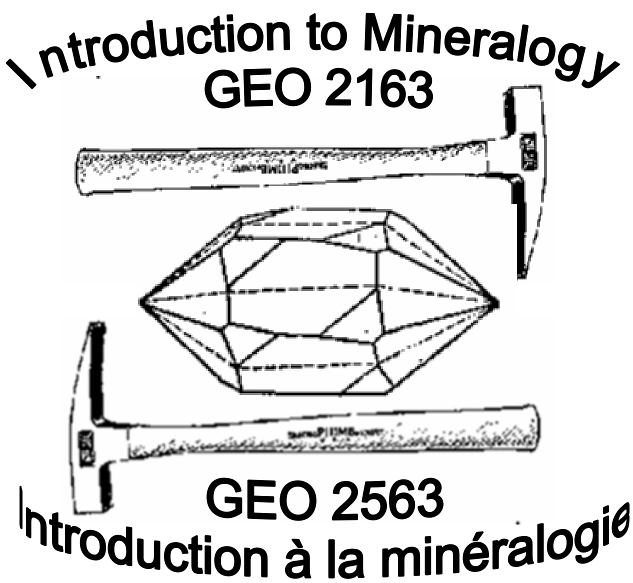
MANUAL OF LABORATORY EXERCISES



FALL 2007

Dept. of Earth Sciences
University of Ottawa

Dr. Paula C. Piilonen

GEO 2163 (2005)

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Webpage for lab manual, lecture notes, etc: www.lightbox.ca/~pcpiilonen

LECTURES: 1.5 hours, Mondays 10:00 - 11:30am, Rm 221
LAB: Thursdays 2:30 - 5:30pm, Room 222

Introduction

This first course in mineralogy is designed to be an introduction to mineralogy for students in the Earth sciences or in science in general. The course is divided into two major parts. In the first part, we will discuss the fundamental concepts of symmetry, crystallography, crystal chemistry, physical properties of minerals, and crystal growth. In the second part, we will conduct a systematic survey of the most important mineral species and discuss, in detail, their crystal structures and mineral chemistry. Laboratory and take-home exercises will accompany, as much as possible, the content of the lectures. Students will be presented with approximately 100 different minerals in this course. One field trip will be planned for October to a local mineral locality.

REQUIRED textbook (available at the University bookstore, ≈ $120)**:**

Also very useful:

Klein, C. (2001): 22nd Edition of the Manual of Mineral Science. John Wiley & Sons.
The manual includes the Mineralogy Tutorials CD-ROM. The book is on reserve at the Morisset library, QE 372 .D35 1993.

REQUIRED TOOLS/SUPPLIES:

Starting in October, the laboratory sessions will require you to identify more than 100 minerals. Certain tools will be of use to you in this process and will be available to purchase from the science faculty store. These tools include:

- a hand lens
- a streak plate (unglazed porcelain plate)
- a pencil magnet
- bottle of dilute HCl

Additional tools which you may wish to purchase include a geological hammer and a pocket knife.

The following books or guides may also be useful:

Berry L.G. and Mason B. (1959): *Mineralogy*. W.H. Freeman and Company. QE 363 .B47M 1959.
Blackburn W.H. and Dennen W.H. (1988) *Principles of Mineralogy*. Wm. C. Brown Publishers. QE 362.2 .B54 1988.
Chesterman, C.W. (1978*): The Audubon Society Field Guide to North American Rocks and Minerals*. Alfred A. Knopf Inc., USA. (QE 443.C45 1978)

***Deer, W.A., Howie, R.A. & Zussman, J. (1992 or any of the earlier editions): *An introduction to the rock-forming minerals*. Longman Group Limited, England. (QE 397.D44 1992) (this book will be invaluable to you in your future courses)**

Pough, F.H. (1953): *A field guide to rocks and minerals.* Haughton Mifflin. QE 367 .P6 1953.
Zoltai T. and Stout J.H. (1984): *Mineralogy, concepts and principles*. Burgess Press.

Evaluation

Since considerable effort is required in the laboratory and take-home exercises in this course, I suggest placing greater importance to the exercises in the evaluation of the course. The following mark distribution, which places 55% of the final mark on the exercises handed in throughout the semester, is suggested and will be discussed in class:

Final exam on theory	30%
Laboratory exercises (15 marked exercises)	50%
Mid-term exam on theory	10%
Laboratory exam (specimen identification)	10%

Students will be given one week to complete all the laboratory exercises. Take-home exercises will be allowed either one or two weeks. Exercises handed-in late will be corrected but will <u>not</u> be marked. The demonstrator will be instructed not to allow for any exceptions to these deadlines. Should you not be able to hand in your exercise in time, please consult with the professor.

Starting in October, at the beginning of each lab period you will be given a quiz on the minerals from the previous lab. These quizzes are cumulative. You may be asked to identify the mineral, give the chemical formula, the crystal system, or name forms or other physical or chemical properties.

All minerals for which you must know the chemical formula have been marked with an asterix (*) in each lab.

GEO 2163 Lecture/Lab Schedule (Fall 2007)

Lecture	Topic	Lecture	Lab	Lab
1	definition of a mineral	Sept. 10	Sept. 13	Lecture: Definition of a mineral, intro to course
	introduction to non-translational			introduction to non-translational
	symmetry elements			symmetry elements
2	the 6 crystal systems	Sept. 17	Sept. 20	Lecture: Miller indices, forms
	Hermann Maugin notation			Symmetry of wooden models
3	Crystallization	Sept. 24	Sept. 27	Sept. 22th: Continuation of Lab #1
	Twinning/intergrowths			
4	Twinning/intergrowths	Oct. 1	Oct. 4	Lecture: Introduction to crystal chemistry
				bonding in minerals,
5	Thanksgiving	Oct. 8	Oct. 11	Coordination polyhedra,
				Pauling's rules, substitutions,
				Defects, etc.
6	Continuation of crystal chemistry	Oct. 15	Oct. 18	Midterm Exam
				Assignment #1
6	classification of silicate minerals	Oct. 22	Oct. 25	Lab #2: Lecture on mineral classification,
	Tectosilicates: SiO2 polymorphs,			mineral ID techniques
	feldspar group			Native minerals, oxides, sulphides
7	Feldspars continued	Oct. 29	Nov. 1	Hydroxides, carbonates,
				halides, sulphates
8	Phyllosilicates	Nov. 5	Nov. 8	Lab #4: Tectosilicates
				Assignment #2
9	Inosilicates (pyroxenes/amphiboles	Nov. 12	Nov. 15	Lab #5: Phyllosilicates
10	Al_2SiO_5 polymorphs	Nov. 19	Nov. 22	Lab #6: Inosilicates
11	Colour in minerals	Nov. 26	Nov. 29	Lab #7: Sorosilicates,
				orthosilicates, cyclosilicates
12	Theory review	Dec. 3	Dec. 6	Lab Exam

For those interested in minerals and mineral collecting

There are two very active mineralogy clubs in the Ottawa-Outaouais region. These are:

-The Ottawa Lapsmith and Mineral Club
P.O. Box 5311, Station F
Ottawa, ON K2C 3J1
tel. (613)237-7625

-Le Club de minéralogie de l'Outaouais
26, rue de l'Argile
Hull, QC J8Z 3G2
contactez M. Jacques Chabot, (819)771-0280

The Lapsmith club organizes the annual gem and mineral show that is held at the Nepean Sportsplex. This year's show will be on Saturday **Sept. 22 from 10am to 6pm and on Sunday Sept. 23 from 10am to 5pm**. This is an excellent occasion to see minerals of all kinds and all prices.

