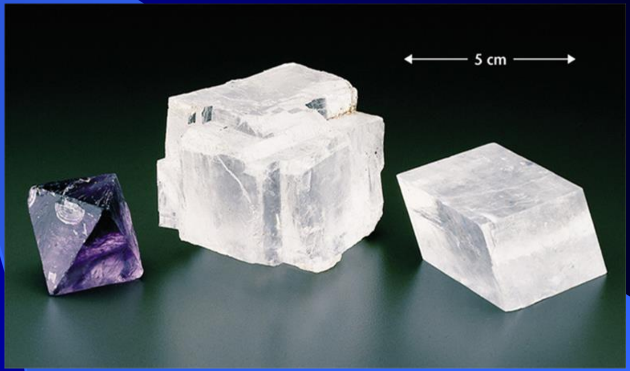
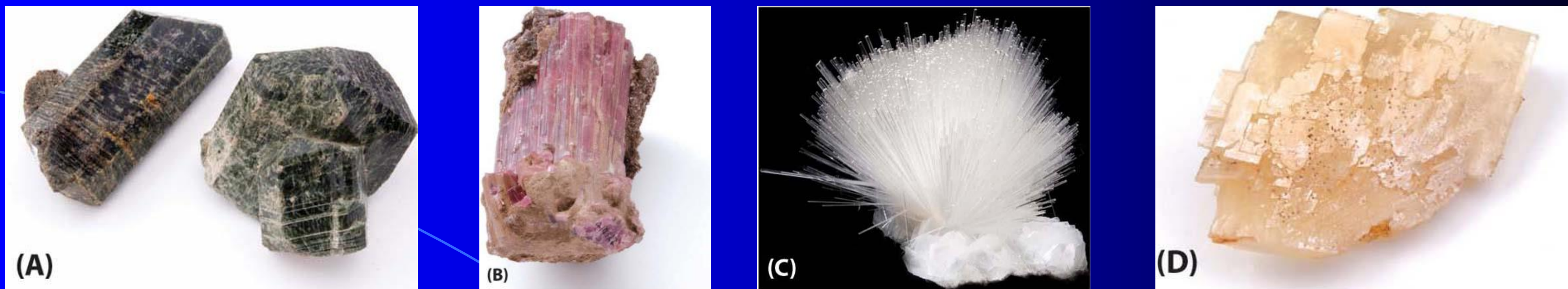
Mineral Identification



Physical Properties:

- Habit
- State of aggregation
- Color
- Luster
- Cleavage
- Hardness
- Specific gravity (density)
- Fluorescence
- Magnetism

Habit – visible external shape of a mineral



A. Prismatic – elongate with the bounding faces forming a prism-like shape

B. Columnar – rounded columns

C. Acicular – “needle-like”

D. Tabular – flat like a board

E. Bladed – elongate and flat

F. Fibrous – threadlike masses

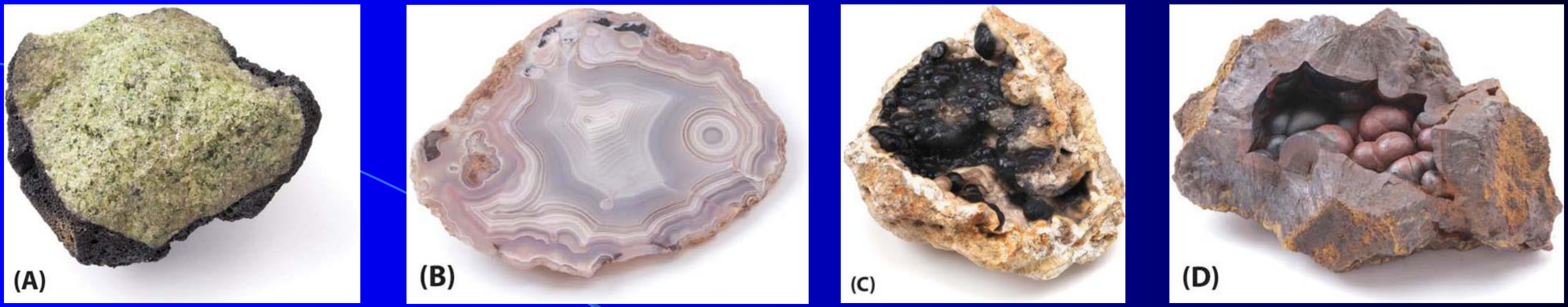
G. Dendritic – leaflike branching

H. Foliated – stack of thin leaves or plates

I. Capillary – hairlike or threadlike thin crystals

J. Massive – specimen totally devoid of crystal faces

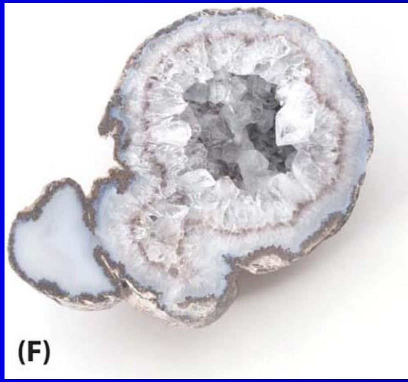
State of aggregation – grouping of small grains



A. Granular – rock and mineral specimens that consist of mineral grains of approximately equal dimension. Compact – no visible grains.

B. Banded – bands of different color or texture that may or may not differ in mineral composition.

C. Botryoidal – surface of rounded shaped. Mammillary – larger scale. Example (D) botryoidal goethite.



E. Renifom – surface resembles the surface of a kidney.

F. Geode – rock cavity partly filled with minerals.

G. Oolitic – mineral grains in rounded masses the size of fish roe. Pisolitic – rounded mineral grains the size of a pea.

H. Example – pisolitic bauxite.

Color and Luster

Luster – interaction of white light with the surface of a mineral

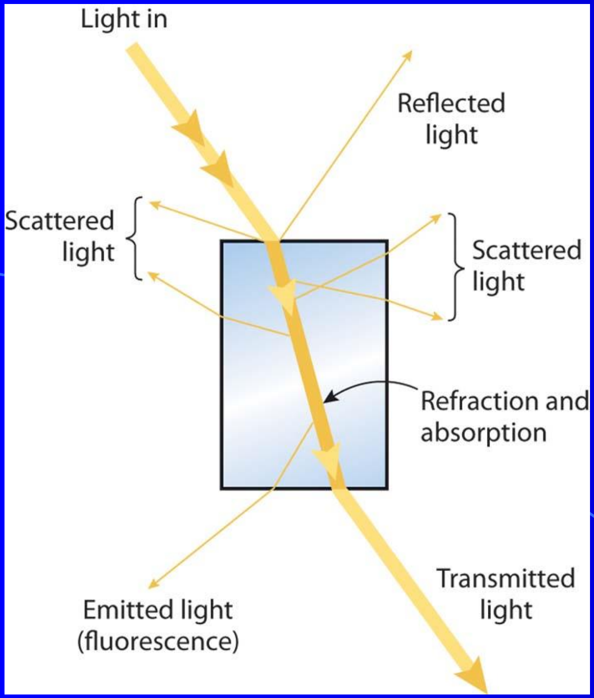
- Metallic – most of the light is reflected or scattered from the surface of the mineral. The mineral is opaque.



