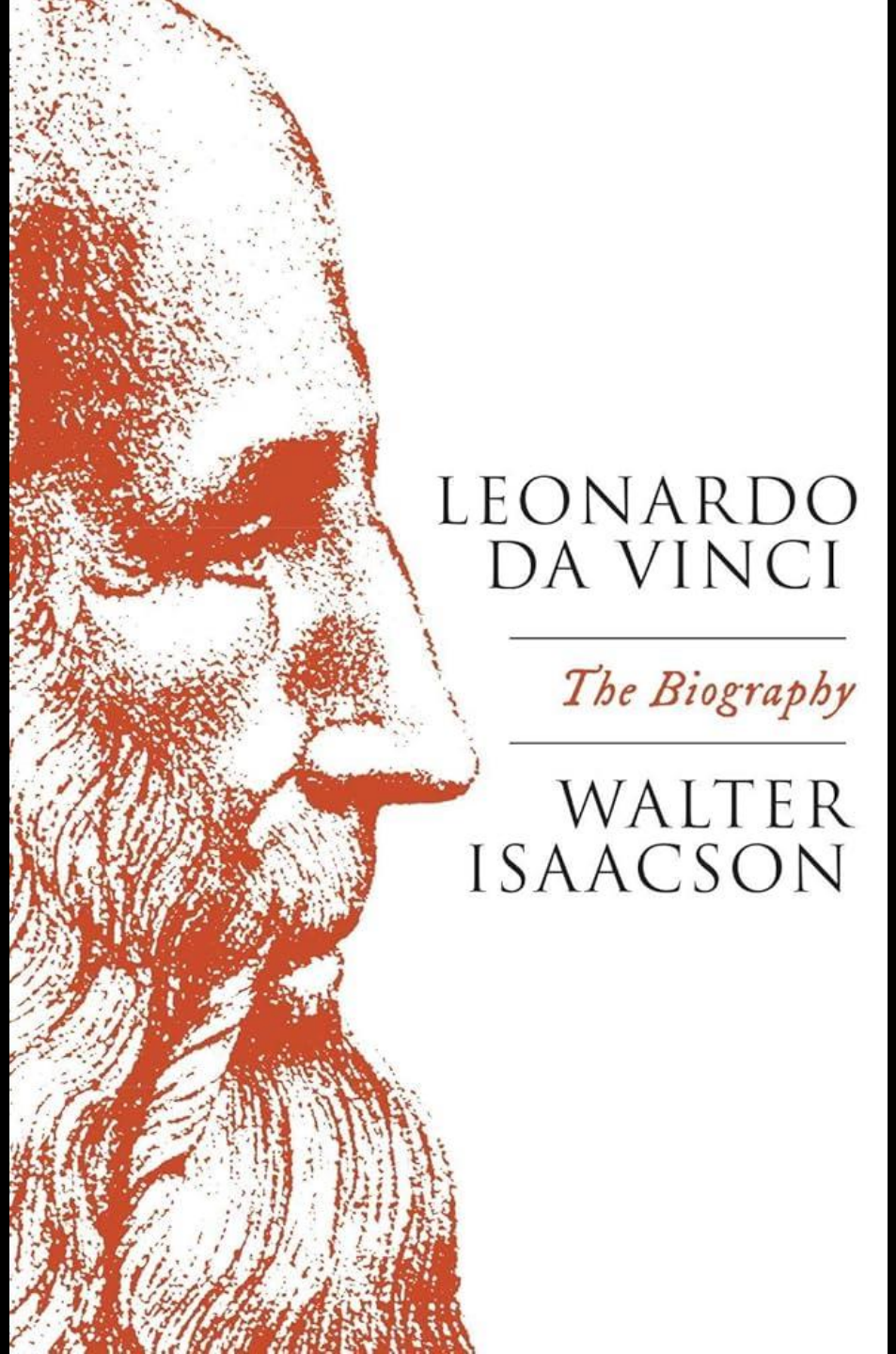
Mona Lisa
Louvre



Wikipedia

Leonardo da Vinci

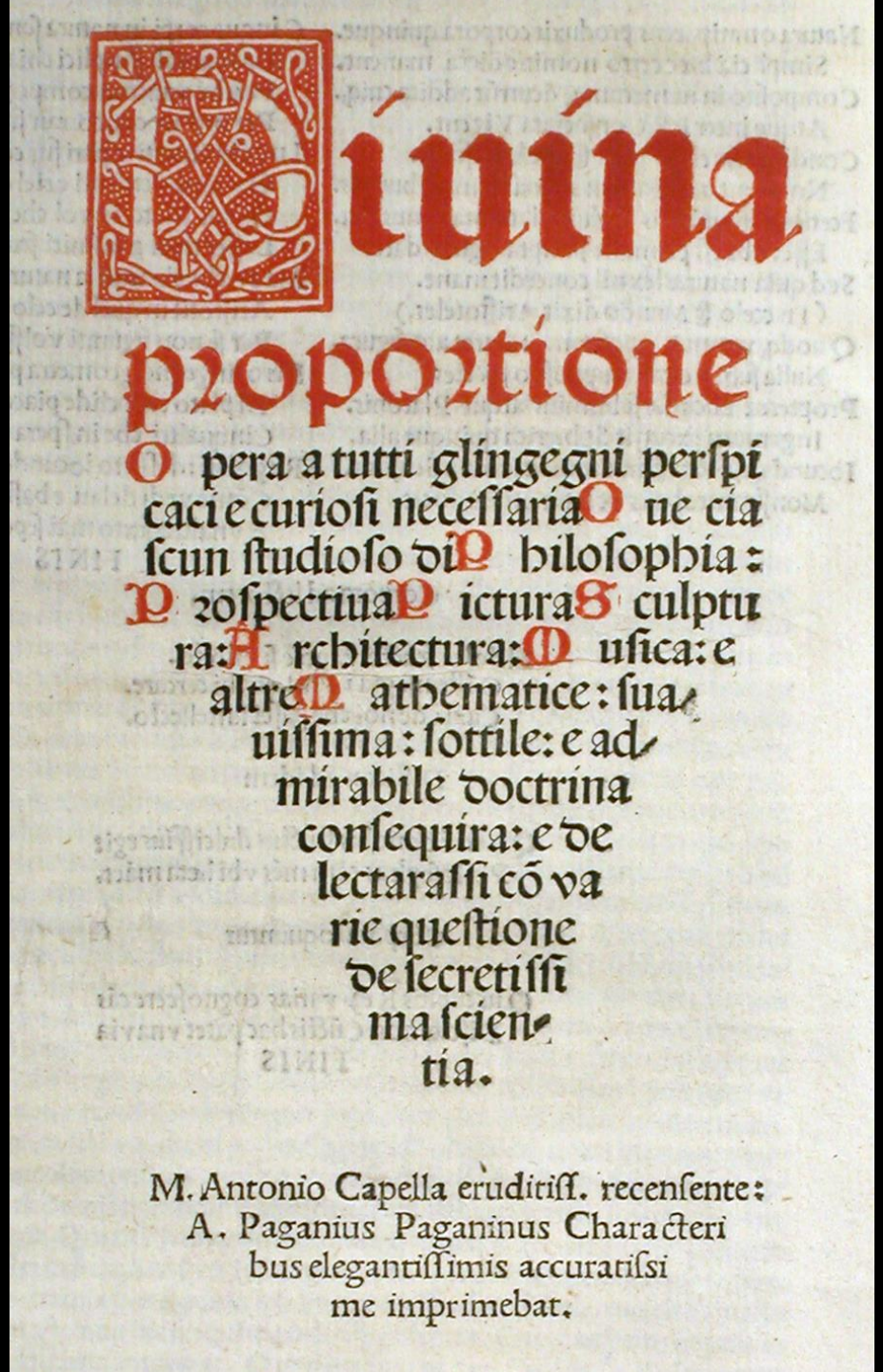
1452 - 1519



‘Infinitely curious, easily distracted, vain and vegetarian, Leonardo is brought tp vivid life in this accomplished biography'
Sunday Times

Luca Pacioli 1447-1517

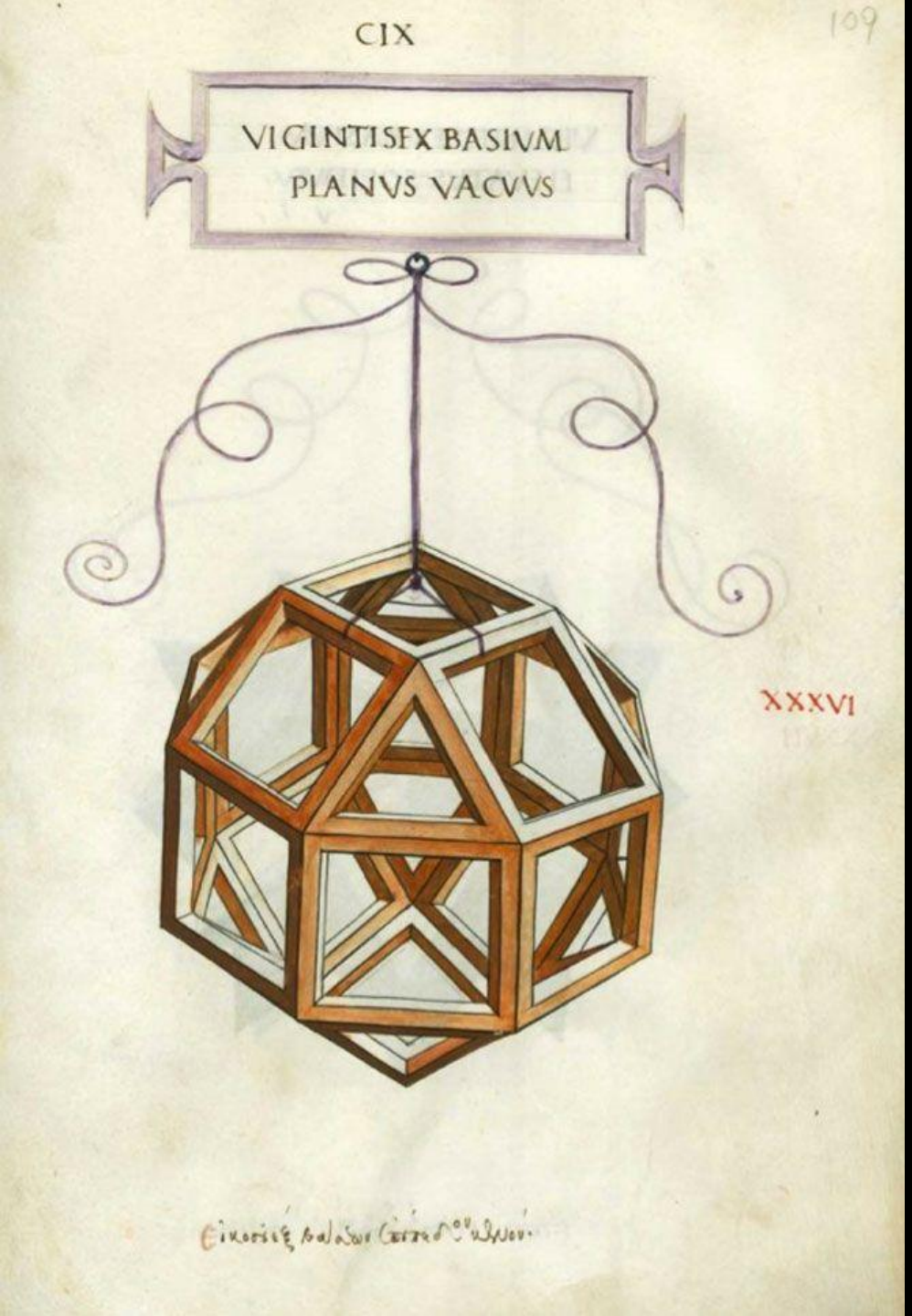
Title page of *De divina proportione* by Luca Pacioli, published 1509 in Venice



Divina
proportione

Opera a tutti glingegni perſpi
caci e curioſi neceſſaria Ouue cia
ſcun ſtudioſo di Philoſophia:
Perſpectiua Pictura Sculptu
ra: Architectura: Muſica: e
altre Mathematice: ſua-
uiſſima: ſottile: e ad-
mirabile doctrina
conſequira: e de
lectaraſſi cõ va
rie queſtione
de ſecretiſſi
ma ſcien-
tia.

M. Antonio Capella eruditiſſ. recenſente:
A. Paganius Paganinus Characteri
bus elegantiſſimis accuratiſsi
me imprimebat.



Leonardo's Rhombicubocatahedon in Pacioli's book

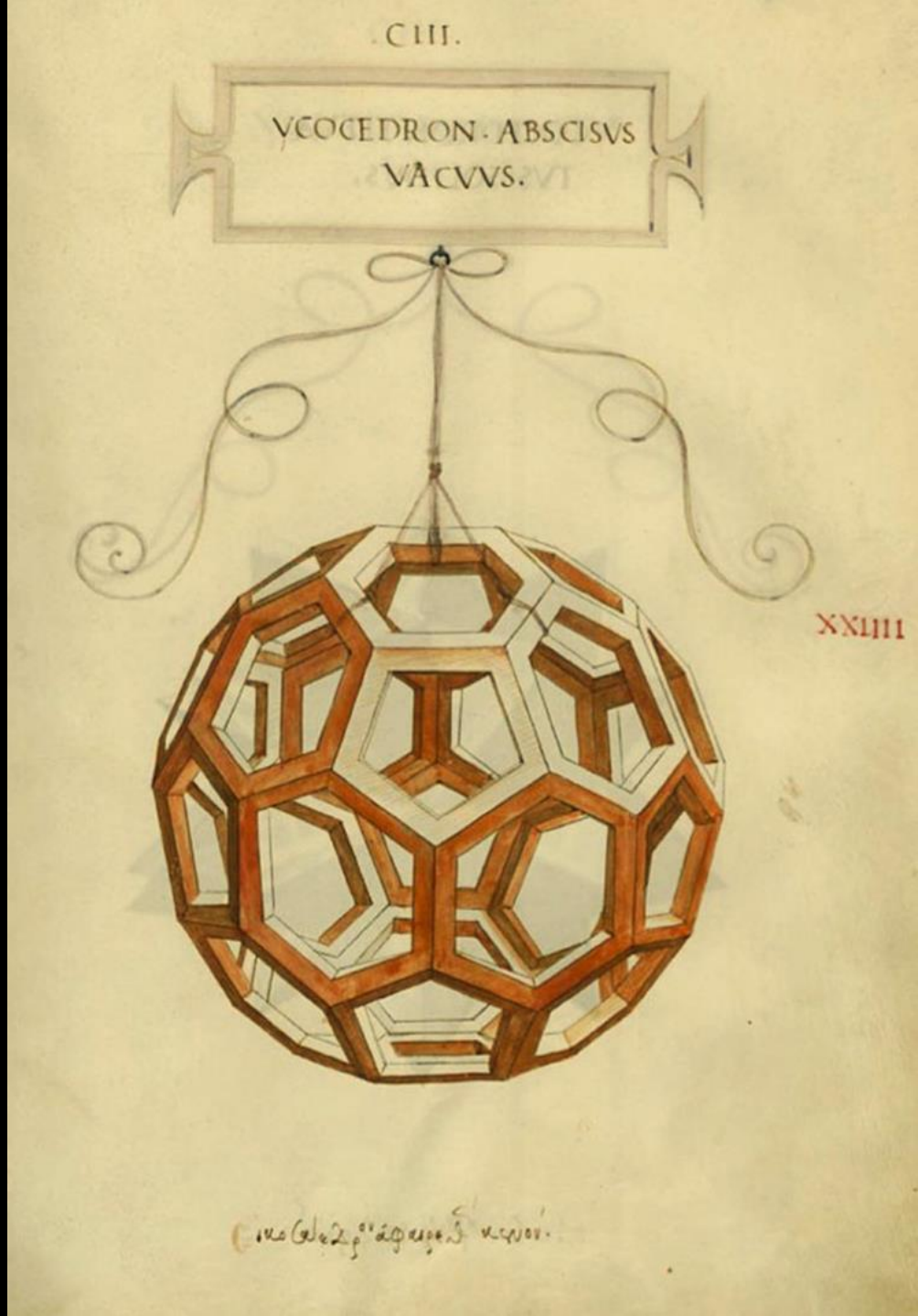
An Archimedean solid: All faces regular polygons, all vertices identical

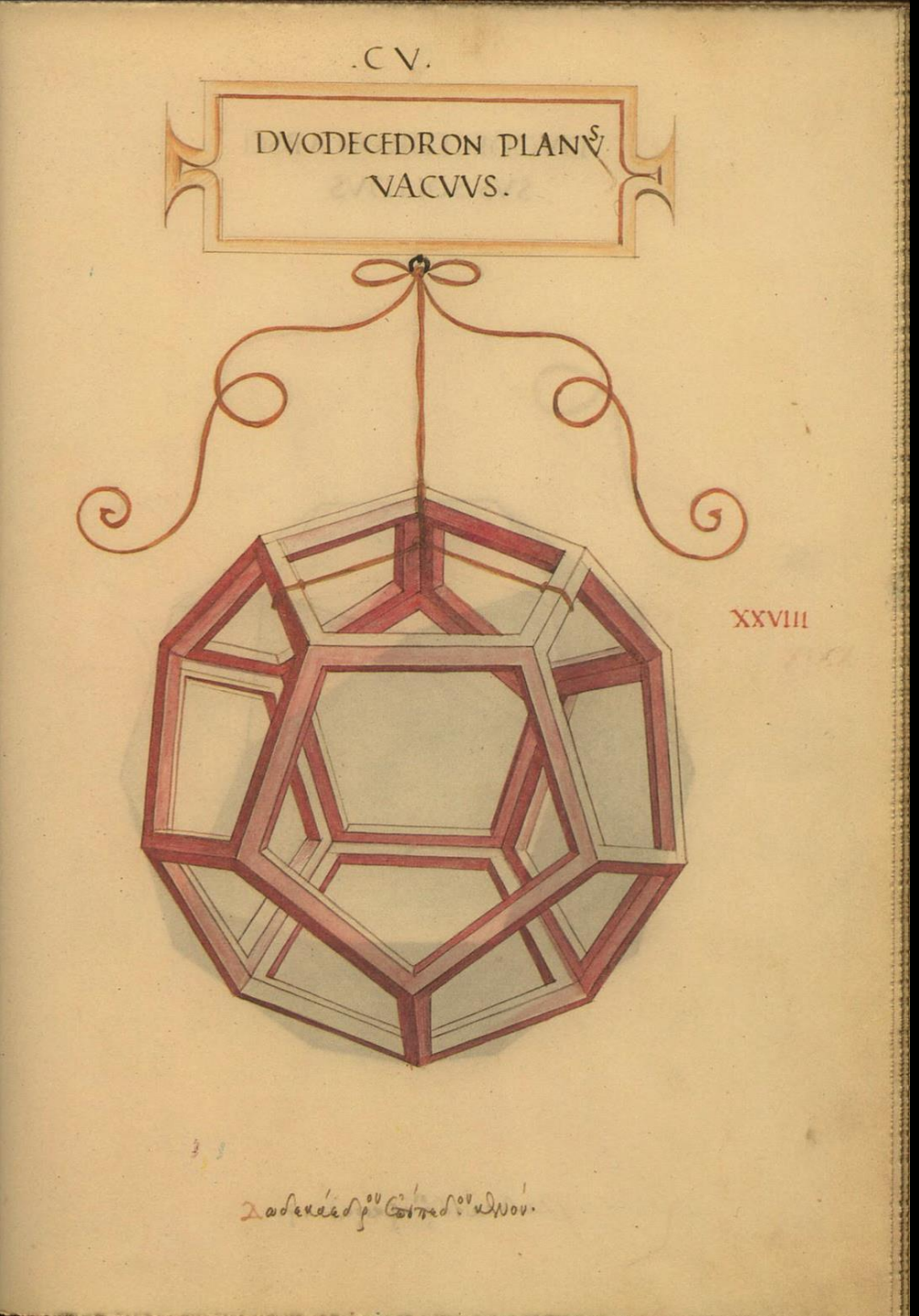
Faces: Squares and equilateral triangles