Laboratory exercise No. 1,

Part I

REVIEW OF THE COMMON ROCK-FORMING MINERALS AND IDENTIFICATION OF NON-TRANSLATIONAL SYMMETRY ON SIMPLE MODELS

A) Review of the common rock-forming minerals

The first objective of this week's exercise is to review the simple physical properties of the 10 most common minerals (or groups of minerals) in the Earth's crust. These minerals are, in my judgement, the following:

1. Feldspar group	Plagioclase	56.4a.1.1
	Plagioclase	56.4a.1.4
	Microcline	56.4b.1.1a
	Microcline	56.4b.1.1b
	Microcline	56.4b.1.1c
2. Quartz	Quartz	56.1a.1.1a
	Quartz	56.1a.1.1c
3. Mica group	Biotite	55.4a.4.1a
	Phlogopite	55.4a.4.3a
	Muscovite	55.4a.1.1a
4. Pyroxene group	Augite	54.1b.4.1a
	Diopside	54.1b.3.1a
5. Amphibole group	Actinolite	54.2b.2.2b
	Hornblende	54.2b.3.2a
6. Calcite	Calcite	14.1.1.1c
7. Olivine	Olivine, forsterite	51.2.1.1
	Olivine, forsterite	51.2.1.2a
8. Apatite	Apatite, crystal	41.7.1.1a
	Apatite, with calcite	41.7.1.1b
9. Iron oxides	Magnetite	7216
	Hematite	4412a
10. Pyrite	Pyrite, crystals	2911

We will obviously study these minerals in greater detail later in the semestre, however, it would be useful to familiarize yourselves now with the simple physical properties of these minerals such as colour, hardness, streak, crystal form (if observed) and also to know their approximate chemical composition (i.e., are they silicates, oxides, carbonates, etc...). The numbers in the column are the specimen identifications in the teaching collection for this course.

B) Identification of non-translational symmetry on simple models

The objective of this second part of the laboratory is to recognize and identify non-translational symmetry operations on simple crystal models. The models that you will work with in this exercise are mostly made of plaster but a few are of wood. The wooden models are of exceptional quality and represent true works of art. Please refrain from writing on these models.

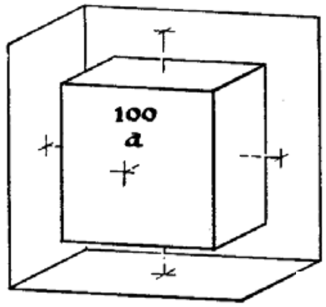
For each of the five models assigned to you in this exercise, answer the following questions:

1) Identify all the different non-translational symmetry operations (e.g. mirrors, rotations, rotoinversions and centre of symmetry) as well as their numbers.
2) On a schematic three-dimensional diagram of the model (a clinographic projection) represent all the symmetry elements that you have identified.
3) Try to express the symmetry of your model with the Hermann-Mauguin notation.

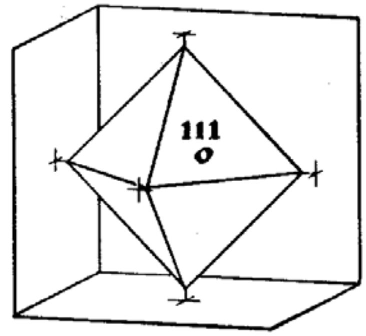
The five assigned models are: 1) the cube, 2) the octahedron, 3) the hexagonal prism (in bronze), 4) gypsum and 5) either augite, zircon or staurolite.

N.B. If you experience difficulty in drawing three-dimensional sketches of your models, try tracing them from the illustrations in your textbook. All of these models are commonly illustrated in mineralogy textbooks.

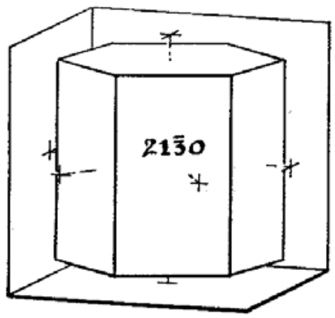
Models for part B of laboratory exercise



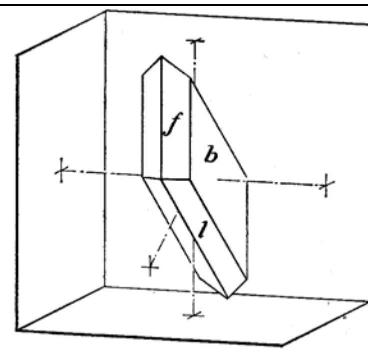
cube



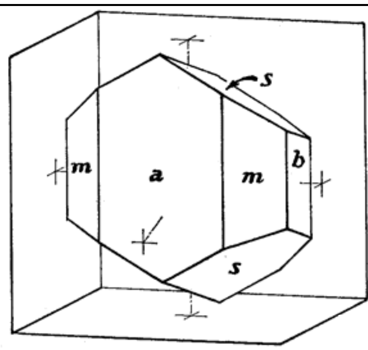
octahedron



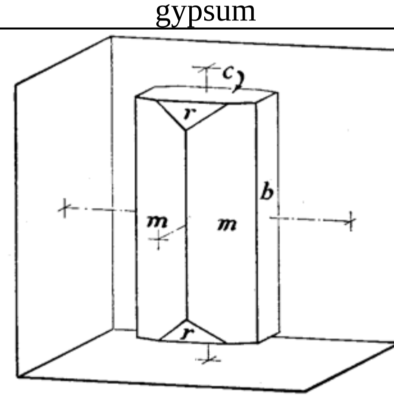
hexagonal prism



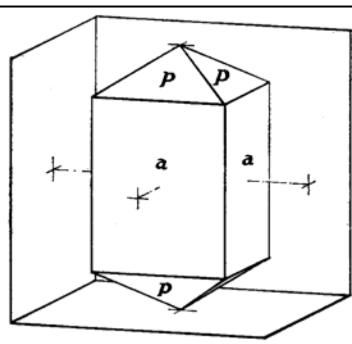
gypsum



augite (pyroxene)



staurolite



zircon

PART II

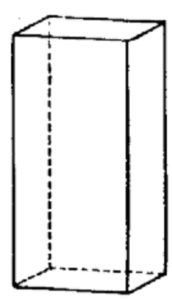
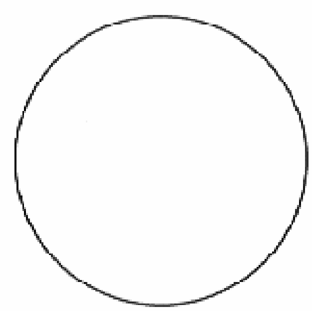
POINT-GROUP SYMMETRY, CRYSTAL SYSTEMS, STEREOGRAPHIC PROJECTIONS AND MILLER INDICES OF WOODEN MODELS