- Nonmetallic – most of the light passes through the mineral. The mineral is translucent.
  - Vitreous – luster of glass
  - Resinous – luster of resin

Vitreous

Resinous



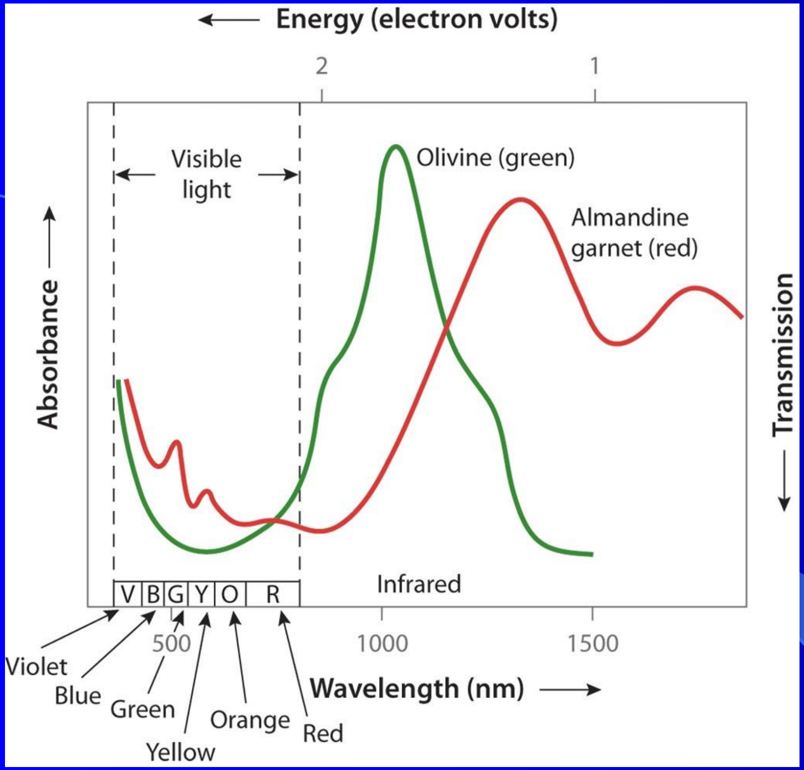
Interaction of light with a translucent material

- Reflected light is responsible for luster.
- Scattered light is responsible for chatoyancy, labradorescence, and asterism.
- Absorption is responsible for color.
- Fluorescence represents electronic transitions in the visible region.

The transition elements (chromophore elements) play a major role in mineral color.

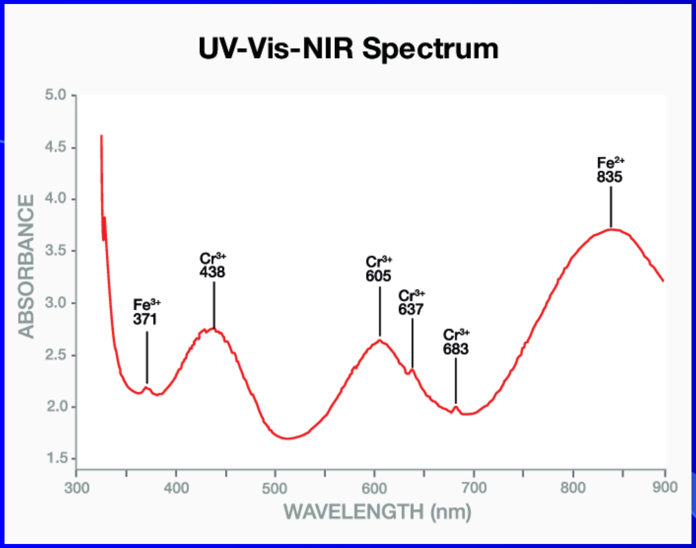
- Crystal field transitions – interaction between the energy of white light and *d* orbitals of chromophore elements that are only partially filled with electrons.
- Molecular orbital transitions – transfer of electrons between adjacent cations in a crystal structure. Electrons are not localized (centered on a specific atom).
- Color centers – defects in crystal structures (vacancies) that become filled with an excess electron to balance the charge of the missing ion.

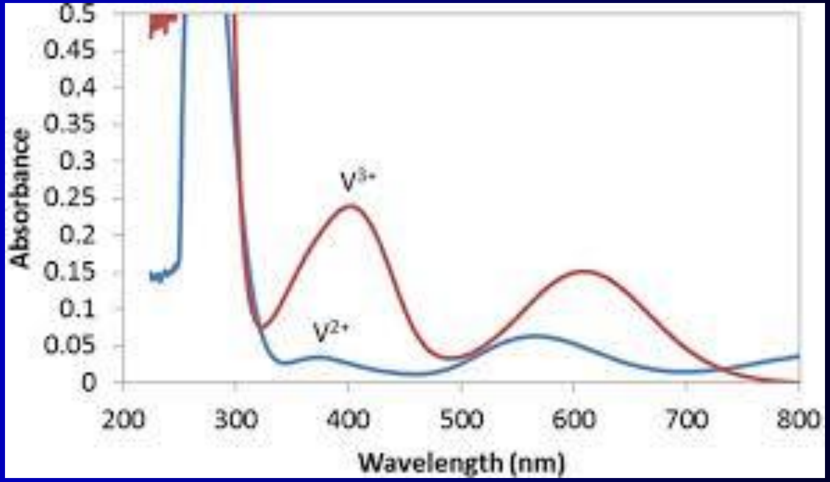
Crystal Field Transitions



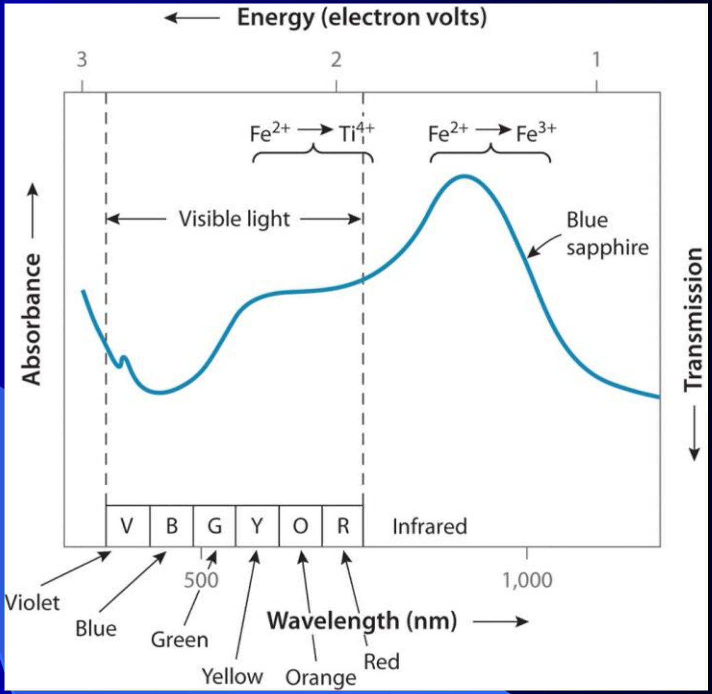
Olivine with 10% FeO is green. Absorbance is in the infrared and red and violet regions of the visible spectrum.
Garnet (almandine) with higher FeO (up to 35%). Absorbance is in the infrared and the orange to violet part of the visible spectrum. Absorbance least in the red region.

Emerald – Cr and V are the chromophore elements.



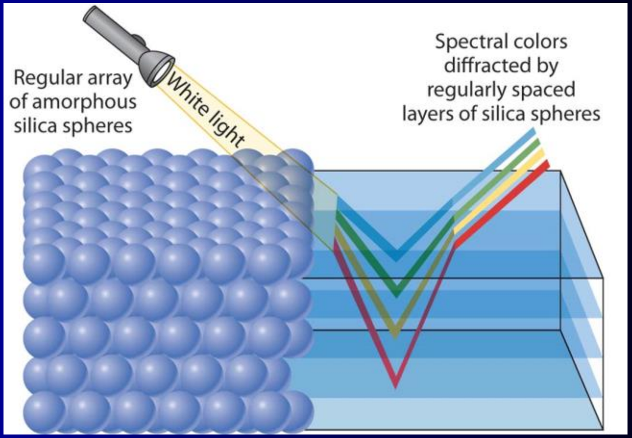


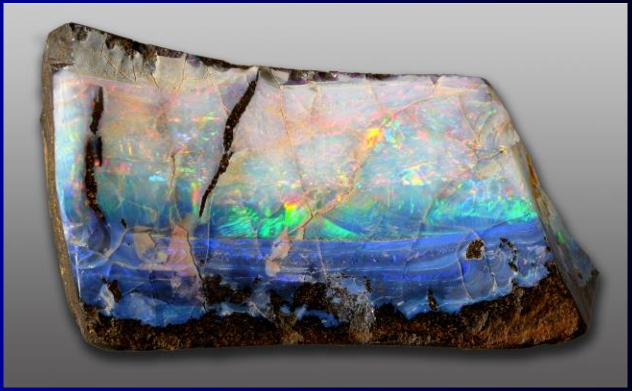
A tale of two gem minerals – Ruby and Sapphire. Both are corundum (Al_2O_3). Ruby has trace amounts of Cr^{3+} (crystal field transition) while Sapphire has trace amounts of Fe^{2+} and Ti^{4+} (molecular orbital transitions).