Leonardo's
Truncated Icosahedron
in Pacioli's book

Familiar?
Football or C60

An Archimedean solid
Faces: regular pentagons and hexagons





Leonardo's Pentagonal Dodecahedron in Pacioli's book

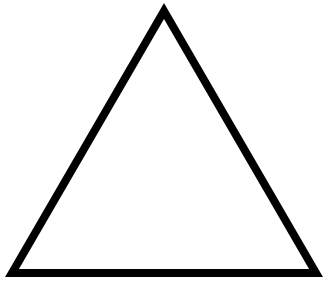
A Platonic solid:
All faces *Congruent* regular polygons, all vertices identical

Faces: Regular pentagons

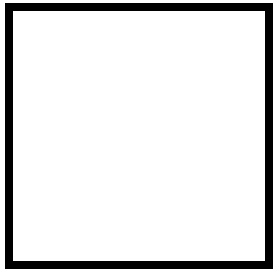
Luca Pacioli 1447-1517

Pentagonal Dodecahedron

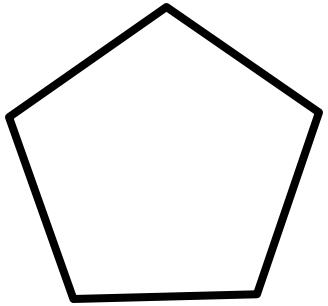
Regular Polygons:
All sides equal and all angles equal



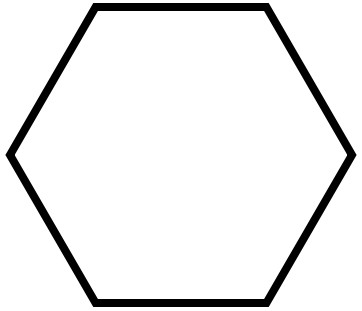
Equilateral Triangle



Square



Regular Pentagon



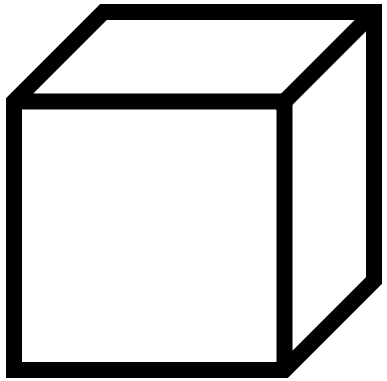
Regular Hexagon

How many regular polygons are possible?

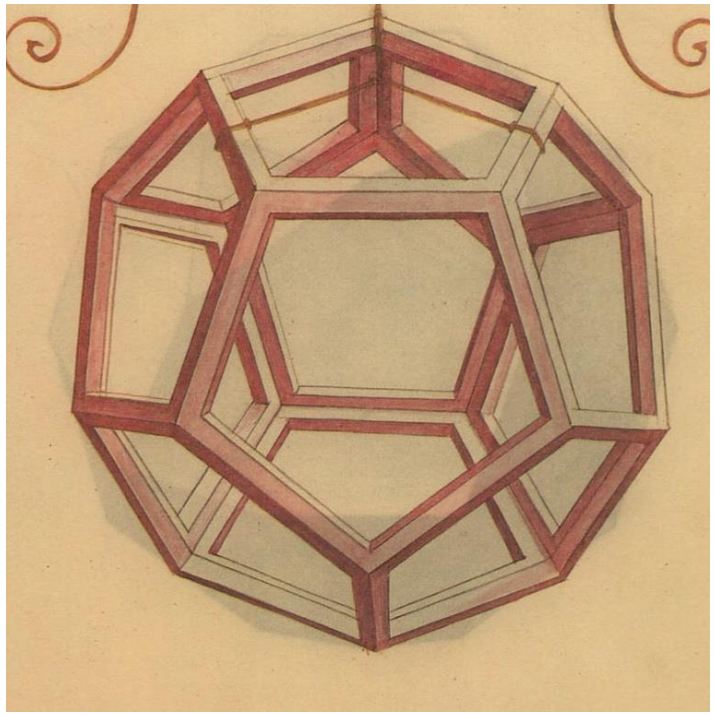
There are infinitely many regular polygons

3D: Regular Polyhedra or Platonic Solids

All faces regular congruent polygons, all corners identical.



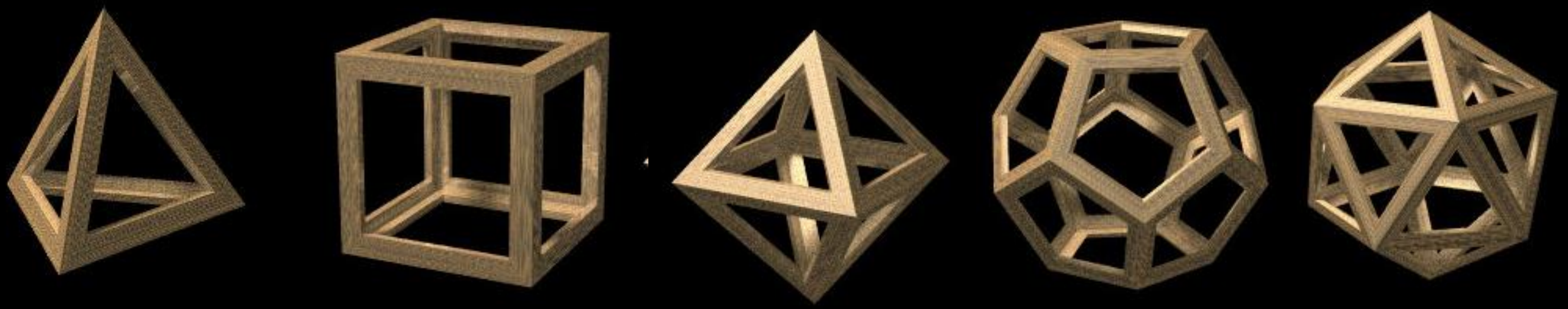
Cube



Pentagonal Dodecahedron

How many regular solids?

The Five Platonic Solids



Tetrahedron Cube Octahedron Dodeca-hedron Icosahedron

"…the discovery of the last two is certainly one of the most beautiful and singular discoveries made in the whole history of mathematics."

Hermann Weyl in *Symmetry*

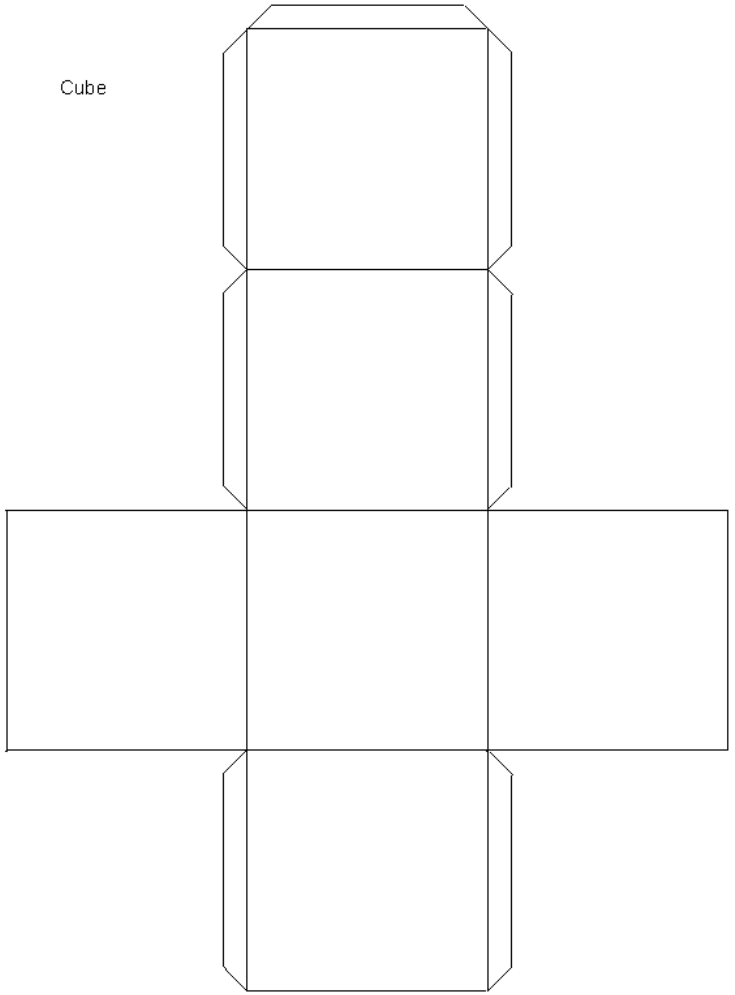
MLL100 Experiment 1

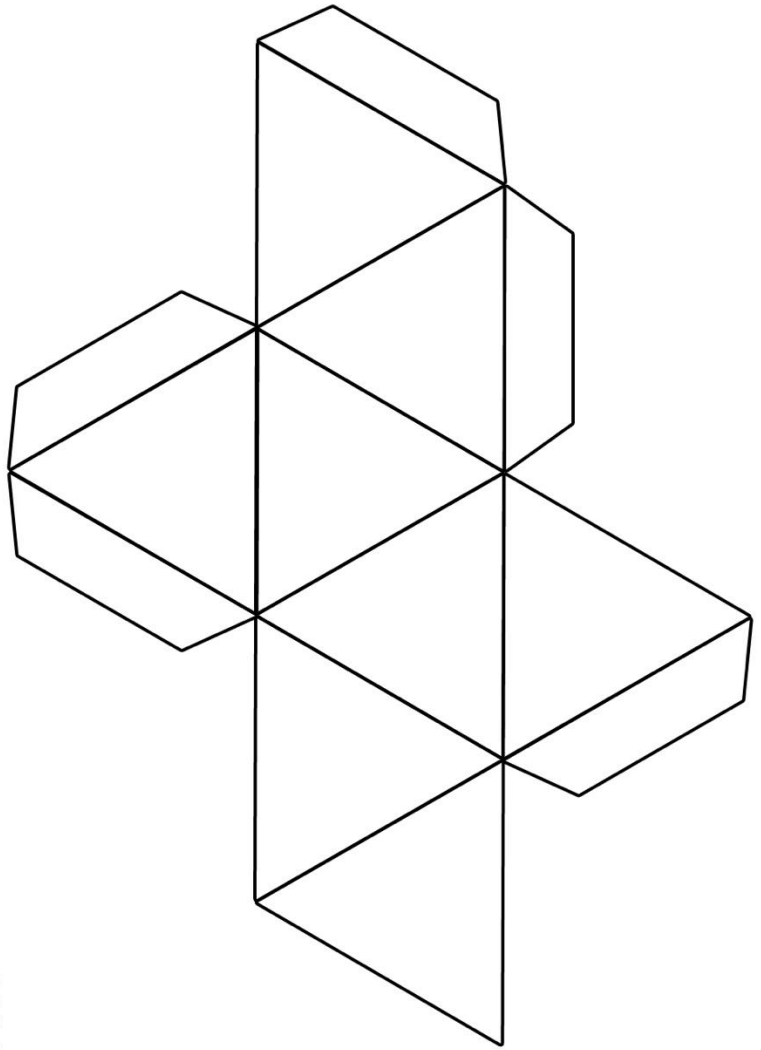
Construction of Paper models of polyhedra

1. Please bring cut-out sheets from Scoops.
2. Please bring a carry bag to carry your models back with you

Cube {4,3}: Plato's Earth

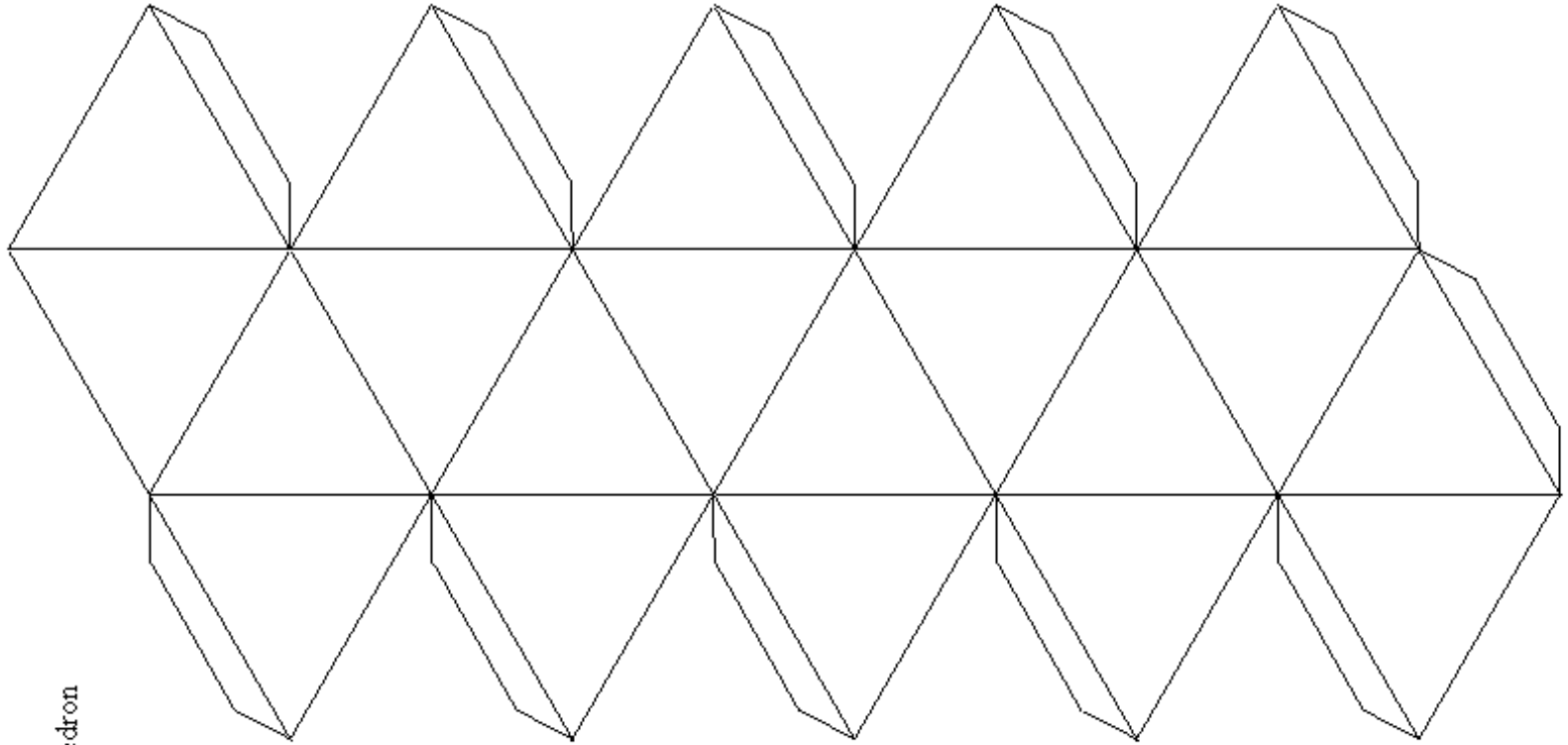
Conventional cell of cubic crystal system





Octahedron {3,4}: Plato's Air

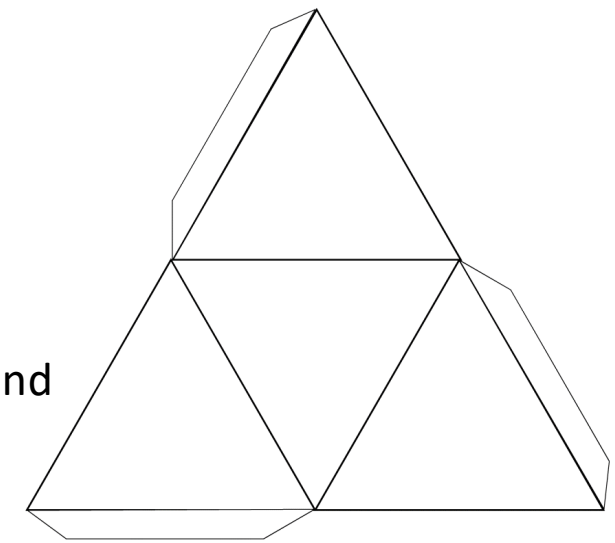
Interrstitial voids in Cubic Close-Packed (CCP) and Hexagonal Close-Packed (HCP) crystals



