2.0 Rocks, Minerals, and Crystal Systems

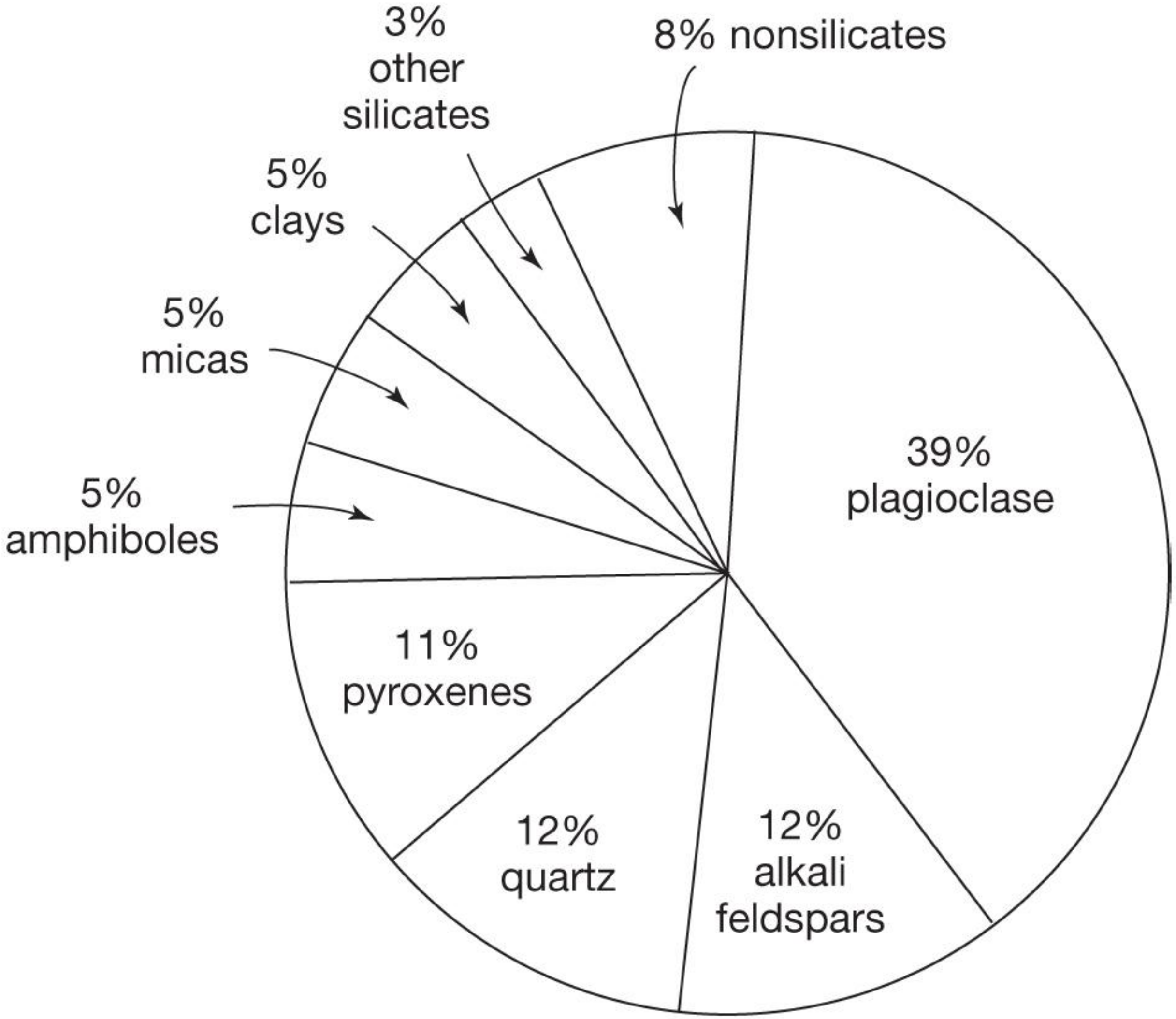
ROCKS and MINERALS (Definition)

ROCKS: Composed of aggregates of mixture of MINERALS (such as SHALE, GRANITE, DOLOMITE etc.),

MINERALS: Have a definite chemistry, crystal morphology, and physical properties (such as QUARTZ, MICA, CALCITE).

- So far nearly 3000 mineral species are established,

- 8 of 103 elements cover 98.5 % in the Earth's crusts.


3% other silicates
8% nonsilicates
5% clays
5% micas
5% amphiboles
39% plagioclase
11% pyroxenes
12% quartz
12% alkali feldspars

Weathering Pathways

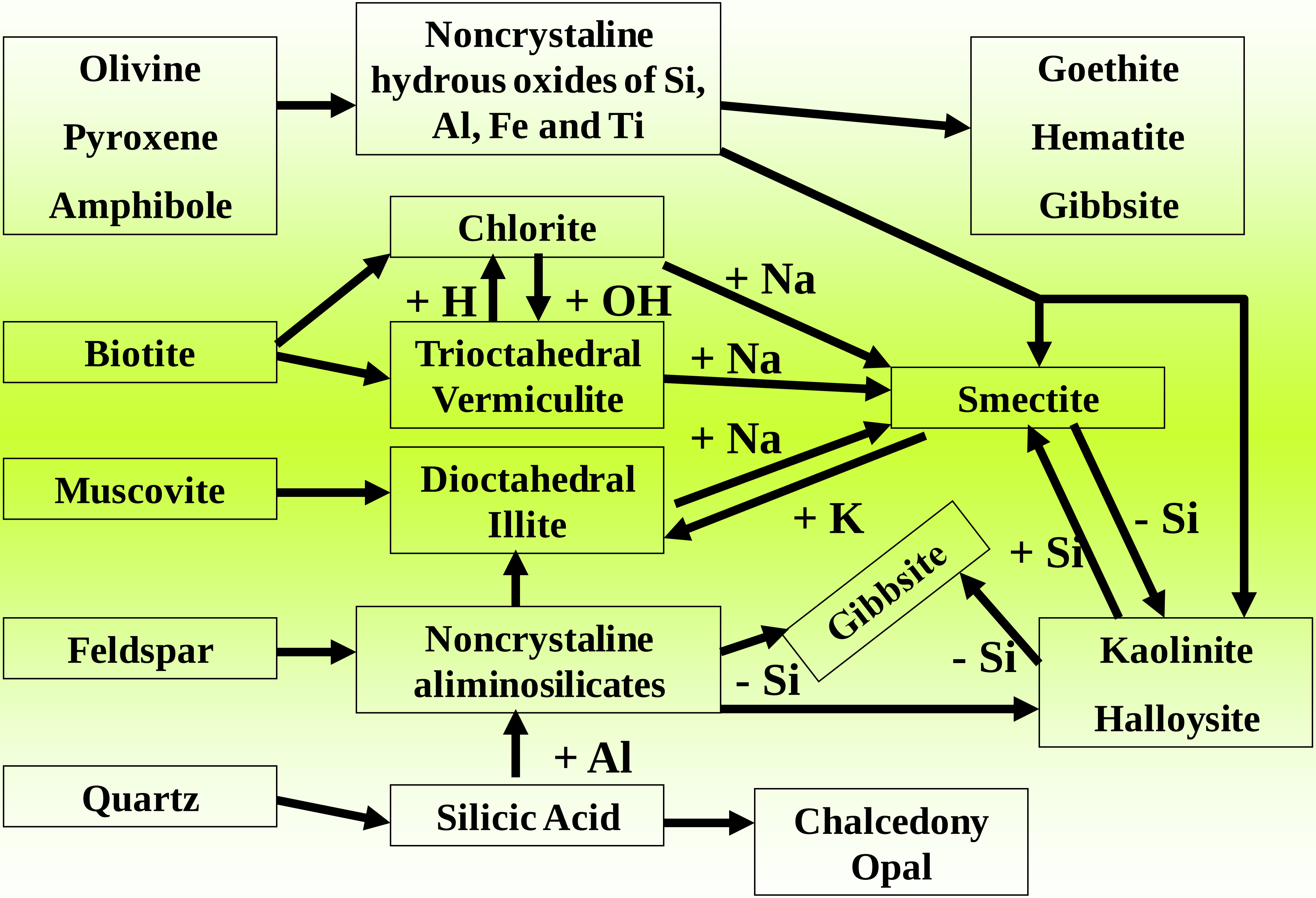
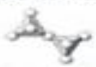
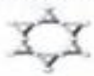
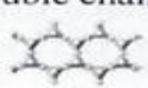


Table 1–2. Common nonsilicate minerals in soils.