Molecular orbital transitions involve the exchange of an electron between two neighboring sites one occupied by Fe and the other by Ti. These sites are normally occupied by Al. The transfer of the electron leads to alternating charges Fe^{2+} Ti^{4+} goes to Fe^{3+} Ti^{3+}. Minimum absorption is in the blue portion of the visible spectrum.

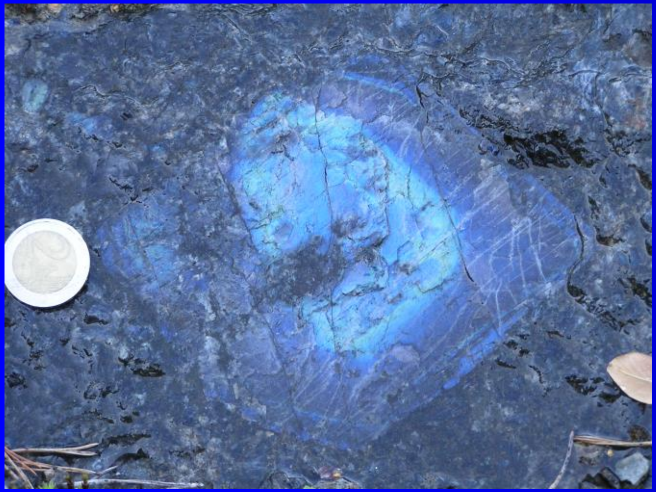
Play of color – example Opal ($SiO_2 \cdot nH_2O$) - stacked 3000 Å amorphous silica spheres causes diffraction. This leads to the display of colors.





Chatoyancy – as the mineral is tilted light moves from side to side. This is due to the presence of closely spaced fibers, inclusions or cavities.

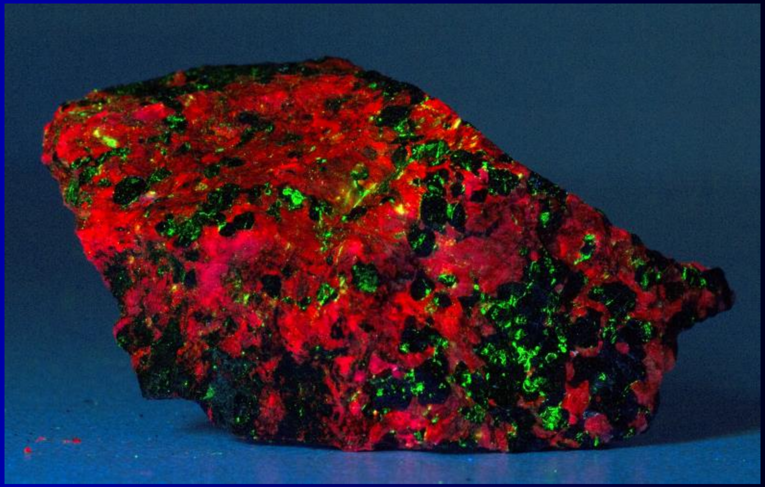
Labradorescence – presence of closely spaced, parallel planar lamellae (exsolution lamellae). Scattered light diffracts from the microstructures producing colors.



Spectrolite

Asterism – six-rayed optical phenomenon due to the alignment of inclusions along crystallographic directions. Seen in star rubies and star sapphires when cut perpendicular to *c*. The inclusions are fine needles of rutile (TiO_2).

Fluorescence – occurs when UV light promotes electrons to higher energy levels. When the electrons return to an intermediate energy level the emitted photon is in the visible region of the spectrum.

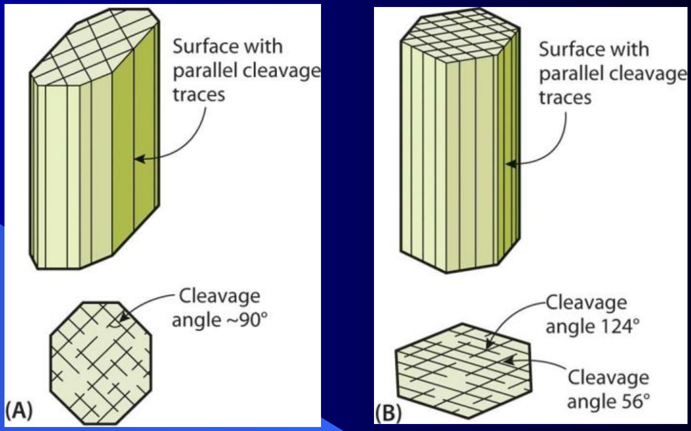


Streak – color of powdered mineral. The color is usually more consistent. Most useful for metallic minerals.

Cleavage – breaking of minerals long planes of weakness. These planes are crystallographic planes. The cleavage planes are controlled by weak bonds or large interplanar spacings across atomic planes in a crystal structure.

Types of cleavage:

- Planar – cleavage along a single planar direction
- Prismatic – two different cleavage directions whose lines of intersection are commonly parallel to a specific crystallographic direction. In hand specimen, the distinction between an amphibole and a pyroxene is largely based on the intersection of the cleavage planes (~90^{o} for pyroxene, 56^{o} and 124^{o} for amphibole). Feldspars also show approximately right-angle cleavage intersections.



- Cubic – three cleavages at right angles. Isometric minerals such as halite and galena.
- Rhombohedral – three cleavage directions not at right angles. Example calcite
- Octahedral – breaking along four different directions. Example fluorite
- Conchoidal fracture – no specific directions. Irregular fracture pattern. Quartz and glasses show this type of fracture.

Cubic

Rhombohedral

Octahedral

Conchoidal

Hardness – resistance to abrasion or indentation.

Absolute hardness – weight in grams required to produce a standard scratch. This is done using an instrument known as a sclerometer. Note that grams are a unit of mass, not force. The correct measurement would be in dynes cm^{-2}. On the scale to the right the values should be multiplied by 980 to get the force in dynes cm^{-2}.

The Turner-sclerometer test consists of microscopically measuring the width of a scratch made by a diamond under a fixed load, and drawn across the face of the specimen under fixed conditions.

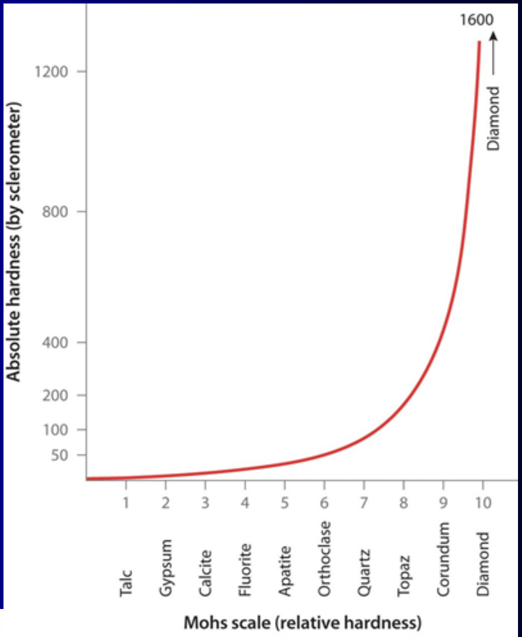


Table 3.1 Mohs hardness scale minerals.

