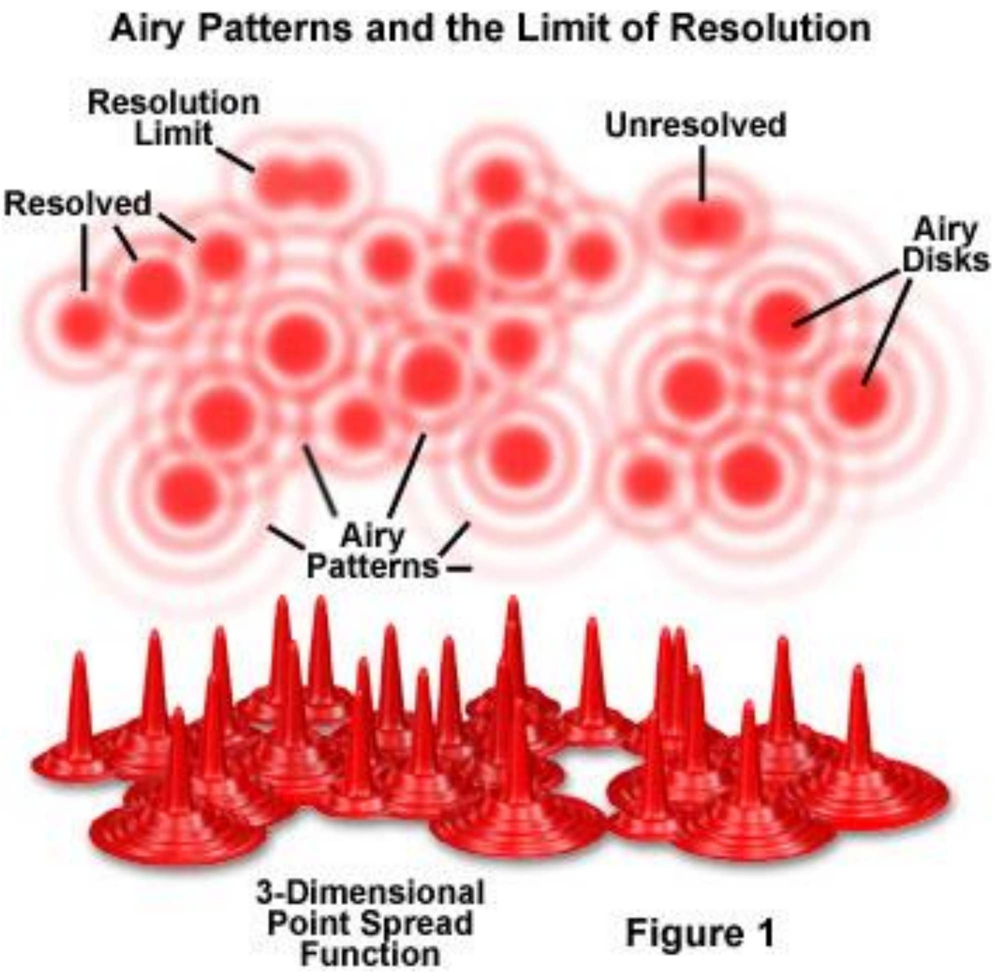
Lecture 5

Resolution and Numerical Aperture

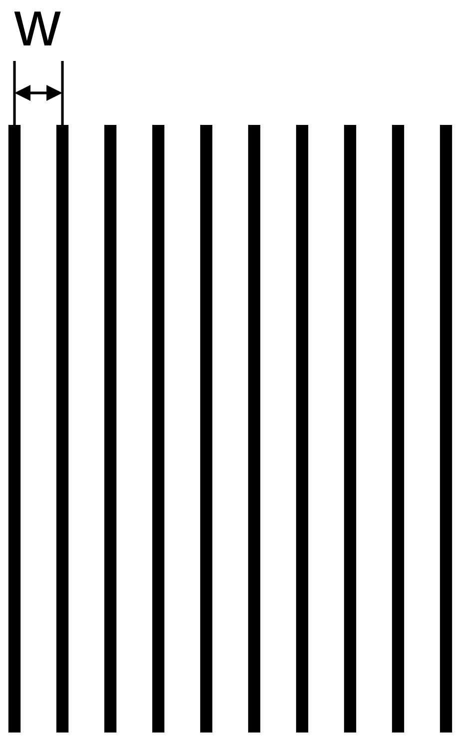
Resolution

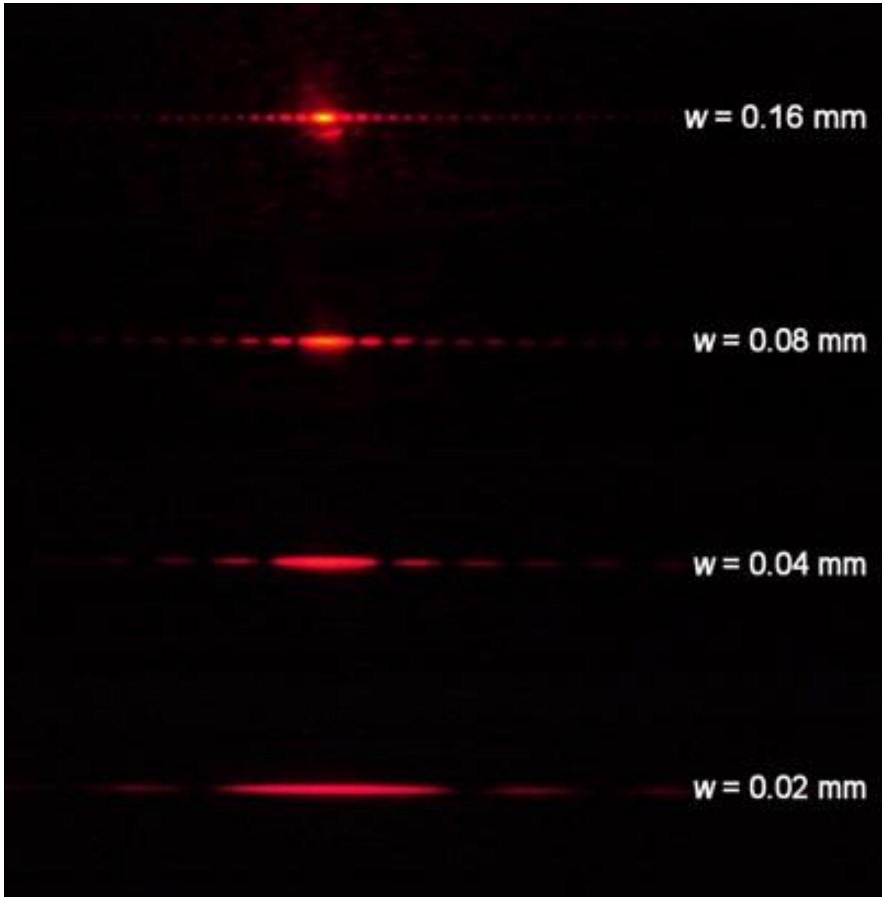
Smallest distance between two points that can be distinguished



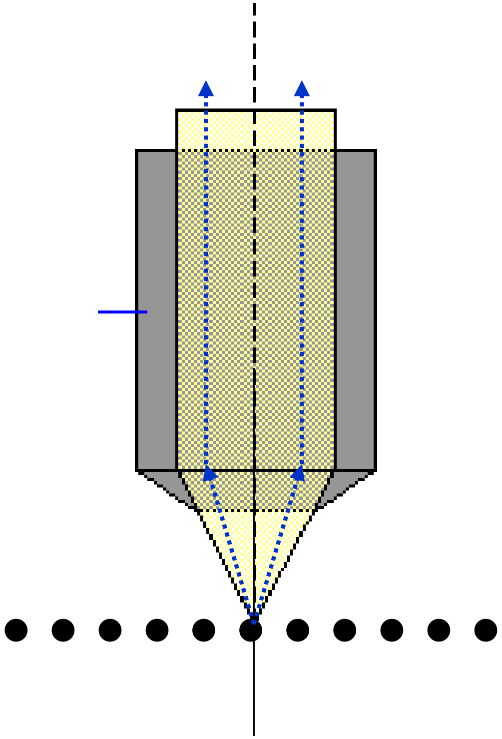
Fine Detail Acts As a Diffraction Grating

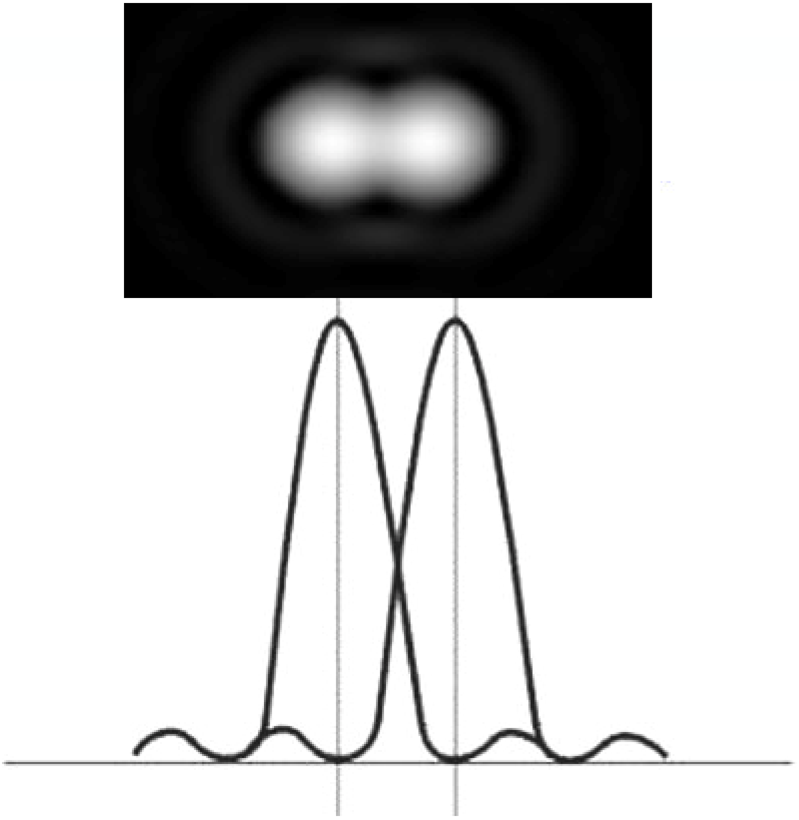
Visible light induces diffraction if two points are close





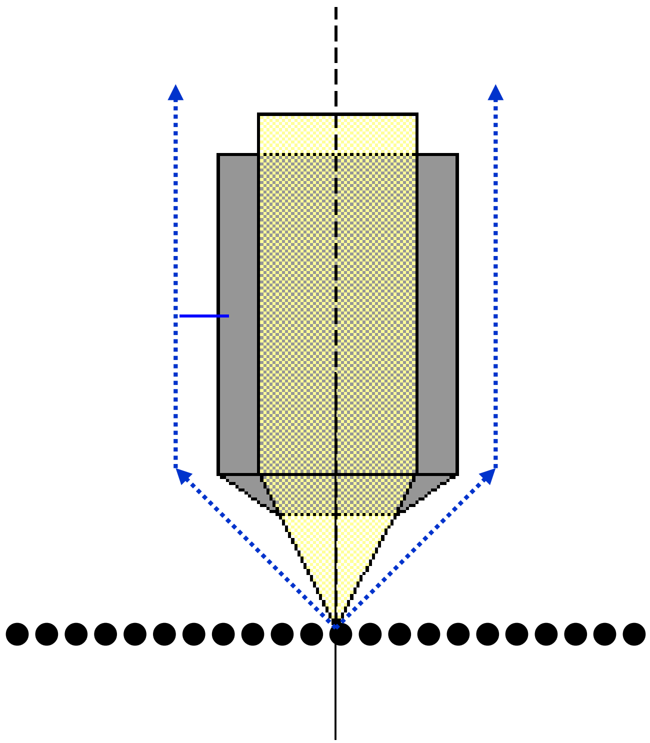
Diffraction vs Resolution

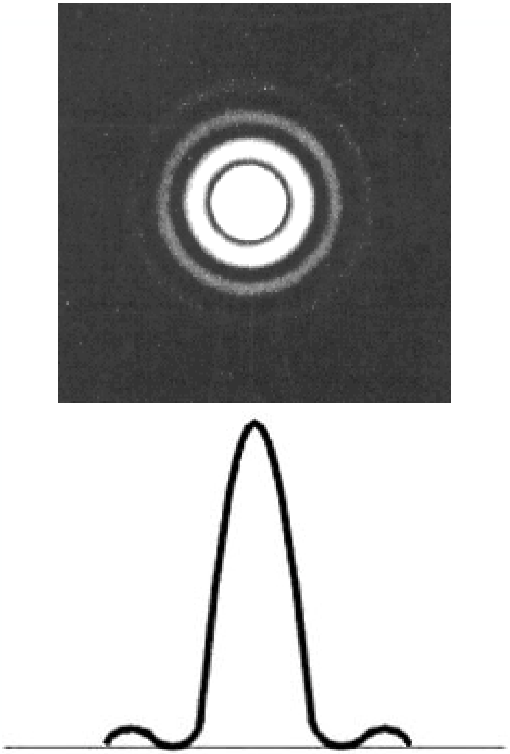




Spacing resolved: we can see the separation of two spots

Diffraction vs Resolution





Space not resolved: you can collect only one of the rays from the diffraction pattern

Resolution

Resolution (x) = $(0.61*\lambda)/(\mathrm{NA})$

Numerical Aperture (NA)

NA = $\mathbf{n}*\sin(\mathbf{A}/2)$

where **n** is the index of refraction of the medium in which the lens is working, and **A** is the angular aperture of the lens

Resolution depends on <u>wavelength, n, and A</u> (distance)