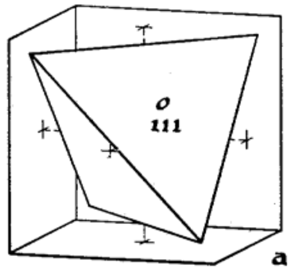
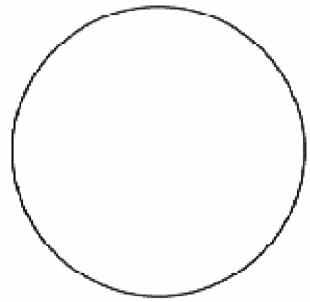
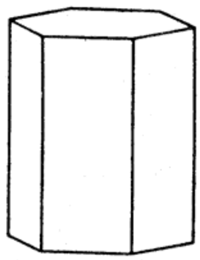
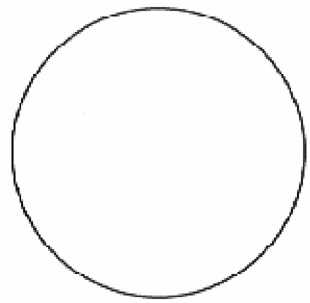
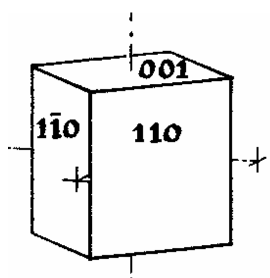
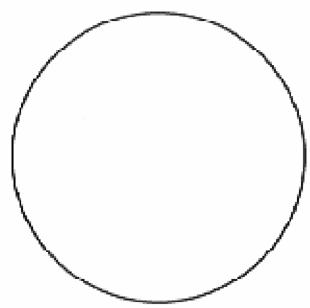
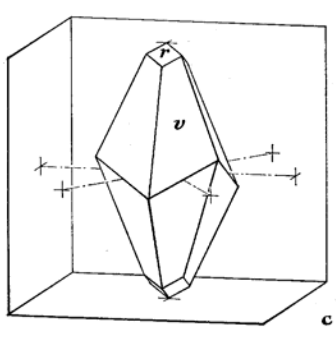
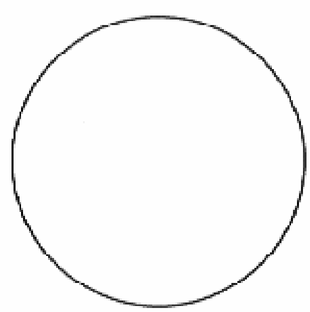
This week's exercise has three principal objectives; 1) to be able to recognize the point group symmetry of a crystal model and consequently, to determine its crystal system, 2) to be able to represent qualitatively on a stereographic projection the symmetry elements, crystal faces and axes of a model, and 3) to be able to compute the Miller indices of different planes in a planar lattice.

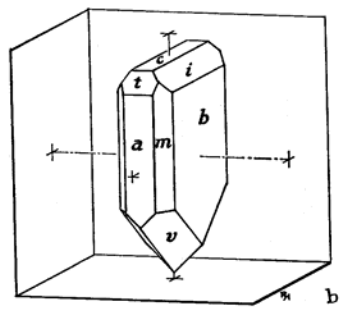
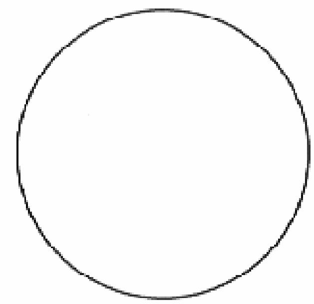
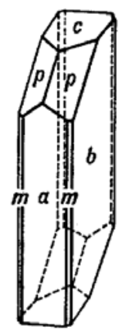
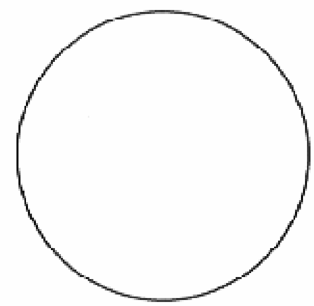
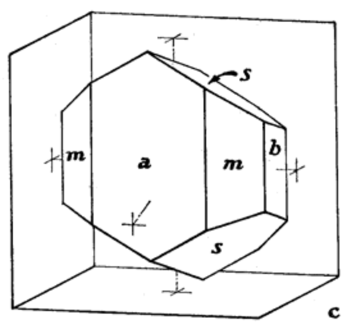
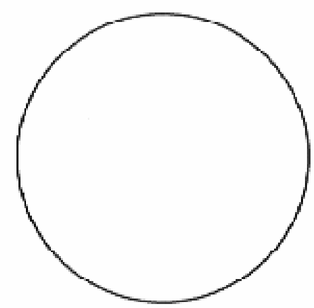
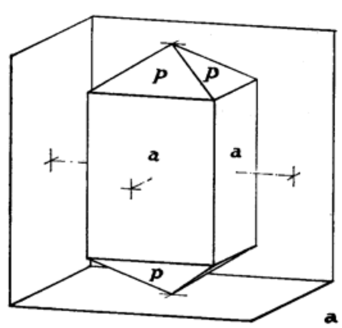
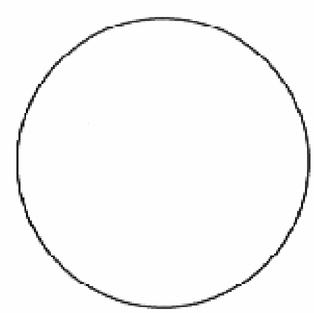
The exercise is divided into two sections. In section A, you will identify the point-group symmetry and crystal systems of twenty different wooden models. In addition, you will have to draw (qualitatively) all symmetry elements and crystal axes on a stereographic projection. In section B, you will compute the Miller indices of the traces of planes in a planar lattice.

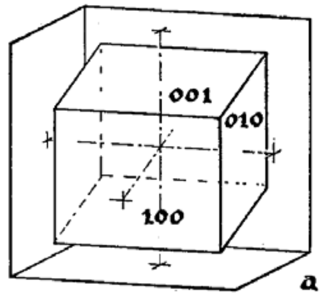
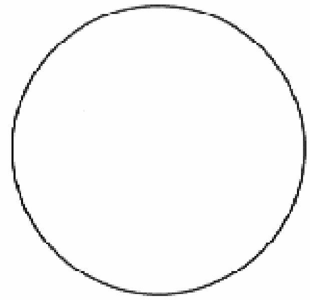
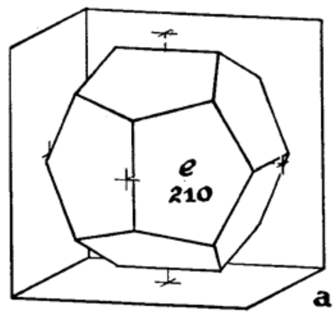
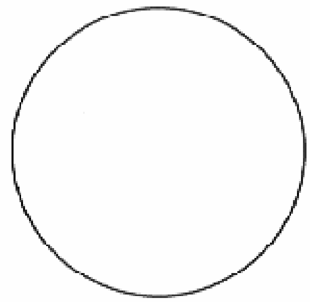
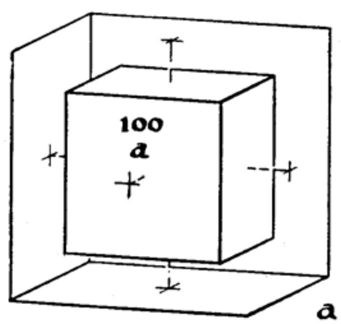
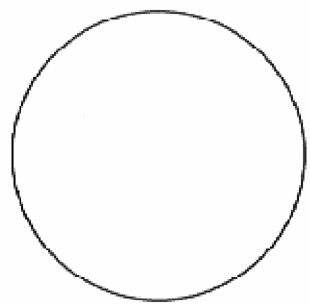
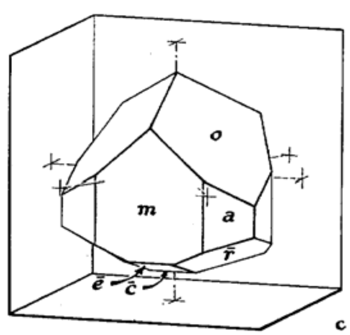
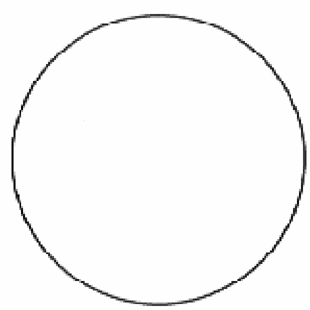
A) Symmetry of crystal models