Hardness number (**H**)	Mineral name	Chemical formula	Remarks
1	Talc	$Mg_3Si_4O_{10}(OH)_2$	Soft, greasy feel; flakes are left on the fingers
2	Gypsum	$CaSO_4 \cdot 2H_2O$	Can be easily scratched by the fingernail *fingernail hardness ~2.2*
3	Calcite	$CaCO_3$	Can be easily scratched with a knife and just scratched by a copper penny *copper penny hardness ~3.2*
4	Fluorite	CaF_2	Less easily scratched by a knife than calcite
5	Apatite	$Ca_5(PO_4)_3(F, Cl, OH)$	Is scratched by a knife with difficulty *pocket knife hardness ~5.1* *glass plate hardness ~5.5*
6	Orthoclase	$KAlSi_3O_8$	Not scratched by a knife and will scratch ordinary glass
7	Quartz	SiO_2	Scratches glass easily *porcelain streak plate hardness ~7*
8	Topaz	$Al_2SiO_4(F, OH)_2$	Scratches glass very easily[a]
9	Corundum	Al_2O_3	Cuts glass[a]
10	Diamond	C	Used as a glass cutter[a]

[a] There are few minerals that are as hard as, or harder than, quartz, and these include several of the highly prized gems.

Specific Gravity – the density of a mineral compared to the density of water. Specific gravity is non-dimensional.

Specific gravity for minerals is determined by

- The atomic weight of the elements that comprise the mineral
- Atomic packing - the way in which the atoms are packed in the crystal structure

Other Physical Properties:

- Magnetism – magnetite (Fe_3O_4) and pyrrhotite ($Fe_{1-x}S$)
- Solubility in acid – carbonates – aragonite and calcite ($CaCO_3$) versus dolomite [$CaMg(CO_3)_2$] , magnesite ($MgCO_3$), siderite ($FeCO_3$) , and rhodochrosite ($MnCO_3$) .
- Radioactivity – Uraninite (UO_2), Carnotite [$K_2(UO_2)_2(VO_4)_2$- 1-3H_2O], Thorite [$(Th, U)SiO_4$]

A Practical Introduction to X-Ray Diffraction

Next six slides provided by

Asst. Prof. Daniel F. Schmidt

Department of Plastics Engineering /

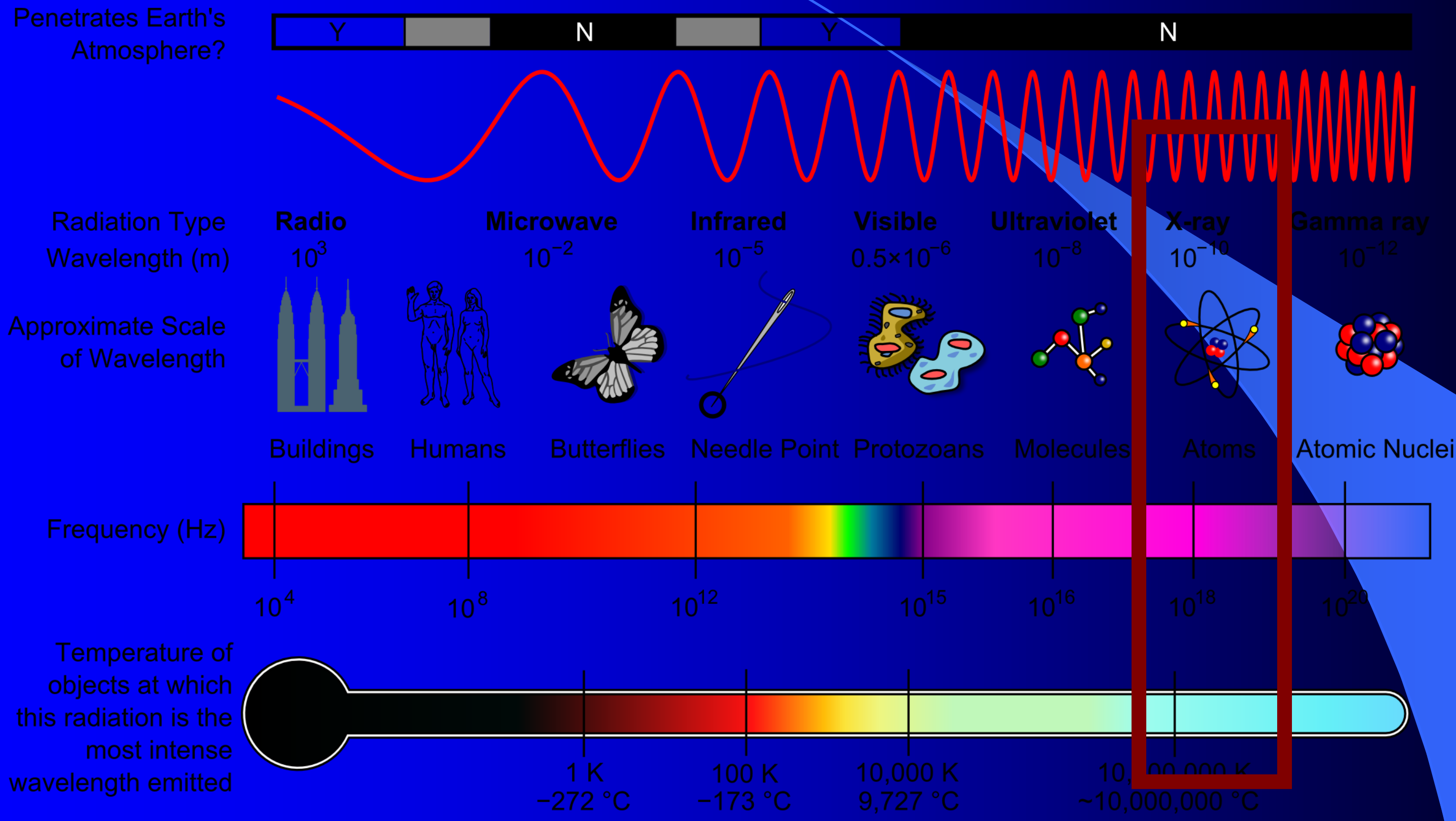
Nanomanufacturing Center at UML

University of Massachusetts Lowell

X-rays

- General Characteristics
  - Energy (E) ~ 120 eV to 120 keV
  - Frequency (ν) ~ 3×10^{16} to 3×10^{19} Hz
  - Wavelength (λ) ~ 0.01-10 nm (0.1-100 Å)
- Health Issues
  - Ionizing radiation – can remove electrons from nuclei
  - Low doses → cancer, mutations
  - High doses → radiation burns, death
- Scientific Utility
  - Interactions occur with electron clouds of atoms
    - Can be used to identify atoms
    - Can be used to identify atomic structure
  - Can be surface-sensitive or sensitive in-depth