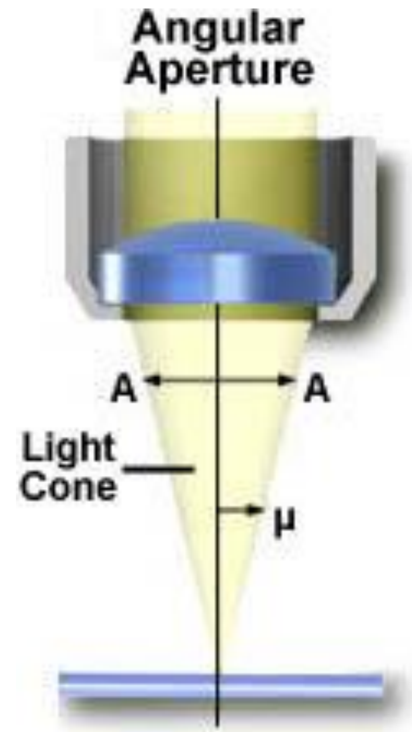
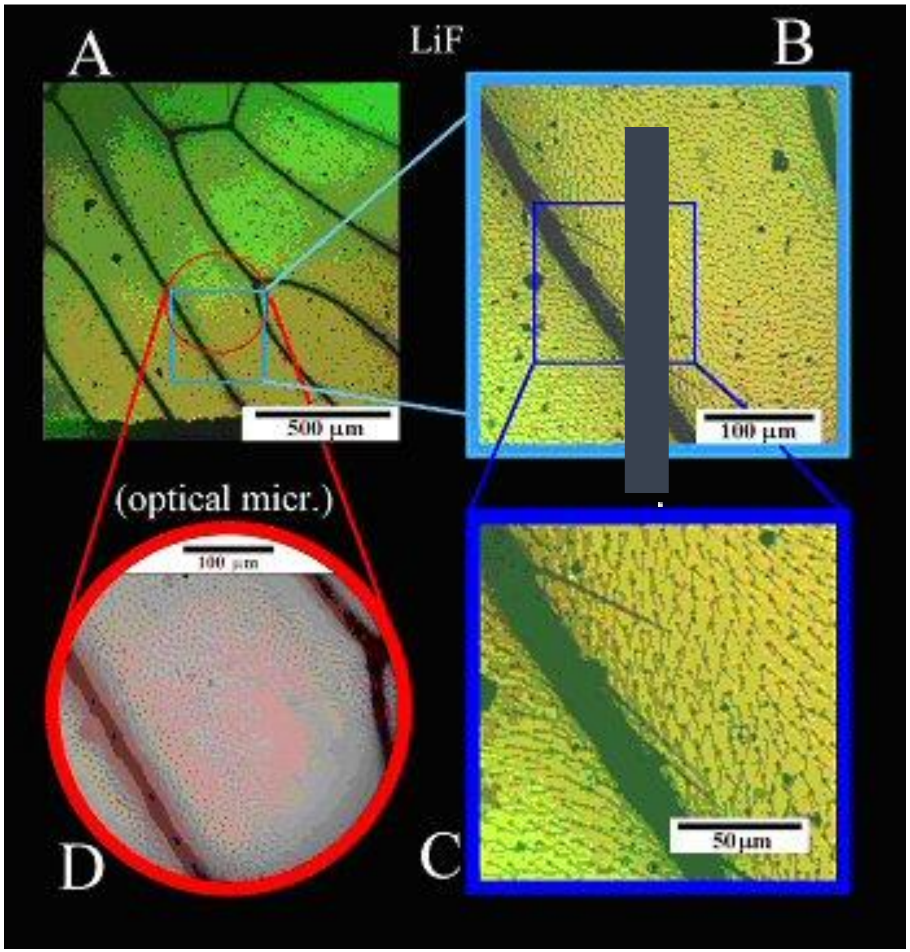


Figure 1

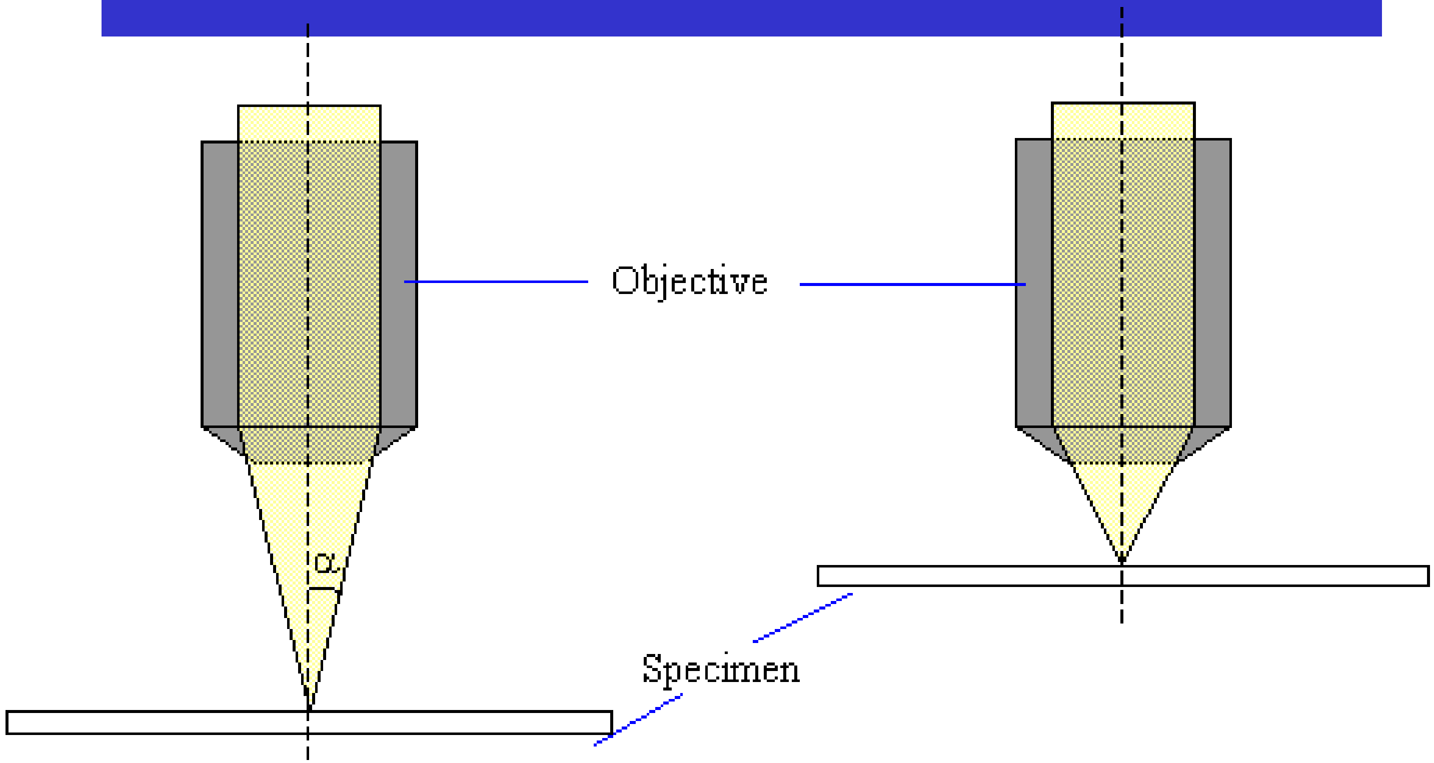
Resolution: Wavelength

Blue (400 nm) is better than red (650 nm)



Wavelength (Nanometers)	Resolution (Micrometers)
360	.19
400	.21
450	.24
500	.26
550	.29
600	.32
650	.34
700	.37

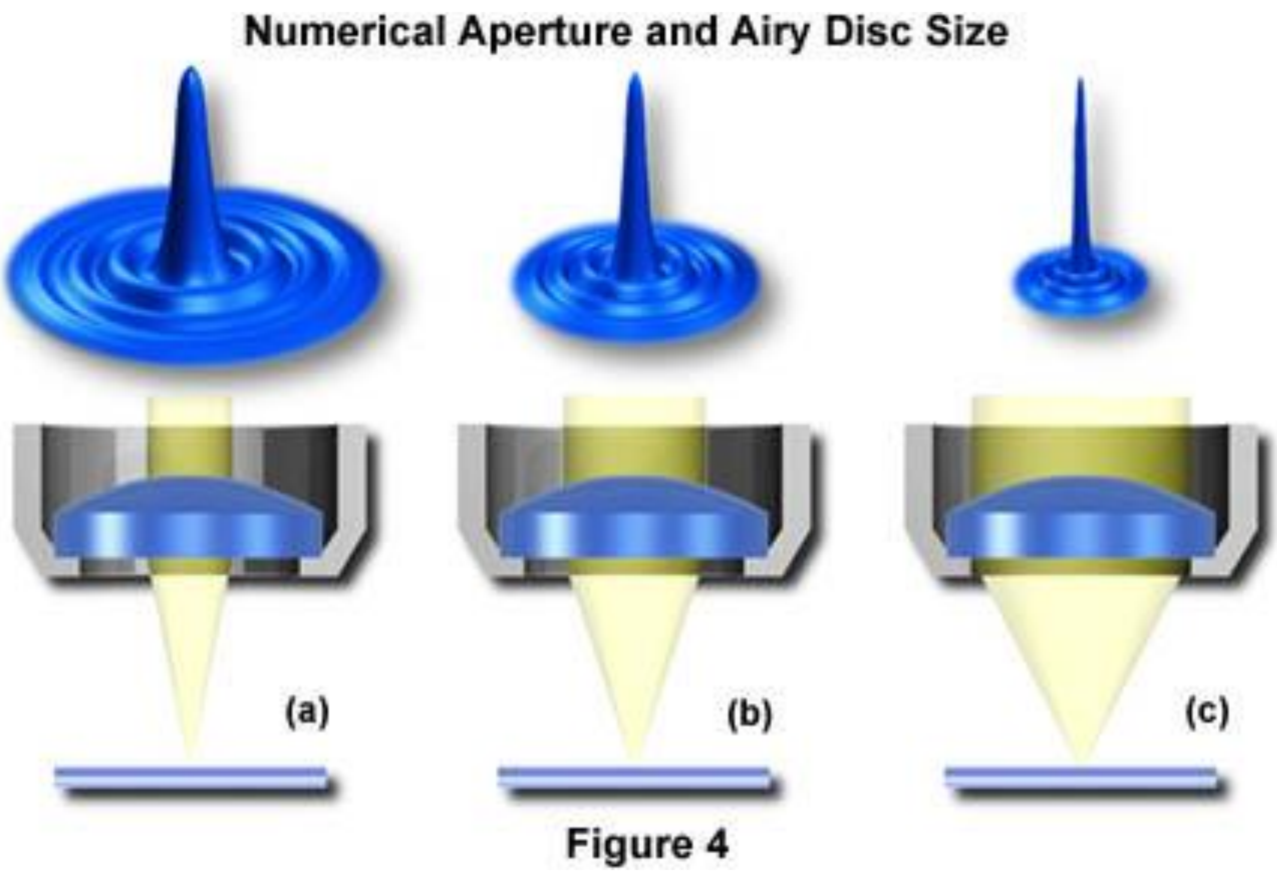
Resolution: NA



Low value for angular
Aperture A (α)
Low numerical aperture (NA)
Large X
Low resolution

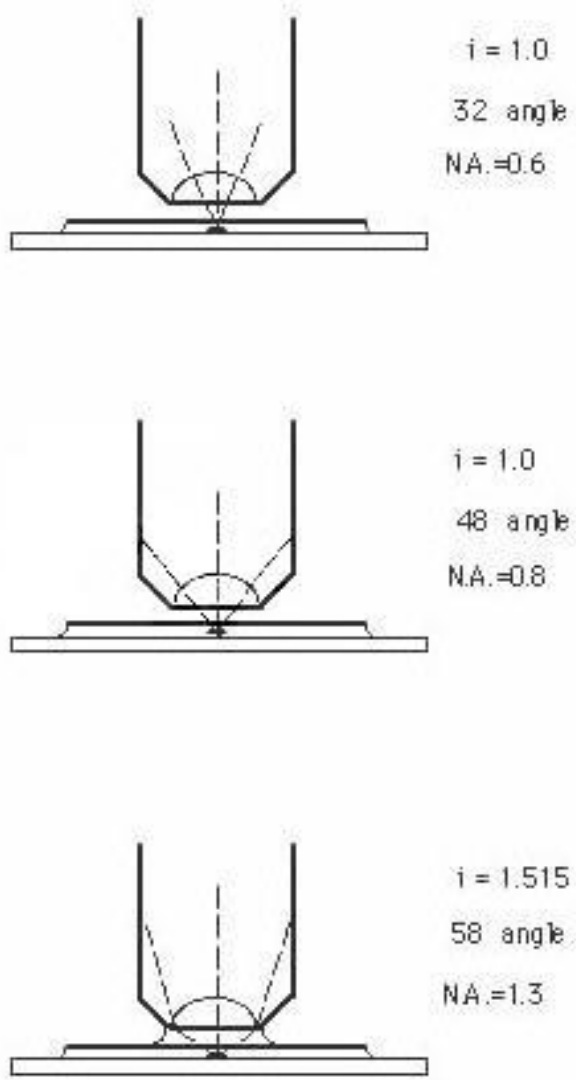
High value for angular
Aperture, A (α)
High numerical aperture (NA)
Small X
High resolution