Mineral class	Mineral	Chemical formula†
Halides	Halite	$NaCl$
Sulfates	Gypsum	$CaSO_4{\cdot}2H_2O$
	Jarosite	$KFe_3(SO_4)_2(OH)_6$
Sulfides	Pyrite	FeS_2
Carbonates	Calcite	$CaCO_3$
	Dolomite	$CaMg(CO_3)_2$
	Nahcolite	$NaHCO_3$
	Trona	$Na_2CO_3{\cdot}NaHCO_3{\cdot}2H_2O$
	Soda	$Na_2CO_3{\cdot}10H_2O$
Oxides and hydroxides		
Aluminum	Gibbsite	$Al(OH)_3$
Iron	Hematite	Fe_2O_3
	Goethite	$FeOOH$
	Lepidocrocite	$FeOOH$
	Maghemite	Fe_2O_3
	Ferrihydrite	$Fe_5O_7(OH){\cdot}4H_2O$
	Magnetite	Fe_3O_4
Manganese	Birnessite	$(Na,Ca,Mn^{2+})\ Mn_7O_4{\cdot}2.8\ H_2O$
	Lithiophorite	$LiAl_2Mn_2{}^{4+}Mn^{3+}\ O_6(OH)_6$
	Hollandite	$Ba(Mn^{4+},Mn^{3+})_8O_{16}$
	Todorokite	$(Na,Ca,K)_{0\cdot3\text{-}0.5}(Mn^{4+},Mn^{3+})_6\ O_{12}{\cdot}3.5H_2O$
Titanium	Rutile	TiO_2
	Anatase	TiO_2
	Ilmenite	$Fe^{2+}TiO_3$

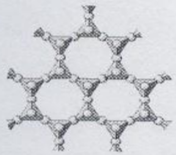
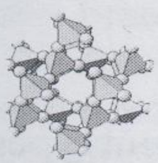
† After Klein & Hurlburt (1993), Kämpf et al. (1999).

Table 1–3. Classification of silicate minerals.

Silicate class, unit composition, arrangement of SiO_4 tetrahedra†	Mineral	Ideal formula‡
Nesosilicates $(SiO_4)^{4-}$	Olivine	$(Mg,Fe)_2SiO_4$
	Forsterite	Mg_2SiO_4
	Fayalite	Fe_2SiO_4
	Zircon	$ZrSiO_4$
	Sphene	$CaTiO(SiO_4)$
	Topaz	$Al_2SiO_4(F,OH)_2$
	Garnets	$X_3Y_2(SiO_4)_3$, $X = Ca,Mg,Fe^{2+}, Mn^{2+}$, $Y = Al,Fe^{3+},Cr^{3+}$
	Andalusite	Al_2SiO_5
	Sillimanite	Al_2SiO_5
	Kyanite	Al_2SiO_5
	Staurolite	$Fe_2Al_9O_6(SiO_4)_4(O,OH)_2$
Sorosilicates $(Si_2O_7)^{6-}$ 	Epidote	$Ca_2(Al,Fe)Al_2O(SiO_4)(Si_2O_7)(OH)$
Cyclosilicates $(Si_6O_{18})^{12-}$ 	Beryl	$Be_3Al_2(Si_6O_{18})$
	Tourmaline	$(Na,Ca)(Li,Mg,Al)(Al,Fe,Mn)_6(BO_3)_3(Si_6O_{18})(OH)_4$
Inosilicates (single chains) $(SiO_3)^{2-}$	Pyroxenes	
	Augite	$(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$
	Enstatite	$MgSiO_3$
	Hypersthene	$(Mg,Fe)SiO_3$
	Diopside	$CaMgSi_2O_6$
	Hedenbergite	$CaFeSi_2O_6$
	Pyroxenoids	
	Wollastonite	$CaSiO_3$
	Rhodonite	$MnSiO_3$
Inosilicates (double chains) $(Si_4O_{11})^{6-}$	Amphiboles	
	Hornblende	$(Ca,Na)_{2\text{-}3}(Mg,Fe,Al)_5Si_6(Si,Al)_2O_{22}(OH)_2$
	Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$
	Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
	Cummingtonite	$(Mg,Fe)_7Si_8O_{22}(OH)_2$
	Grunerite	$Fe_7Si_8O_{22}(OH)_2$

(continued on next page)

Table 1–3. Continued.

Silicate class, unit composition, arrangement of SiO_4 tetrahedra†	Mineral	Ideal formula‡
Phyllosilicates $(Si_2O_5)^{2-}$	Micas	
	Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$
	Biotite	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$
	Phlogopite	$KMg_3(AlSi_3O_{10})(OH)_2$
	Chlorites	$(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2$ $(Mg,Fe)_3(OH)_6$
	Clay minerals (selected examples)	
	Talc	$Mg_3Si_4O_{10}(OH)_2$
	Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$
	Kaolinite	$Al_2Si_2O_5(OH)_4$
	Smectite	$M^+_{0.3}Al_2(Al_{0.3}Si_{3.7})O_{10}(OH)_2$, $M^+ = Ca^{2+}, Mg^{2+}, K^+$, etc.
	Vermiculite	$M^+_{0.7}Al_2(Al_{0.7}Si_{3.3})O_{10}(OH)_2$, $M^+ = Ca^{2+}, Mg^{2+}, K^+$, etc.
	Serpentines	
	Antigorite	$Mg_3Si_2O_5(OH)_4$
	Chrysotile	$Mg_3Si_2O_5(OH)_4$
Tectosilicates $(SiO_2)^0$	Feldspars	
	Orthoclase	$KAlSi_3O_8$
	Albite	$NaAlSi_3O_8$
	Anorthite	$CaAl_2Si_2O_8$
	SiO_2 Group	
	Quartz	SiO_2
	Tridymite	SiO_2
	Cristobalite	SiO_2
	Zeolites	
	Analcime	$NaAlSi_2O_6 \cdot H_2O$
	Feldspathoids	
	Nephelene	$(Na,K)AlSiO_4$

† After Allen & Fanning (1983).
‡ Klein & Hurlbut (1993).

TABLE 2.5 Mineral Classes

Class	Anion, Anionic Complex, or Key Elements	Example Mineral	Chemical Formula
silicates	$(SiO_n)^{4-2n}$	quartz	SiO_2
halides	Cl^-, F^-, Br^-, I^-	halite	NaCl
oxides	O^{2-}	corundum	Al_2O_3
hydroxides	$(OH)^-$	gibbsite	$Al(OH)_3$
carbonates	$(CO_3)^{2-}$	calcite	$CaCO_3$
nitrates	$(NO_3)^-$	nitratite	$NaNO_3$
borates	$(BO_3)^{3-}$ or $(BO_4)^{5-}$	sinhalite	$MgAlBO_4$
sulfates	$(SO_4)^{2-}$	gypsum	$CaSO_4 \cdot 2H_2O$
chromates	$(CrO_4)^{2-}$	crocoite	$PbCrO_4$
tungstates	$(WO_4)^{2-}$	scheelite	$CaWO_4$
molybdates	$(MoO_4)^{2-}$	wulfenite	$PbMoO_4$
phosphates	$(PO_4)^{3-}$	apatite	$Ca_5(PO_4)_3(OH,F,Cl)$
arsenate	$(AsO_4)^{3-}$	scorodite	$FeAsO_4 \cdot 4H_2O$
vanadate	$(VO_4)^{3-}$	vanadinite	$Pb_5(VO_4)_3Cl$
native elements	single elements	copper	Cu
sulfides	S	pyrite	FeS_2
sulfosalts	S, As, Sb	niccolite	NiAs

The common original and secondary minerals found in soils.