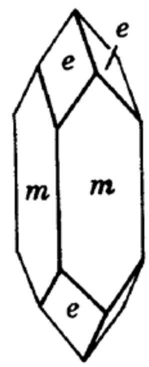
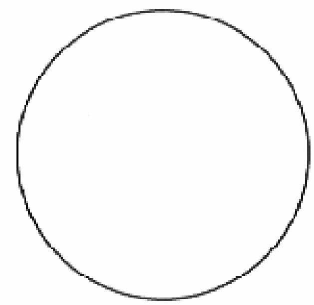
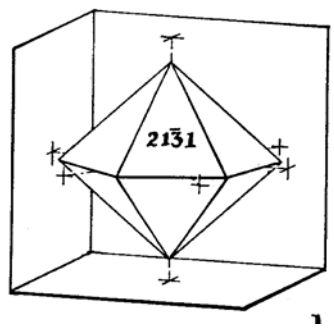
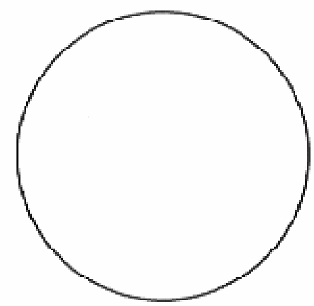
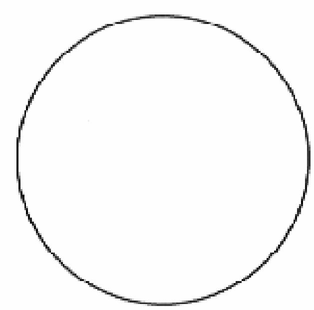
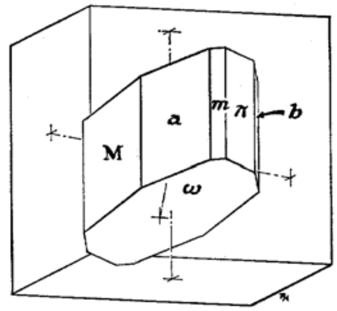
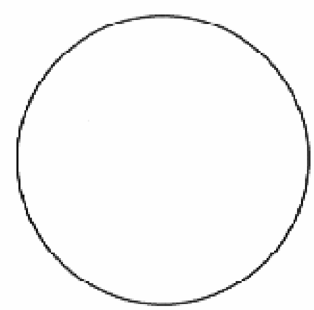
Determine the point-group symmetry of one wooden model from each of the twenty groups listed below. For each of these models, give the corresponding crystal system. Make sure to identify each model in your lab report with its identification number. In addition, represent the symmetry elements on the stereographic projection.

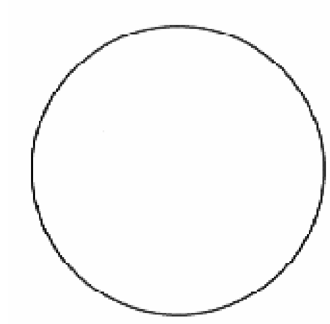
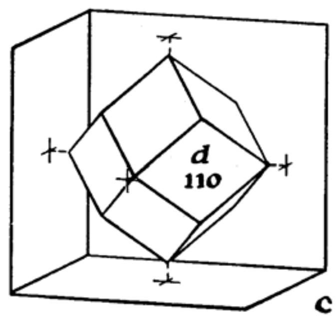
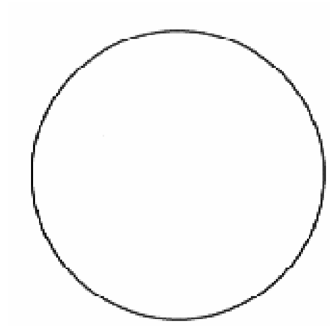
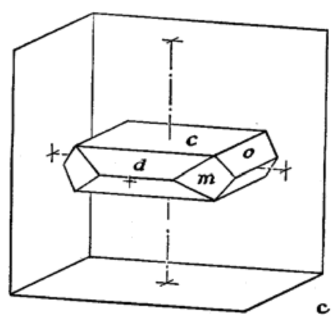
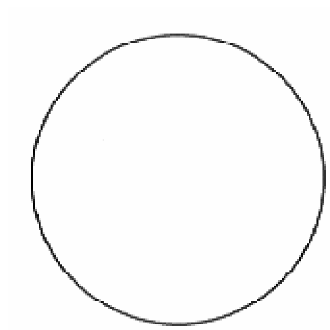
	Clinographic projection	Stereographic projection
1- Model 31 Point group:		

2- Model 13 Point group:		
3- Models 96 or 21 Point group:		
4- Models 37 or 150 Point group:		
5- Model 125 Point-group:		

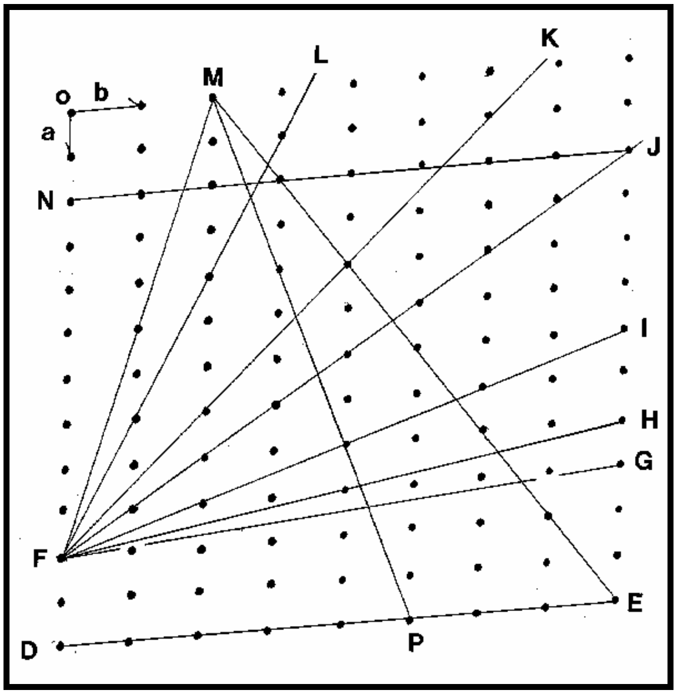
6- Model 167 Point group:		
7- Model 174 Point group:		
8- Models. 46 or 176 Point group:		
9- Model 33 Point group:		

10- Models 43 or 170 Point group:		
11- Models 27 or 34 Point group:		
12- Model 2 Point group:		
13- Model 136 Point group:		

14- Model 68 Point group:		
15- Model 142 Point group:		
16- Model 184 Point group:	No illustration is available for this model	
17- Model 50 Point group:	 Illustration is slightly different than actual model.	

18- Model 87 Point group:	No illustration is available for this model	
19- Model 3 Point group:		
20- Model 157 Point group:		

B) Miller indices



A planar lattice net is illustrated above. The origin of the net is marked “o”, the *a* and *b* cell-edges are identified and *c* is perpendicular to the page. For all labeled planes plotted in this lattice give: 1) the axis intercepts, 2) the corresponding Miller indices (assume that all planes are parallel to the *c*-axis), and 3) the linear density of points on the trace of the plane. The linear density is simply the number of points on the plane per unit length. Present your data in the form of a table. Once this is done, rank the various planes in terms of their probability of occurrence. Discuss your results.