Icosahedron

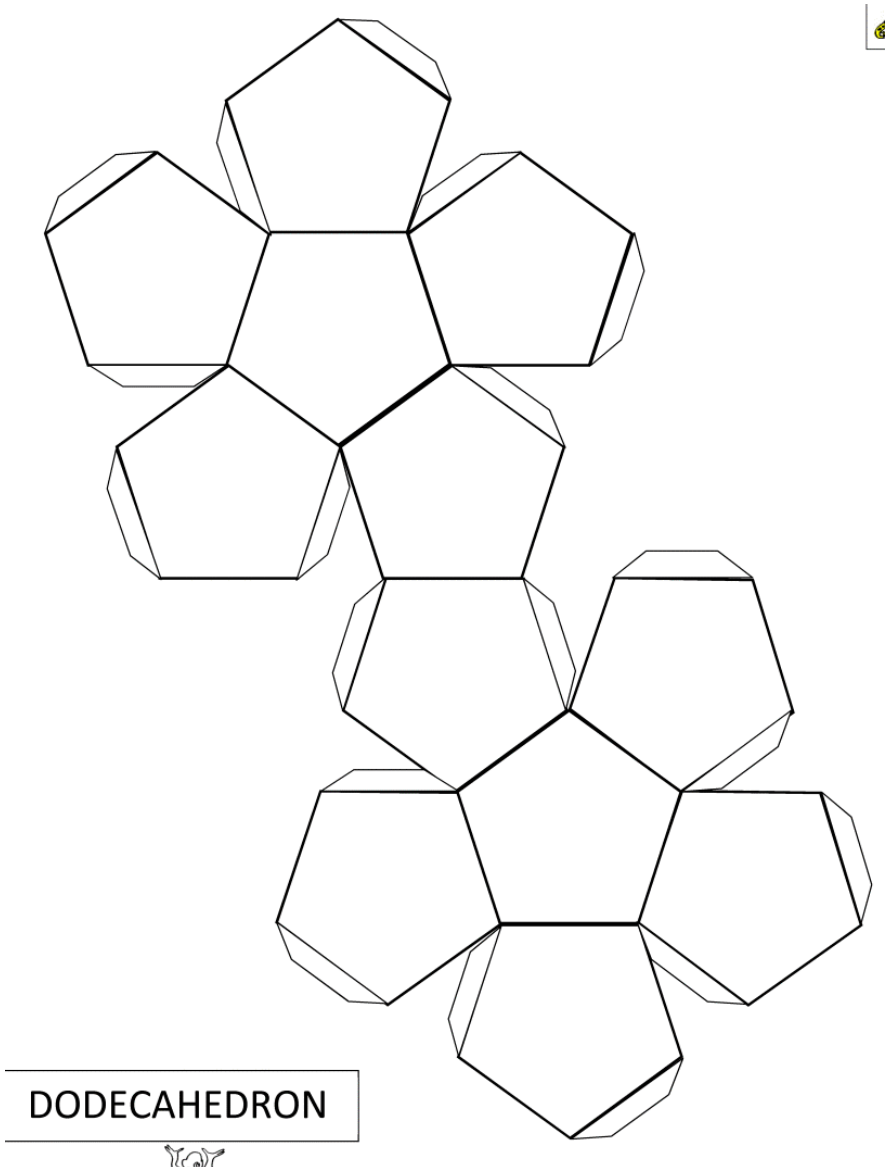
www.korthalsaltes.com

Icosahedron {3,5}: Plato's Water
Has five-fold symmetry not consistent with crystallographic symmetry

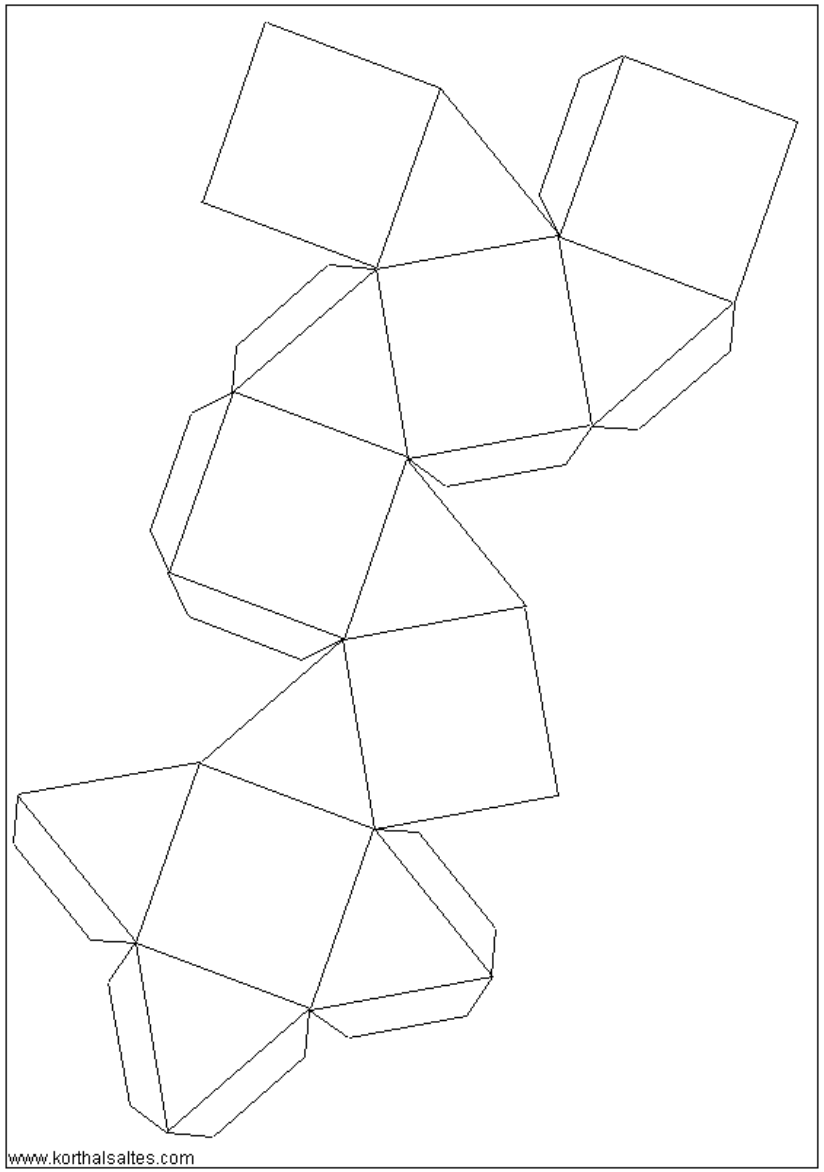


Tetrahedron {3,3}: Plato's Fire
Interstitial void in cubic close-packed (CCP) and hexagonal close-packed (HCP) crystals

Dodecahedron {5,3}: Plato's Universe
Has five-fold symmetry not consistent with crystallographic symmetry (Platonic)

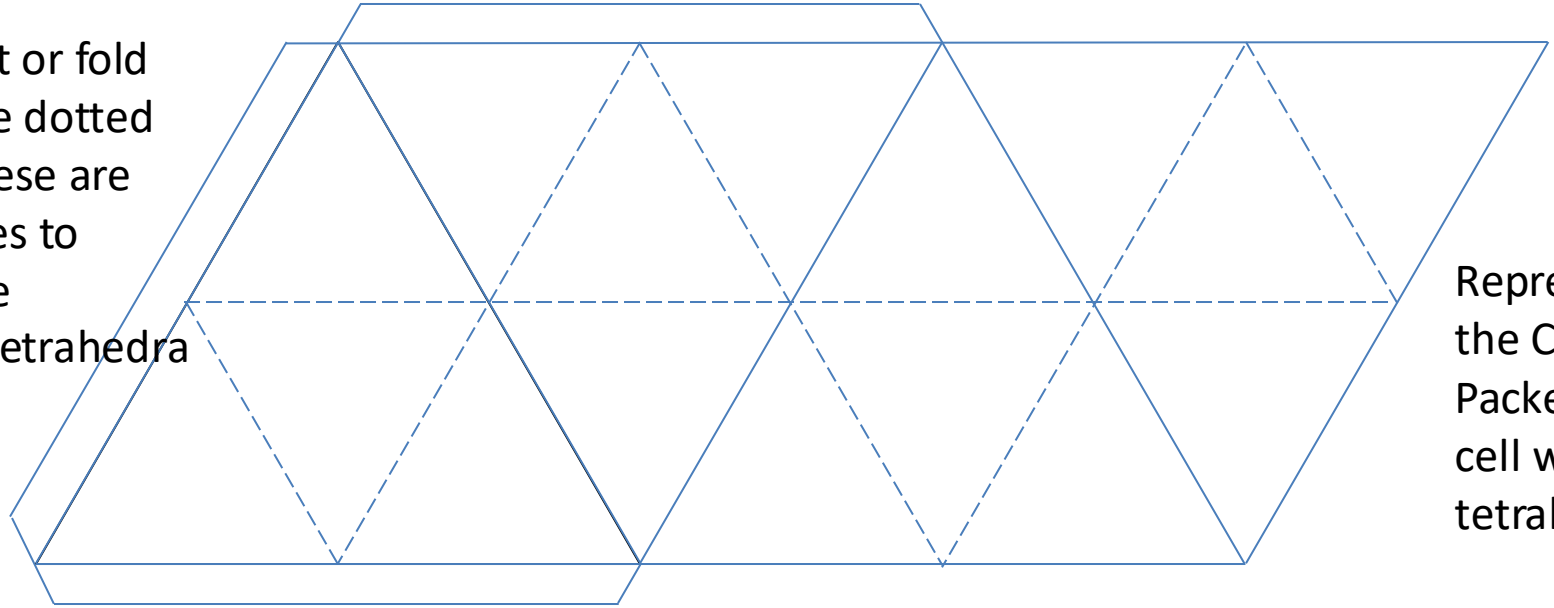


Cuboctahedron or Truncated Cube: Coordination Polyhedron for Cubic Close-Packed (CCP) Crystal. (Archimedean)

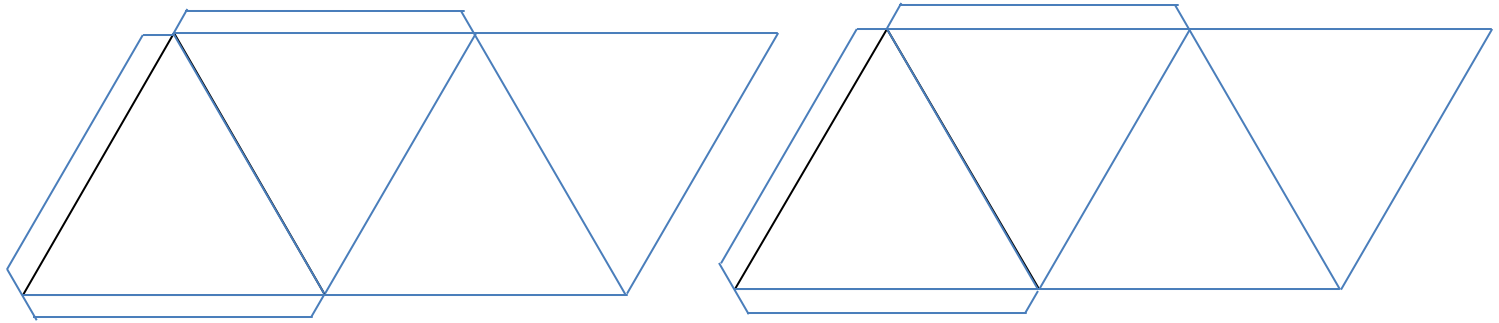


Kepler's Stella Octangula or the eight-pointed star or the compound of two tetrahedra

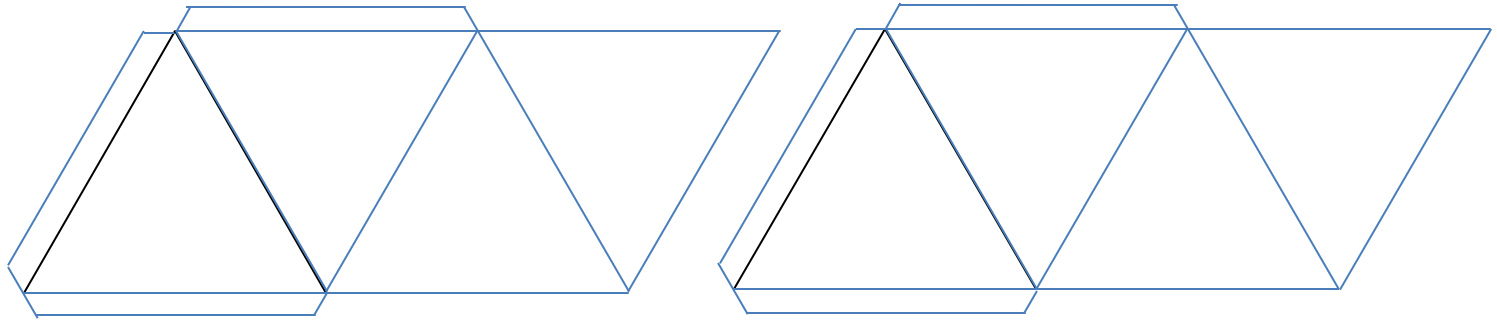
Don't cut or fold along the dotted lines. These are guidelines to paste the smaller tetrahedra on these faces.



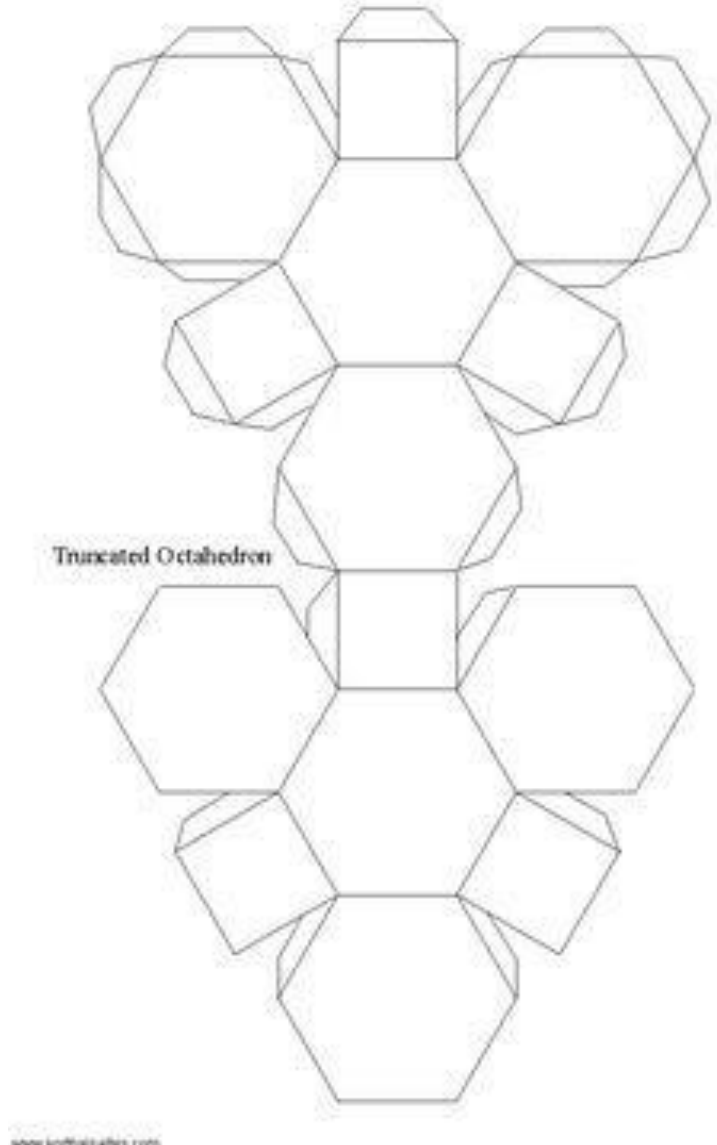
Represents the Cubic Close-Packed (CCP) Unit cell with eight tetrahedral voids.



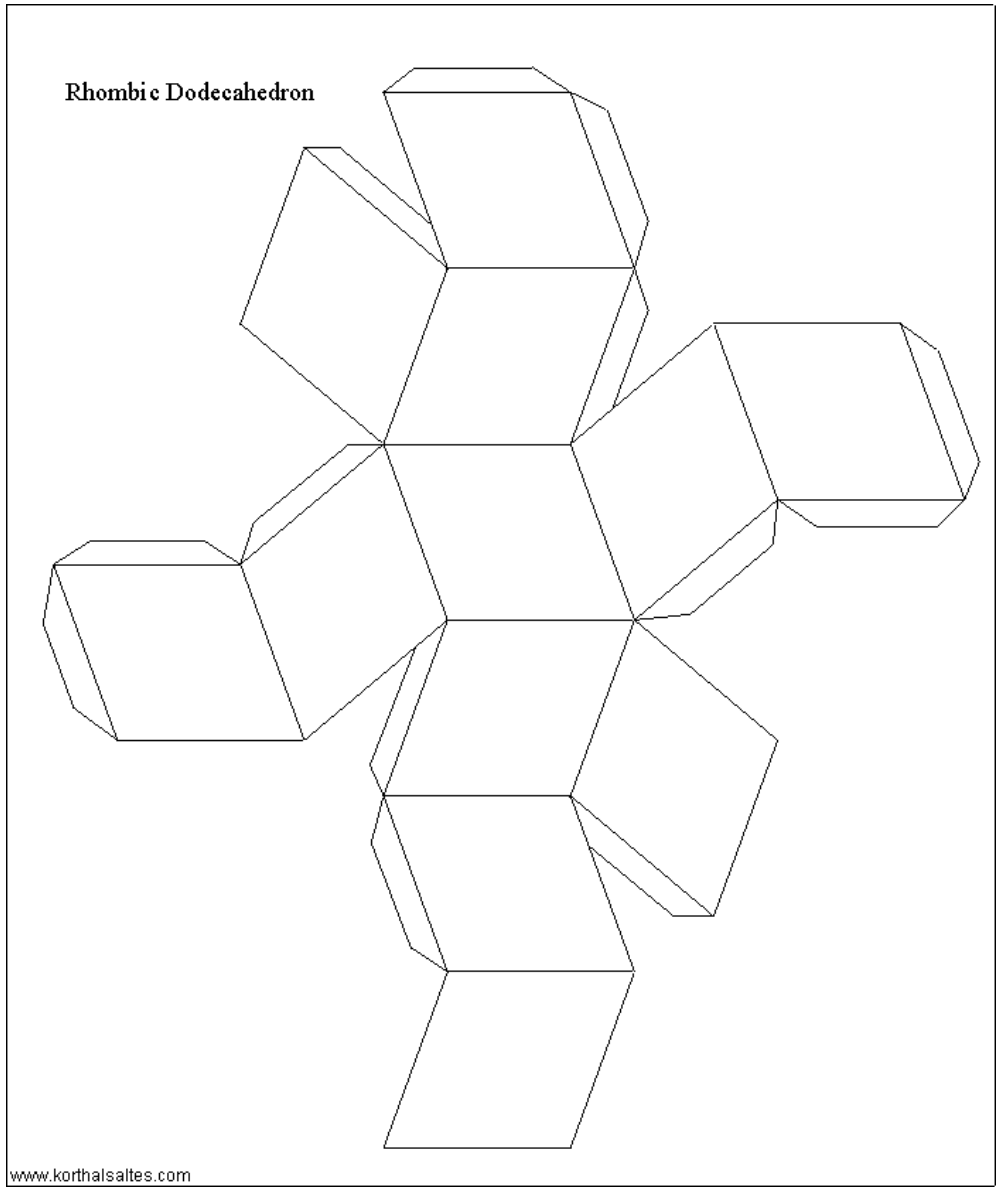
These four smaller tetrahedra should be pasted on the faces of the larger one.