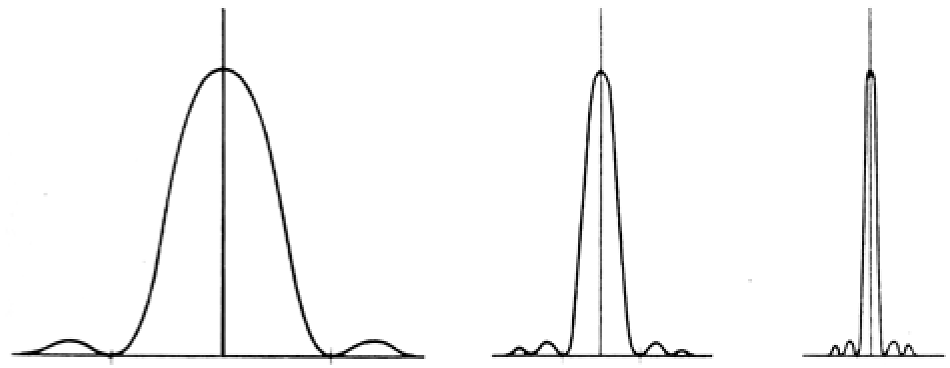
Resolution: Objectives



4X 10X 20X

Resolution: n





Resolution

	Objective Type					
	Plan Achromat		Plan Fluorite		Plan Apochromat	
Magnification	N.A.	Resolution (µm)	N.A.	Resolution (µm)	N.A.	Resolution (µm)
4x	0.10	2.75	0.13	2.12	0.20	1.375
10x	0.25	1.10	0.30	0.92	0.45	0.61
20x	0.40	0.69	0.50	0.55	0.75	0.37
40x	0.65	0.42	0.75	0.37	0.95	0.29
60x	0.75	0.37	0.85	0.32	0.95	0.29
100x	1.25	0.22	1.30	0.21	1.40	0.20
N.A. = Numerical Aperture						

Objective Lens

Color code (X5: Red, X40: Blue, etc)

Plan Achromatic correction

X10 and NA

Tube length and thickness of cover slip

http://www.microscopyu.com/articles/optics/objectiveintro.html
http://www.microscopyu.com/articles/optics/objectivespecs.html

Lecture 6

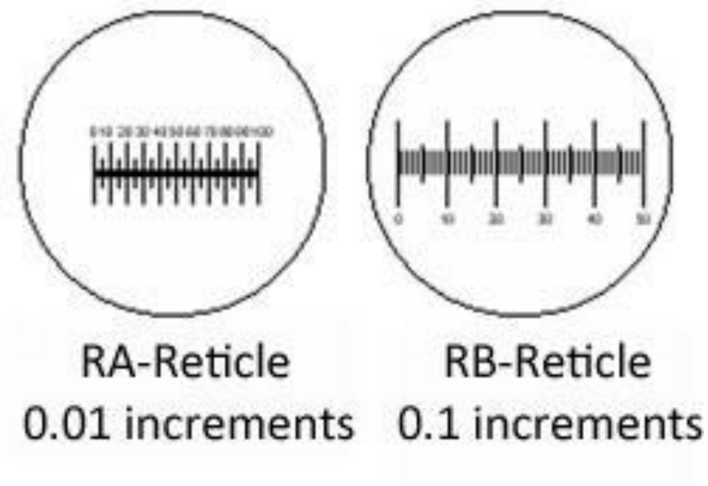
Micrometry

Micrometry

Measurement through microscope

Millimeter, μm (micron)

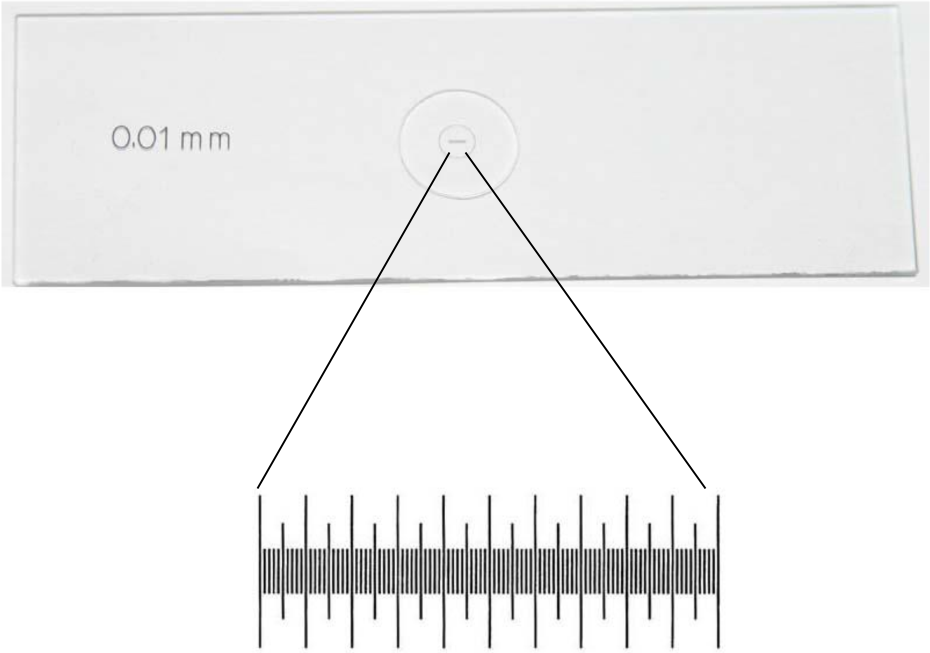
Eyepieces with reticles are required



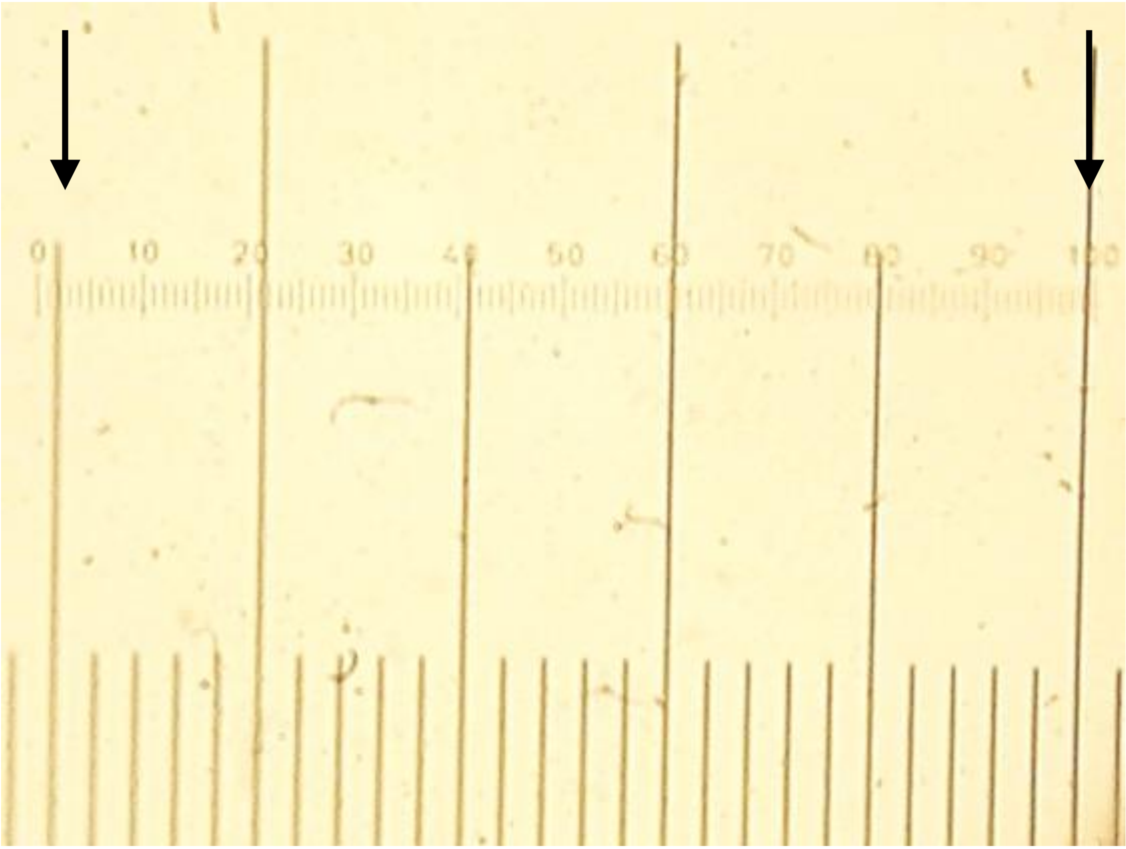
Stage Micrometer for Calibration

1 division = 0.01 mm (10 μm)

Total 100 divisions
100*0.01 = 1 mm



Calibration 1 (Demo Required)



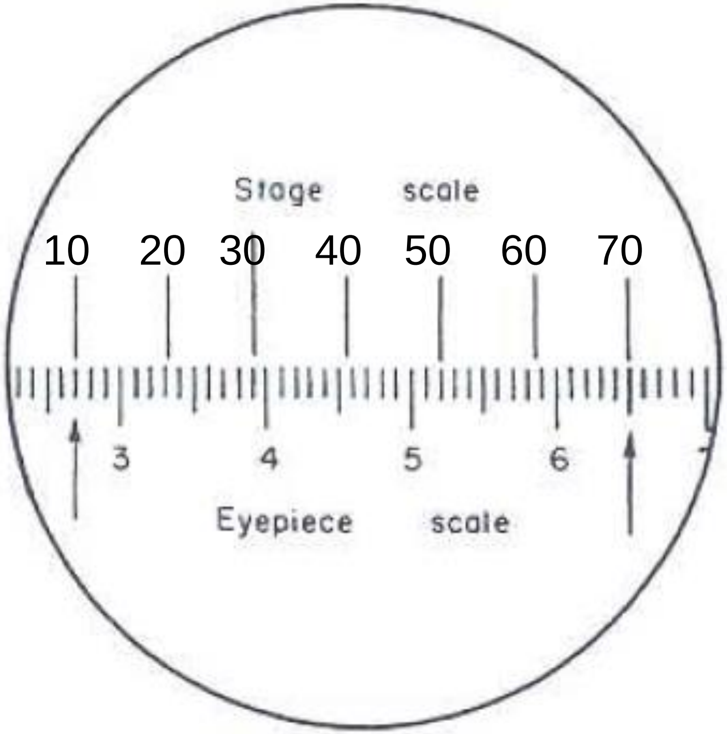
OS (from reticles)