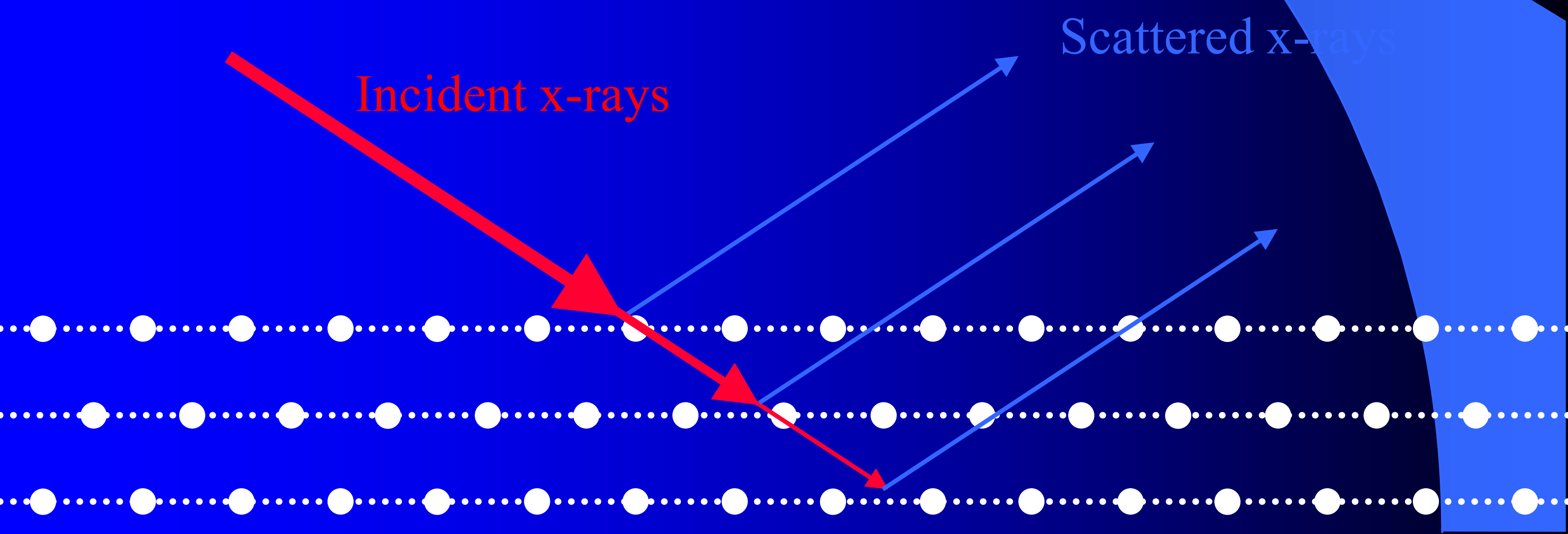
X-rays in Context



From http://en.wikipedia.org/wiki/Electromagnetic_spectrum

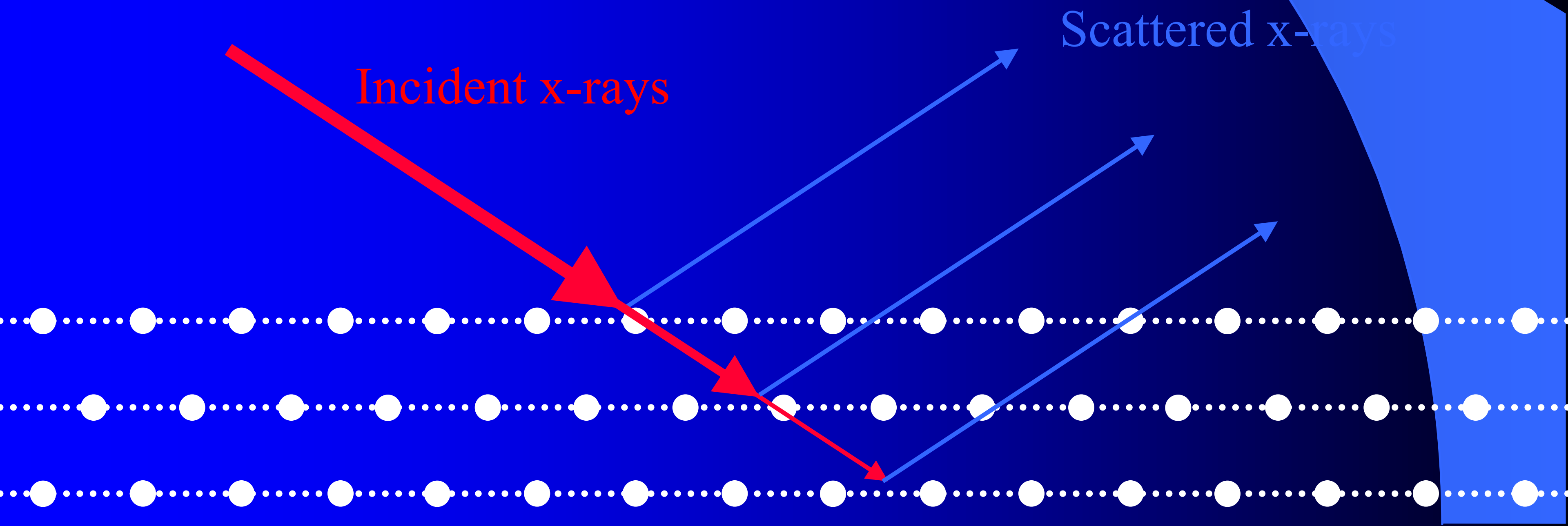
X-Ray Diffraction

- X-rays diffract, or scatter, when they encounter variations in electron density
- If variations are periodic, constructive interference can occur



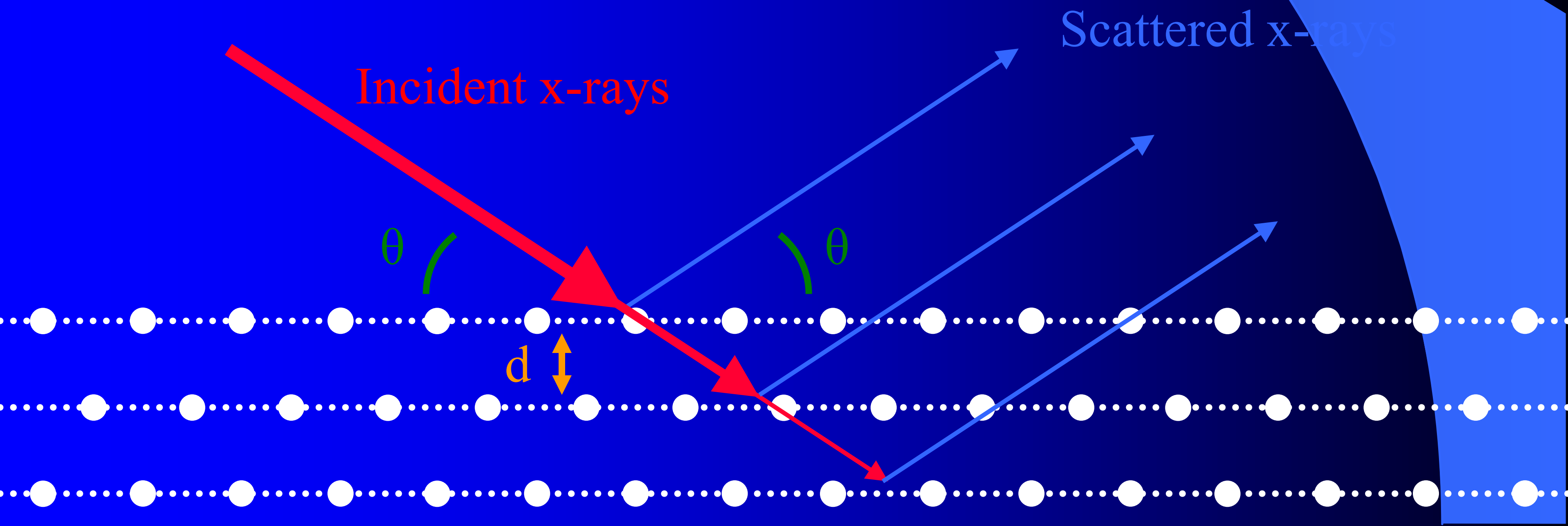
Constructive Interference

- For constructive interference, path length difference must be integer multiple of x-ray wavelength