Tetrakaidecahedron or Truncated Octahedron: Voronoi cell of monatomic Body Centred Cubic (BCC) crystal (Archimedian)



Rhombic Dodecahedron: Voronoi cell of Cubic Close-packed (CCP) crystal



Euler's Equation

Descartes Equation

Dual Solids

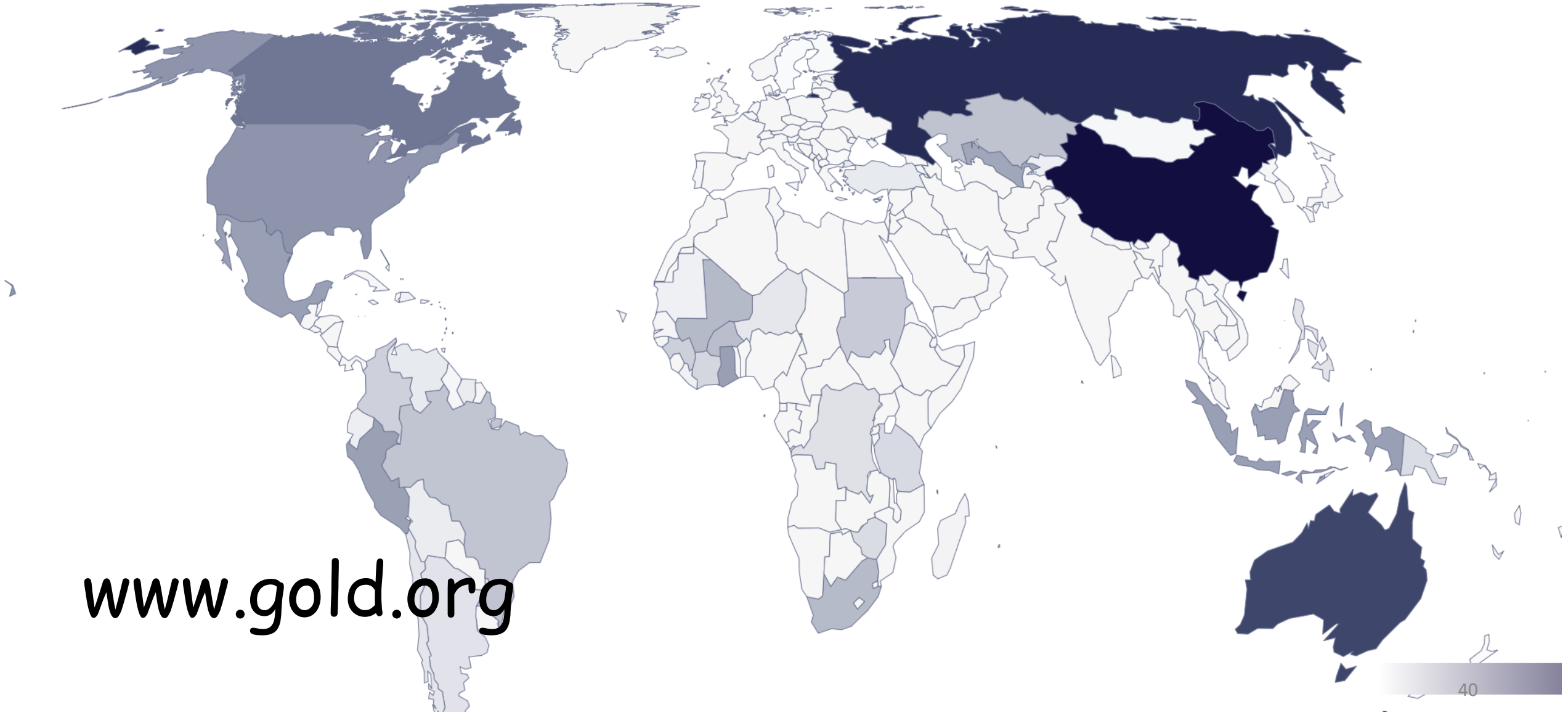
Symmetry

End of Lec 1

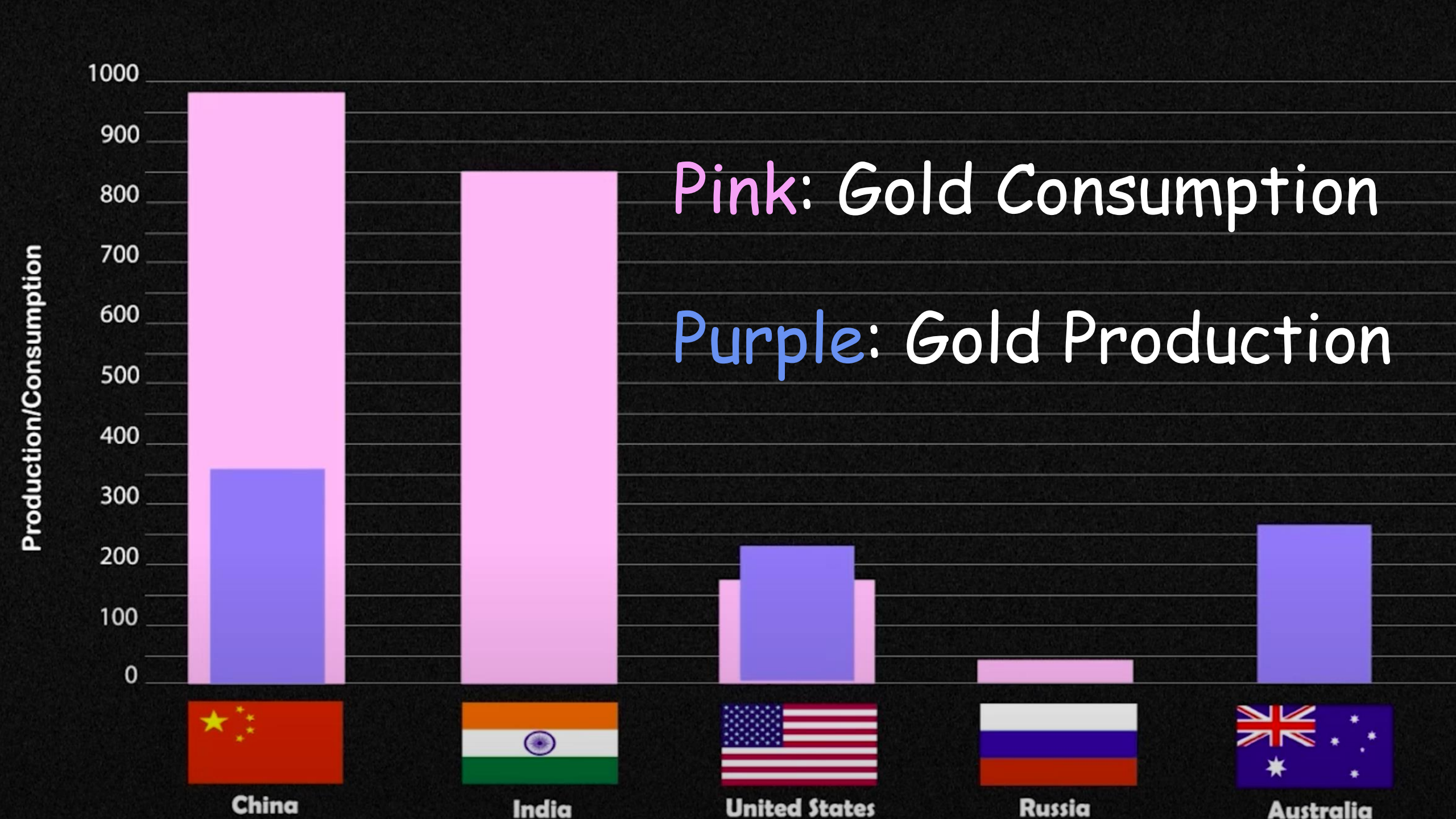
MLL 100
Lec 2 Tuesday 29.07.2025

1. India's gold production vs. consumption
2. Environmental issues in gold production
3. Price vs. Importance of things
4. Oath against food wastage
5. Sand and salt as examples of low price but high importance
6. Feynman's statement on importance of atoms
7. Crystal=Lattice+Motif

Gold Production



www.gold.org


Pink: Gold Consumption
Purple: Gold Production
Production/Consumption
1000
900
800
700
600
500
400
300
200
100
0
China
India
United States
Russia
Australia

Gold Imports and the Pressure on the Rupee

However, there is a downside. India does not produce much gold. Most of it has to be imported from other countries. While India exports around $32 billion worth of gold jewellery, it imports about $55 billion worth of gold. This gap puts pressure on India’s current account deficit and affects the value of the rupee. Since gold and oil are the two biggest import items, any rise in their prices can create problems for India’s currency and economy.

https://weekendinvesting.com/indias-gold-consumption

1000 kg of ore

=

3 g of gold ring

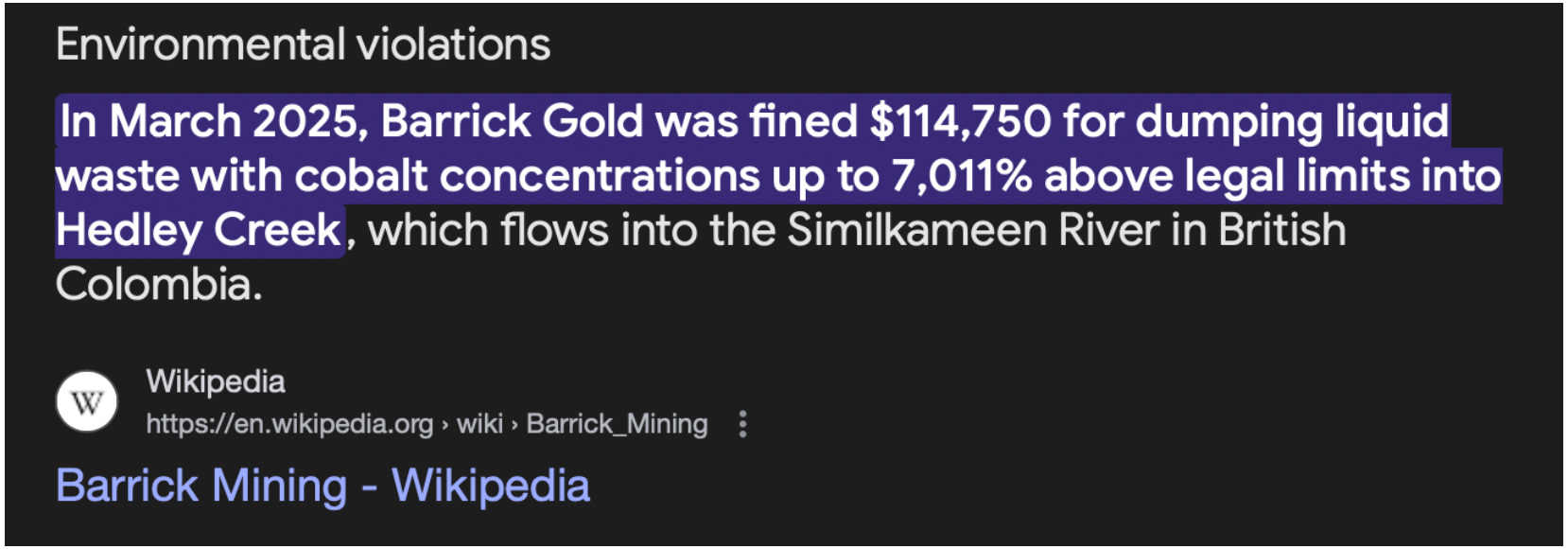
Wikipedia: Gold Mining

Super Pit gold mine at Kalgoorlie in Western Australia, 2005

https://im-mining.com/

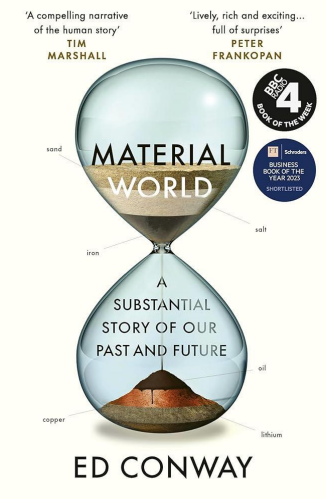
Gold Extraction from ore

Cyanide Process using Na, K or Ca cyanide



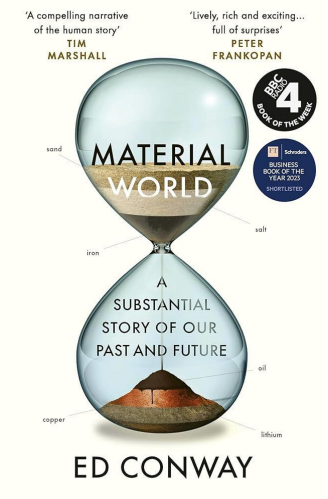
"The world would probably not cease to function, nor civilization grind to halt, if we suddenly ran out of gold"

Ed Conway in Material World

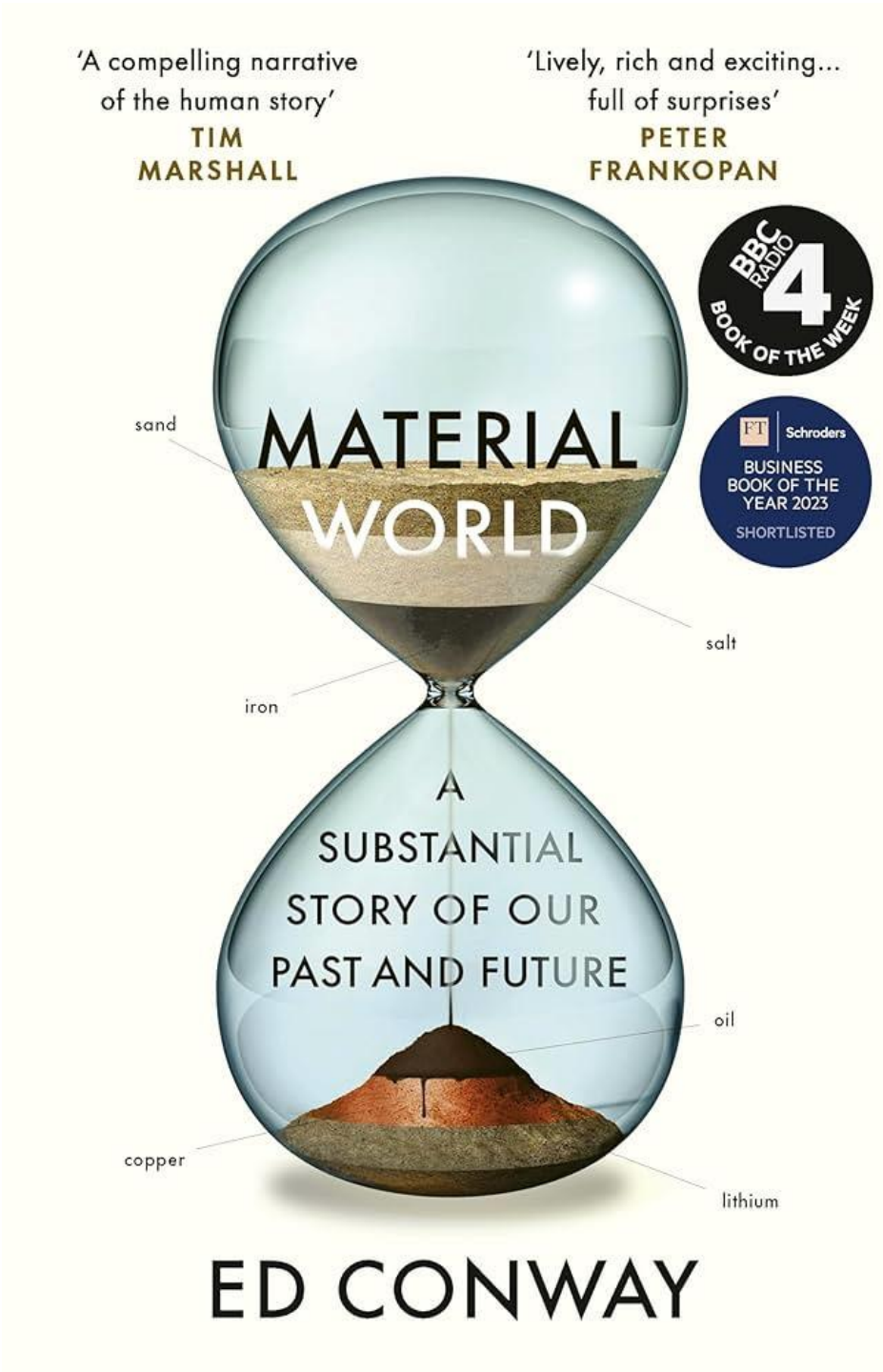


"It is all very well knowing the *price* of something, but the price is not the same thing as *importance*."