SS from a stage micrometer

	left	right	# of divisions
OS (ocular scale)	2	99	97
SS (stage scale)	5	30	25

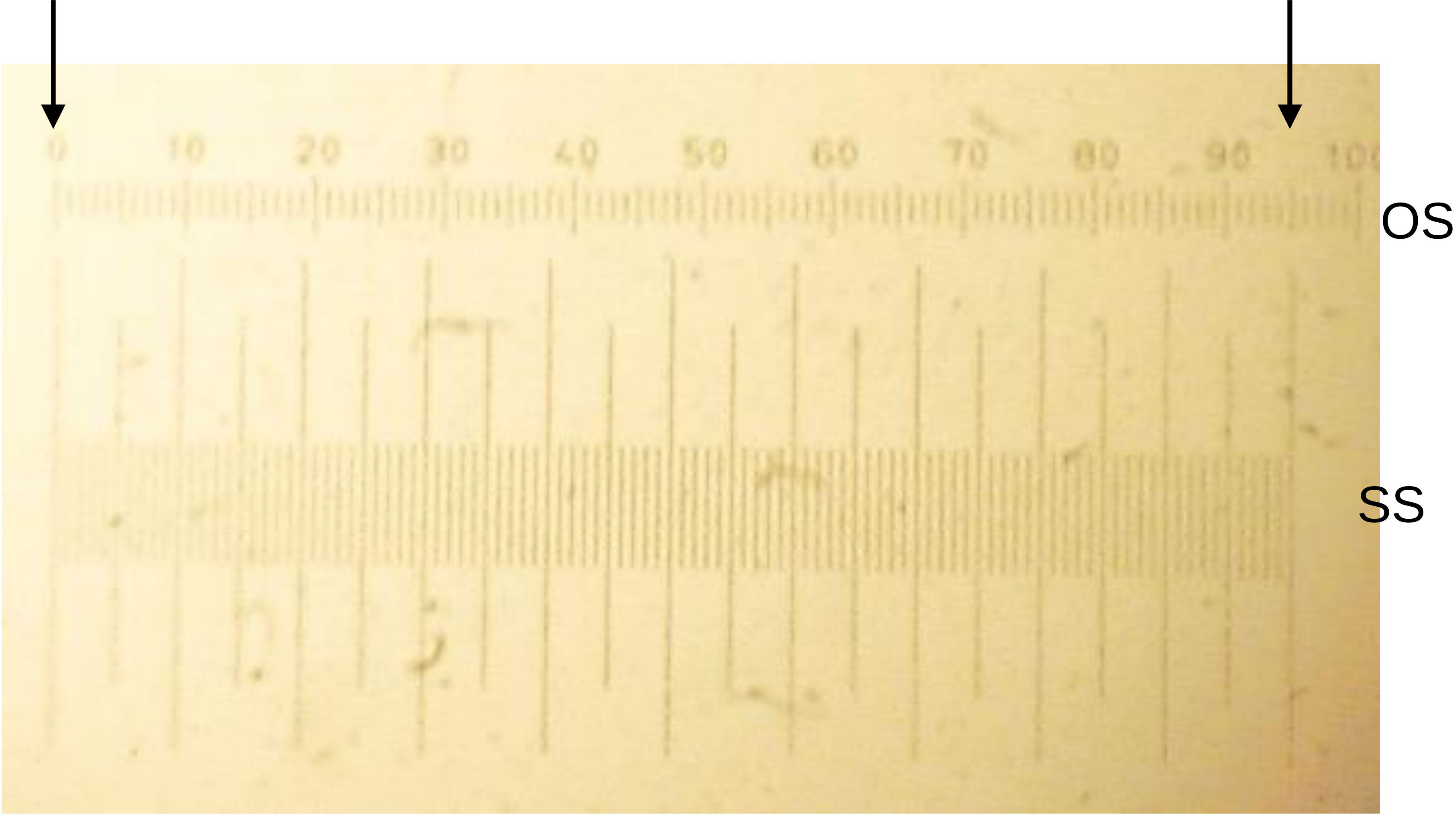
$(25/97)*10 = 2.58\ \mu m$

Calibration 2



	left	right	# of divisions
OS (ocular scale)	27	65	38
SS (stage scale)	10	70	60

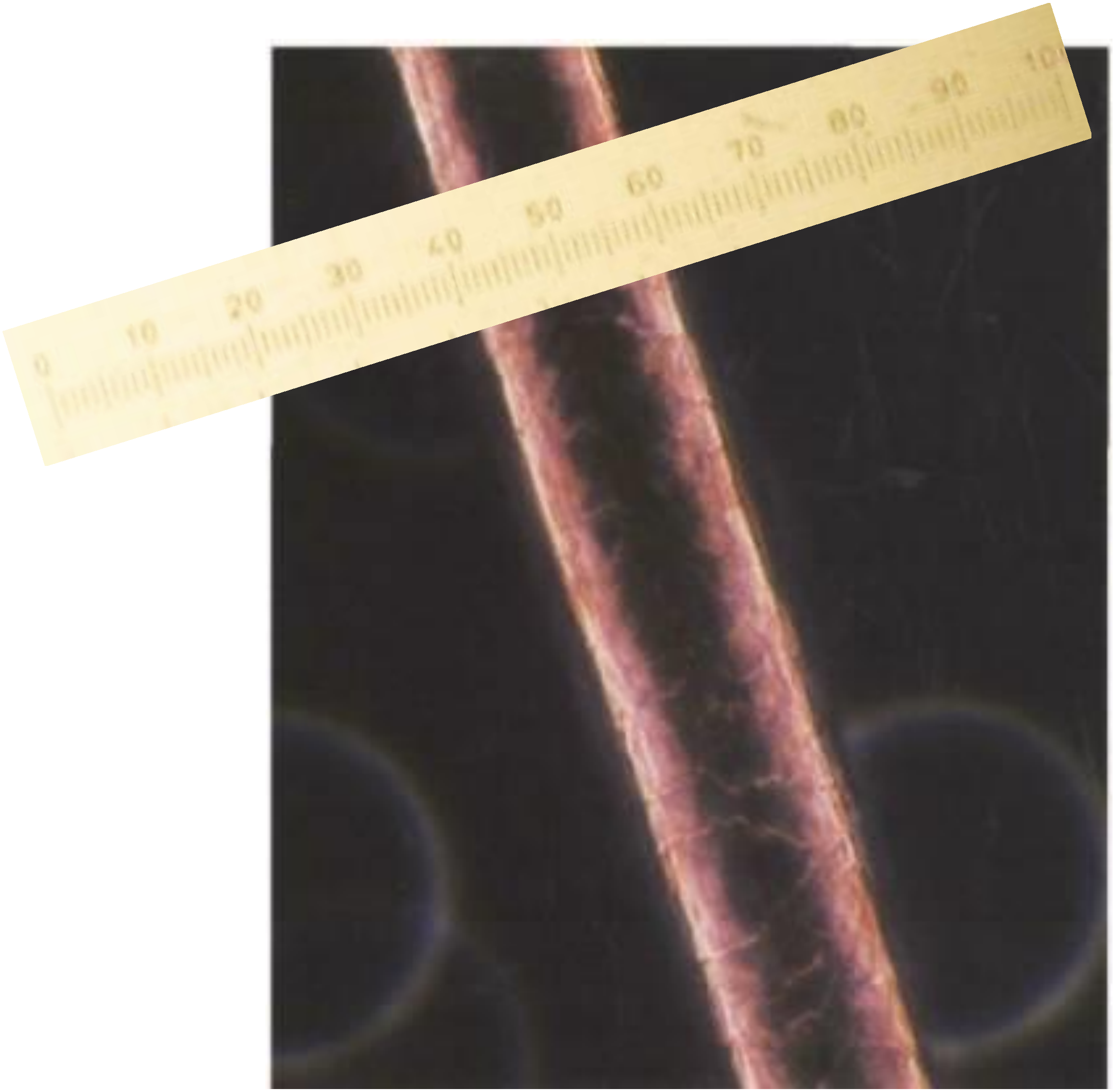
$(60/38)*10 = 15.8\ \mu m$



	left	right	# of divisions
OS (ocular scale)	0	95	95
SS (stage scale)	0	100	100

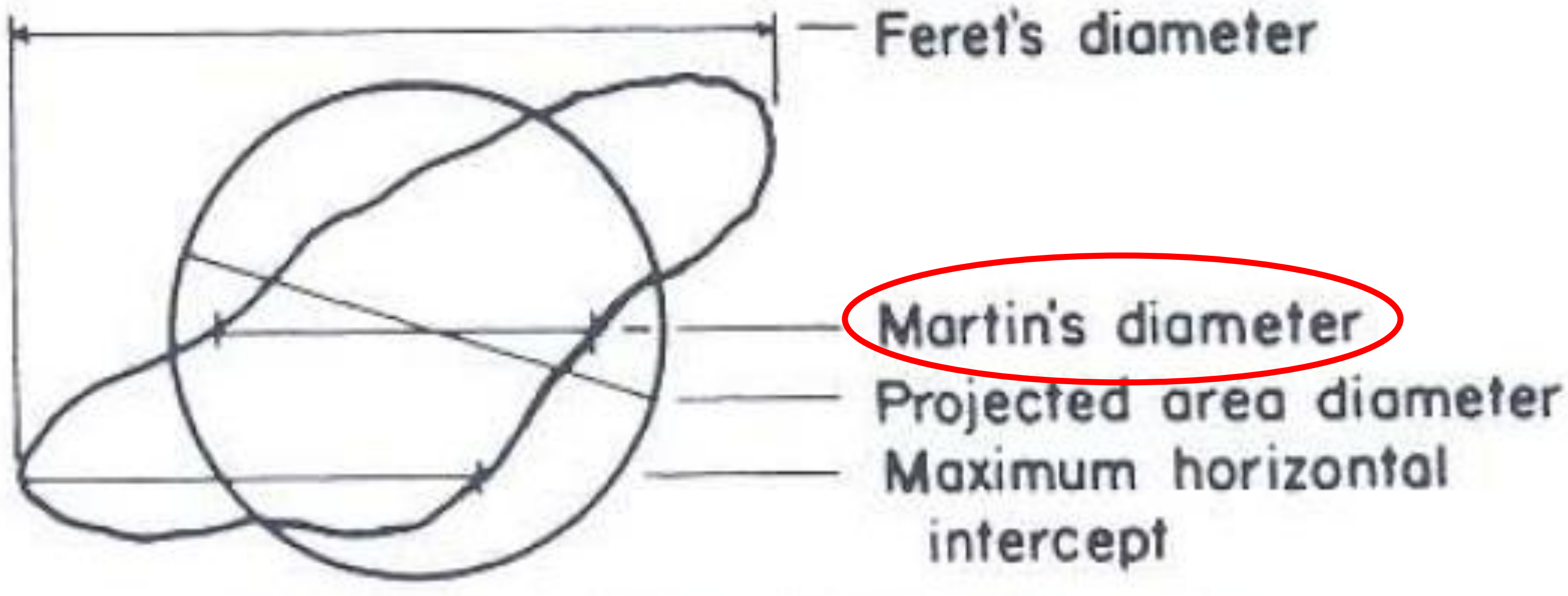
(100/95)*10 = 10.5 μm

What's the Size?

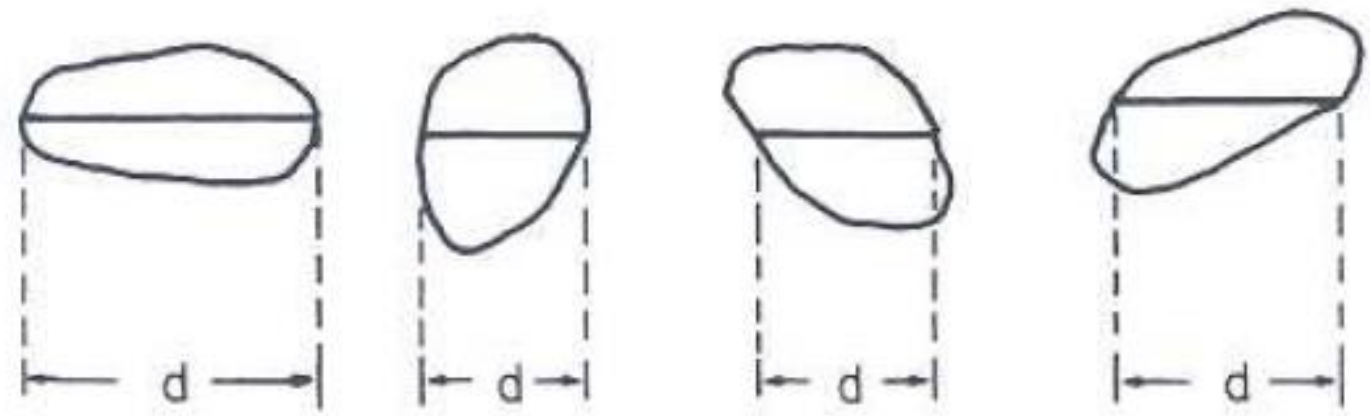


What's the Size?