Plane	intercepts	Miller indices	linear density
FM			
FL			
FK			
FJ			
FI			
FH			
FG			
MP			
ME			
NJ			
DE			

Part III

CRYSTAL FORMS ON WOODEN MODELS

Part III of this exercise is aimed at familiarizing you with the notion of crystal form and the identification of the 48 different crystal forms.

The concept of crystal form

A ***crystal form*** is **a set of crystal faces that are related to each other by symmetry.** To designate a crystal form (which could imply many faces) we use the Miller Index, or Miller-Bravais Index notation enclosing the indices in curly braces, i.e.

$$\{101\} \text{ or } \{11\bar{2}1\}$$

On real crystals they show the same physical appearance, that is to say, the same luster, striations, edge pits and other surficial characteristics; but they need not be equal in size and shape. An important point to note is that a form refers to a face or set of faces that have the same arrangement of atoms. Thus, **the number of faces in a form depends on the symmetry of the crystal.**

General Forms and Special Forms

A ***general form*** is a form in a particular crystal class that contains faces that intersect all crystallographic axes at different lengths. It has the form symbol {hkl} All other forms that may be present are called ***special forms***. In the monoclinic, triclinic, and orthorhombic crystal systems, the form {111} is a general form because in these systems faces of this form will intersect the a, b, and c axes at different lengths because the unit lengths are different on each axis. In crystals of higher symmetry, where two or more of the axes have equal length, a general form must intersect the equal length axes at different multiples of the unit length. Thus in the tetragonal system the form {121} is a general form. In the isometric system a general form would have to be something like {123}.

Open Forms and Closed Forms

A ***closed form*** is a set of crystal faces that completely enclose space. Thus, in crystal classes that contain closed forms, a crystal can be made up of a single form.

An ***open form*** is one or more crystal faces that do not completely enclose space.

- Example 1. Pedions are single faced forms. Since there is only one face in the form a pedion cannot completely enclose space. Thus, a crystal that has only pedions, must have at least 3 different pedions to completely enclose space.

- Example 2. A prism is a 3 or more faced form wherein the crystal faces are all parallel to the same line. If the faces are all parallel then they cannot completely enclose space. Thus crystals that have prisms must also have at least one additional form in order to completely enclose space.

- Example 3. A dipyramid has at least 6 faces that meet in points at opposite ends of the crystal. These faces can completely enclose space, so a dipyramid is closed form. Although a crystal may be made up of a single dipyramid form, it may also have other forms present.

There are 48 possible forms that can be developed as the result of the 32 combinations of symmetry. We here discuss some, but not all of these forms.

EXERCISE

Choose **5** models. Identify the form or forms present on each of the models. If the model shows more than one form, begin with the largest faces and visualize the polyhedron that would result if no faces of another form were present. Name the form, try to express its Miller indices, *e.g.* {h,k,l}. Do the same for the remaining forms on the model.

Your data should be presented in table form, with the following headings: model#, name of form, Miller indices of form, number of faces in the form, open or closed, polar or homopolar.

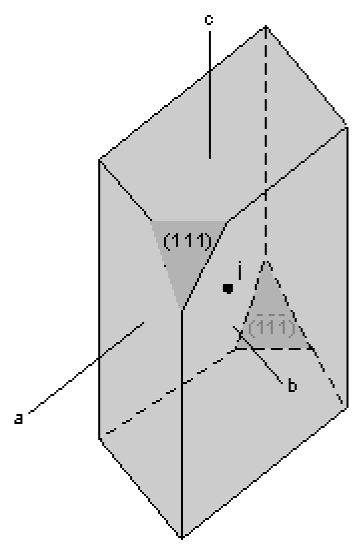
Do not be afraid to consult your textbook!!

Pedions

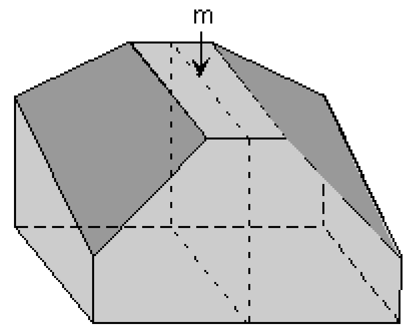
A pedion is an open**,** one faced form. Pedions are the only forms that occur in the Pedial class (1). Since a pedion is not related to any other face by symmetry, each form symbol refers to a single face. For example the form {100} refers only to the face (100), and is different from the form {$\bar{1}$00} which refers only to the face ($\bar{1}$00). Note that while forms in the Pedial class are pedions, pedions may occur in other crystal classes.

Pinacoids

A Pinacoid is an open 2-faced form made up of two **parallel** faces. In the crystal drawing shown here the form {111} is a pinacoid and consists of two faces, (111) and ($\bar{1}\bar{1}\bar{1}$). The form {100} is also a pinacoid consisting of the two faces (100) and ($\bar{1}$00). Similarly the form {010} is a pinacoid consisting of the two faces (010) and (0$\bar{1}$0), and the form {001} is a two faced form consisting of the faces (001) and (00$\bar{1}$). In this case, note that at least three of the above forms are necessary to completely enclose space. While all forms in the Pinacoid class are pinacoids, pinacoids may occur in other crystal classes as well.

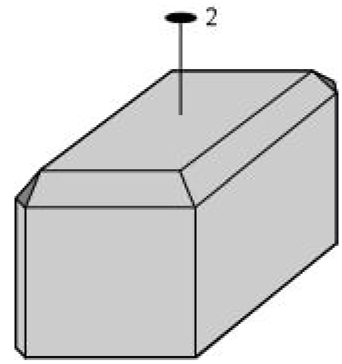


Domes



Domes are 2- faced open forms where the 2 faces are related to one another by a mirror plane. In the crystal model shown here, the dark shaded faces belong to a dome. The vertical faces along the side of the model are pinacoids (2 parallel faces). The faces on the front and back of the model are not related to each other by symmetry, and are thus two different pedions.

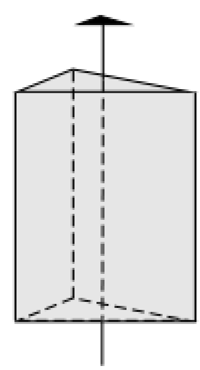
Sphenoids



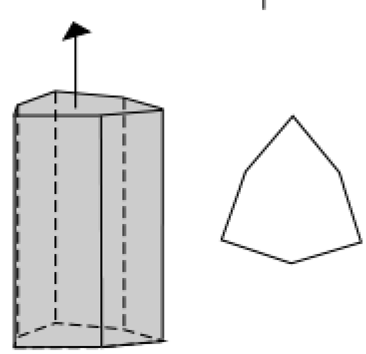
Sphenoids are 2-faced open forms where the faces are related to each other by a 2-fold rotational axis and are **NOT** parallel to each other. The dark shaded triangular faces on the model shown here belong to a sphenoid. Pairs of similar vertical faces that cut the edges of the drawing are also pinacoids. The top and bottom faces, however, are two different pedions.

Prisms

A prism is an open form consisting of three or more parallel faces. Depending on the symmetry, several different kinds of prisms are possible.