Ed Conway in Material World

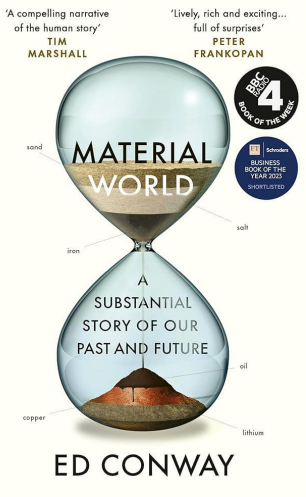


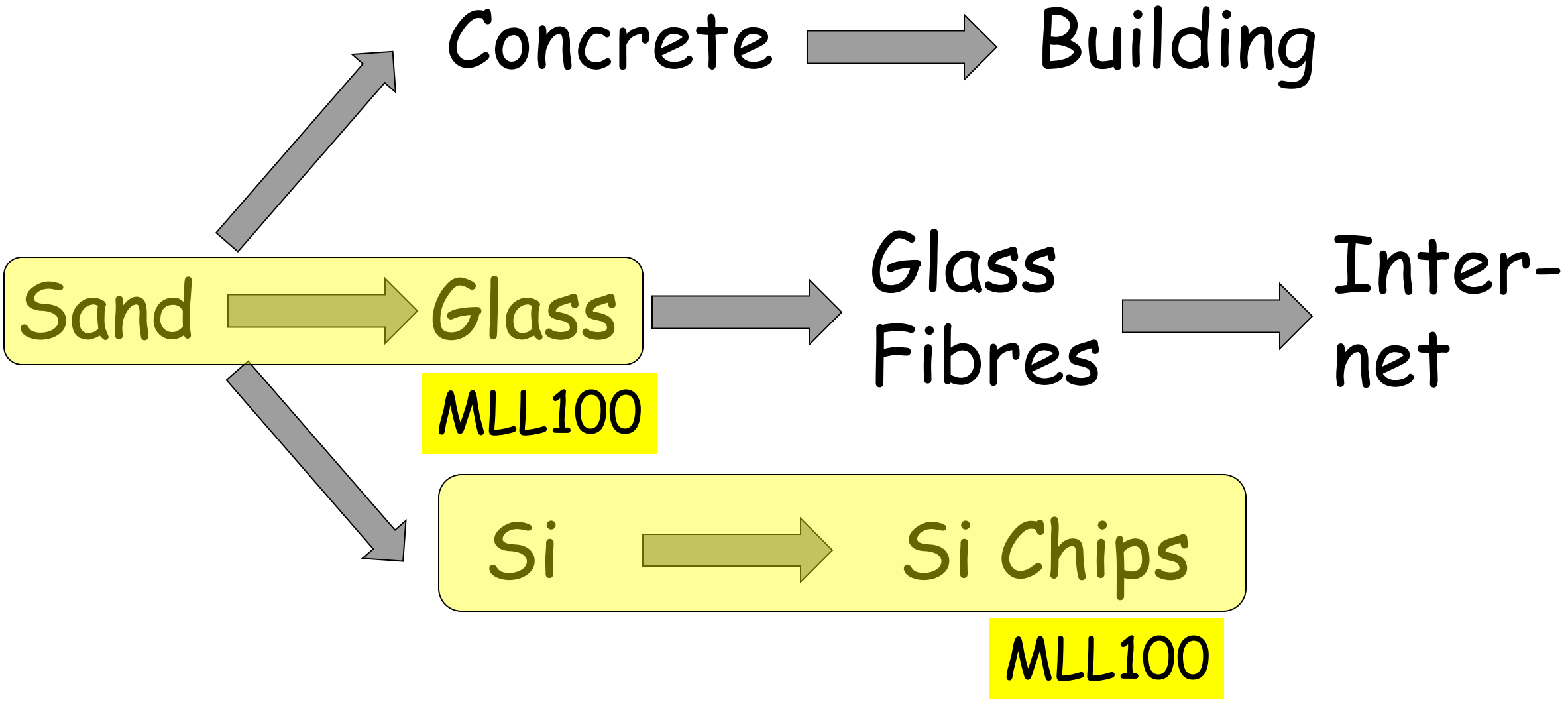
Sand
Salt
Iron
Oil
Copper
Lithium

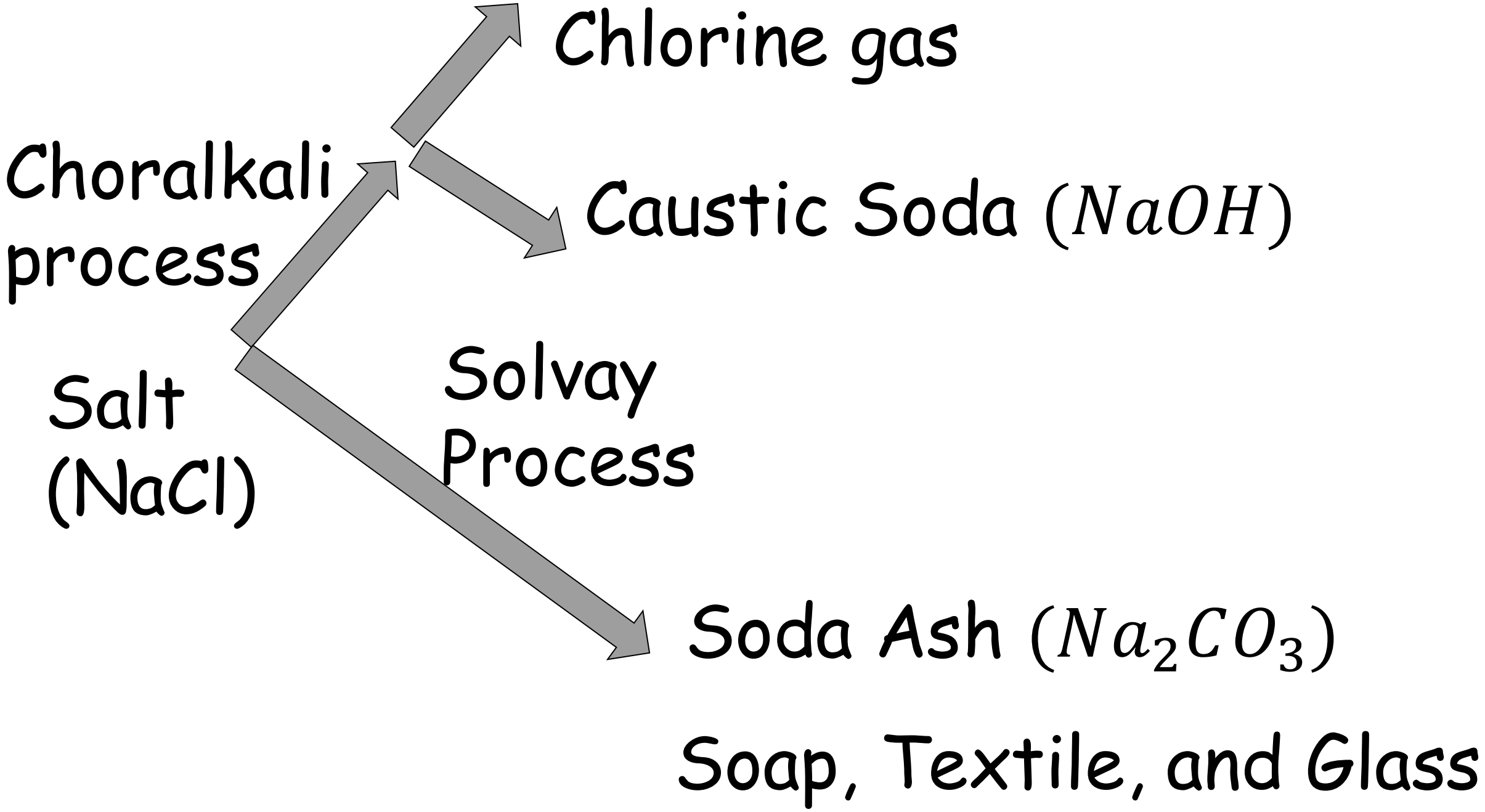


"The world, dare I say, would not end if Twitter or Instagram suddenly ceased to exist; if we suddenly ran out of steel or natural gas, however, that would be a very different story."

Ed Conway in Material World




Concrete
Building
Sand
Glass
MLL100
Glass Fibres
Inter-net
Si
Si Chips
MLL100

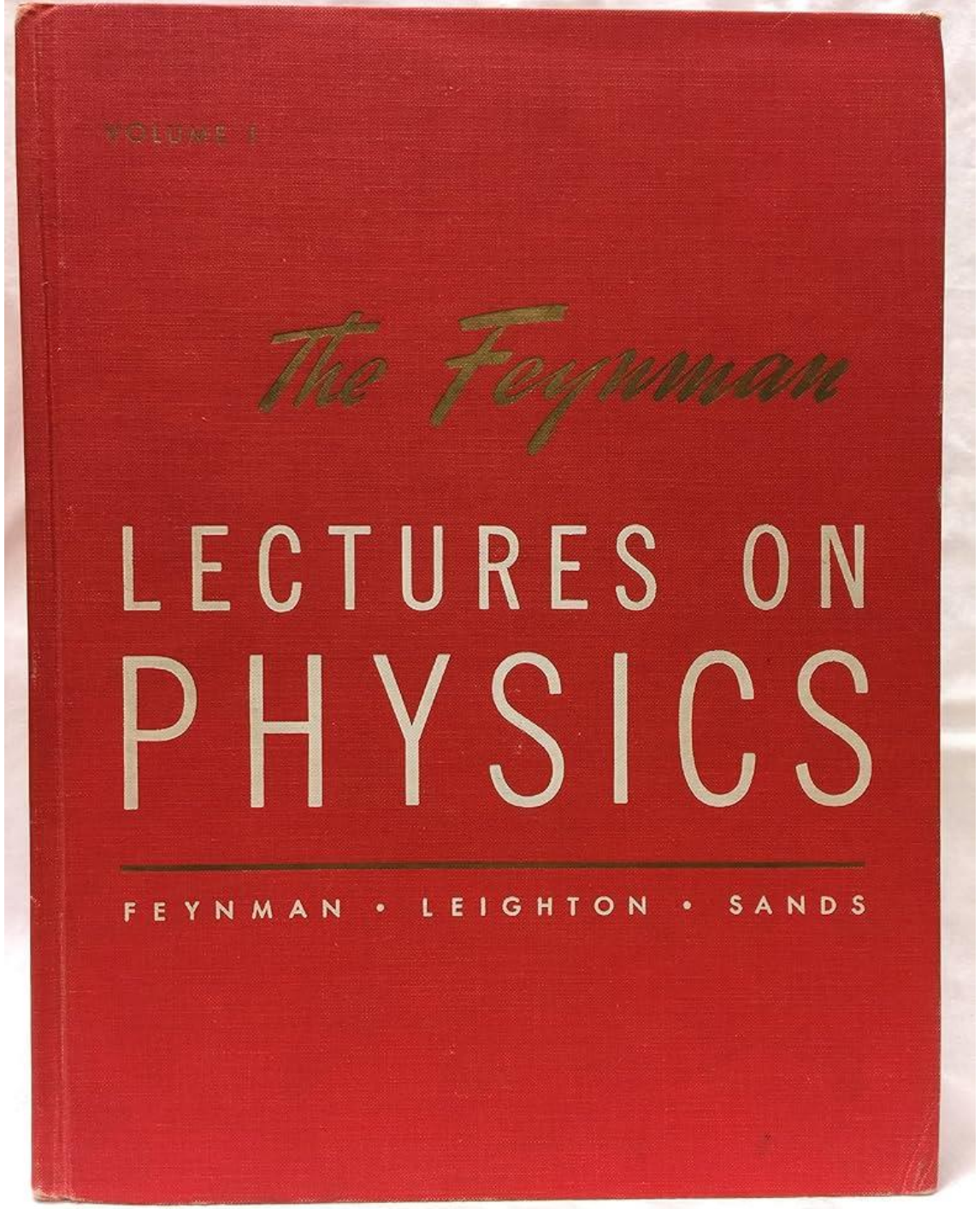

Chlorine gas
Choralkali process
Caustic Soda $(NaOH)$
Salt (NaCl)
Solvay Process
Soda Ash (Na_2CO_3)
Soap, Textile, and Glass

MLL100

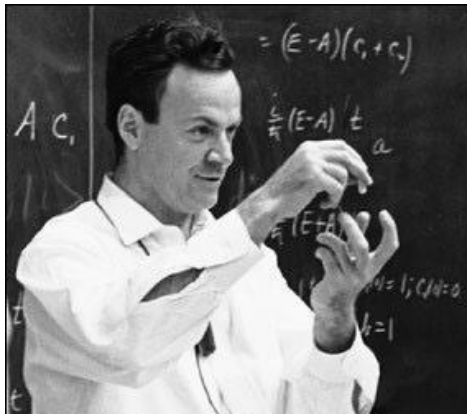
"My hope is that ~~this book~~ inspires you to take a second look at the world we inhabit, where there is magic in everyday objects and wonder in simple substances."

Rajesh Prasad at IITD

~~Ed Conway in Material World~~


VOLUME I
The Feynman
LECTURES ON
PHYSICS
FEYNMAN • LEIGHTON • SANDS

Feynman's Question:



If in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words?

The Feynman Lectures on Physics, Vol. 1, Chapter 1, Section 1.2

Feynman's answer:

Matter is made of atoms

"In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking is applied."

Structure?

Solids

Crystalline Amorphous

Gold: Crystalline or amorphous?

Crystal ?

A translationally periodic arrangement of **atoms** in space.

Lattice?

A translationally periodic arrangement of **points** in space.

Crystal vs. Lattice

Crystal

Translationally periodic arrangement of **atoms**

Lattice

Translationally periodic arrangement of **points**

Relation between crystal and lattice?

Crystal = Lattice + Motif

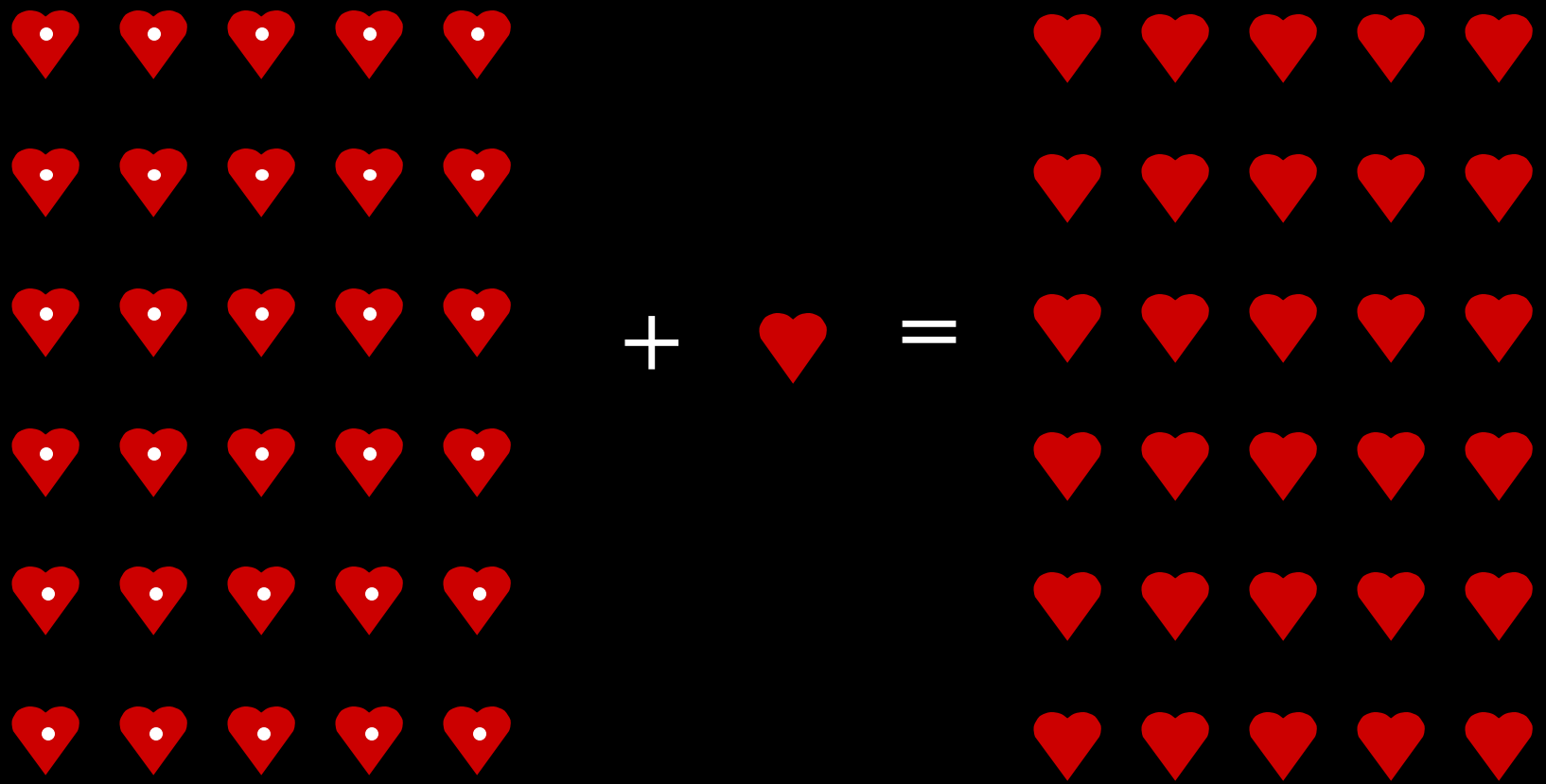
Motif or basis: an atom or a group of atoms associated with each lattice point

Crystal = Lattice + Motif

How to repeat

What to repeat

Lattice + Motif = Crystal



Heartless Lattice + Heart = Heart Pattern

Lattice: How to repeat

Motif: What to repeat

Lattice

All points of a lattice have identical surroundings.

MLL 100 Lec 3, Wed 30.07.2025

1. Lattice: Two definitions
2. Lattice Translations
3. Unit Cells
4. Effective Number of lattice points per cell
5. Primitive and Nonprimtive cells
6. Lattice parameters
7. Classification of Lattices: 7 Crystal Systems and 14 Bravais Lattice
8. Crystal System defined as unit cell shapes (To be shown incorrect in the next lecture)
9. Highlighting of trigonal system

Lattice

A translationally periodic set of points is called a lattice.

Lattice

All points of a lattice have identical surroundings.