Various Statistical Diameter



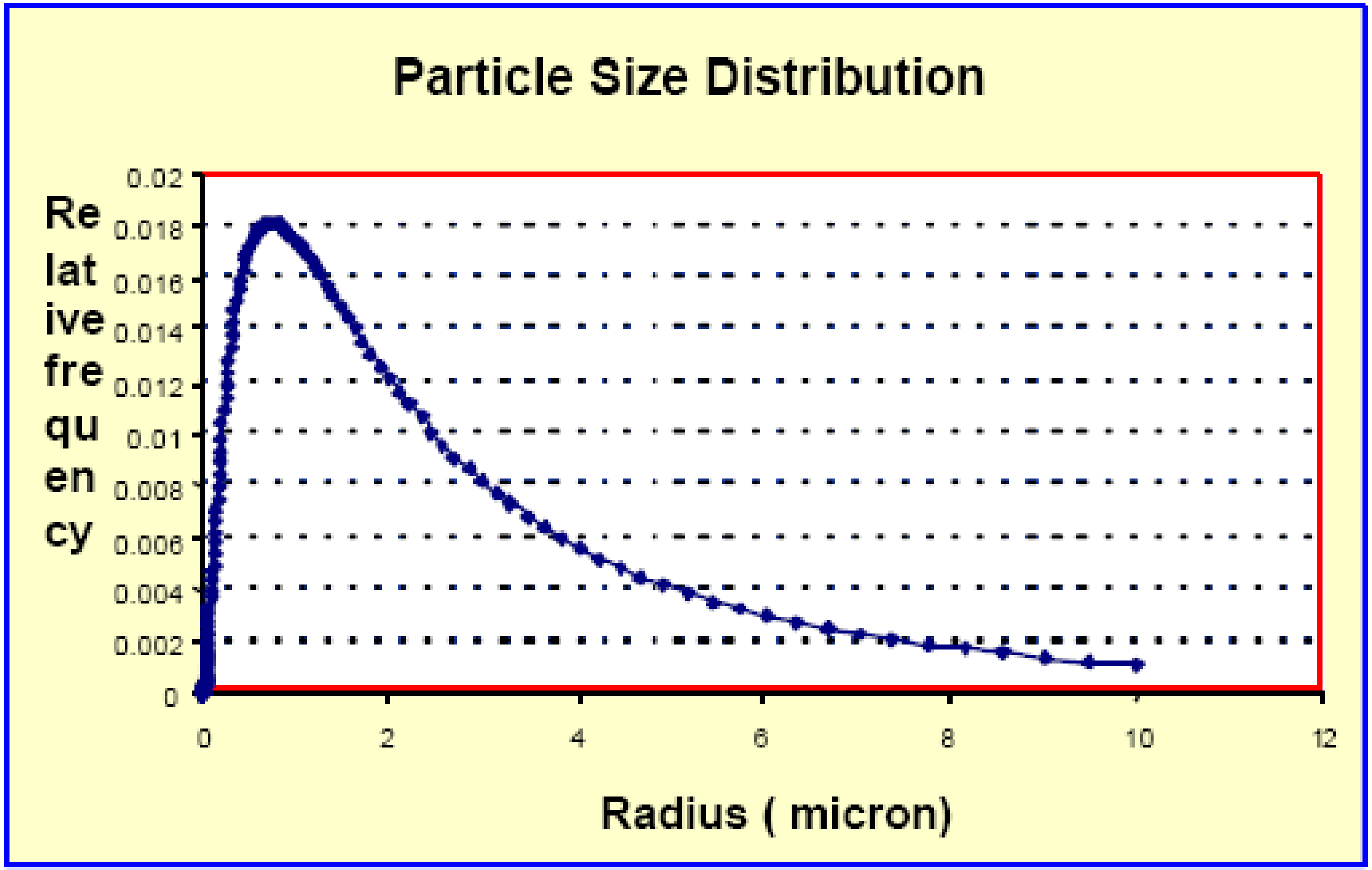
Martin’s Diameter



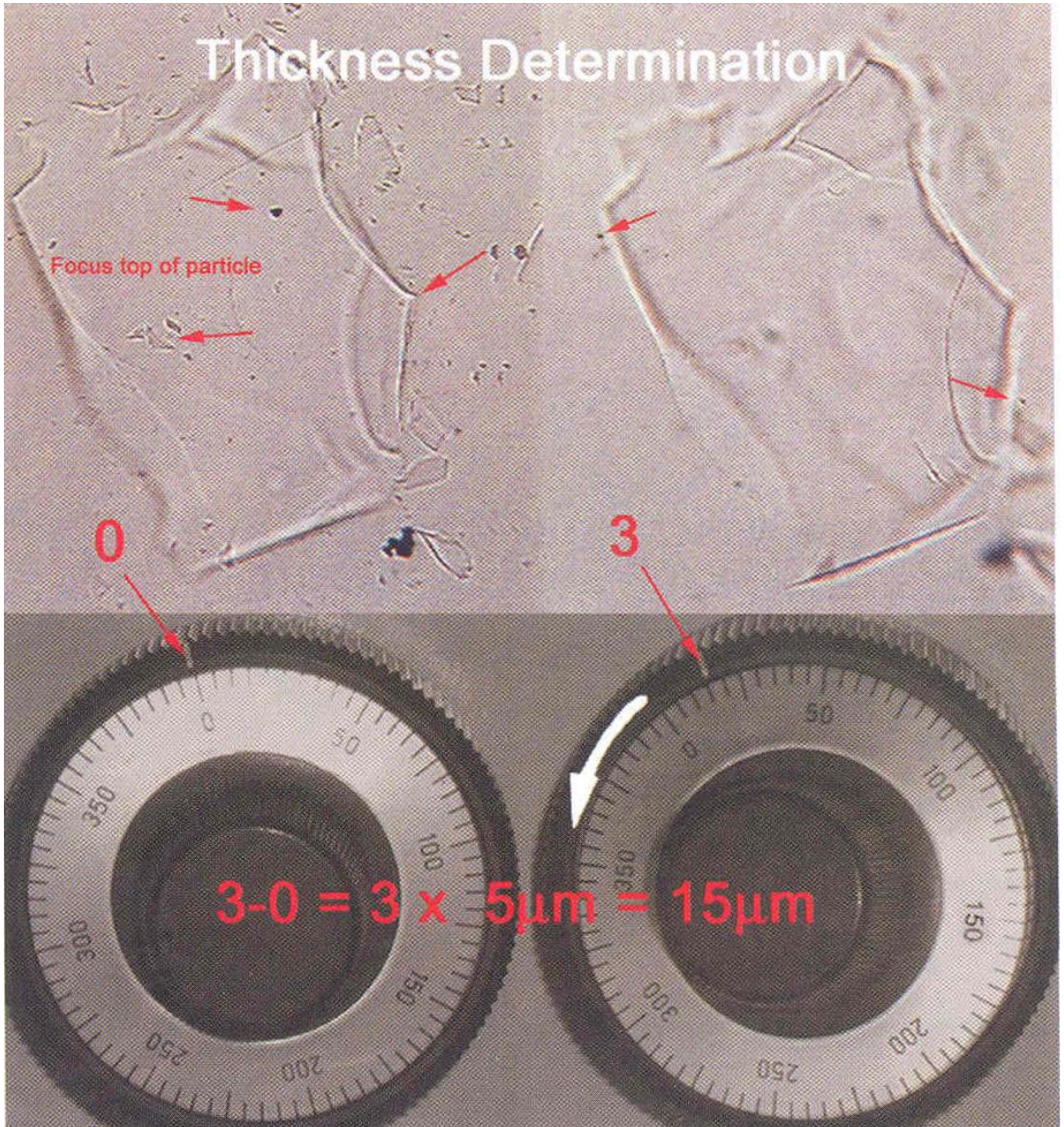
Martin’s diameter:

- The simplest means of measuring for irregular particles
- Sufficiently accurate when averaged for a large number of particles

Particle Size Distribution



Thickness Measurements



1. Top surface is sharply focused (left)
2. Micrometer reading (0)
3. Bottom (edge) was focused
4. Micrometer reading (3)
5. Difference $= 3 - 0 = 3$
6. One reading = 3 μm
7. (depends on manufacture)
8. Thickness $\approx$ 9 μm

Exercise 3

1. Precisely measure the size of one division in X10 and X40 objectives

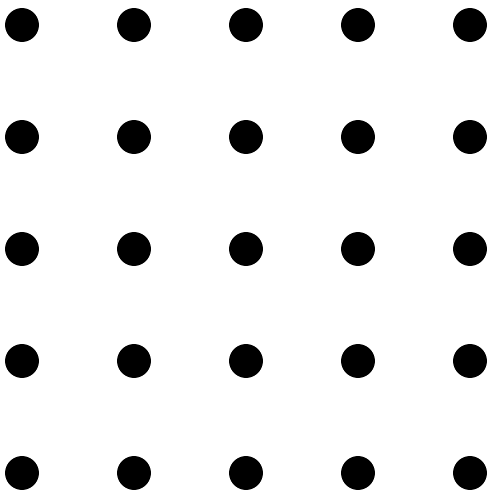
2. Choose four samples (two from group A and two from group B) and measure sample sizes (or thicknesses) and height at three different places (or particles) using either X10 or X40 objectives

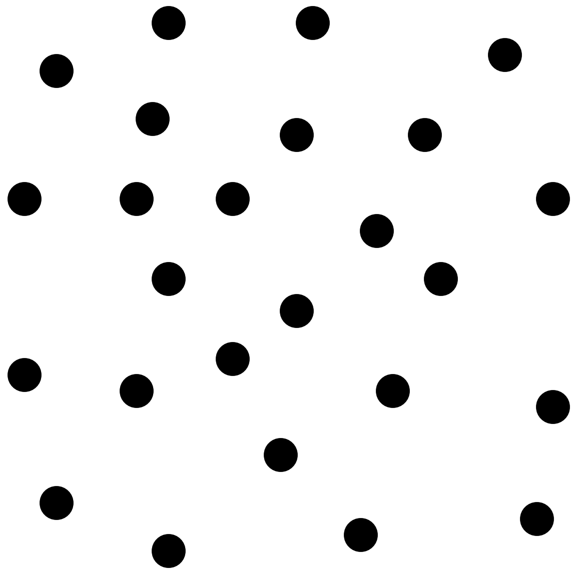
A division of fine adjusting knob in your microscope is 3 μm.