Name		Formula
	Primary Minerals	
Oxides	Quartz	SiO_2
Feldspars	Microcline Orthoclase	$KAlSi_3O_8$
	Na-plagioclase	$NaAlSi_3O_8$
	Ca-plagioclase	$CaAl_2Si_2O_8$
Micas	Muscovite	$KAl_3Si_3O_{10}(OH)_2$
	Biotite	$K(Mg,Fe)_3\ (Al,Fe)Si_3O_{10}(OH,F)_2$
Amphiboles	Hornblende[1]	$Ca_2Na(Mg,Fe^{+2})_4(Al,Fe^{+3},Ti)(Al,Si)_2O_{22}(OH)_2$
Pyroxenes	Augite[1]	$(Ca,Na)\ (Mg,Fe,Al)\ (Al,Si)_2O_6$
	Secondary Minerals	
Carbonates	Calcite	$CaCO_3$
	Dolomite	$CaMg(CO_3)_2$
Sulphates	Gypsum	$CaSO_4 . 2H_2O$
Phosphates	Apatite	$Ca_{10}(F,OH,Cl)_2(PO_4)_6$
Oxides	Hydrated Fe-oxides	$2Fe_2O_3 . 3H_2O$
	Hematite	Fe_2O_3
	Gibbsite	$Al(OH)_3$
Silicates	Clay minerals	Al-silicates

[1] These are general formulae, in nature they are very variable in their composition

Some characteristics of soil separates:

Separates	Diameter mm(a)	Diameter mm(b)	Number of particles per gram	Surface area in g.cm^2
Very coarse sand	2.00-1.00	------------	90	11
Coarse sand	1.00-0.50	2.00-0.20	720	23
Medium sand	0.50-0.25	------------	5700	45
Fine sand	0.25-0.10	0.20-0.02	46,000	91
Very fine sand	0.10-0.05	------------	772,000	227
Silt	0.05-0.002	0.20-0.002	5,776,000	454
Clay	< 0.002	< 0.002	90,260,853,000	8,000,000 (c)

(a) United States Dept. Agr. system.

(b) Int. Soil Sci. Soc. system.

(c) Surface area of platy shaped montmorillonite clay particles (800 m^2)

(from Foth, 1978).

Summary of the main properties of the three soil separates:

Property	sand	Silt	Clay
Diameter (USDA) mm	2.00-0.05	0.05-0.002	< 0.002
Shape	Rounded, irregular angular, plate like	Irregularly fragmental	Plate like (and cylindrical)
Stickiness (cohesion)	Non-existant, unless coated with clay and silt particles	Low[1]	High
Plasticity	None	Some, because of adhering film of clay	High
Water holding capacity	Low	Medium-low	High
Nutrient and gas adsorbing capacity	None-low	Medium-low	High
Specific surface area	Small	Medium-low	High
Buffering capacity	None	Low	Medium-high
Dominant minerals	Fragments of primary minerals (quartz, feldspars, micas, etc.)	Fragments of primary minerals	Secondary minerals (Al-silicates and hydroxides)

[1] Low, medium and high in this table are for quantitative comparison of the three separates only.

Physical characteristics of minerals are more readily recognizable:

- **Crystal Systems,**
- **Crystal Growth habits,**
- **Cleavage, Parting, Fracture,**
- **Hardness,**
- **Luster,**
- **Streak,**
- **Color,**
- **Tenacity,**
- **Transparency,**
- **Specific Gravity,**
- **Other Tests and Properties.**

Crystal Systems (Crystallography)

- Very difficult aspect to master, CRYSTALLOGRAPHY: deals with crystal systems.

- Crystals have solid boundaries and smooth external faces with angular shapes. This is due to the result of the manifestation of orderly atomic structure.

MINERALOIDS (Amorphous, poorly crystalline).

Symmetry elements

- Rotation axes
- Mirror(reflection) plane
- Centers of symmetry
- Rotoinversion axes