Lattice translations

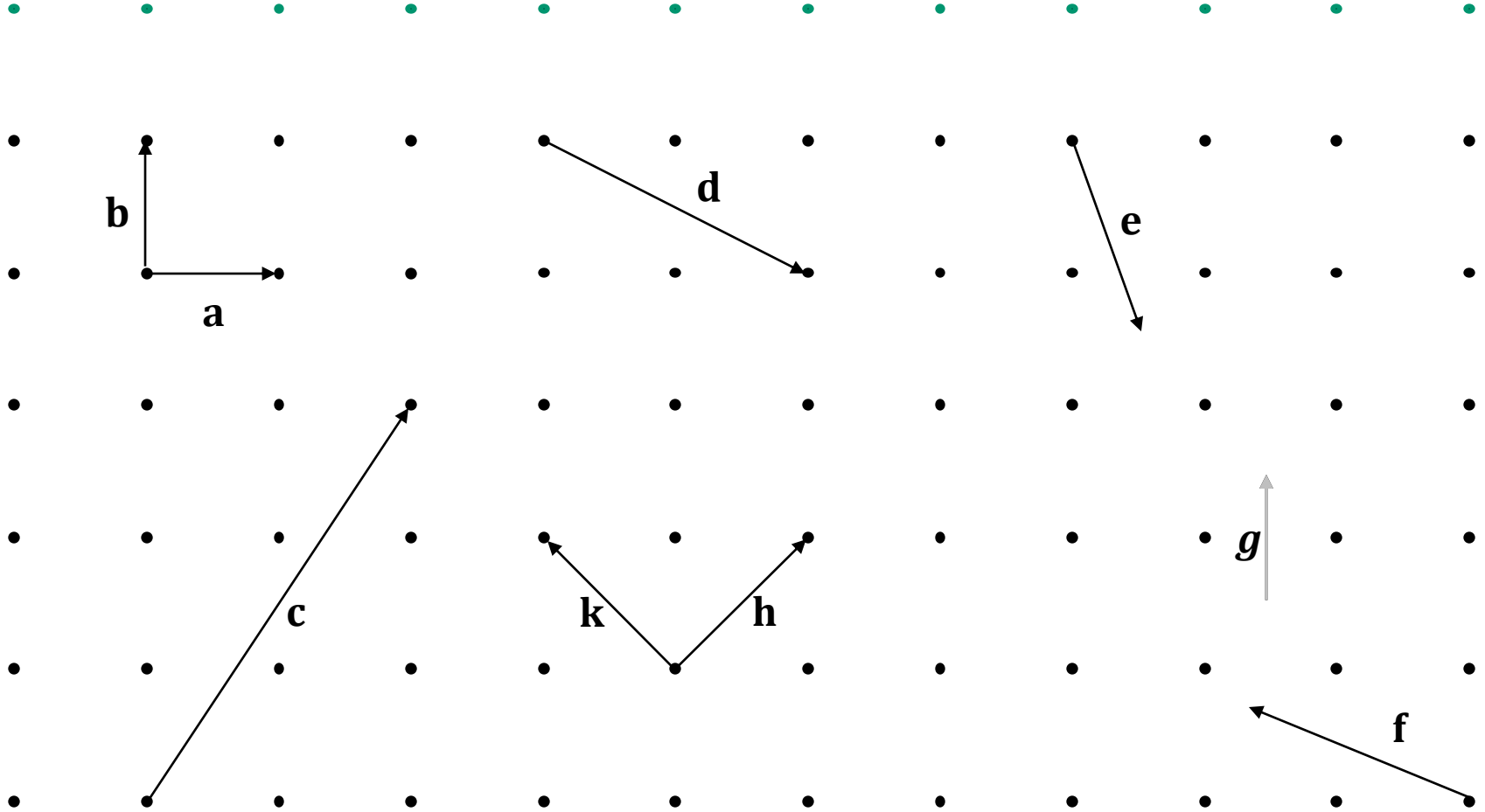
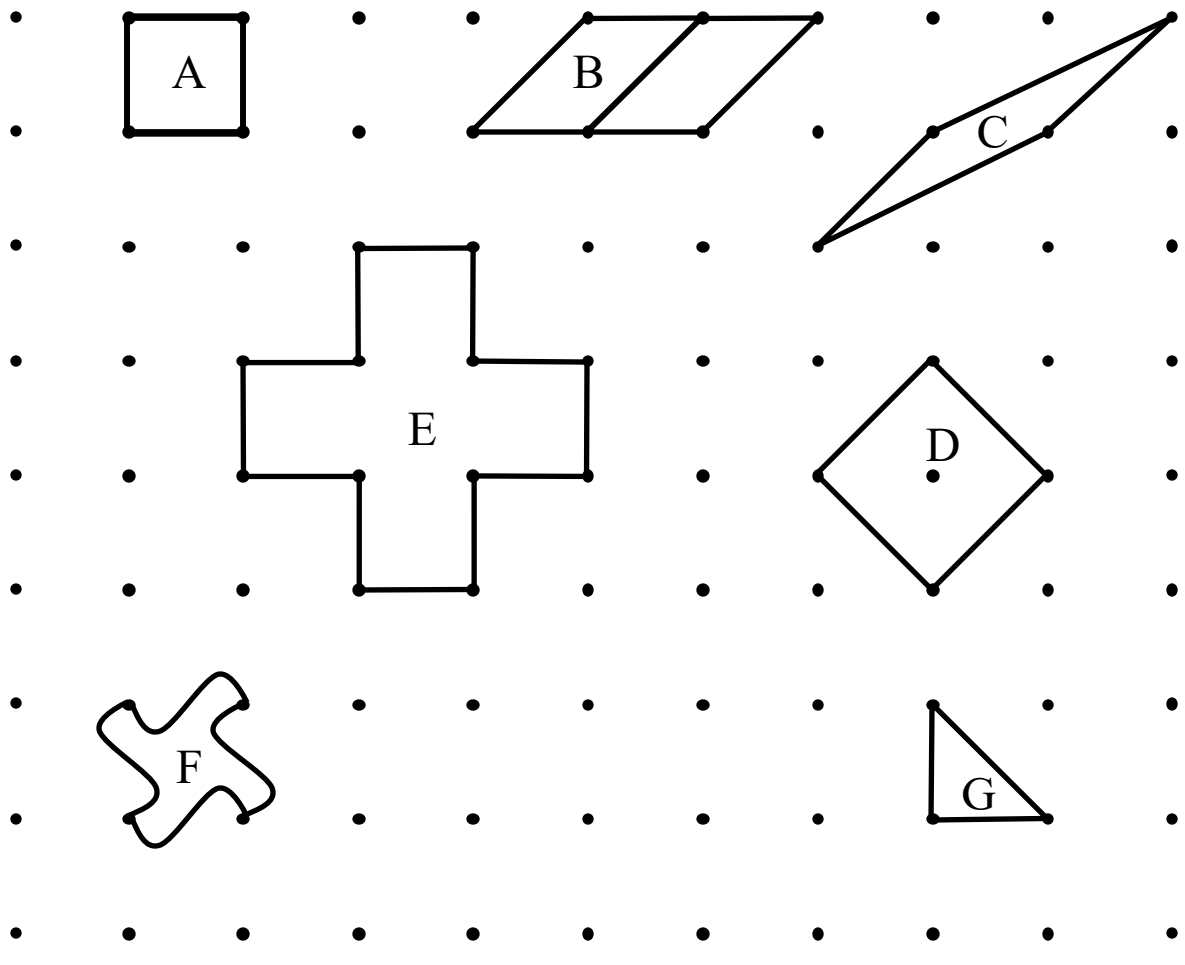


Figure 2.6 Some examples of lattice and non-lattice translations in a two-dimensional lattice

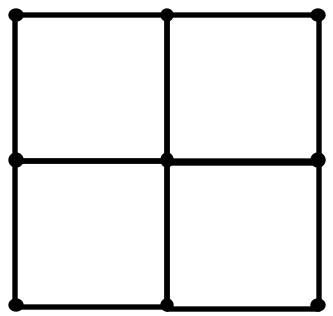
A region of space which when translated by all lattice translations or a subset of lattice translations generates the entire lattice or crystal without gaps or overlaps is a unit cell of the lattice or crystal.



Conventionally we prefer a parallelogram unit cell (2D) or a parallelopiped unit cell (3D)

Every lattice and a crystal can be described by a unit cell

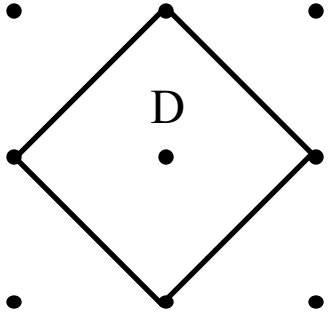
Effective number of lattice points per cell



Every lattice point is shared by 4 unit cells.

Number of lattice points per cell

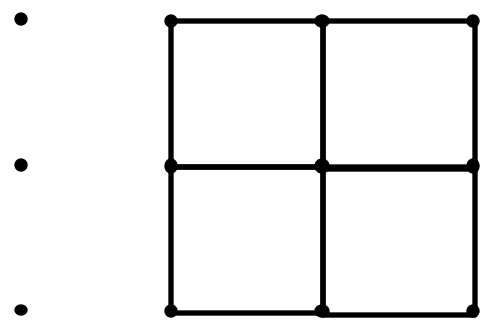
$$4 \times \frac{1}{4} = 1$$



Number of lattice points per cell

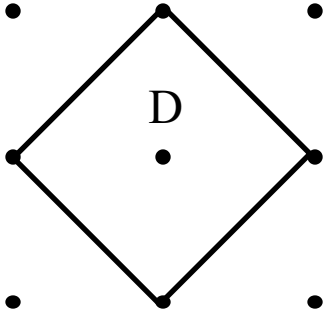
$$4 \times \frac{1}{4} + 1 = 2$$

Primitive and Nonprimitive unit cells

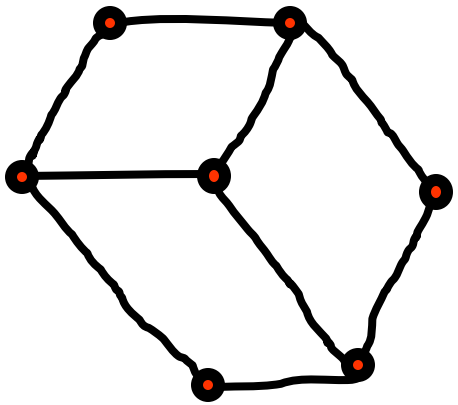


If the effective number of lattice points is.1 the cell is called PRIMITIVE

If the effective number of. lattice points is greater than 1 the cell is called NONPRIMITIVE



UNIT CELL:



In 3D lattice:
a parallelepiped with lattice points at corners.

Primitive Unit Cell: Lattice Points **only** at corners

eg. Simple Cubic Unit Cell

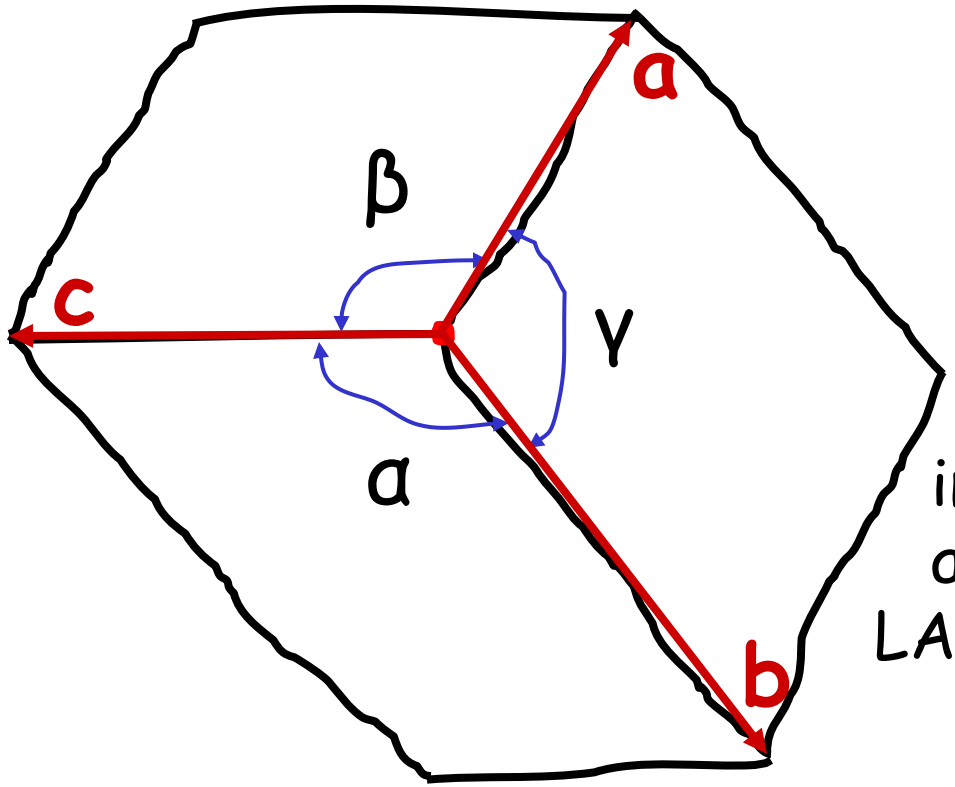
Non-Primitive Unit cell: Lattice Point at corners as well as some other points

eg. Body Centred Cubic Unit Cell

Lattice Parameters:

1. A corner as origin

2. The vectors **a**, **b**, **c** along the edges of the unit cell are called the **basis vectors**



3. The three lengths *a*, *b*, *c* and the three interaxial angles α, β, γ are called the LATTICE PARAMETERS

Classification of Lattices

Lattices

|

7 crystal systems

|

14 Bravais Lattices

Crystal System?

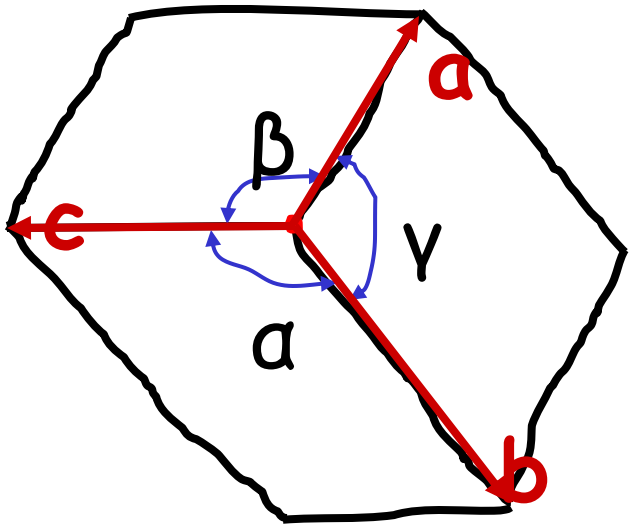
Cubic Crystal System?

$$a = b = c$$

$$\alpha = \beta = \gamma = 90°$$

7 crystal Systems

Unit Cell Shape	Crystal System
1. $a = b = c;\ \alpha = \beta = \gamma = 90°$	Cubic
2. $a = b \neq c;\ \alpha = \beta = \gamma = 90°$	Tetragonal
3. $a \neq b \neq c;\ \alpha = \beta = \gamma = 90°$	Orthorhombic
4. $a = b \neq c;\ \alpha = \beta = 90°, \gamma = 120°$	Hexagonal
5. $a = b = c;\ \alpha = \beta = \gamma \neq 90°$ $a = b \neq c;\ \alpha = \beta = 90°, \gamma = 120°$	Trigonal
6. $a \neq b \neq c;\ \alpha = \beta = 90°, \gamma \neq 90°$	Monoclinic
7 $a \neq b \neq c;\ \alpha \neq \beta \neq \gamma$	Triclinic



Seven Crystal Systems and 14 Bravais Lattices (Exp 2 Starting This Friday)

Seven Crystal System	Fourteen Bravais Lattices				
	P	*I*	*F*	*S*	*R*
Triclinic	*aP*				
Monoclinic	*mP*			*mS*	
Orthorhombic	*oP*	*oI*	*oF*	*oS*	
Tetragonal	*tP*	*tI*			
Trigonal					*hR*
	hP				
Hexagonal	*hP*				
Cubic	*cP*	*cI*	*cF*		

P: *Primitive or simple*

I: *Body-centred*

F: *Face–centred*

R: *Rhombohedral–centred*

S: *Side–centred*
or Base–centred
or End–centred

S: *A, B or C*

a in aP lattice stands for anorthic

Trigonal crystal system has **TWO** lattices associated with it not one.

hP lattice belongs to both trigonal and hexagonal crystal systems

R-centering is a special centering for trigonal lattice.

Trigonal crystal system has **TWO** lattices associated with it not one.

Sorry to NPTEL Viewers since (2018)
and
Generations of IITD students Since (1996)

MLL 100 Lec 4, Fri 01.08.2025

1. Meaning of different centering symbols: A, B, C, F, I, P, R, S
2. Two Bravais lattices in trigonal system and two conventional cells of the hR lattice
3. Mystery of missing Bravais lattices
4. $cS \rightarrow tP$ based on unit cell reasoning (later to be shown as correct result obtained on the basis of incorrect reasoning)
5. $cF \rightarrow tI$
6. Unit cell shapes can't be the basis classification
7. Symmetry definition, rotation symmetry types (folds) and crystallographic restriction
8. Symmetry based definition of crystal systems

Seven Crystal Systems and 14 Bravais Lattices (Exp 2 Starting This Friday)

Seven Crystal System	Fourteen Bravais Lattices				
	P	*I*	*F*	*S*	*R*
Triclinic	*aP*				
Monoclinic	*mP*			*mS*	
Orthorhombic	*oP*	*oI*	*oF*	*oS*	
Tetragonal	*tP*	*tI*			
Trigonal					*hR*
	hP				
Hexagonal	*hP*				
Cubic	*cP*	*cI*	*cF*		

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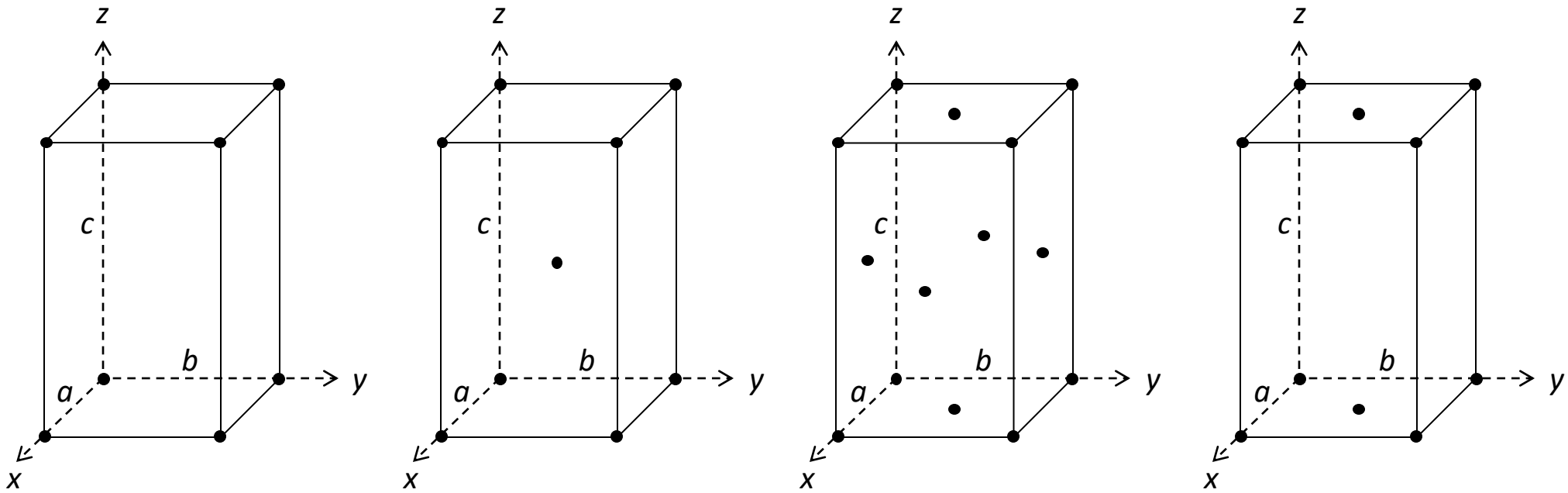


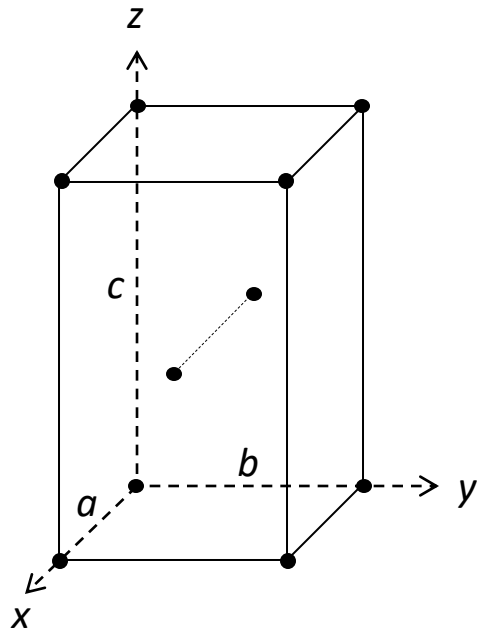
Orthorhombic *P*
(*oP)*
or
Primitive
orthorhombic
or
Simple
Orthorhombic

Orthorhombic I
(*oI)*
or
Body-centred
orthorhombic

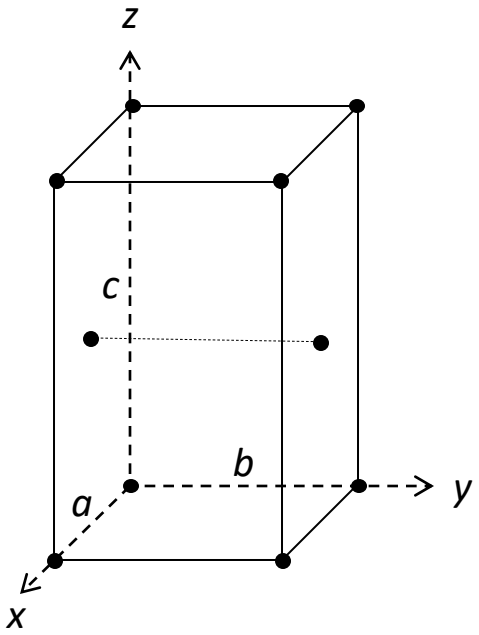
Orthorhombic F
(*oF)*
or
Face-centred
orthorhombic

Orthorhombic S
(*oS)*
or
End-centred
Orthorhombic
or
Base-centred
orthorhombic

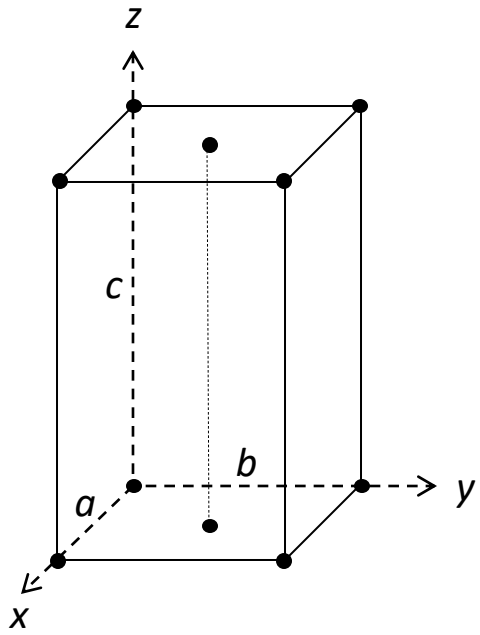
Figure 2.9 Diagrams for the conventional unit cells for the four Bravais lattices in the Orthorhombic crystal system.