Lecture 7

Crystal Morphology

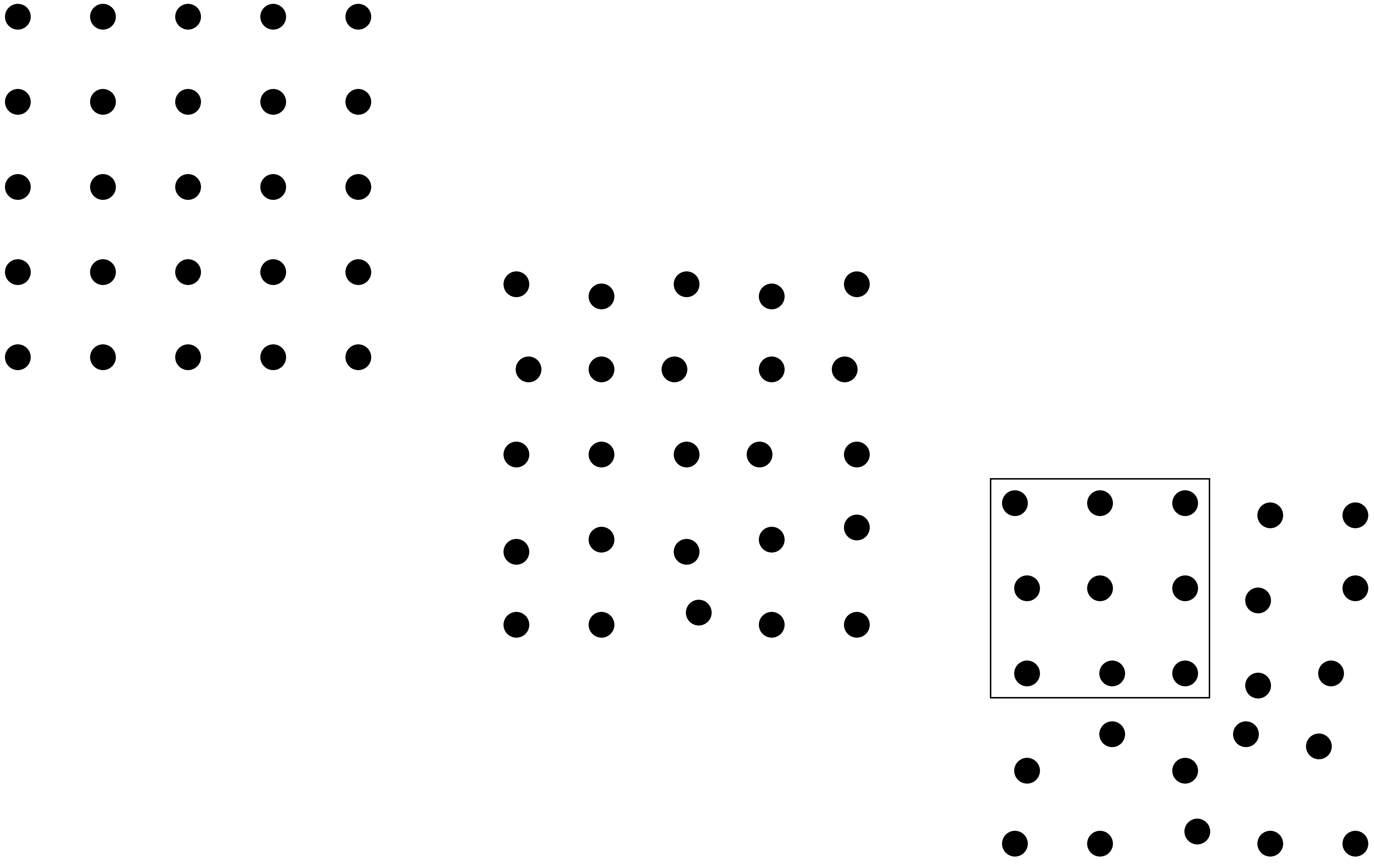
Crystalline and Noncrystalline



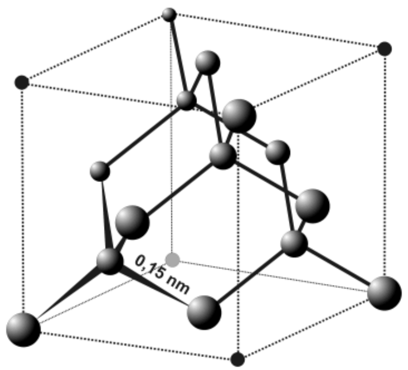


Two dimensional representation

Degrees of Crystallinity



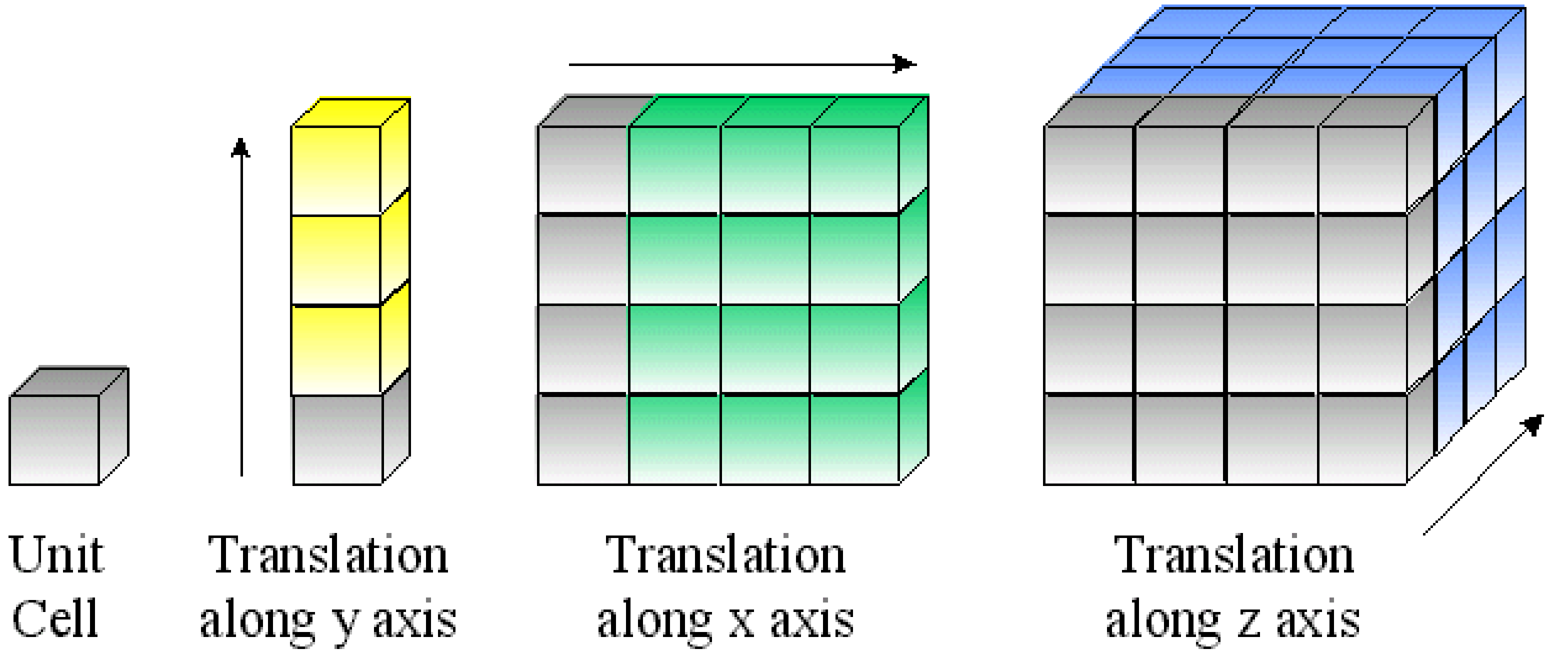
Crystal Structure



diamond

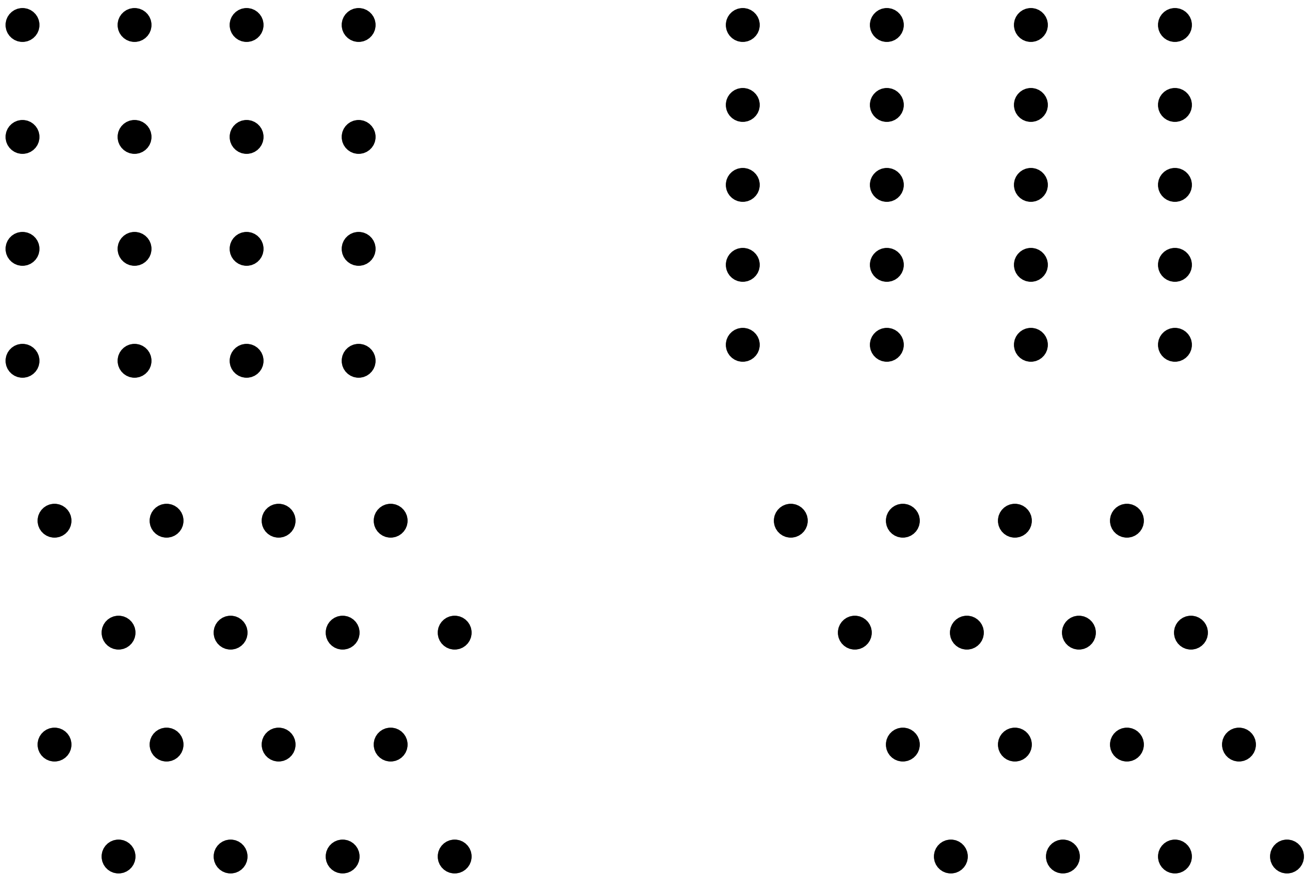
- Unit cell
- The arrangement of unit cell in space

A Crystalline Solid Can Be Constructed From
A "Unit Cell" Plus Translational Operators



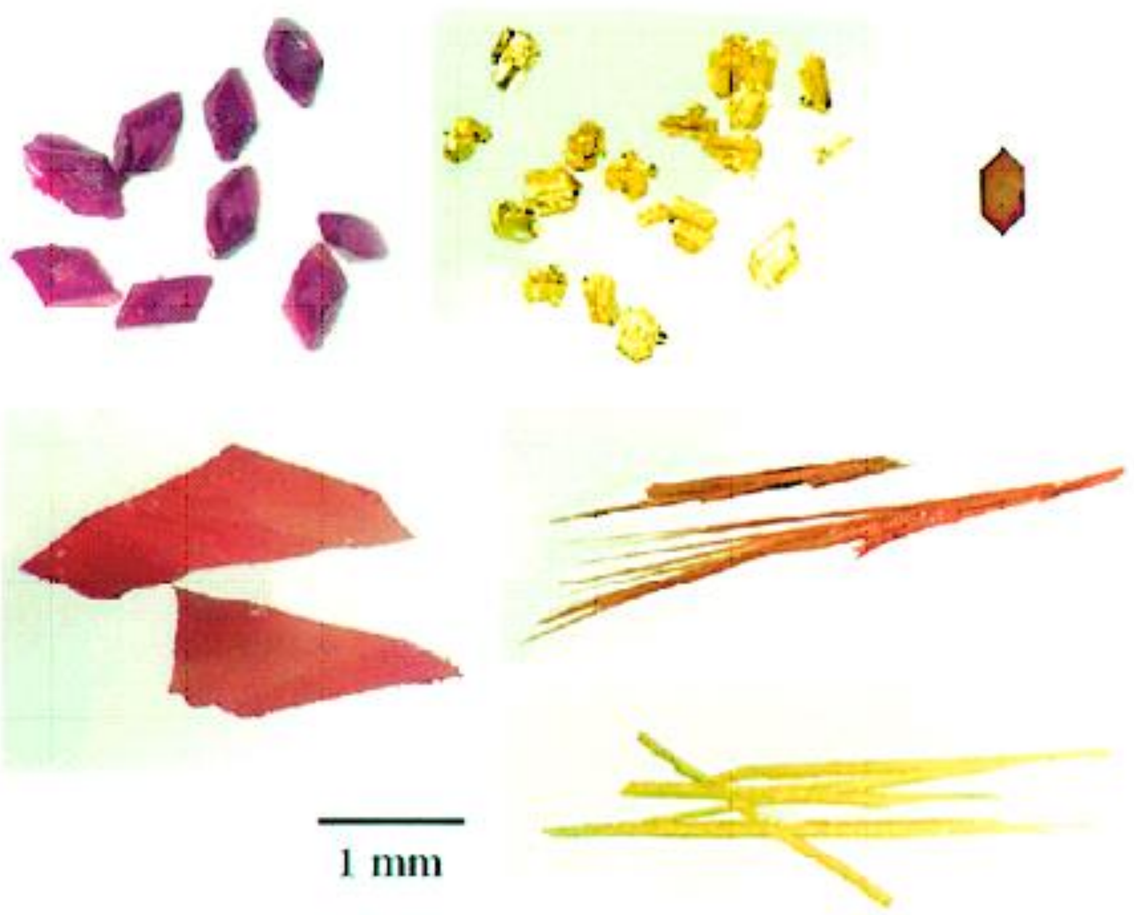
Polymorphism 1

- The ability of a solid material to exist in more than one form or crystal structure.
- Same building block, but different 3-dimensional arrangements

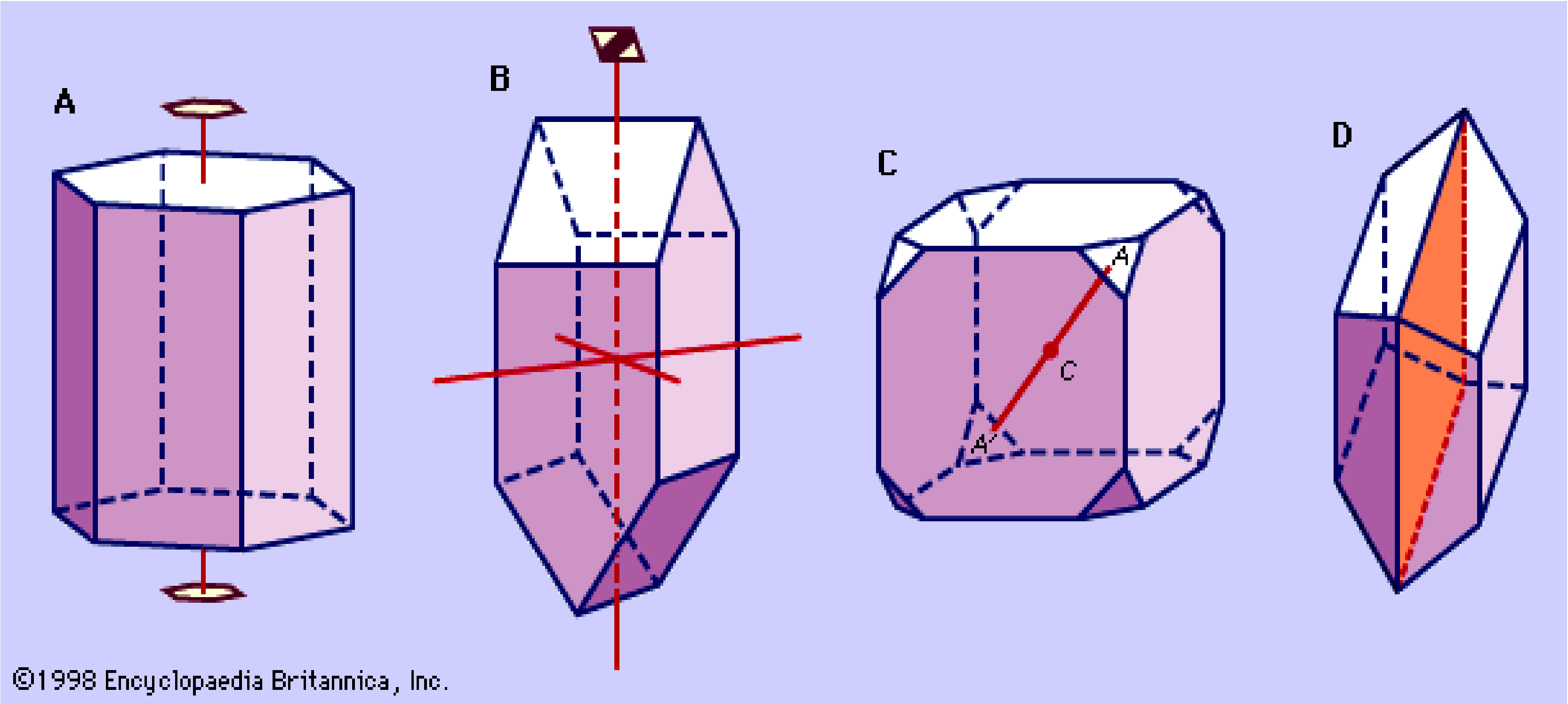


Polymorphism 2

- Same building block, but different 3-dimensional arrangements
- Different macroscopic shapes