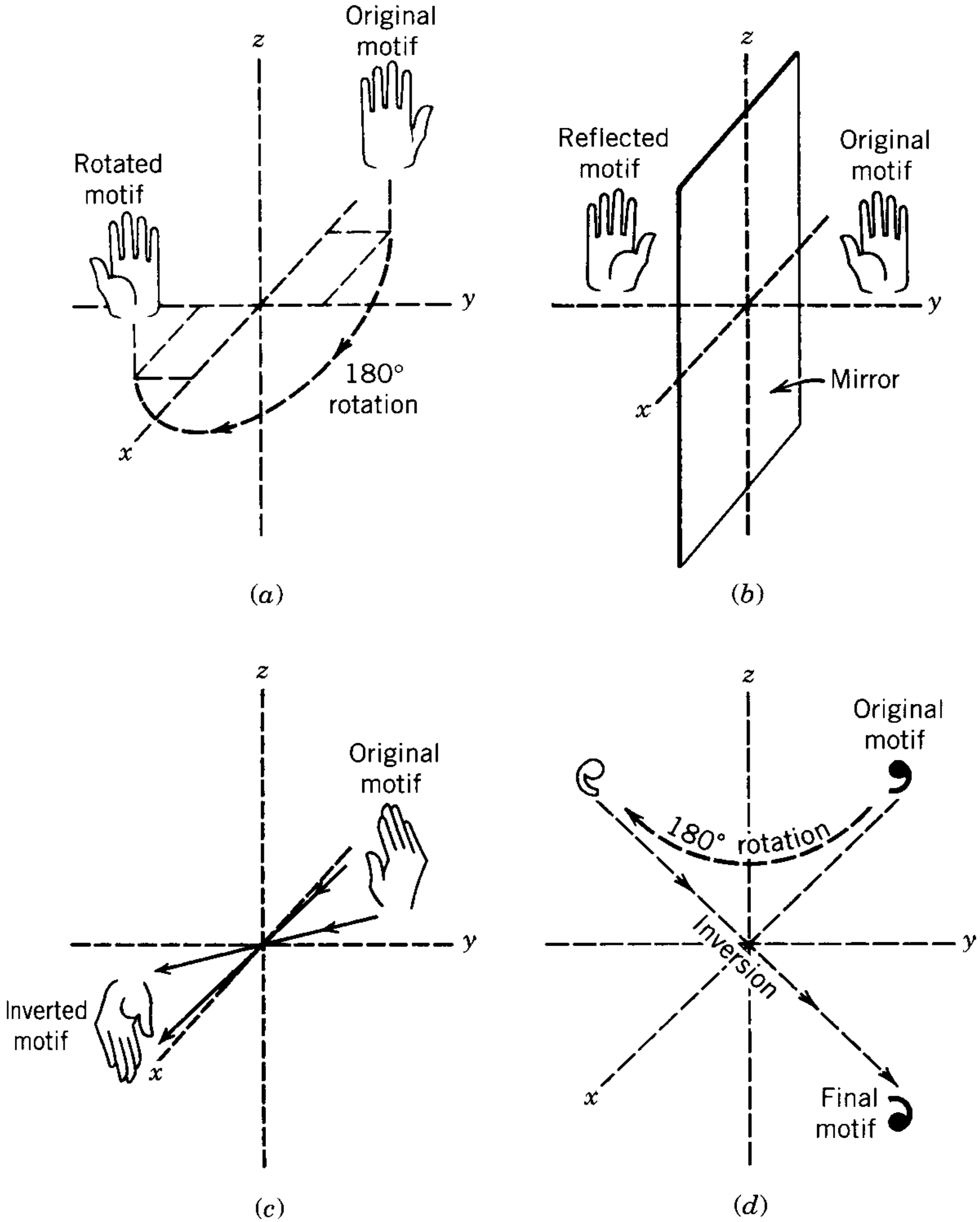
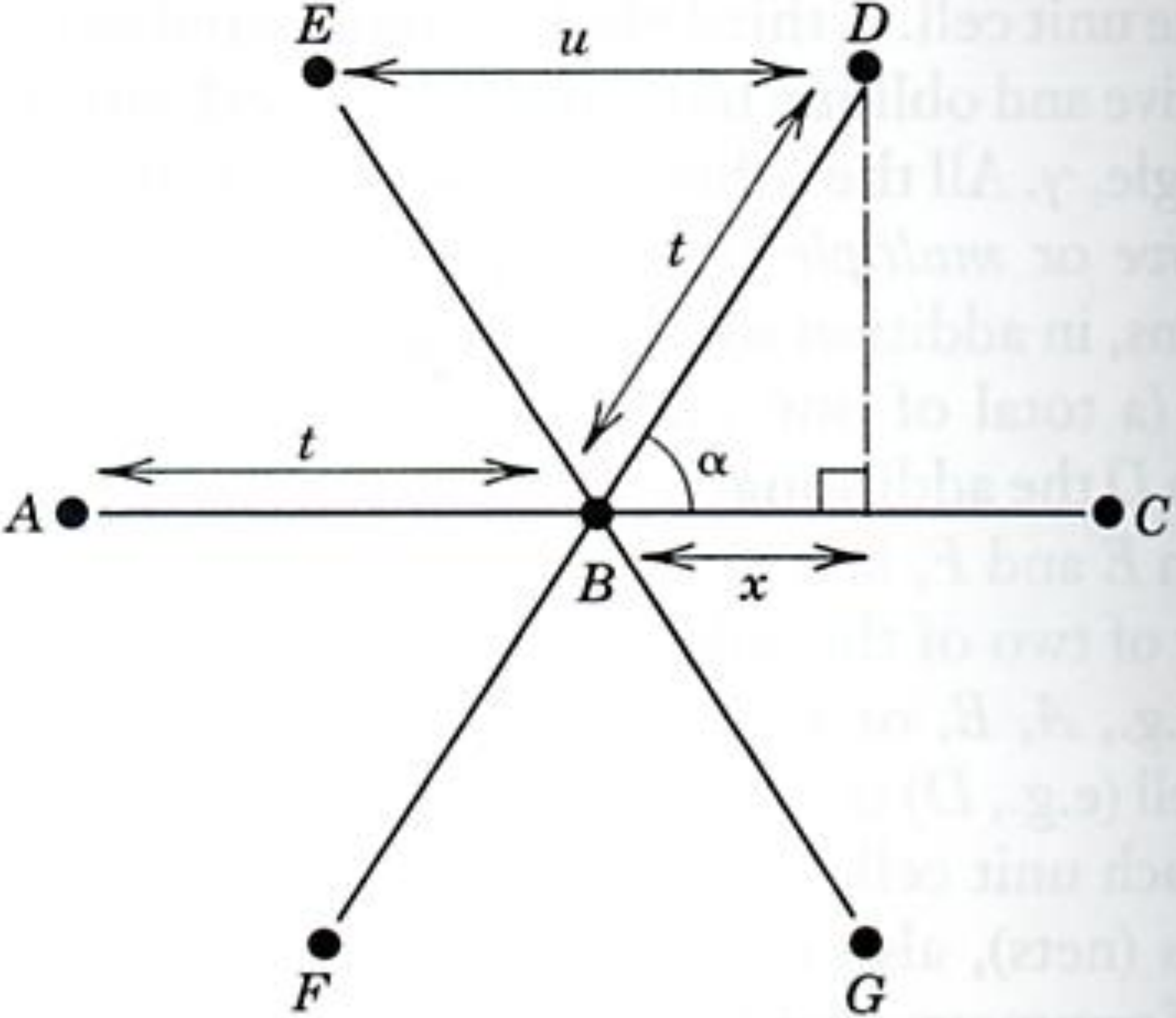


FIG. 6.9 Examples of symmetry operations. (a) Generation of a pattern by rotation of a motif through an angle of 180°. (b) Motifs as related by a mirror reflection. (c) Motifs related by inversion through a center. (d) Motifs related by 180° rotation and subsequent inversion; known as rotoinversion (see also Fig. 6.14a).


E
u
D
t
t
α
A
B
x
C
F
G

ereof. In other words, $ED = u = mt$, where m = inte-
er. If the rotation by which A, F, G, C, D, and E are re-
ted, is through an angle α, the following geometric
elations hold:

$\cos\alpha = x/t$ and also $x = \frac{1}{2} ED = \frac{1}{2} u$

$\therefore \cos\alpha = \frac{1}{2} u/t = u/2t$

$\therefore 2t\cos\alpha = u$

ombining $u = mt$ and $u = 2t\cos\alpha$ gives

$mt = 2t\cos\alpha$ or $\cos\alpha = m/2$

For $m = 2$

$m/2 = 1, \alpha = 0°$ or $360°$ ($=A_1$)

For $m = 1$

$m/2 = 1/2, \alpha = 60°$ ($=A_6$)

For $m = 0$

$m/2 = 0°, \alpha = 90°$ ($=A_4$)