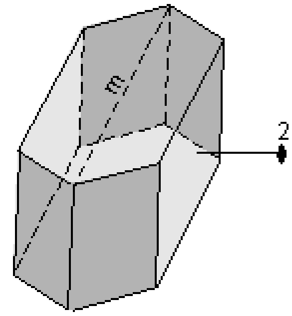


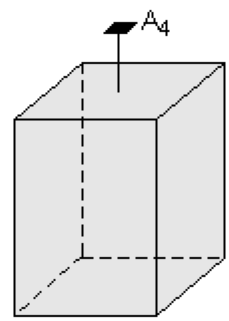
- Trigonal prism: 3 - faced form with all faces parallel to a 3 -fold rotation axis



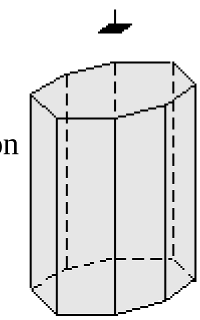
- Ditrigonal prism: 6-faced form with all 6 faces parallel to a 3-fold rotation axis. Note that the cross section of this form (shown to the right of the drawing) is not a hexagon, i.e. it does not have 6-fold rotational symmetry.

- Rhombic prism: 4-faced form with all faces parallel to a line that is not a symmetry element. In the drawing to the right, the 4 shaded faces belong to a rhombic prism. The other faces in this model are pinacoids (the faces on the sides belong to a side pinacoid, and the faces on the top and bottom belong to a top/bottom pinacoid).

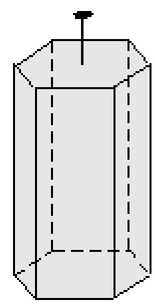




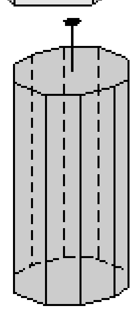
- Tetragonal prism: 4-faced open form with all faces parallel to a 4-fold rotation axis or $\bar{4}$. The 4 side faces in this model make up the tetragonal prism. The top and bottom faces make up the a form called the top/bottom pinacoid.



- Ditetragonal prism: 8-faced form with all faces parallel to a 4-fold rotation axis. In the drawing, the 8 vertical faces make up the ditetragonal prism.



- Hexagonal prism: 6-faced form with all faces parallel to a 6-fold rotation axis. The 6 vertical faces in the drawing make up the hexagonal prism. Again the faces on top and bottom are the top/bottom pinacoid form.

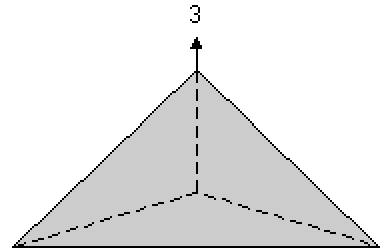


- Dihexagonal prism: 12-faced form with all faces parallel to a 6-fold rotation axis. Note that a horizontal cross-section of this model would have apparent 12-fold rotation symmetry. The dihexagonal prism is the result of mirror planes parallel to the 6-fold rotation axis.

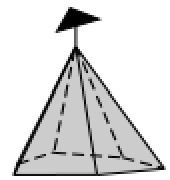
Pyramids

A pyramid is a 3, 4, 6, 8 or 12 faced open form where all faces in the form meet, or could meet if extended, at a point.

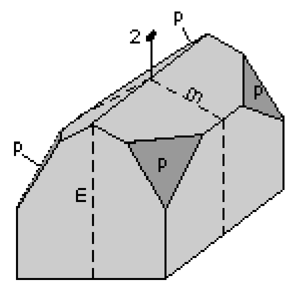
- Trigonal pyramid: 3-faced form where all faces are related by a 3-fold rotation axis.



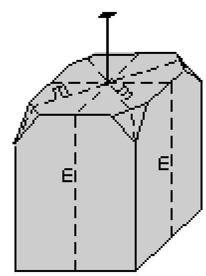
- Ditrigonal pyramid: 6-faced form where all faces are related by a 3-fold rotation axis. Note that if viewed from above, the ditrigonal pyramid would not have a hexagonal shape; its cross section would look more like that of the trigonal prism discussed above.



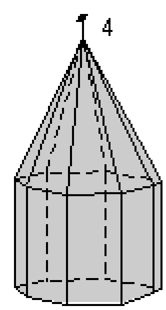
- Rhombic pyramid: 4-faced form where the faces are related by mirror planes. In the drawing shown here the faces labeled "p" are the four faces of the rhombic pyramid. If extend, these 4 faces would meet at a point.



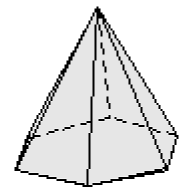
- Tetragonal pyramid: 4-faced form where the faces are related by a 4 axis. In the drawing the small triangular faces that cut the corners represent the tetragonal pyramid. Note that if extended, these 4 faces would meet at a point.



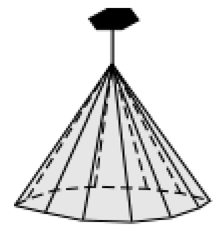
- Ditetragonal pyramid: 8-faced form where all faces are related by a 4 axis. In the drawing shown here, the upper 8 faces belong to the ditetragonal pyramid form. Note that the vertical faces belong to the ditetragonal prism.



- Hexagonal pyramid: 6-faced form where all faces are related by a 6 axis. If viewed from above, the hexagonal pyramid would have a hexagonal shape.



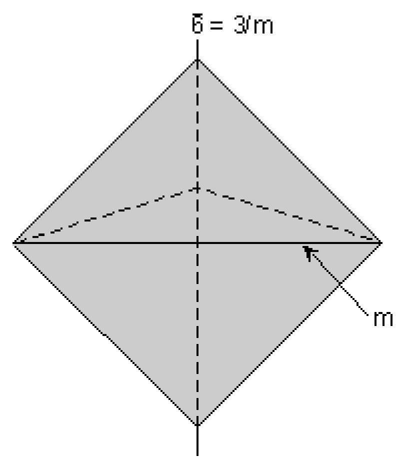
- Dihexagonal pyramid: 12-faced form where all faces are related by a 6-fold axis. This form results from mirror planes that are parallel to the 6-fold axis.



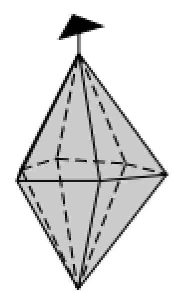
Dipyramids

Dipyramids are closed forms consisting of 6, 8, 12, 16, or 24 faces. Dipyramids are pyramids that are reflected across a mirror plane. Thus, they occur in crystal classes that have a mirror plane perpendicular to a rotation or rotoinversion axis.

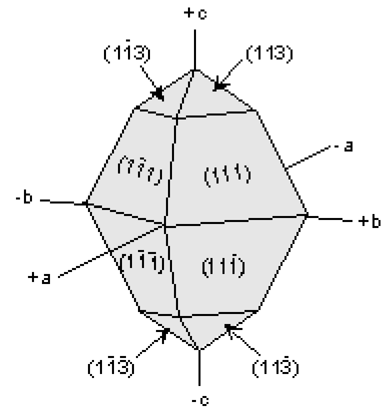
- Trigonal dipyramid: 6-faced form with faces related by a 3-fold axis with a perpendicular mirror plane. In this drawing, all six faces belong to the trigonal-dipyramid.



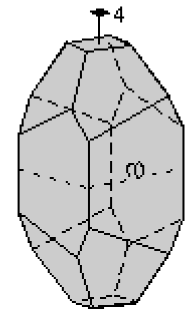
- Ditrigonal -dipyramid: 12-faced form with faces related by a 3-fold axis with a perpendicular mirror plane. If viewed from above, the crystal will not have a hexagonal shape, rather it would appear similar to the horizontal cross-section of the ditrigonal prism, discussed above.