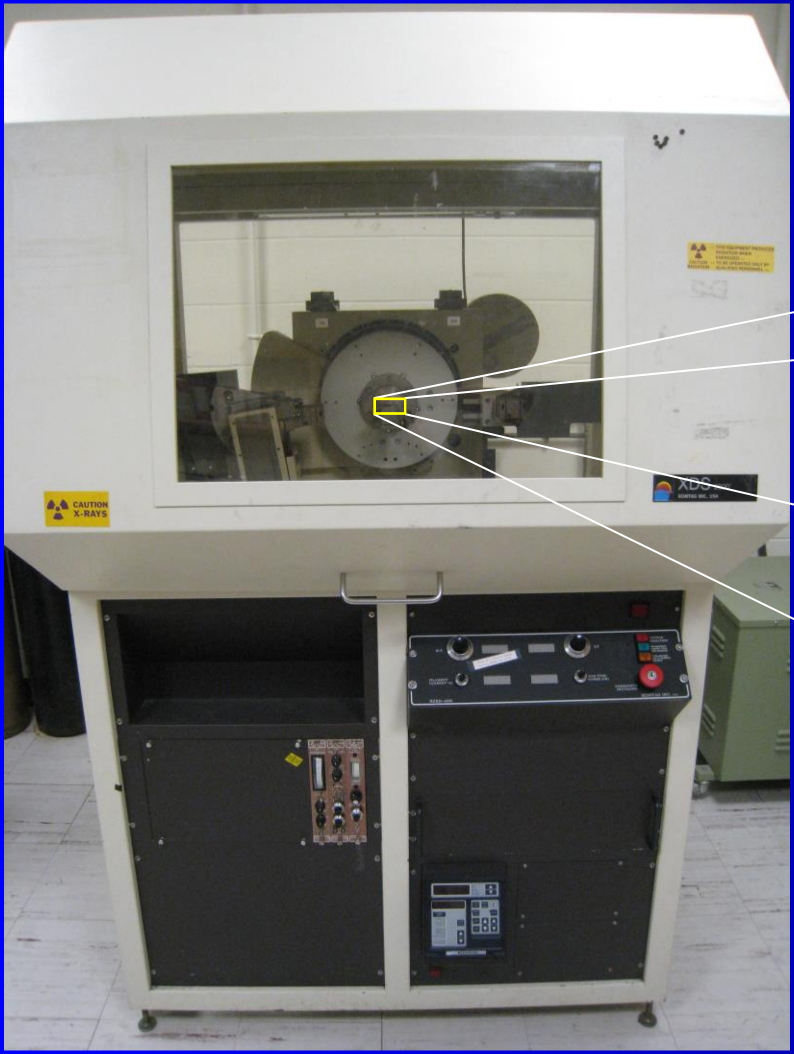


Mathematics of Bragg's Law

$$2d \sin \theta = n\lambda$$

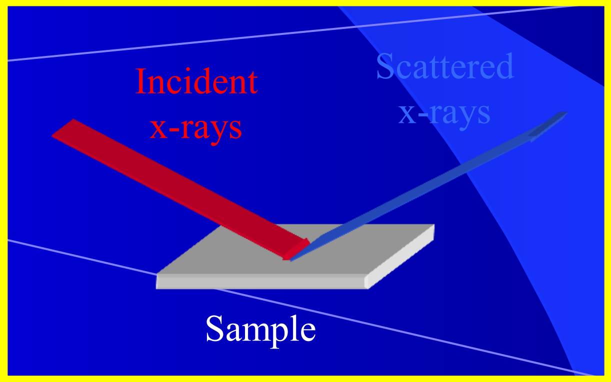


Our Instrument: Scintag XDS-2000 (Olney G6)

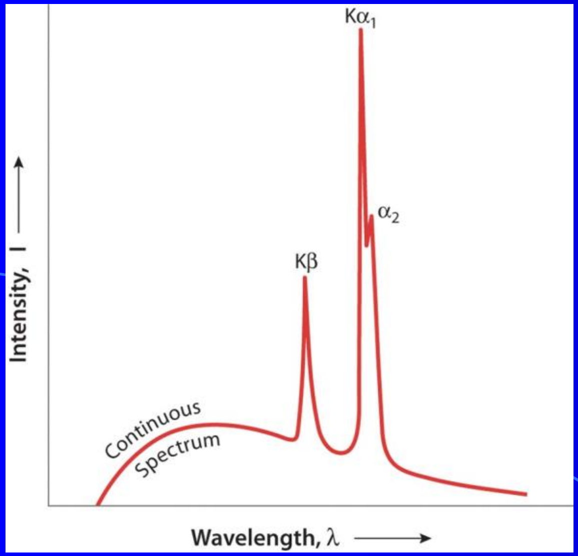


Cu K_α x-ray source

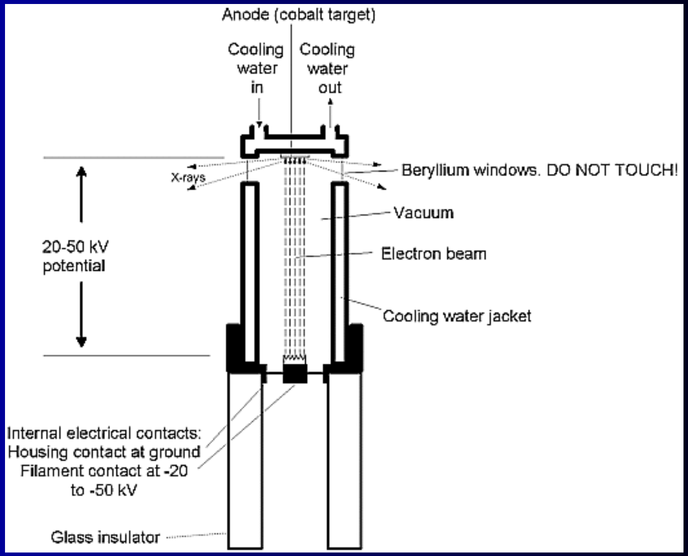
$\lambda = 0.154$ nm $= 1.54$ Å

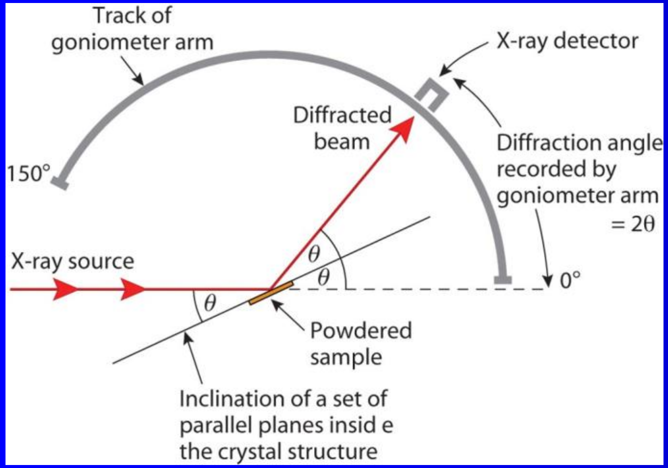


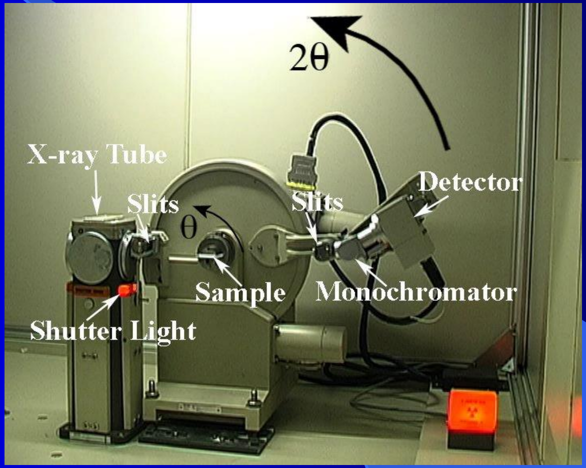
Sample may be a powder, or a solid sheet or plate (30mm square)

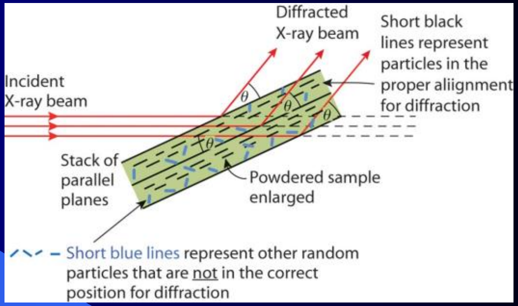


X-rays generated by an X-ray tube. Common tubes are Cu, Fe, and Mo.