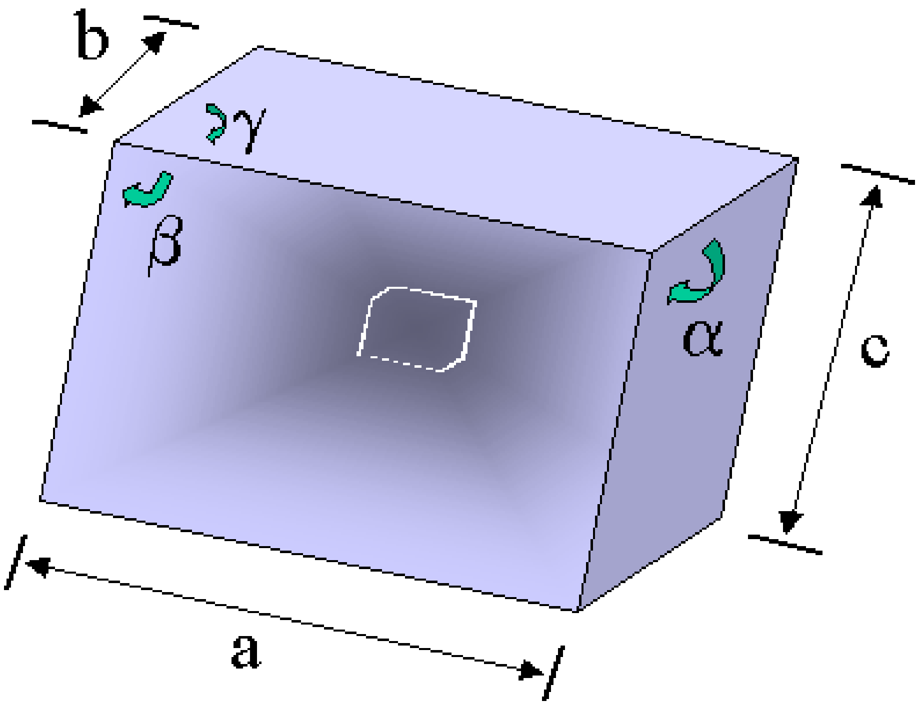
Symmetry Element



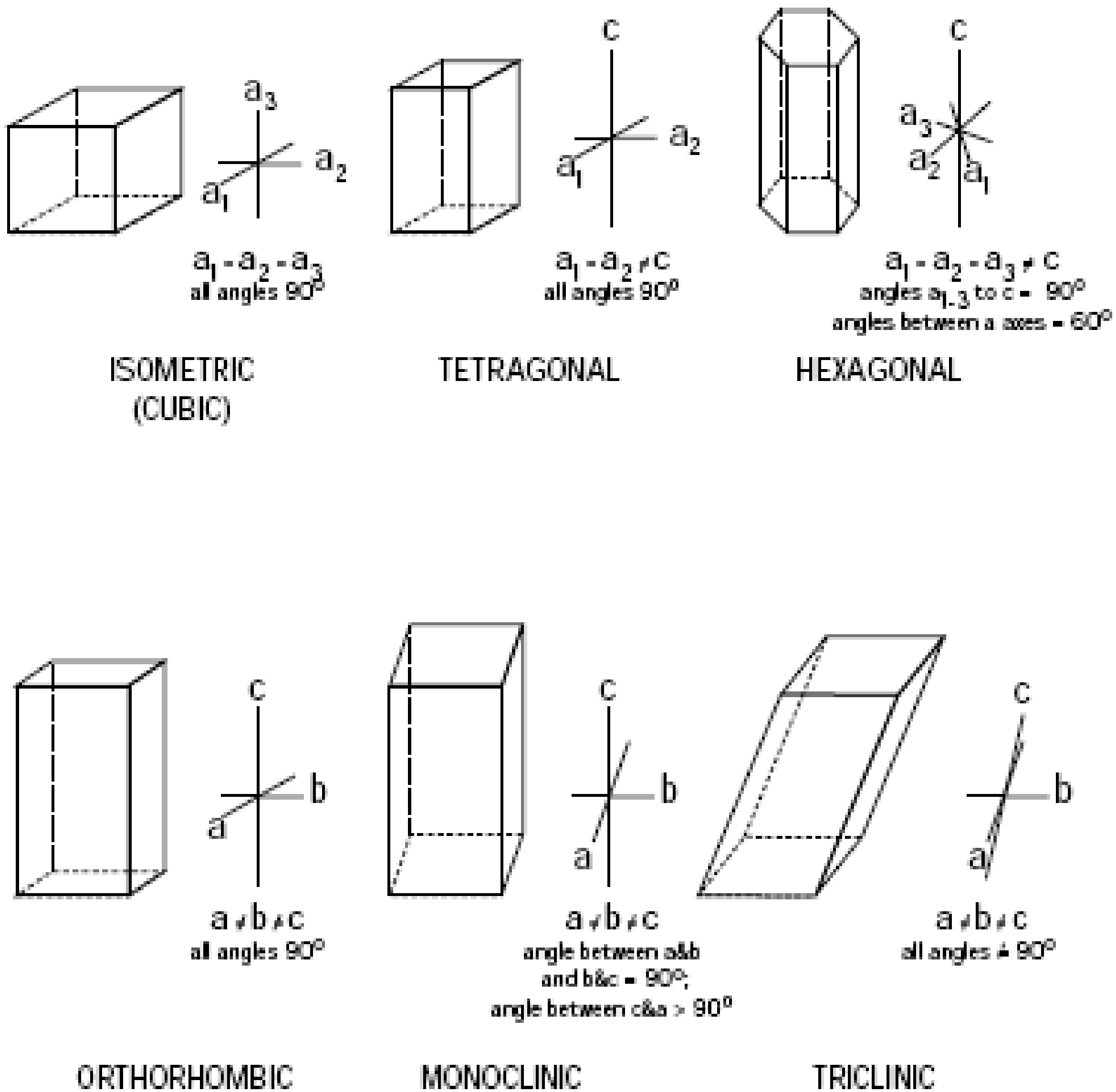
Rotation: 2, 3, 4, 6
Center
Plan

Unit Cell and Crystal Parameters

Crystals are characterized by repeating units. This repeating unit is called the **unit cell**.



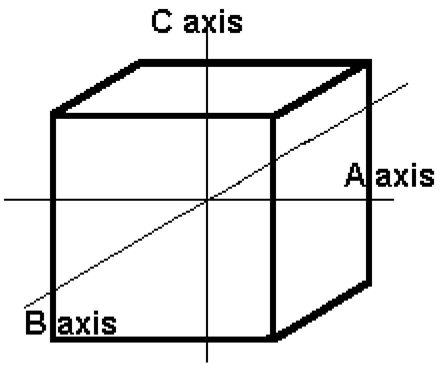
Six Crystal Systems



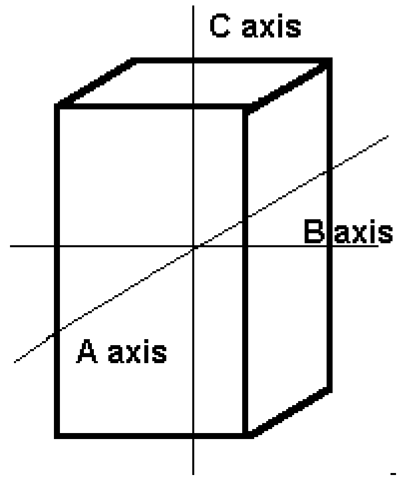
Six Crystal Systems

Crystal System	Edge lengths and angles (parameters)
Cubic	a=b=c ; $\alpha=\beta=\gamma=90^o$
Hexagonal	a=b, c ; $\alpha=\beta=90^o$, $\gamma=120^o$
Tetragonal	a=b, c ; $\alpha=\beta=\gamma=90^o$
Orthorhombic	a, b, c ; $\alpha=\beta=\gamma=90^o$
Monoclinic	a, b, c ; $\alpha=\gamma=90^o$; β not equal to 90^o
Triclinic	a, b, c ; α not equal to β not equal to γ not equal to 90^o

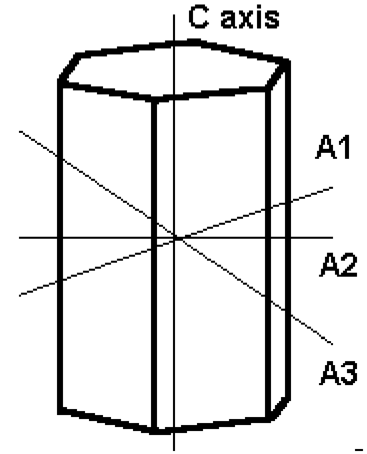
Crystal Forms: (Pinacoids)