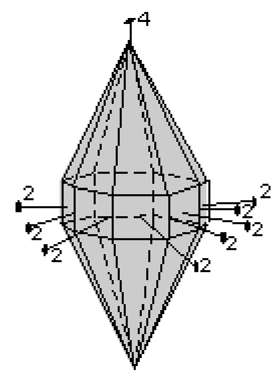
- Rhombic dipyramid: 8-faced form with faces related by a combination of 2-fold axes and mirror planes. The drawing to the right shows 2 rhombic dipyramids. One has the form symbol {111} and consists of the four larger faces shown plus four equivalent faces on the back of the model. The other one has the form symbol {113} and consists of the 4 smaller faces shown plus the four on the back.



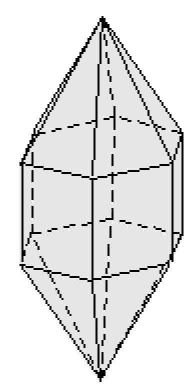
- Tetragonal dipyramid: 8-faced form with faces related by a 4-fold axis with a perpendicular mirror plane. The drawing shows the 8-faced tetragonal dipyramid. Also shown are the 4-faced tetragonal prism and the 2-faced top/bottom pinacoid.



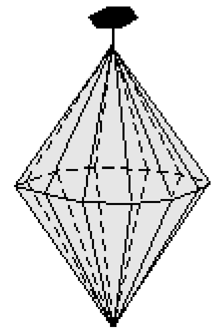
- Ditetragonal dipyramid: 16-faced form with faces related by a 4-fold axis with a perpendicular mirror plane. The ditetragonal dipyramid is shown here. Note the vertical faces belong to a ditetragonal prism.



- Hexagonal dipyramid: 12-faced form with faces related by a 6-fold axis with a perpendicular mirror plane. The vertical faces in this model make up a hexagonal prism.

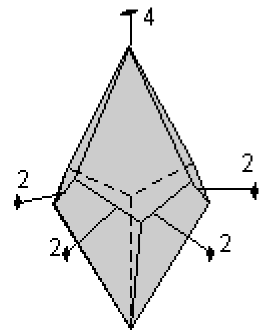


- Dihexagonal dipyramid: 24-faced form with faces related by a 6-fold axis with a perpendicular mirror plane.



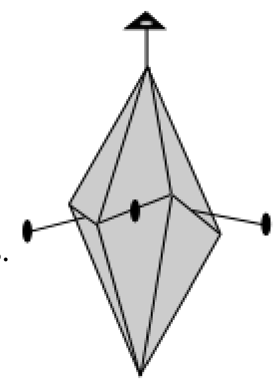
Trapezohedrons

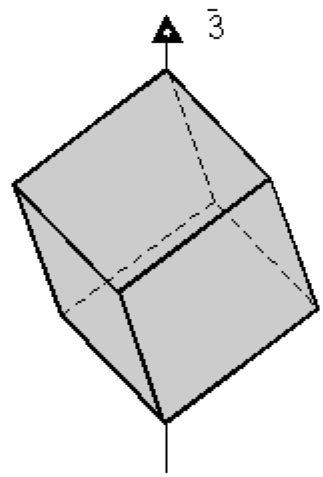
Trapezohedron are closed 6, 8, or 12 faced forms, with 3, 4, or 6 upper faces offset from 3, 4, or 6 lower faces. The trapezohedron results from 3-, 4-, or 6-fold axes combined with a perpendicular 2-fold axis. An example of a tetragonal trapezohedron is shown in the drawing to the right. Other examples are shown in your textbook.



Scalenohedrons

A scalenohedron is a closed form with 8 or 12 faces. In ideally developed faces each of the faces is a scalene triangle. In the model, note the presence of the 3-fold rotoinversion axis perpendicular to the 3 2-fold axes.



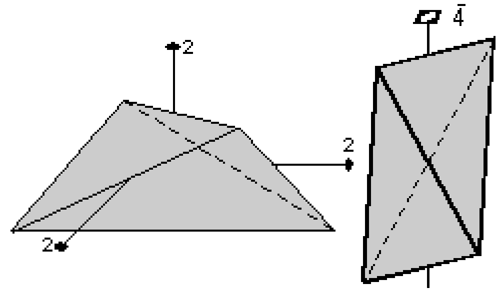


Rhombohedrons

A rhombohedron is 6-faced closed form wherein 3 faces on top are offset by 3 identical upside down faces on the bottom, as a result of a 3-fold rotoinversion axis. Rhombohedrons can also result from a 3-fold axis with perpendicular 2-fold axes. Rhombohedrons only occur in the crystal classes $\bar{3}2/m$, 32, and $\bar{3}$.

Disphenoids

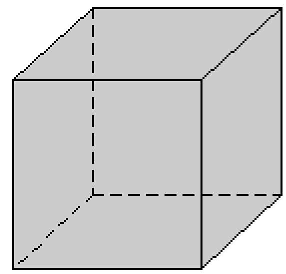
A disphenoid is a closed form consisting of 4 faces. These are only present in the orthorhombic system (class 222) and the tetragonal system (class $\bar{4}$)



The rest of the forms all occur in the isometric system, and thus have either four 3-fold axes or four $\bar{3}$ axes. Only some of the more common isometric forms will be discussed here.

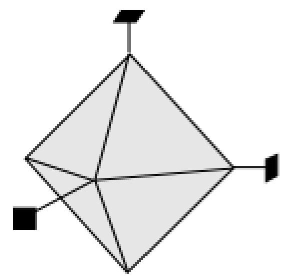
Hexahedron (cube)

A hexahedron is the same as a cube. 3-fold axes are perpendicular to the face of the cube, and four $\bar{3}$axes run through the corners of the cube. Note that the form symbol for a hexahedron is {100}, and it consists of the following 6 faces: (100), (010), (001), $(\bar{1}00)$, $(0\bar{1}0)$, and $(00\bar{1})$.



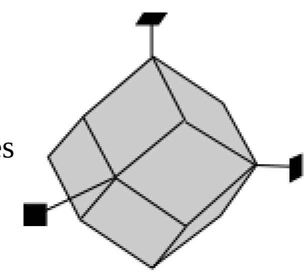
Octahedron

An octahedron is an 8 faced form that results form three 4-fold axes with perpendicular mirror planes. The octahedron has the form symbol {111}and consists of the following 8 faces: (111), $(\bar{1}\bar{1}\bar{1})$, $(1\bar{1}1)$, $(1\bar{1}\bar{1})$, $(\bar{1}\bar{1}1)$, $(\bar{1}1\bar{1})$, $(11\bar{1})$, and $(\bar{1}11)$. Note that four 3-fold axes are present that are perpendicular to the triangular faces of the octahedron (these 3-fold axes are not shown in the drawing).



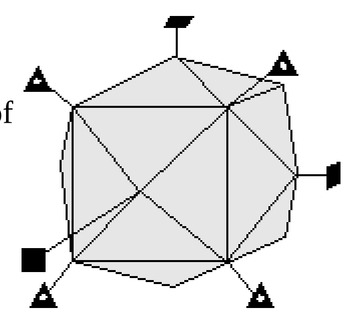
Dodecahedron

A dodecahedron is a closed 12-faced form. Dodecahedrons can be formed by cutting off the edges of a cube. The form symbol for a dodecahedron is {110}. As an exercise, you figure out the Miller Indices for these 12 faces.