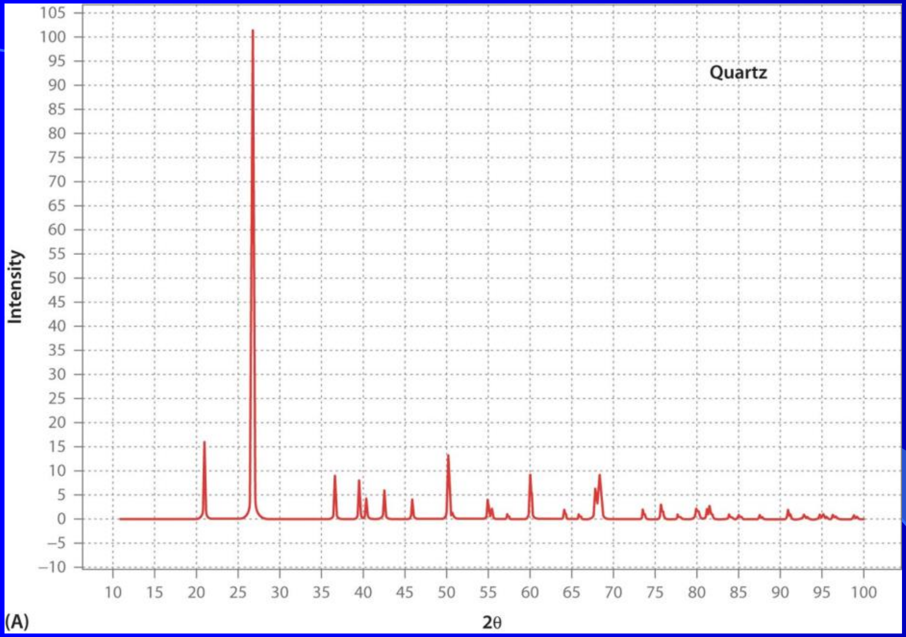


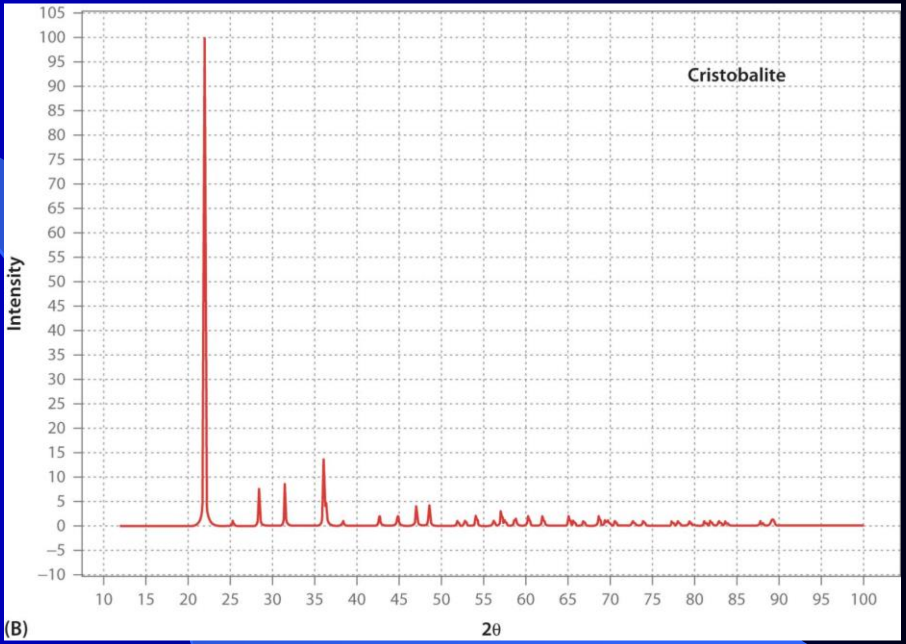




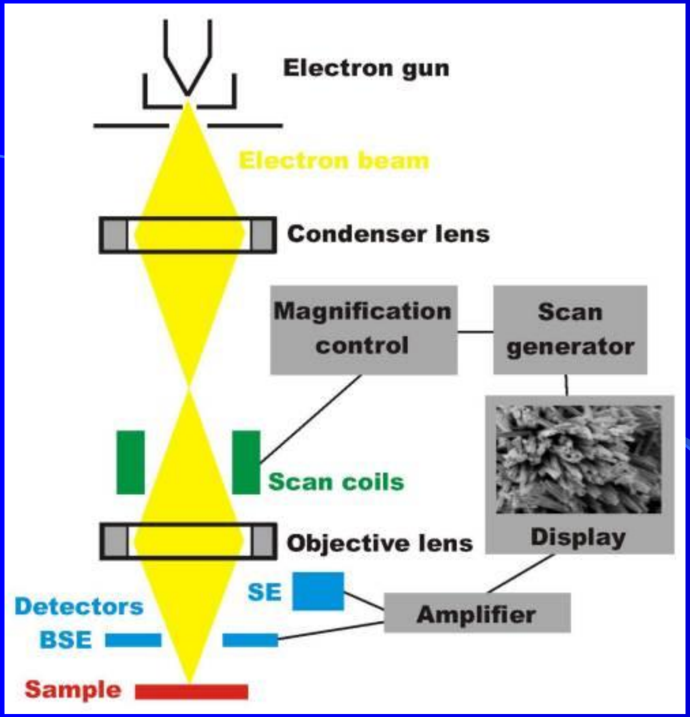


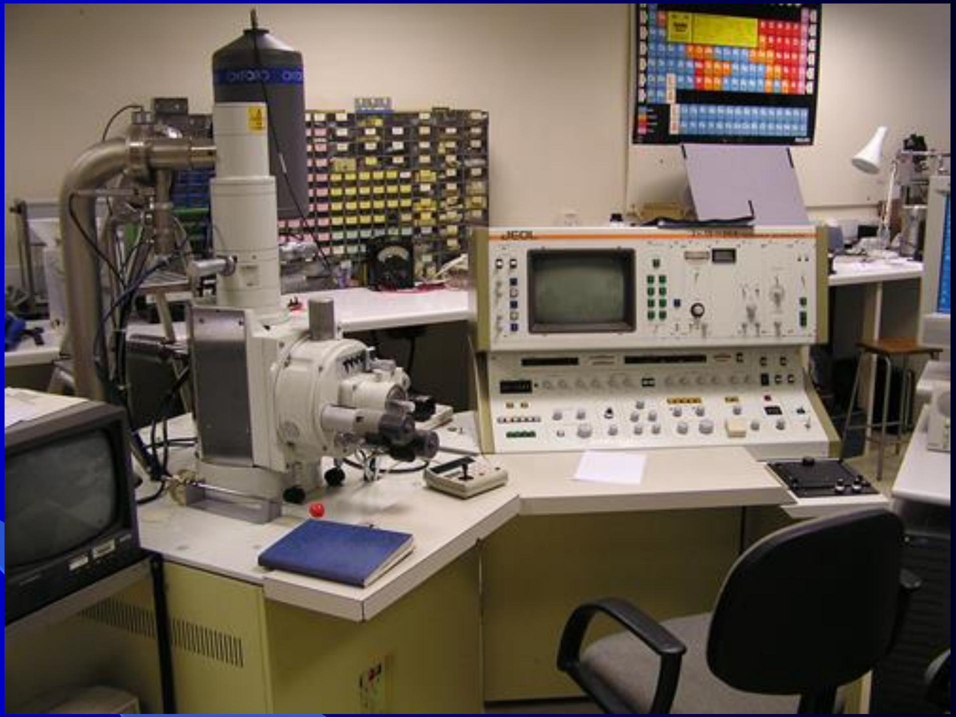
X-ray diffraction patterns for the silica polymorphs – quartz and cristobalite

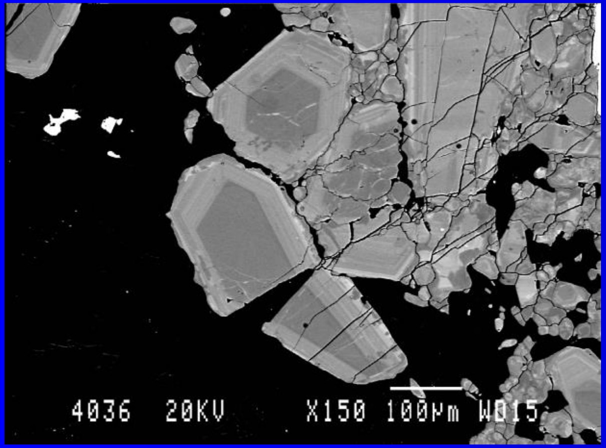


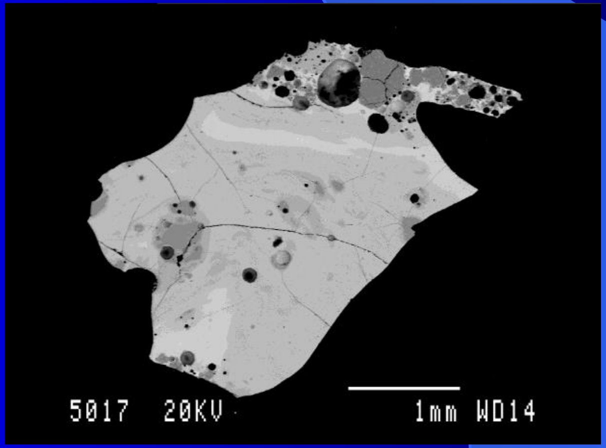


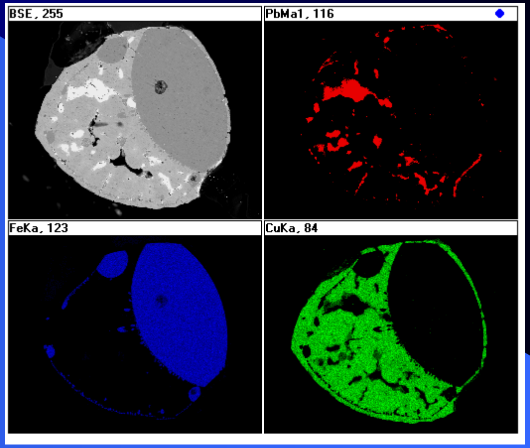
Scanning Electron Microscope (SEM)