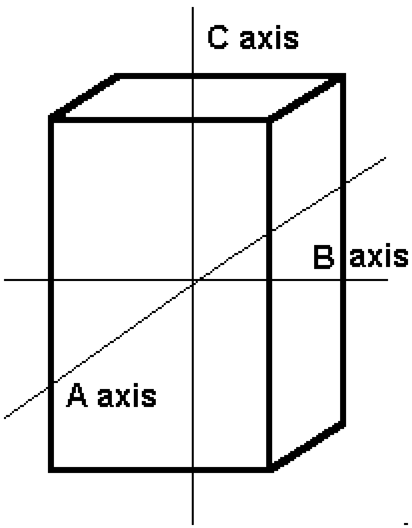
cubic



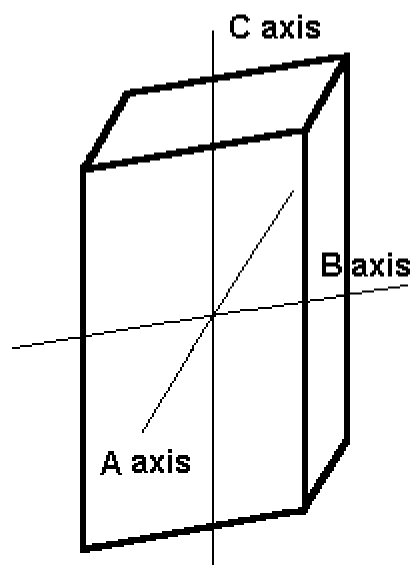
tetragonal



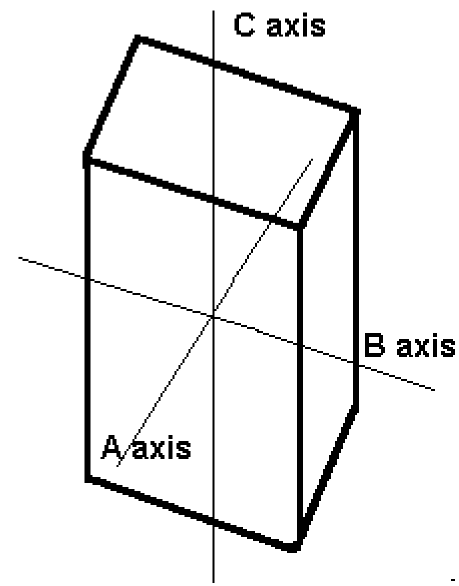
hexagonal



orthorhombic

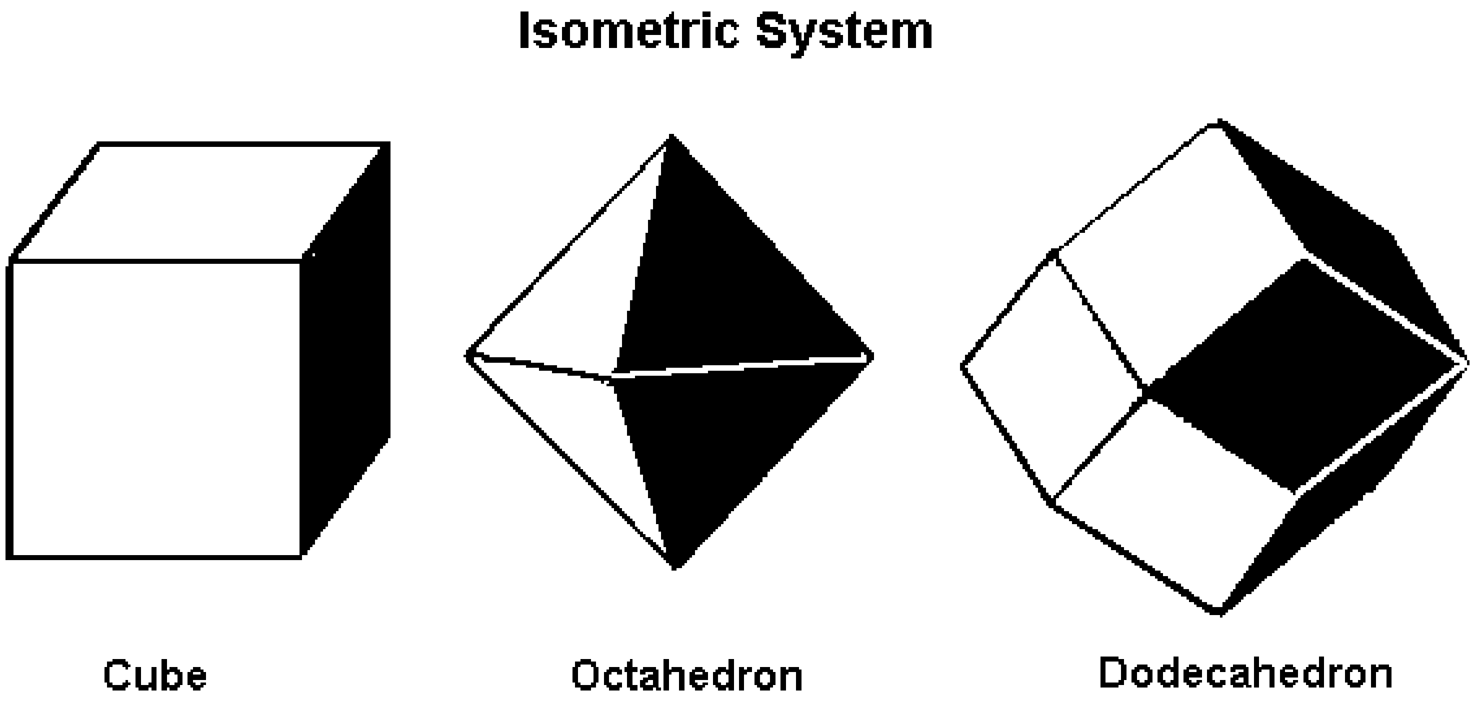


monoclinic

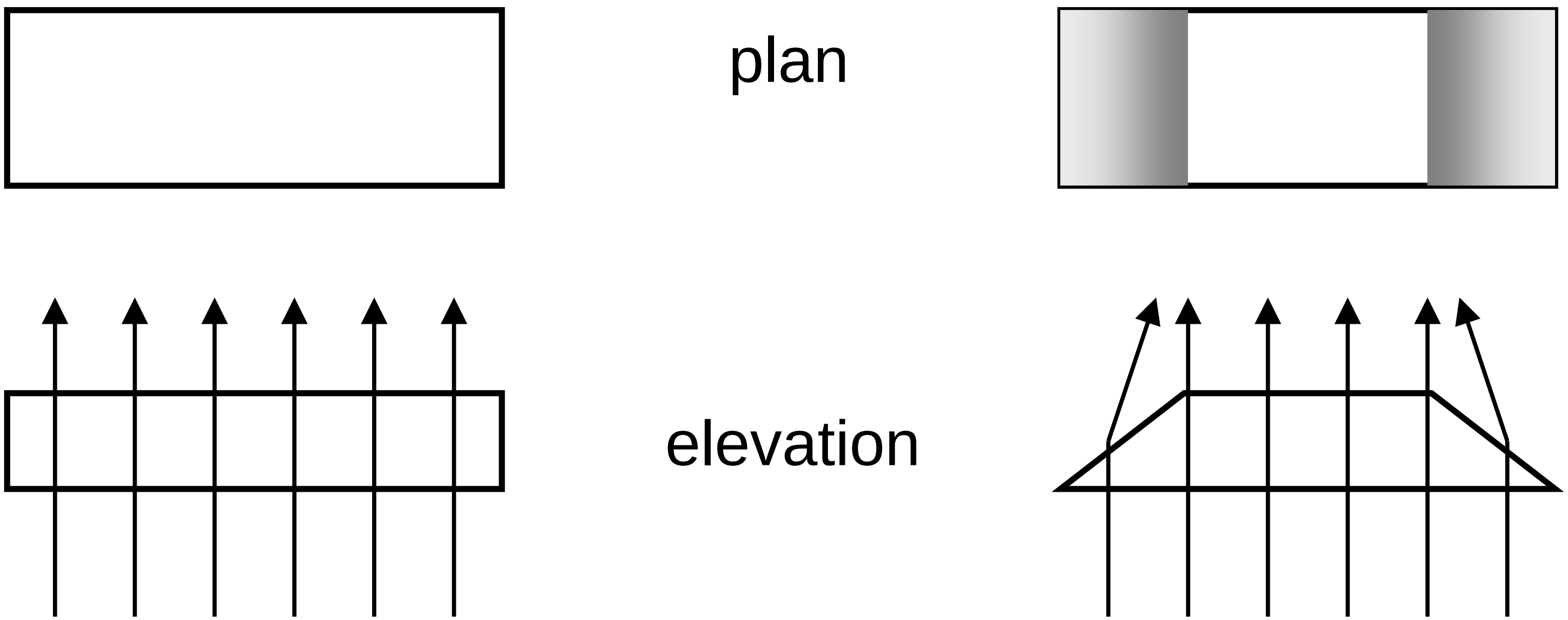


triclinic

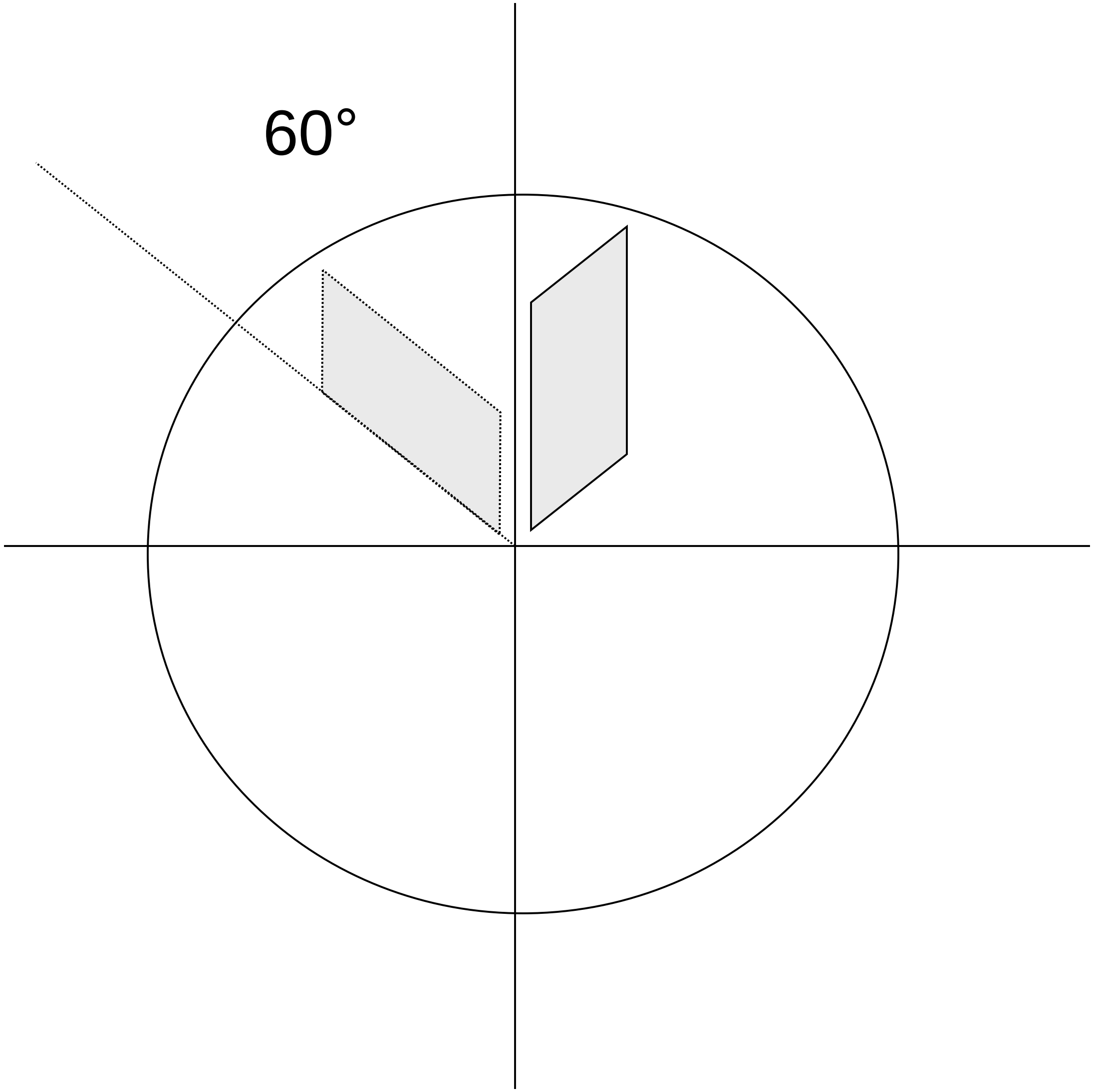
Cubic System



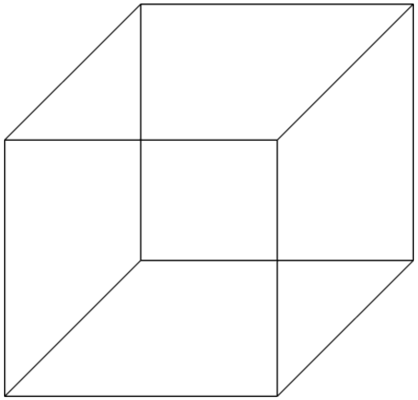
Shading Helps Determine Form

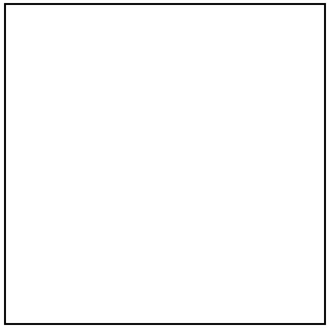


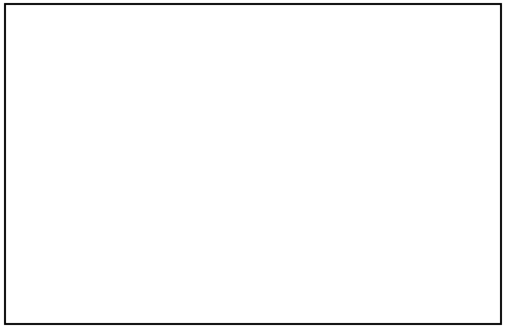
Measurement of Profile Angles

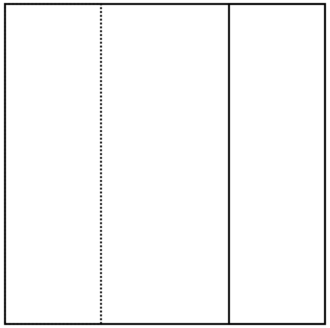


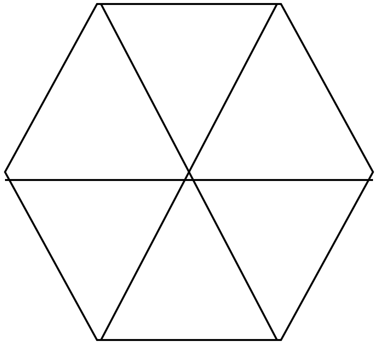
Orientation



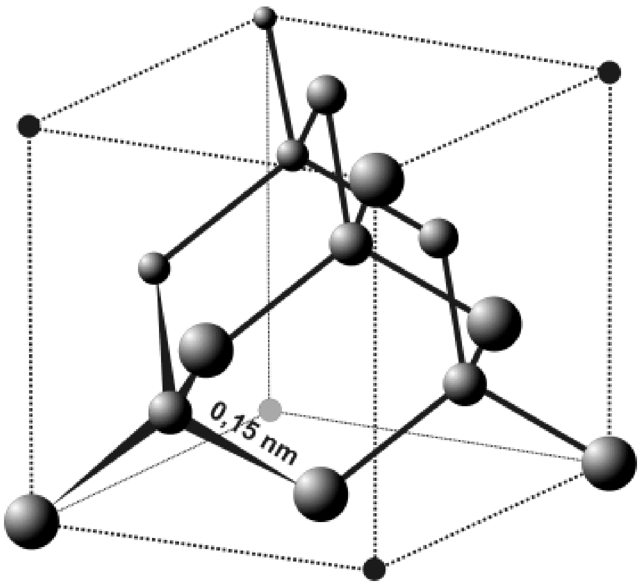




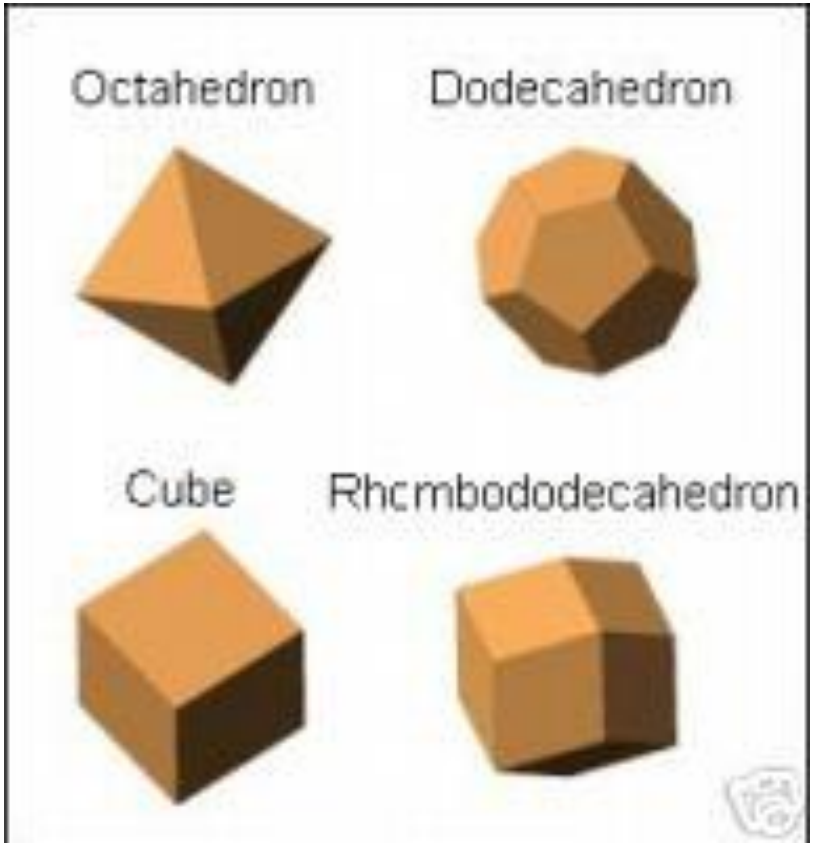




Crystal Habit 1

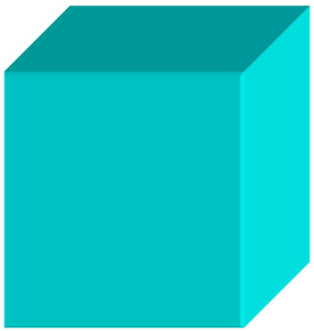


crystal structure



observed crystal forms

Crystal Habit 2



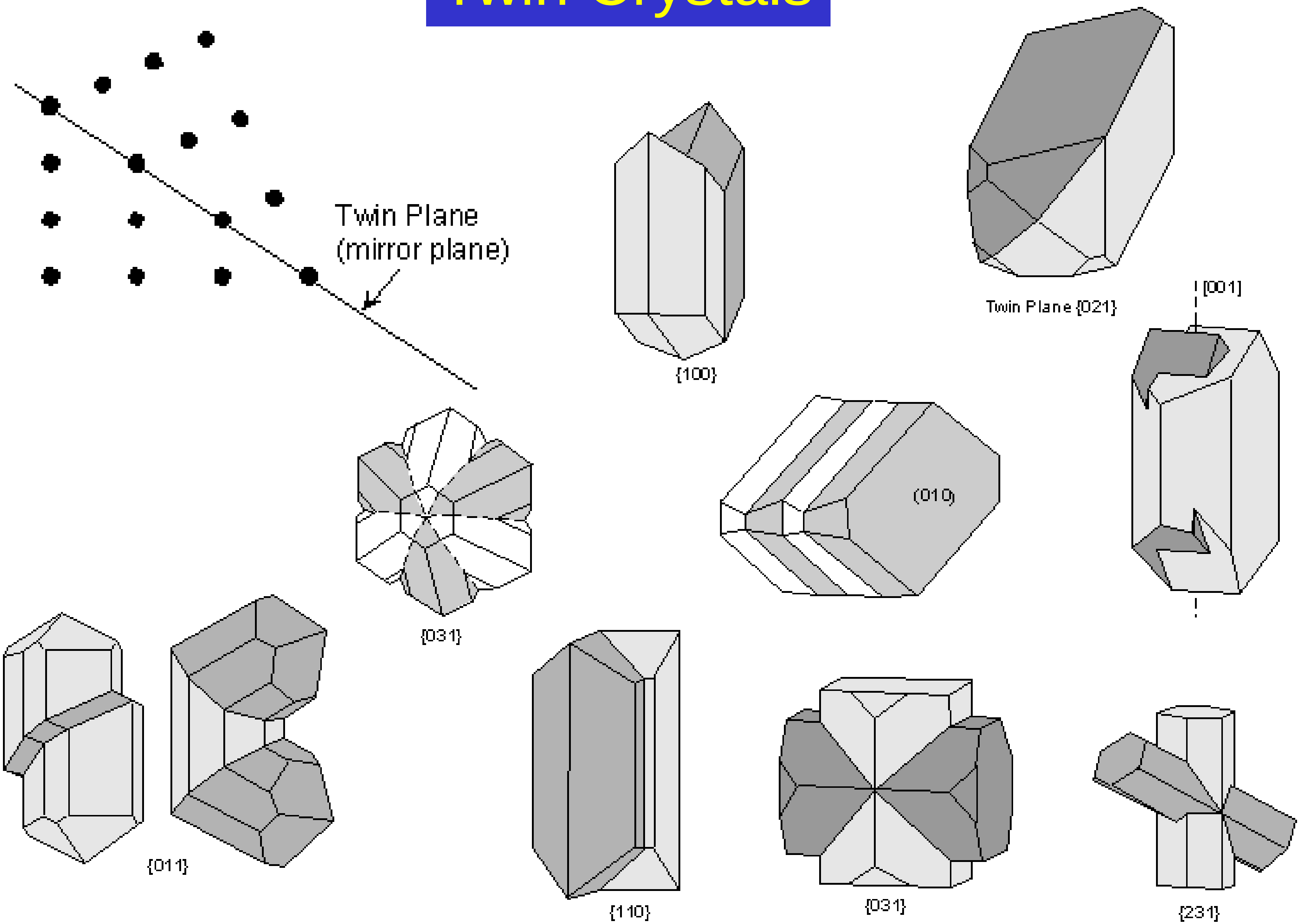
equant or
massive

table

plate or flake

needle

Twin Crystals



http://www.tulane.edu/~sanelson/eens211/twinning.htm

Twin Crystals