Orthorhombic *A*



Orthorhombic *B*



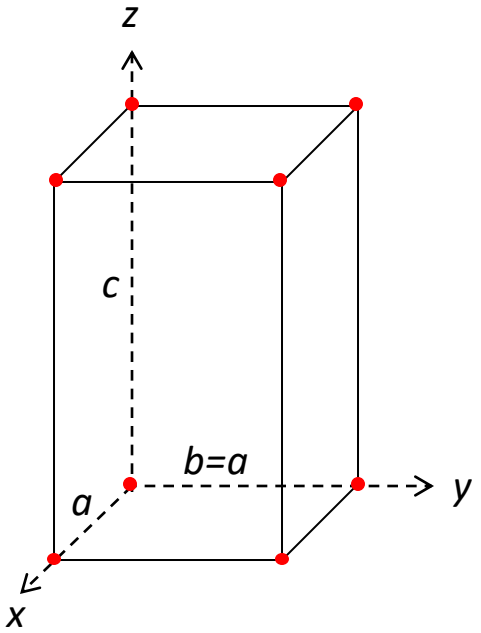
Orthorhombic *C*

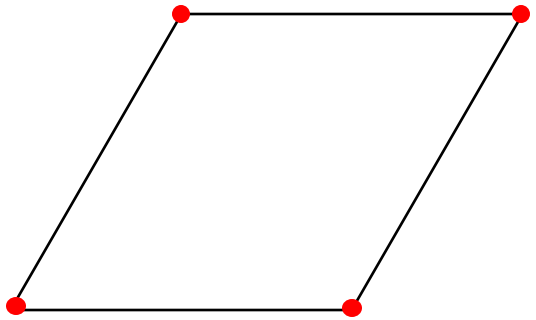
End-centred orthorhombic
Base-centred orthorhombic
Side-centred orthorhombic
One-face-centred orthorhombic

Orthorhombic *S*

TWO Lattices in TRIGONAL Crystal System

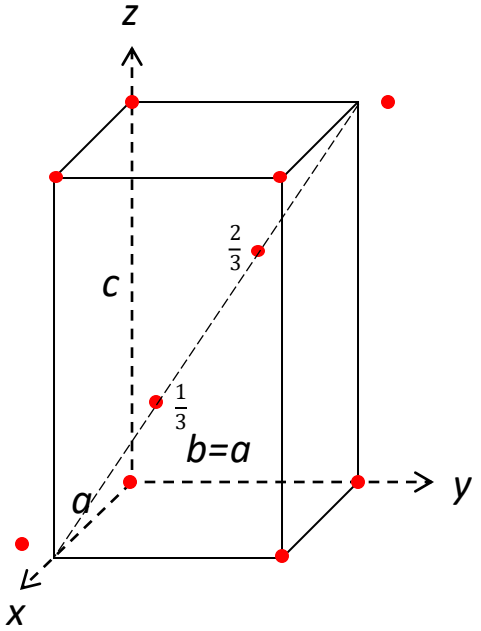
hP

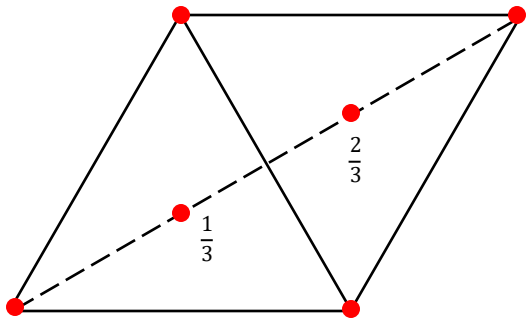




Primitive Hexagonal
One lattice point per cell

hR



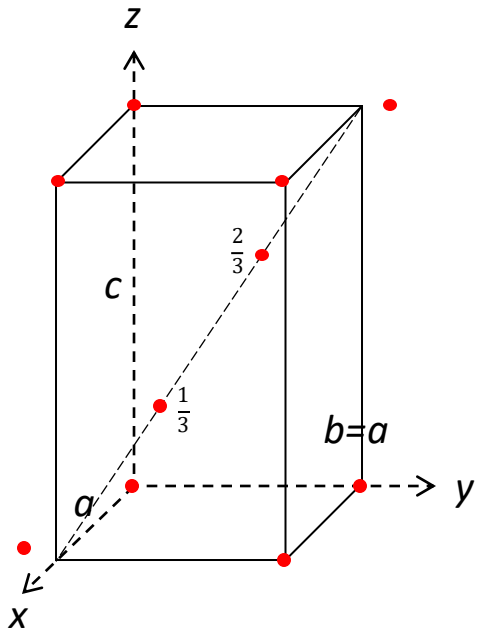


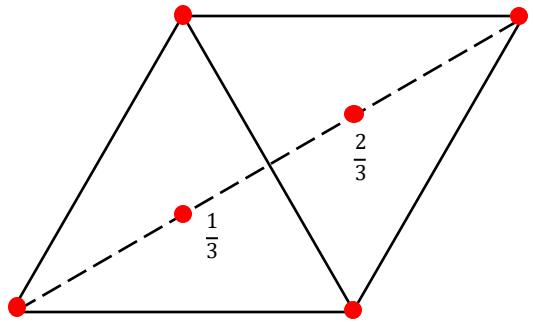
Two additional lattice points at 1/3 and 2/3 locations on a long body diagonal

Rhombohedrally centred Hexagonal
THREE lattice point per cell

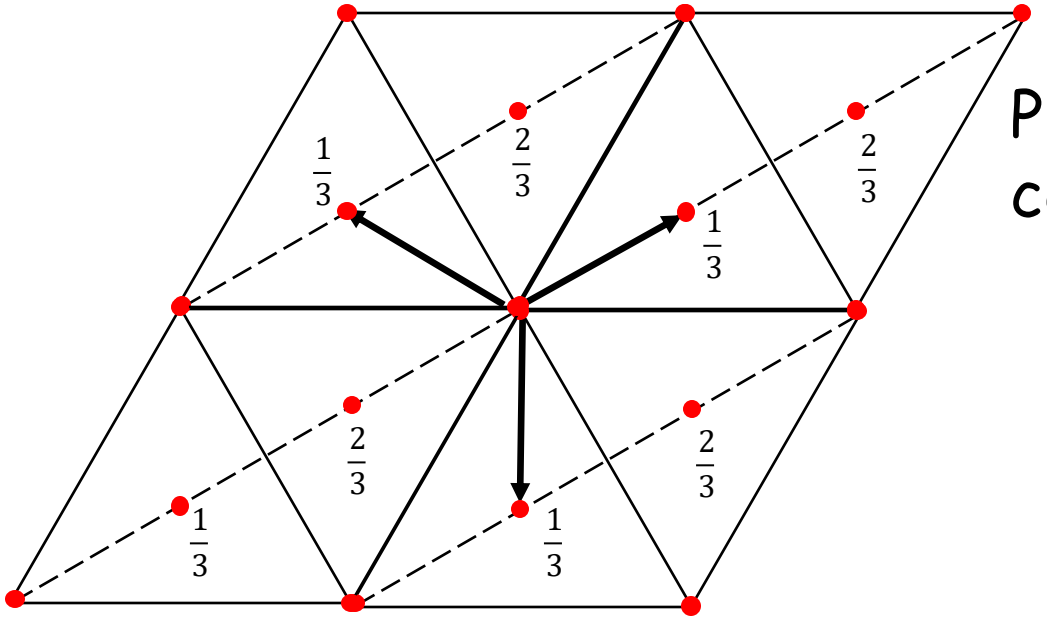
Two conventional unit cells of trigonal hR lattice

hR





Rhombohedrally centred
Hexagonal Cell
THREE lattice point per cell
Non Primitive Conventional Cell



Primitive Rhombohedral cell

$$a = b = c$$
$$\alpha = \beta = \gamma$$

Trigonal Crystal System

~~rhombohedral system~~

Has 2 lattices

hP

hR

Only Bravais lattice to have two different conventional unit cells

Nonprimitive Rhomohedrally centred hexagonal cell

Primitive rhombohedral cell

$a = b = c$

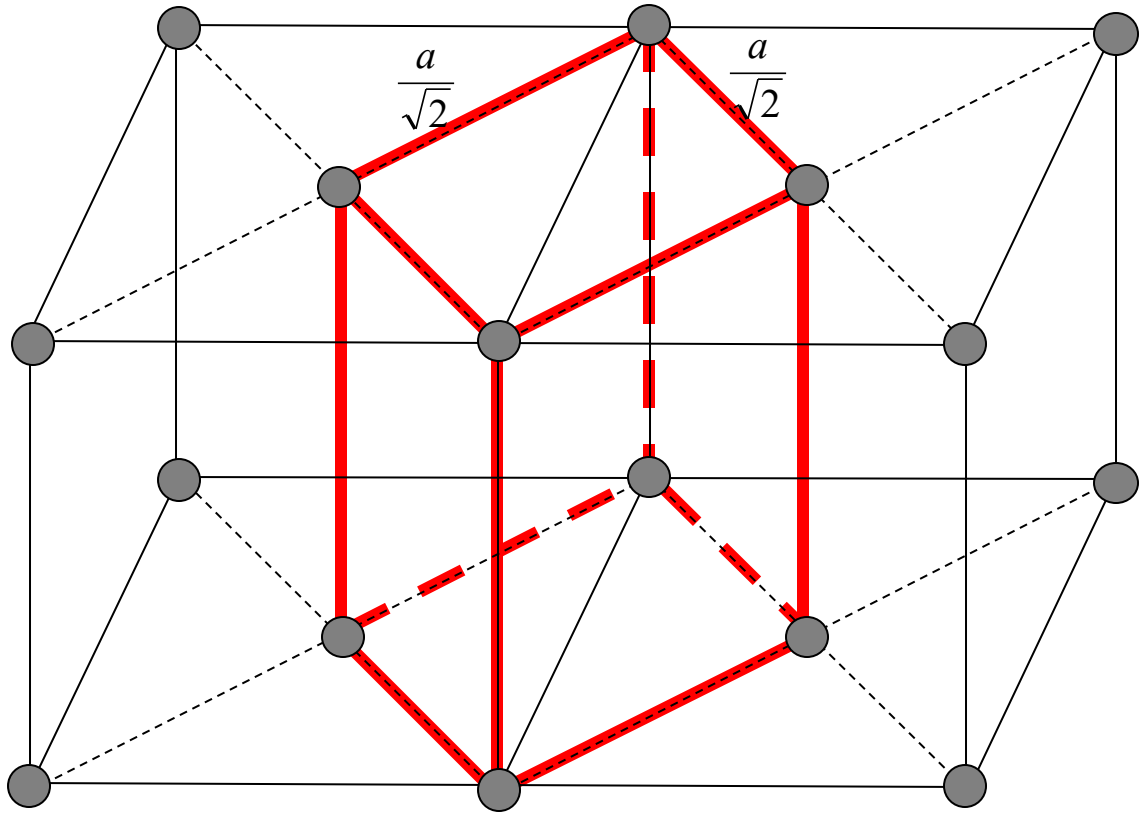
$\alpha = \beta = \gamma \neq 90°$

Mystery: Why so many boxes are empty?

Seven Crystal System	Fourteen Bravais Lattices				
	P	*I*	*F*	*S*	*R*
Triclinic	*aP*				
Monoclinic	*mP*			*mS*	
Orthorhombic	*oP*	*oI*	*oF*	*oS*	
Tetragonal	*tP*	*tI*			
Trigonal					*hR*
	hP				
Hexagonal	*hP*				
Cubic	*cP*	*cI*	*cF*	?	

Why don't we have end-centred cubic (*cS*)?

End-centred cubic not in the Bravais list?



$$a_{Tetragonal} = \frac{a_{Cubic}}{\sqrt{2}};$$

$$c_{Tetragonal} = a_{Cubic}$$

End-centred cubic (cS) = Simple Tetragonal (tP)

Why end-centred cubic not there?

Seven Crystal System	Fourteen Bravais Lattices				
	P	*I*	*F*	*S*	*R*
Triclinic	*aP*				
Monoclinic	*mP*			*mS*	
Orthorhombic	*oP*	*oI*	*oF*	*oS*	
Tetragonal	*tP*	*tI*			
Trigonal					*hR*
	hP				
Hexagonal	*hP*				
Cubic	*cP*	*cI*	*cF*	*cS*	

P: *Primitive or simple*

I: *Body-centred*

F: *Face-centred*

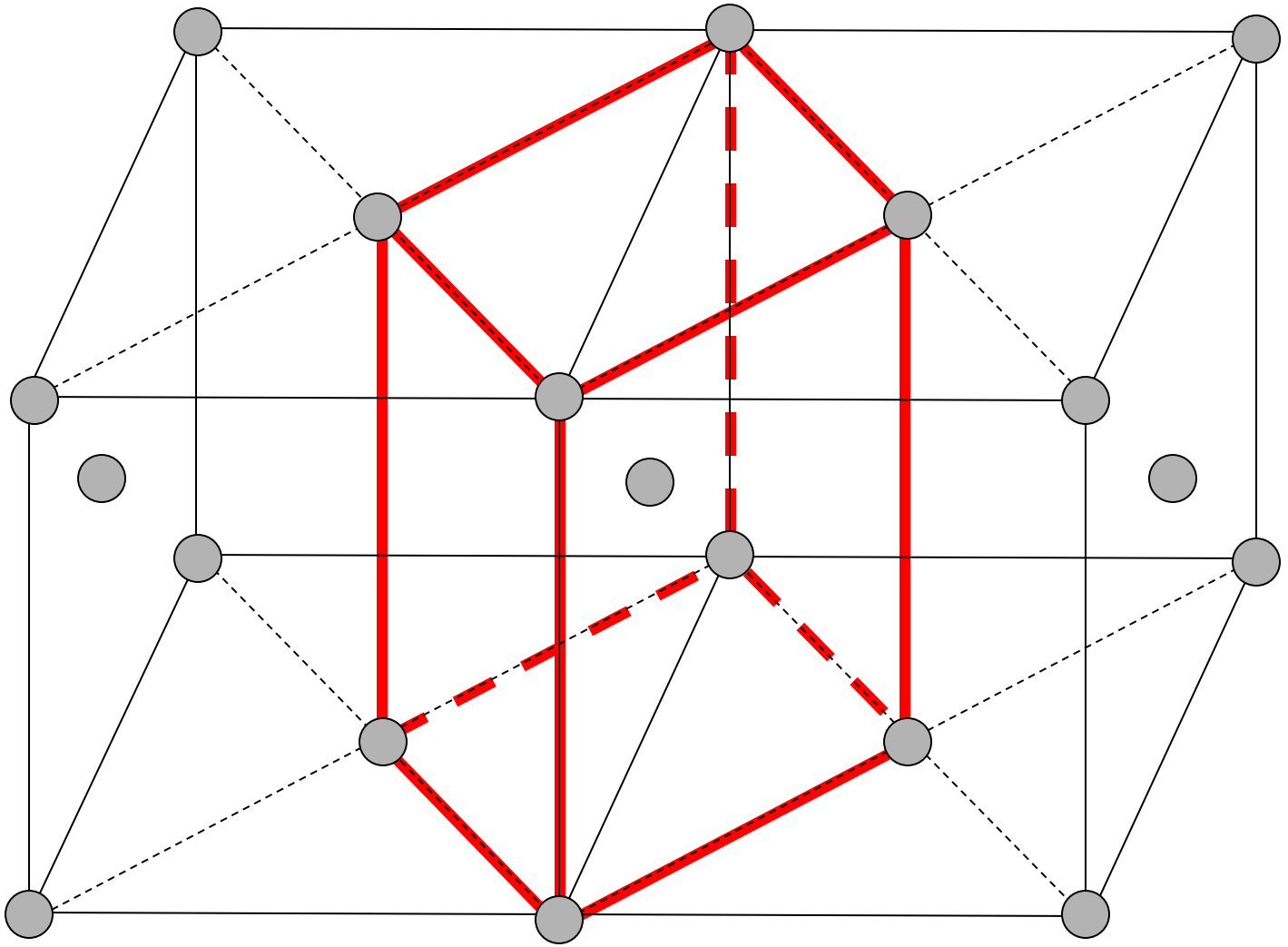
R: *Rhombohedral-centred*

S: *Side-centred*
or Base-centred
or End-centred

S: A, B *or* C

$$Cubic\ S \equiv Tetragonal\ P$$

Now apply the same procedure to the FCC lattice



Cubic F = Tetragonal I ?!!!

Existential Crisis for cubic F!