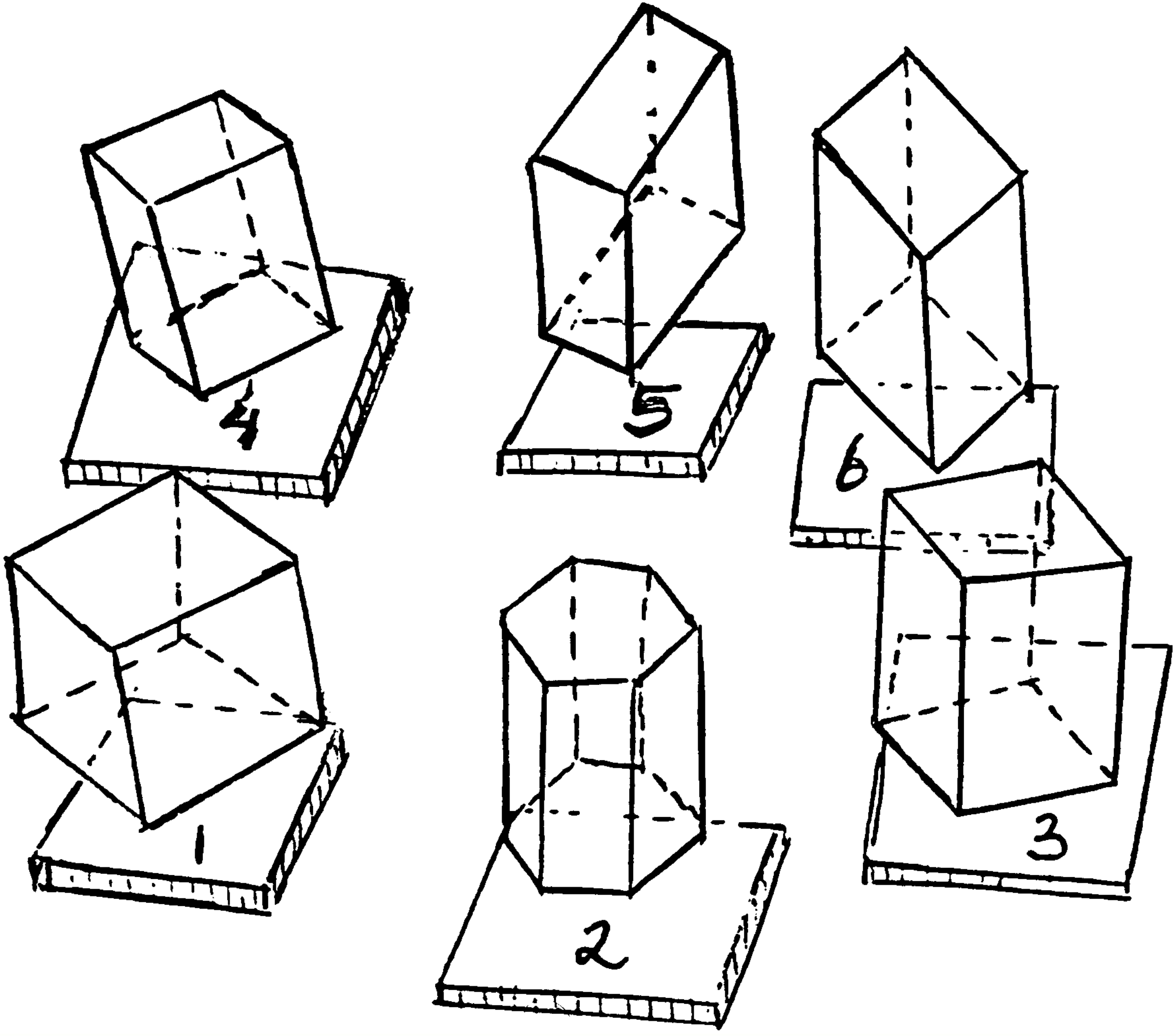
For $m = -1$

$m/2 = -1/2, \alpha = 120°$ ($=A_3$)

For $m = -2$

$m/2 = -1, \alpha = 180°$ ($=A_2$)

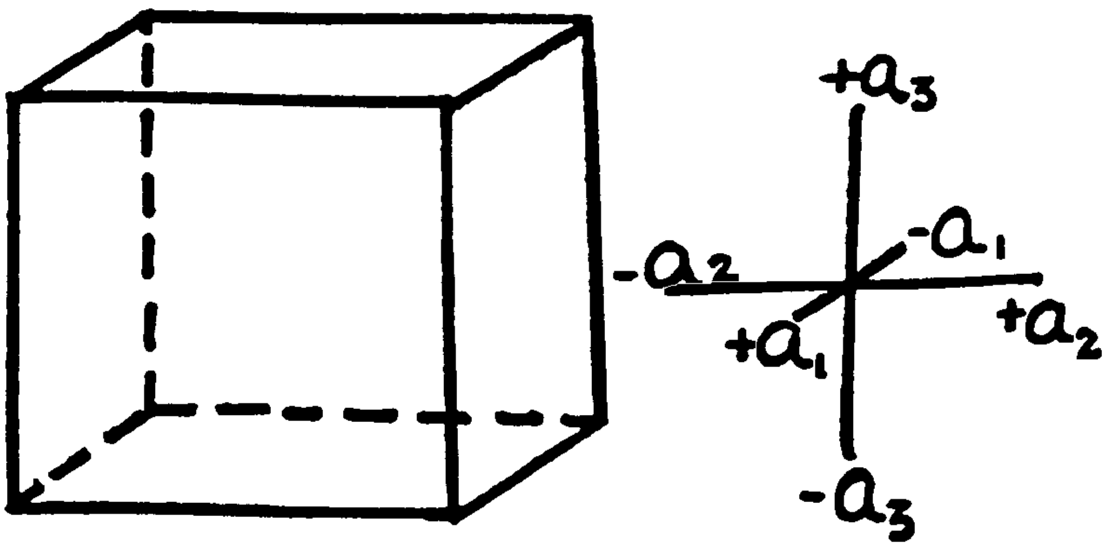
Six Main Mineral Systems

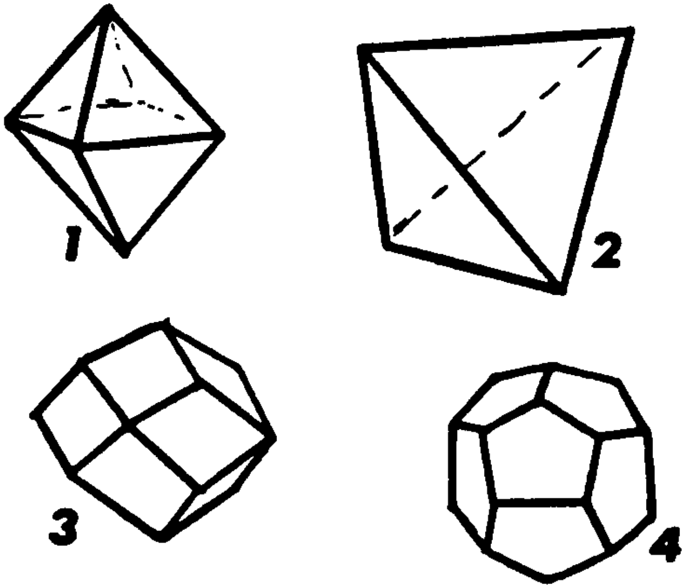


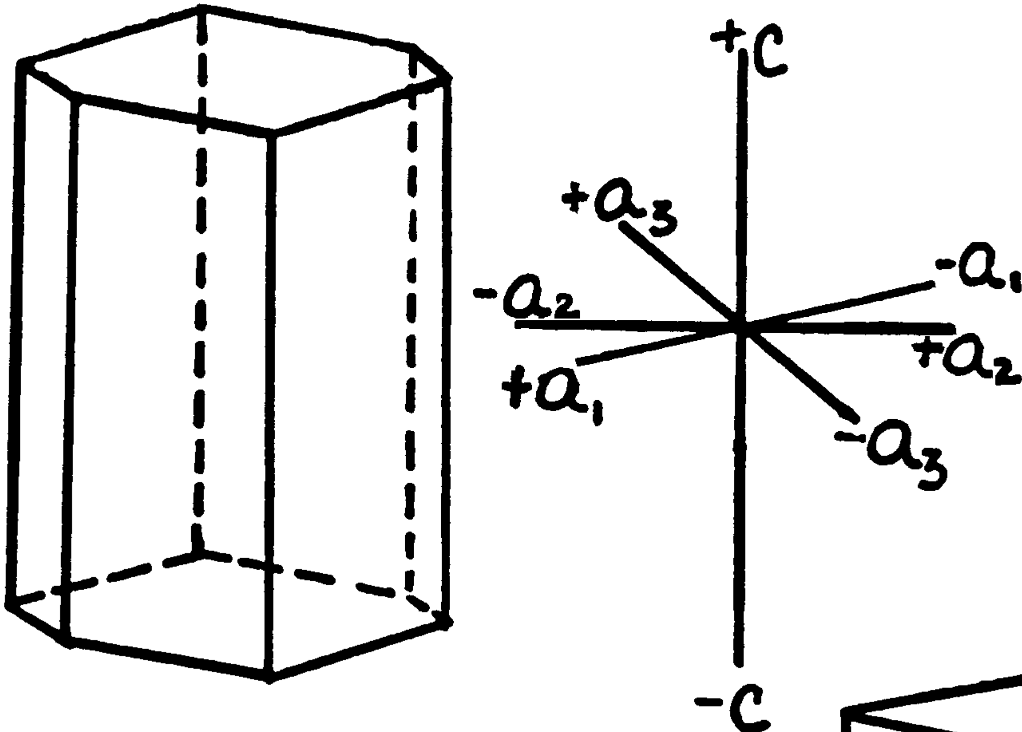
1.The Isometric System

Some variations of the isometric system:

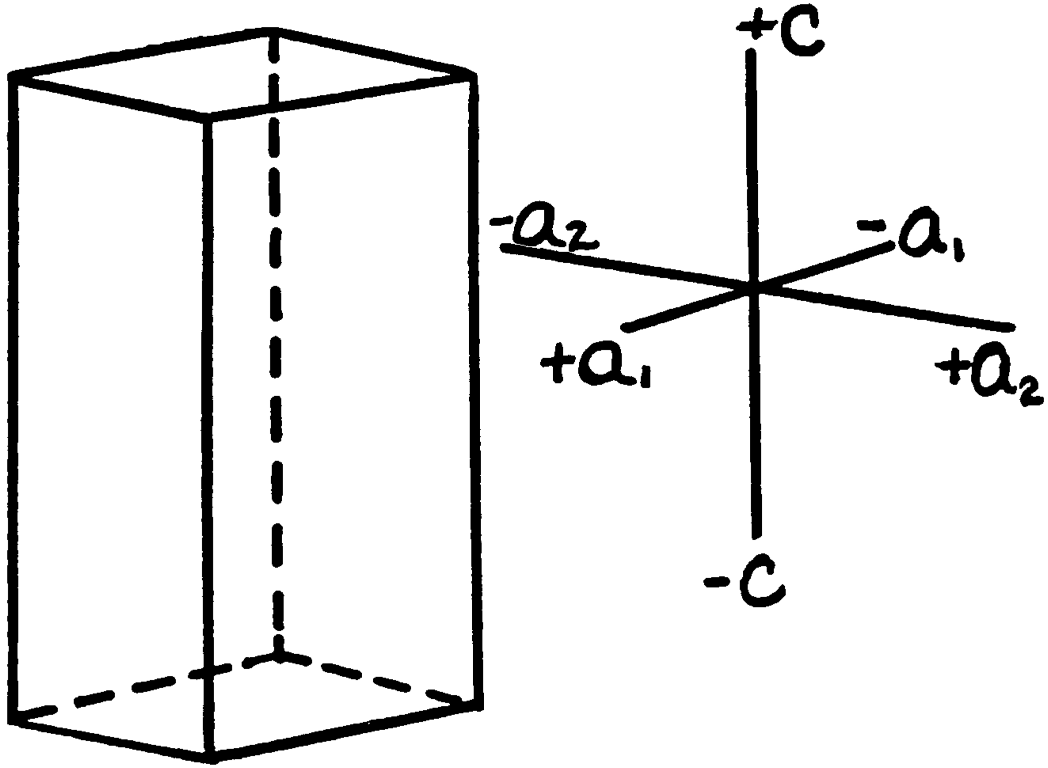
(1) Octahedron,
(2) Teterahedron,
(3) Dodecahedron,
(4) Pyritohedron.