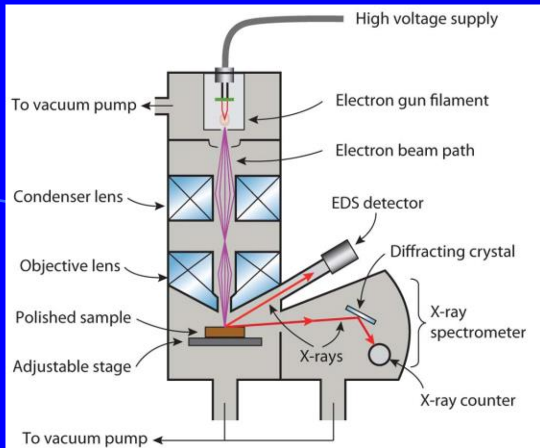


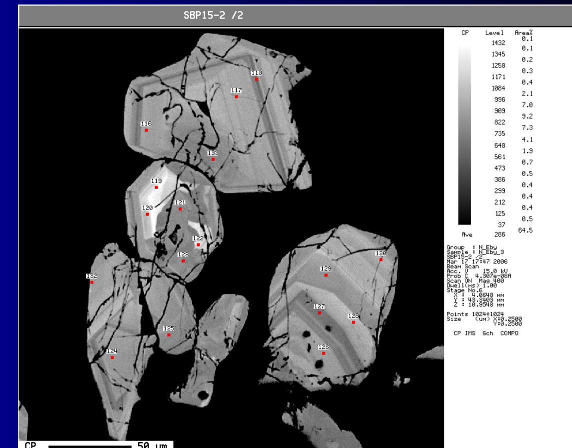






Electron Microprobe Analyzer (EMPA)





No.	SiO2	TiO2	Al2O3	FeO	MnO	CaO	P2O5	V2O3	La2O3	Ce2O3	Pr2O3	Nd2O3	Sm2O3
116	1.9	0	0.004	0	0	0.195	27.559	0	14.72	31.043	3.12	10.051	0.974
117	2.078	0	0	0	0	0.174	27.147	0	13.95	30.607	3.09	10.537	1.116
118	1.065	0	0.019	0.015	0	0.178	28.744	0	14.704	33.228	3.372	10.905	0.998
119	4.321	0	0.015	0.004	0	0.238	23.928	0	11.036	26.526	2.775	10.056	1.319
120	4.9	0	0	0.058	0	0.221	22.894	0	11.211	25.178	2.742	9.962	0.996
121	1.499	0	0.004	0.027	0	0.325	28.174	0	13.629	31.073	3.103	10.644	1.225
122	3.627	0	0.011	0.044	0	0.265	24.925	0	11.756	27.256	2.932	10.618	1.231
123	1.451	0	0	0	0.014	0.176	28.232	0	15.186	32.484	3.095	10.142	1.006
124	1.661	0	0	0.008	0	0.129	27.924	0	15.045	32.451	3.197	10.447	0.861
125	1.433	0	0.004	0.011	0.025	0.153	28.19	0	14.987	32.457	3.289	10.557	0.806
126	1.907	0	0.001	0.04	0.004	0.147	27.454	0	14.344	31.682	3.187	10.534	1.102
127	0.857	0	0.006	0	0.01	0.182	29.241	0	15.73	33.814	3.268	10.563	1.144
128	2.343	0	0	0	0	0.158	26.773	0	14.964	30.944	2.904	9.904	0.87
129	1.54	0	0	0	0	0.186	27.958	0	15.017	32.512	3.169	10.347	0.826
130	2.06	0	0	0.061	0	0.232	27.154	0	14.523	31.369	3.085	10.002	0.861
131	1.818	0	0.007	0.039	0	0.349	27.781	0	14.702	31.238	3.299	10.411	1.119
132	1.839	0	0	0.019	0	0.327	27.376	0	14.735	31.676	3.28	10.54	1.125
133	1.349	0	0.001	0.007	0	0.121	28.336	0	14.824	33.301	3.138	10.859	1.108

No.	Eu2O3	Gd2O3	Tb2O3	Dy2O3	Ho2O3	Er2O3	Tm2O3	Yb2O3	Lu2O3	Y2O3	Nb2O5	PbO	ZrO2	ThO2	UO2
116	0.088	1.183	0.073	0.344	0	0.031	0.046	0	0.06	1.191	0	0.126	0.043	7.589	0.296
117	0.086	1.274	0.125	0.271	0.032	0.123	0.141	0.066	0.065	1.418	0.057	0.112	0.017	8.45	0.33
118	0.089	1.177	0.105	0.434	0	0.097	0.129	0.141	0.169	1.746	0.007	0.096	0.064	3.936	0.325
119	0.195	1.062	0.089	0.329	0.107	0.091	0.007	0.009	0.056	1.573	0.007	0.293	0.039	17.49	0.588
120	0.075	1.042	0.04	0.405	0.017	0.198	0.042	0.078	0.018	1.373	0.042	0.318	0.088	19.277	0.679
121	0.087	1.348	0.176	0.429	0	0.16	0.079	0.204	0.133	1.749	0	0.113	0.047	6.842	0.232
122	0.048	1.303	0.056	0.47	0.246	0.142	0.134	0	0	1.572	0.003	0.253	0.003	14.541	0.514
123	0.068	1.098	0.076	0.354	0.1	0.014	0.048	0.02	0.109	1.078	0.057	0.085	0.007	5.817	0.2
124	0.072	1.019	0.153	0.255	0.135	0.122	0.168	0.09	0	1.235	0.01	0.106	0.04	6.629	0.247
125	0	1.181	0.121	0.259	0.063	0.197	0.118	0	0	1.102	0	0.088	0.027	5.704	0.197
126	0.162	1.082	0.105	0.304	0	0.039	0.006	0.03	0.094	1.269	0.02	0.117	0	7.444	0.278
127	0.094	1.134	0.145	0.379	0.195	0.073	0	0.035	0.065	1.464	0	0.052	0.104	3.06	0.299
128	0.051	1.03	0.081	0.304	0.106	0	0.115	0	0	1.162	0	0.13	0.03	9.334	0.304
129	0.13	1.015	0.154	0.378	0.144	0.146	0.029	0.009	0	1.337	0	0.096	0.09	6.07	0.313
130	0	1.111	0	0.334	0	0.126	0.073	0.14	0.059	1.098	0.05	0.129	0	8.094	0.232
131	0.015	1.317	0.153	0.514	0.139	0.142	0.089	0.08	0.002	1.255	0	0.111	0.11	7.014	0.264
132	0.096	1.237	0.154	0.395	0.037	0.096	0.03	0	0.082	1.304	0	0.11	0.053	7.174	0.272
133	0.135	1.079	0.093	0.306	0.004	0.043	0	0.039	0.167	1.175	0.084	0.082	0.06	5.364	0.192

The analyzed mineral is monazite

monazite-Ce (Ce, La, Pr, Nd, Th, Y)PO_4