Seven Crystal System	Fourteen Bravais Lattices				
	P	*I*	*F*	*S*	*R*
Triclinic	*aP*				
Monoclinic	*mP*			*mS*	
Orthorhombic	*oP*	*oI*	*oF*	*oS*	
Tetragonal	*tP*	*tI*			
Trigonal					*hR*
	hP				
Hexagonal	*hP*				
Cubic	*cP*	*cI*	*cF*	*cS*	

P: *Primitive or simple*

I: *Body-centred*

F: *Face–centred*

R: *Rhombohedral–centred*

S: *Side–centred*
or Base–centred
or End–centred

S: *A, B or C*

If Cubic S ≡ Tetragonal P *Then Cubic F ≡ Tetragonal I*

History:

ML **Frankenheim**

1801-1869

1835: 15 lattices

1856: 14 lattices

Auguste Bravais

1811-1863

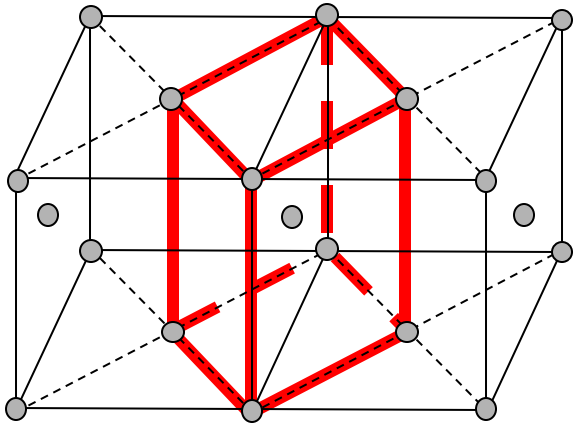
1850: 14 lattices

MLL100

01.08.2025

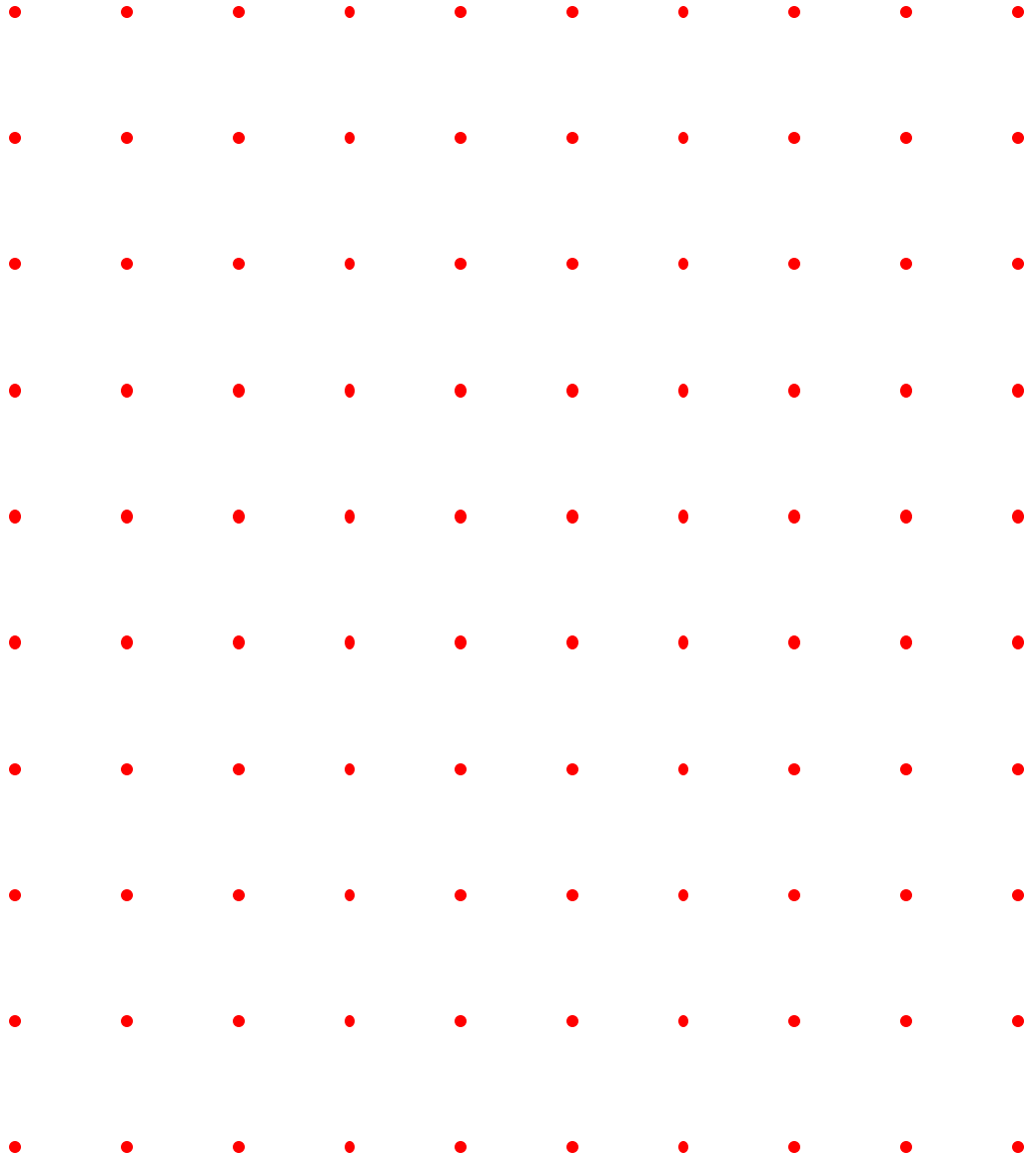
13 lattices

Couldn't find his photo on the net



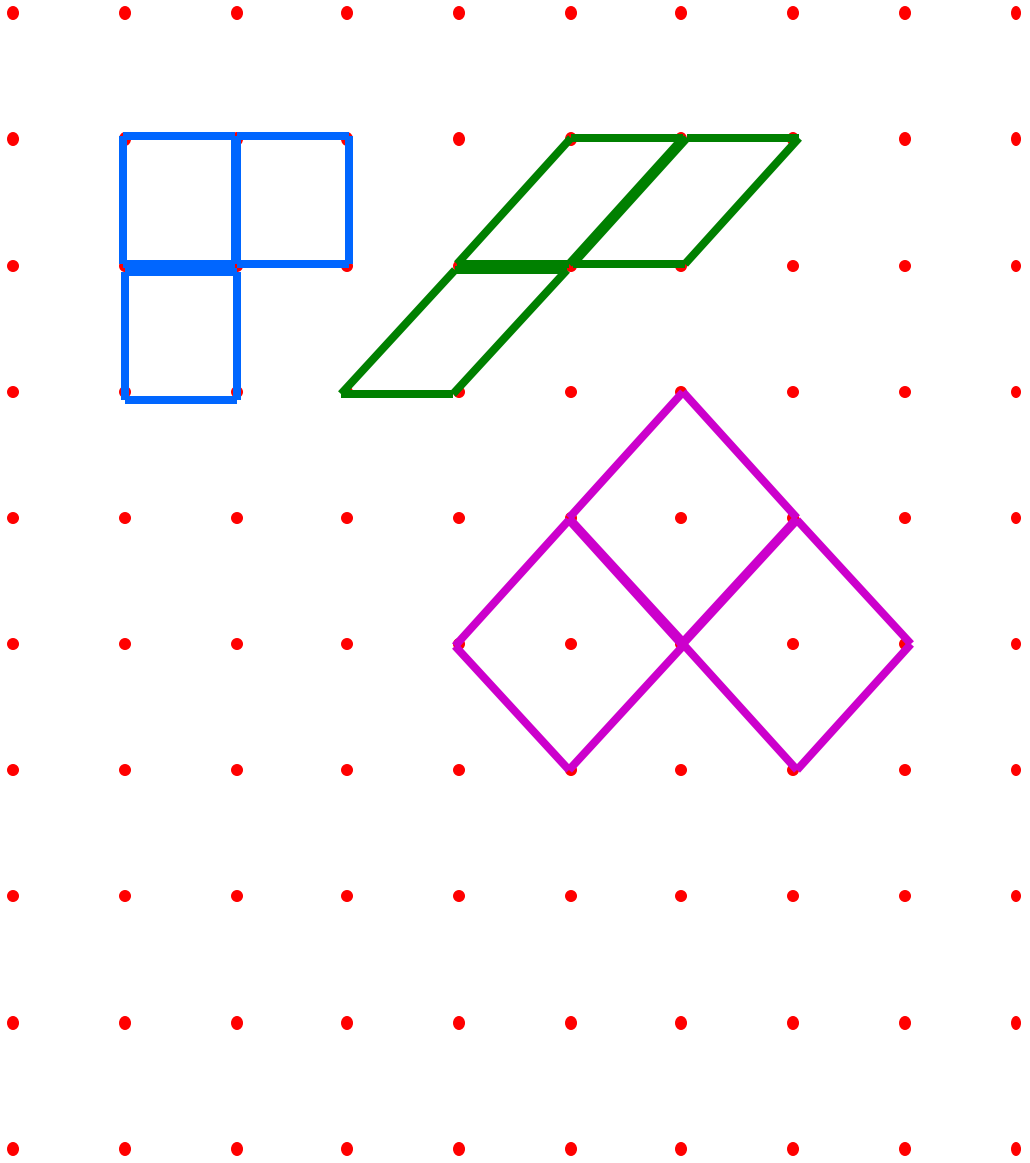
More than one unit cell for the same lattice: FCC or BCT

Unit cells are not unique :-(



Lattice worksheet

UNIT CELLS OF A LATTICE



A unit cell of a lattice is **NOT unique.**

Unit cell shape **CANNOT** be the basis for classification of Lattices

Cubic Crystal system?

$$a = b = c$$

$$\alpha = \beta = \gamma = 90°$$

7 crystal Systems

Unit Cell Shape	Crystal System
1. a=b=c, α=β=γ=90°	Cubic
2. a=b≠c, α=β=γ=90°	Tetragonal
3. a≠b≠c, α=β=γ=90°	Orthorhombic
4. a=b≠c, α=β=90° , γ=120°	Hexagonal
5. a=b=c, α=β=γ≠90°	Trigonal
6. a≠b≠c, α=β=90° γ≠90°	Monoclinic
7 a≠b≠c, α≠β≠γ	Triclinic

Not Definitions

Unit cell shape

CANNOT

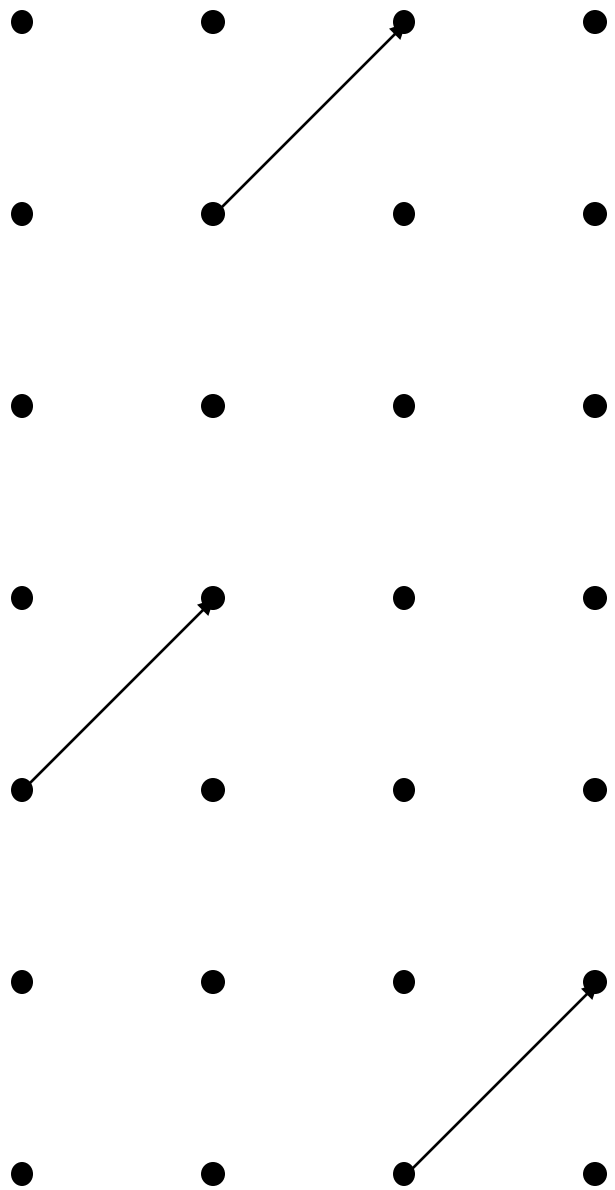
be the basis for classification of Lattices

What is the basis for
for
7 crystal systems?

Symmetry

Symmetry?

If an object is brought into self-coincidence after some operation it is said to possess symmetry with respect to that operation.



Translational symmetry

Lattice translation: a vector from one lattice point to another

Symmetric wrt lattice translations

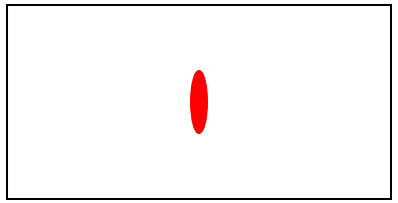
defining symmetry of a lattice

LATTICE: a set of points having translational symmetry

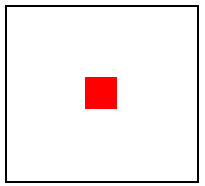
Rotation Axis

n-fold Rotation Axis:
smallest non-zero rotation angle of

$$\theta = \frac{360^{\circ}}{n}$$



$\theta = 180^{\circ}$ $n = 2$ 2-fold rotation axis



$\theta = 90^{\circ}$ $n = 4$ 4-fold rotation axis

Examples of Rotational Symmetry

Z     

Angles:

180°	120°	90°	72°	60°	45°
Fold:					
2	3	4	5	6	8

Graphic symbols

Crsytallographic Restriction

Only possible rotational symmetries for crystals

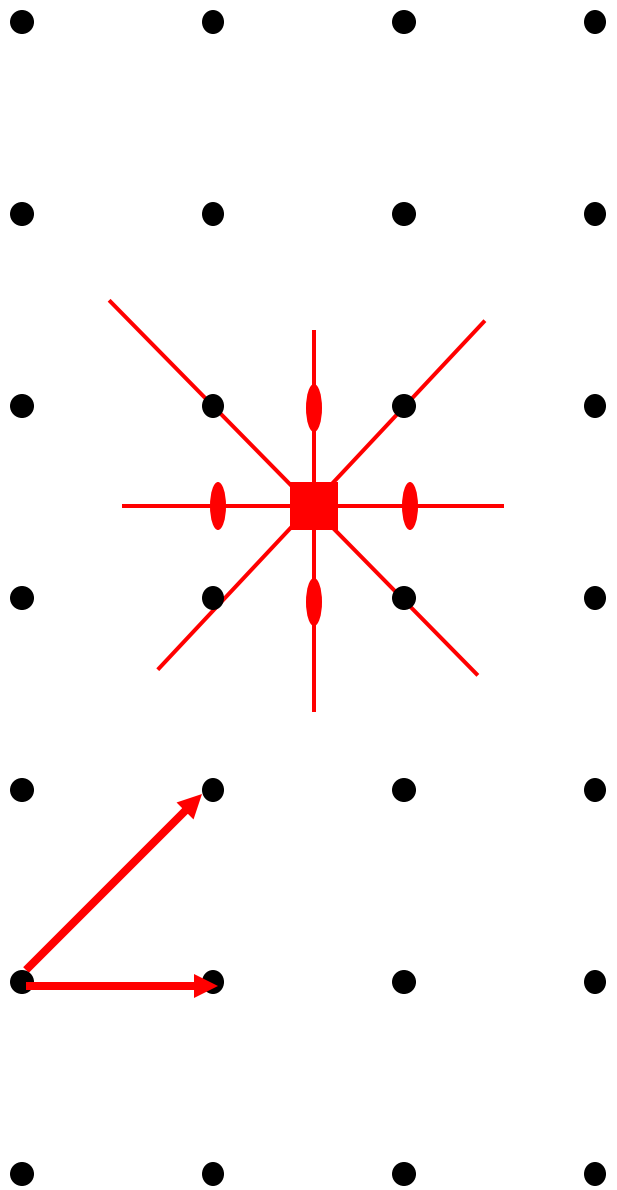
Symmetry of lattices

Lattices have

Translational symmetry

Rotational symmetry

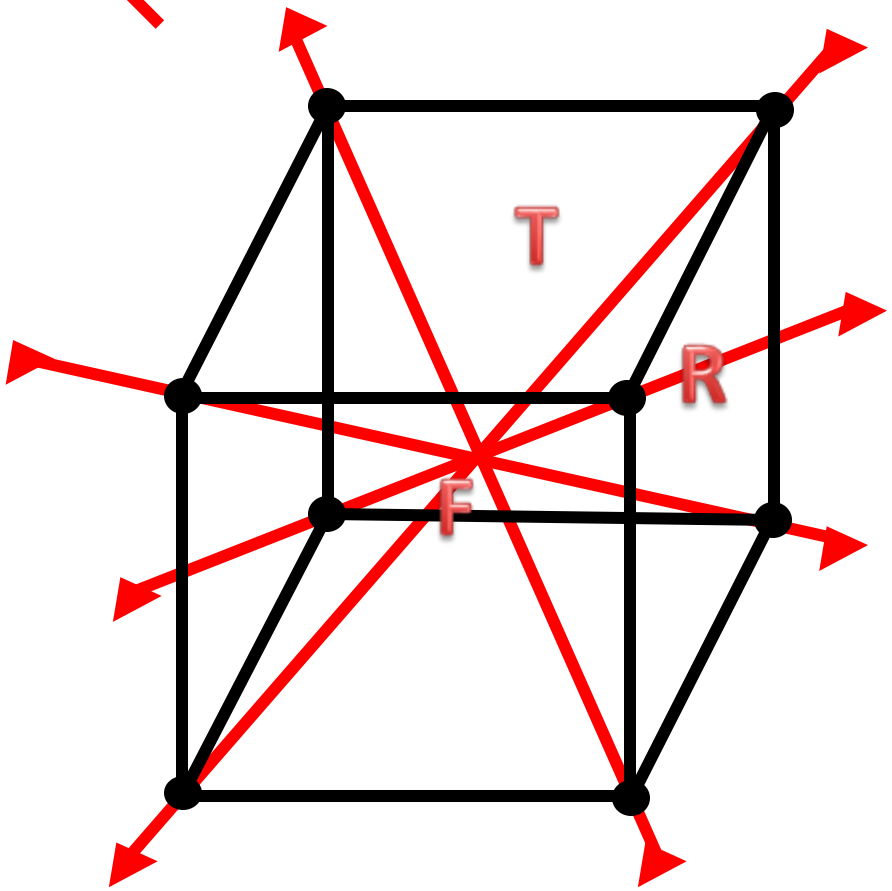
Reflection symmetry



Cubic Symmetry

~~3 Four-Fold Axes~~

4 Three-Fold Axes



NaClO3

Sodium chlorate

Point Group 23

Has 4 3fold but
Not 4-fold.

7 crystal Systems

7 types of rotational symmetry of a lattice

Defining symmetry → Crystal system ⇏ ⇒ Conventional unit cell

4  → Cubic → $a=b=c$, $\alpha=\beta=\gamma=90°$

7 crystal Systems

Defining symmetry	Crystal system	Conventional unit cell
$Four\ 3\ fold$	Cubic	$a = b = c;\ \alpha = \beta = \gamma = 90°$
$Single\ 4\ fold$	Tetragonal	$a = b \neq c;\ \alpha = \beta = \gamma = 90°$
$Three\ 2\ fold$	Orthorhombic	$a \neq b \neq c;\ \alpha = \beta = \gamma = 90°$
$Single\ 6\ fold$	Hexagonal	$a = b \neq c;\ \alpha = \beta = 90°, \gamma = 120°$
$Single\ 3\ fold$	Trigonal	$a = b = c;\ \alpha = \beta = \gamma \neq 90°$ $a = b \neq c;\ \alpha = \beta = 90°, \gamma = 120°$
$single\ 2\ fold$	Monoclinic	$a \neq b \neq c;\ \alpha = \beta = 90°, \gamma \neq 90°$
$No\ symmetry\ or\ 1fold$	Triclinic	$a \neq b \neq c;\ \alpha \neq \beta \neq \gamma$