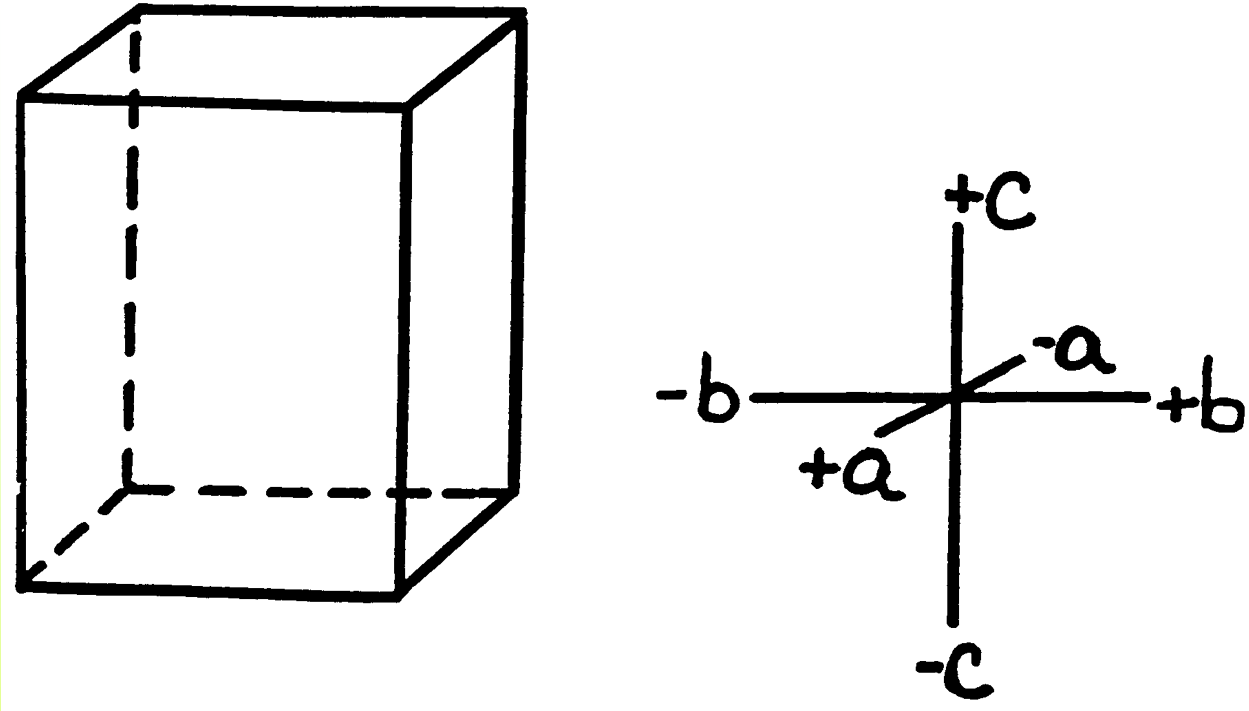


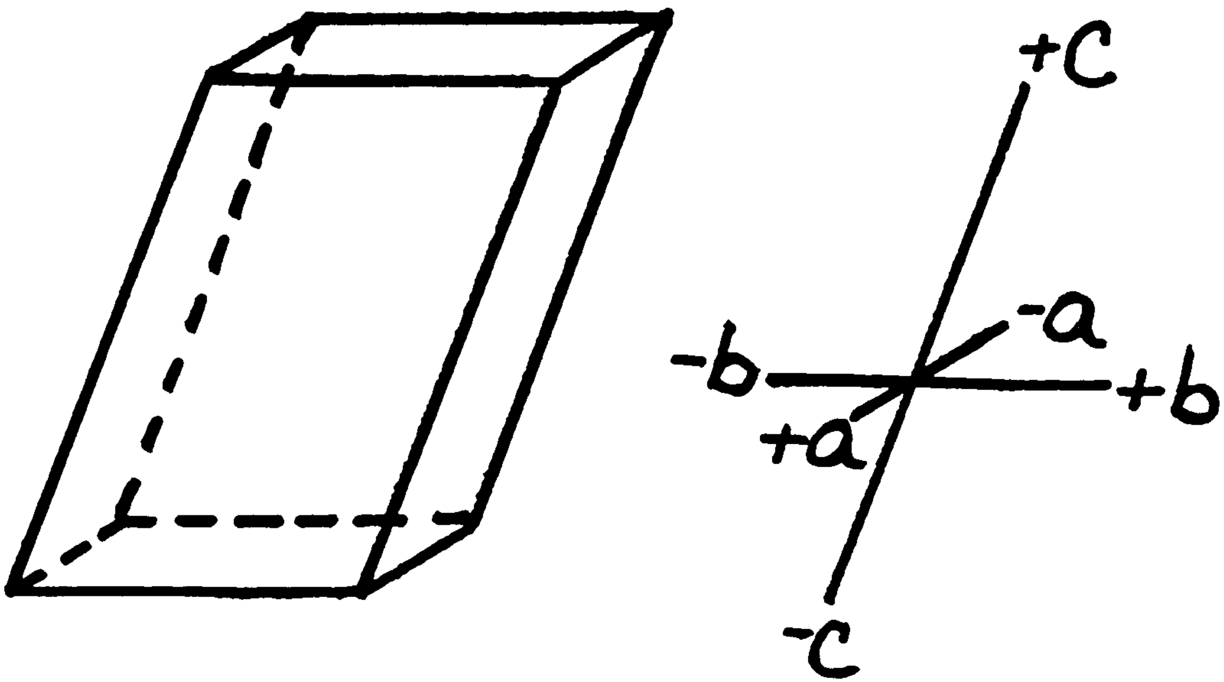
2. The Hexagonal system



3. The Tetragonal system

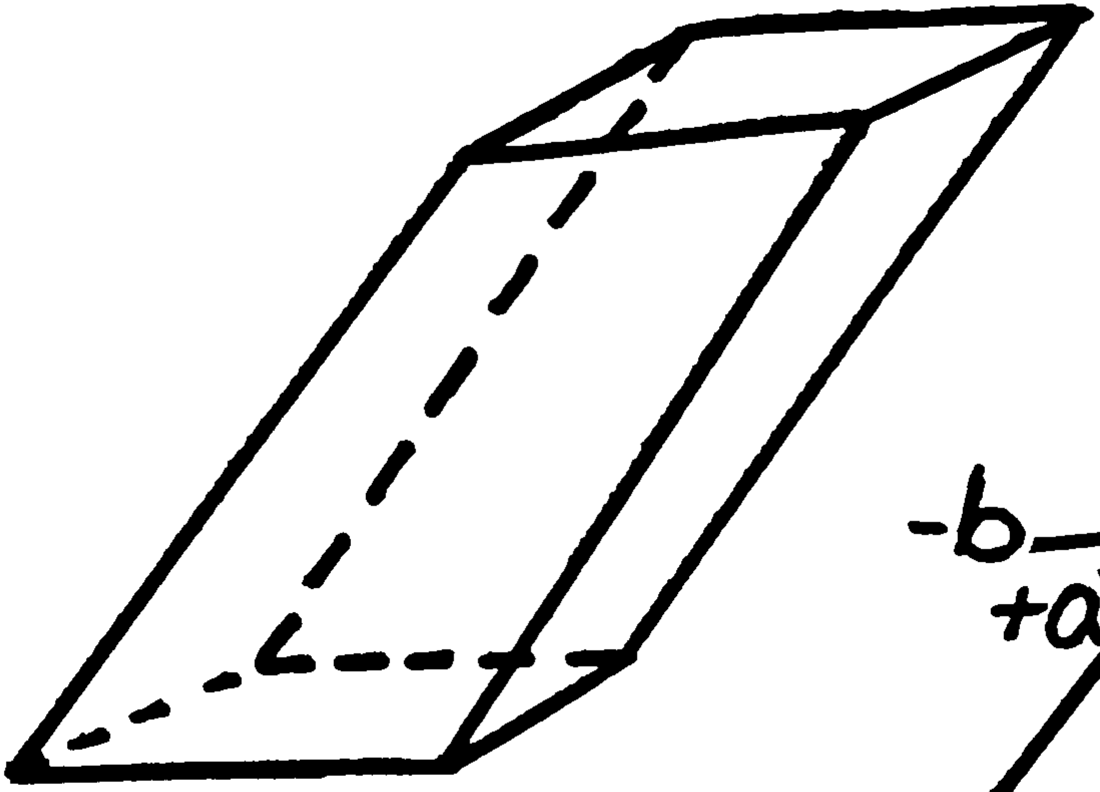
4. The Orthorhombic system

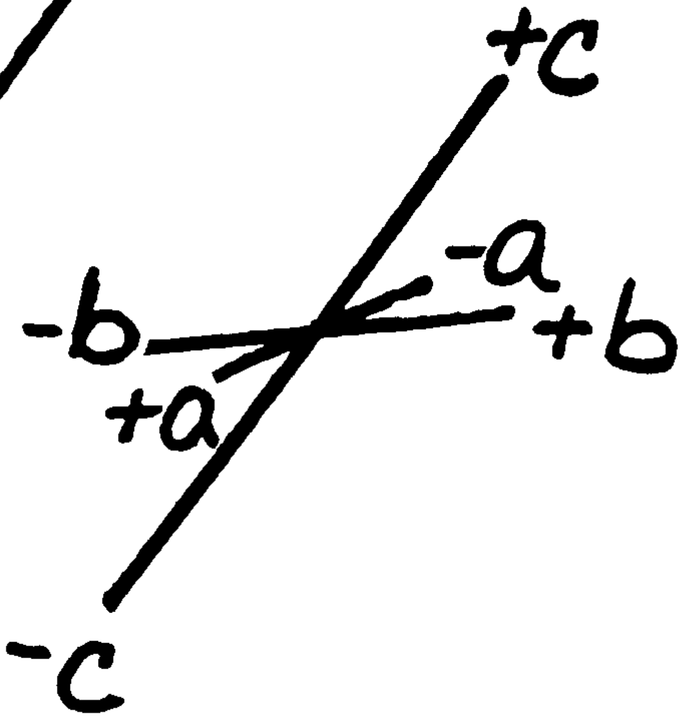




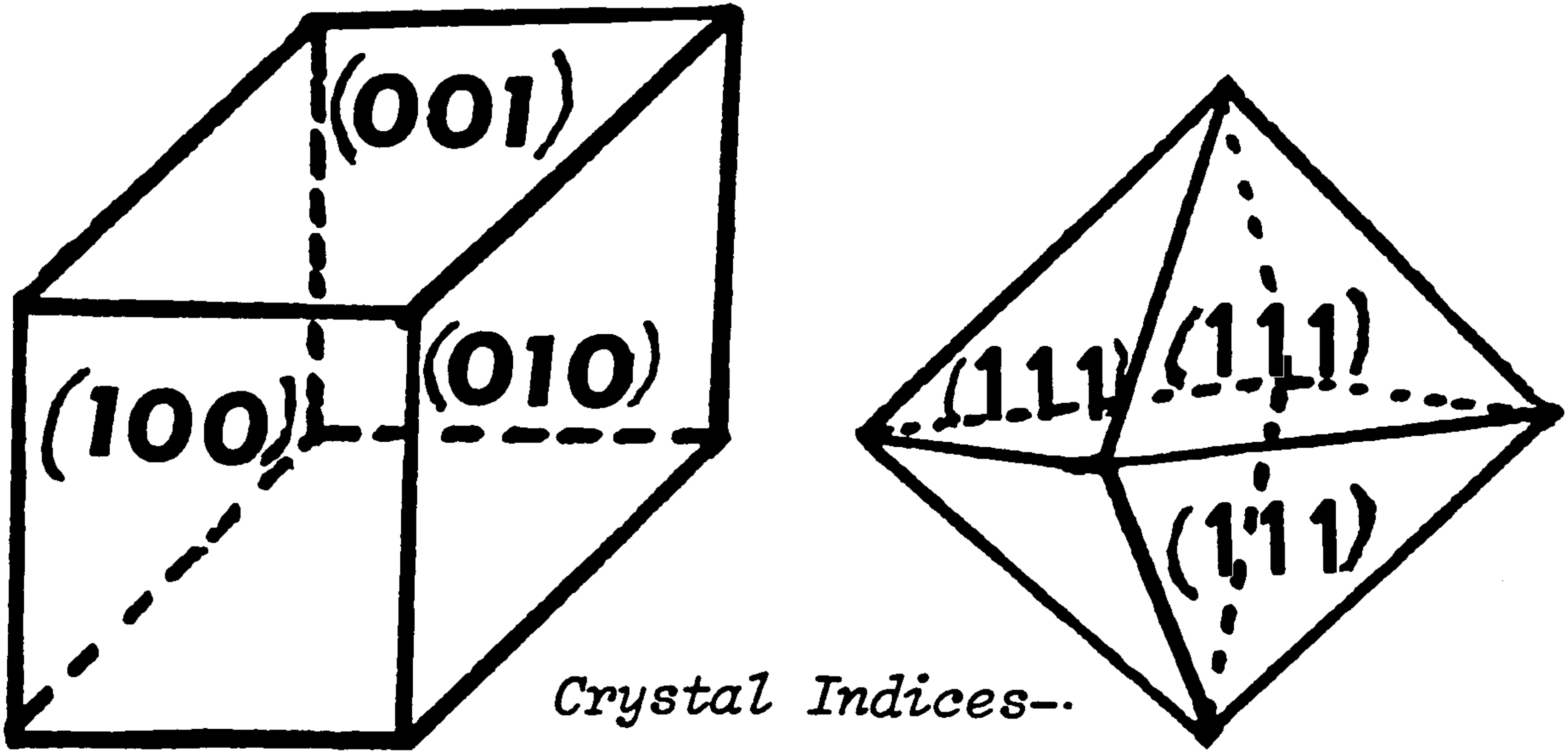
5. The Monoclinic system

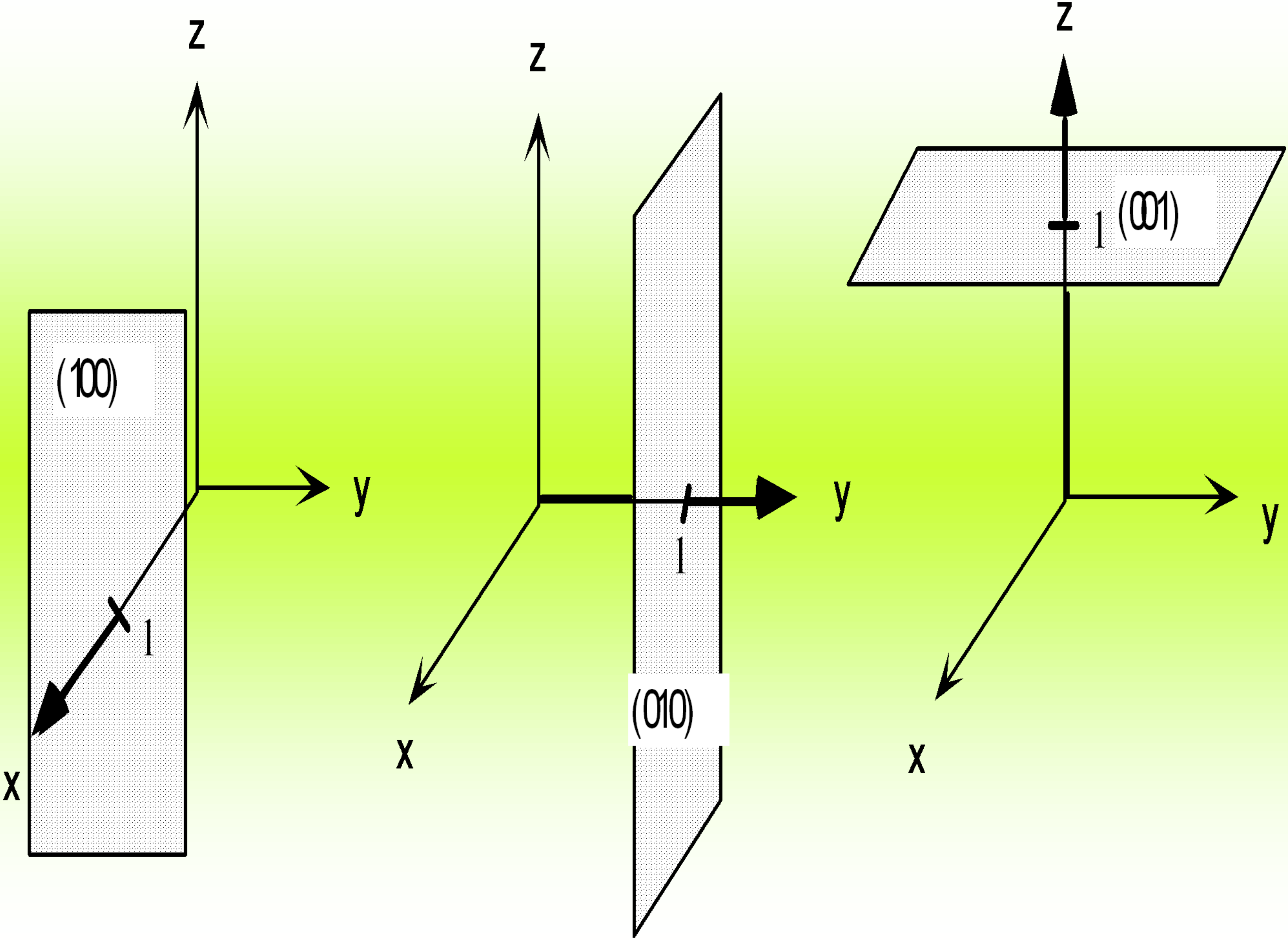
6. The Triclinic system





Designations used on crystal faces





z
y
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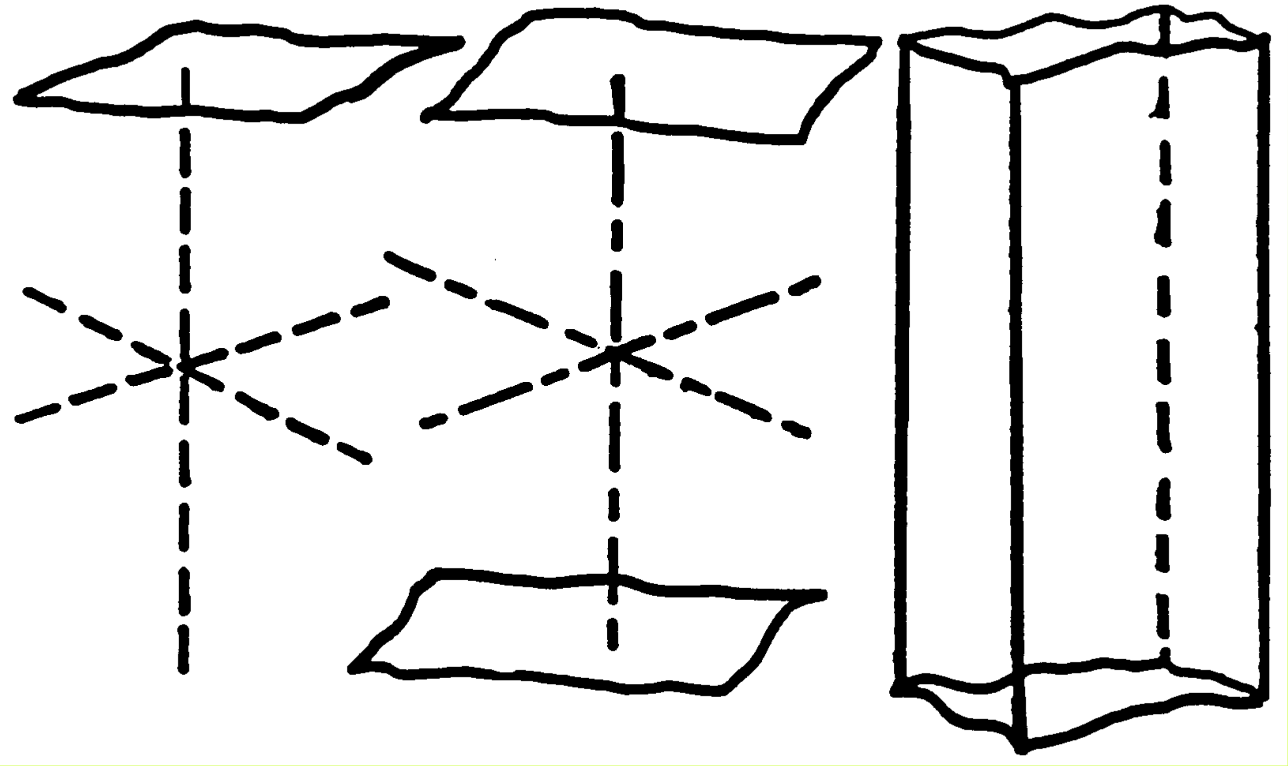
1



Some basic crystal faces:
From left to right, a pedion, a pinacoid, and a prism.

***Pedion*- an open form composed of a single face.**

***Pinacoid*- an open form consisting of two parallel faces.**

***Prism*- an open form whose faces parallel the vertical axis and intersect one or more of the other axes.**