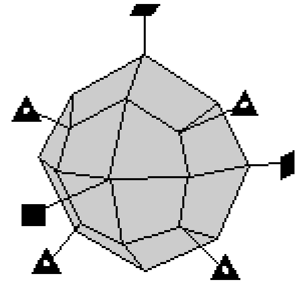
Tetrahexahedron

The tetrahexahedron is a 24-faced form with a general form symbol of {0hl} This means that all faces are parallel to one of the a axes, and intersect the other 2 axes at different lengths.



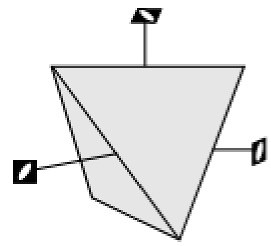
Trapezohedron

An isometric trapezohedron is a 12-faced closed form with the general form symbol {hhl}. This means that all faces intersect two of the a axes at equal length and intersect the third a axis at a different length.



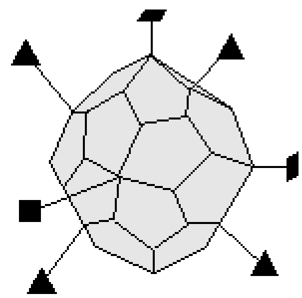
Tetrahedron

The tetrahedron occurs in the class $\bar{4}3m$ and has the form symbol {111}(the form shown in the drawing) or $\{1\bar{1}1\}$ (2 different forms are possible). It is a four faced form that results form three $\bar{4}$axes and four 3-fold axes (not shown in the drawing).



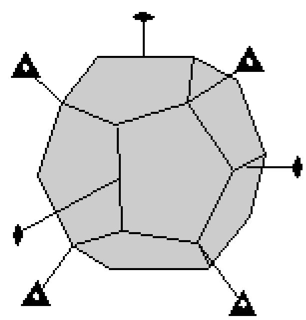
Gyroid (pentagon-trioctahedron)

A gyroid is a form in the class 432 (note no mirror planes)



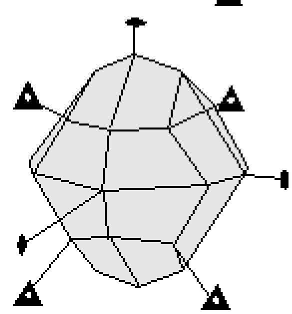
Pyritohedron

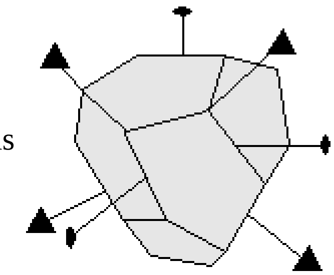
The pyritohedron is a 12-faced form that occurs in the crystal class $2/m\bar{3}$. Note that there are no 4-fold axes in this class. The possible forms are {h0l} or {0kl} and each of the faces that make up the form have 5 sides.



Diploid (didodecahedron)

The diploid is the general form {hkl} for the diploidal class ($2/m\bar{3}$). Again there are no 4-fold axes.





Tetartoid (pentagon tritetrahedron)

Tetartoids are general forms in the tetartoidal class (23) which only has 3-fold axes and 2-fold axes with no mirror planes.

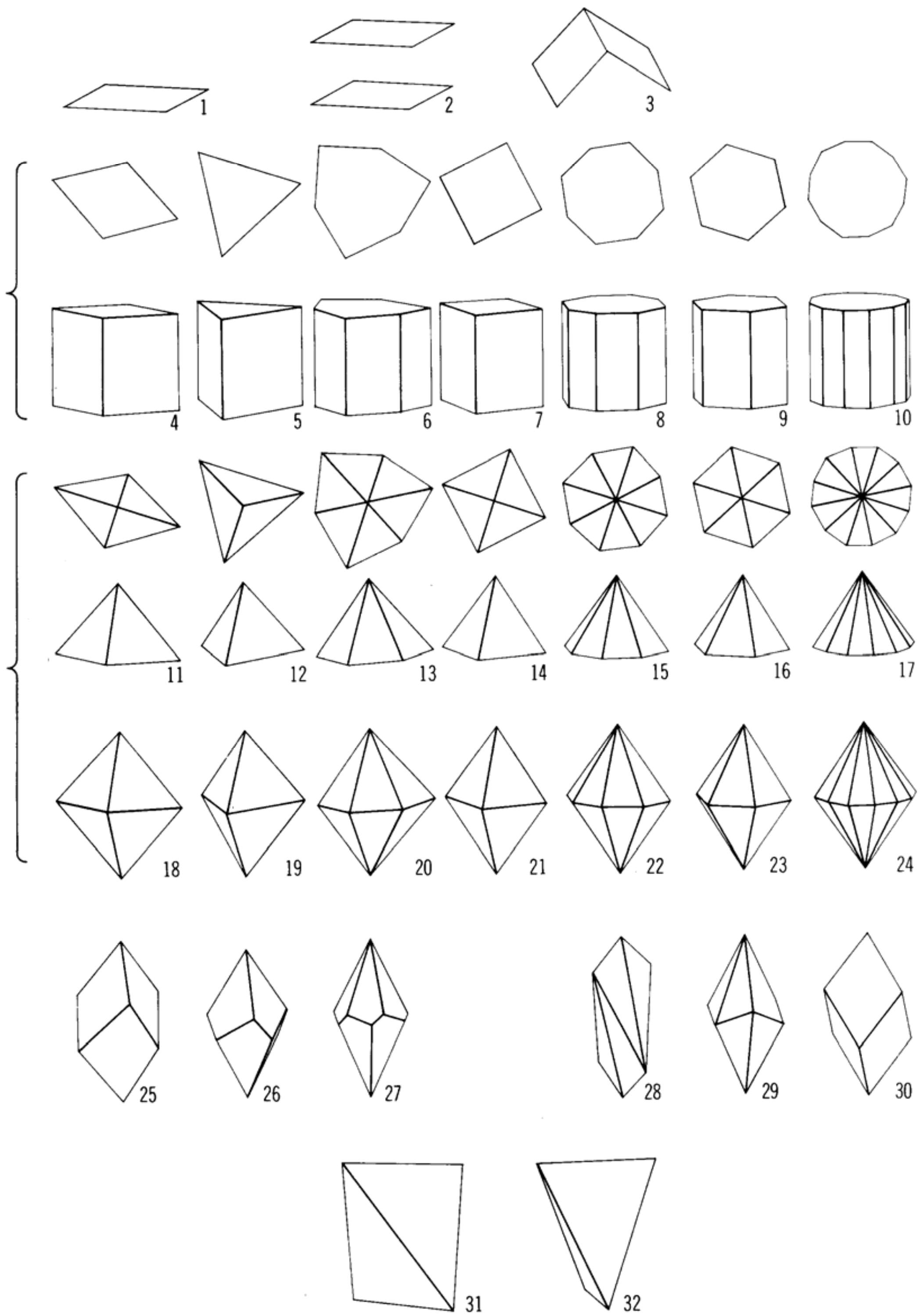
THE 47 DIFFERENT CRYSTAL FORMS: Fedorov terminology

1. Monohedron (or pedion) (l)
2. Parallelohedron (or pinacoid) (2)
3. Dihedron (a general term that includes the dome & sphenoid) (2)
4. Rhombic prism (4)
5. Trigonal prism (3)
6. Ditrigonal prism (6)
7. Tetragonal prism (4)
8. Ditetragonal prism (8)
9. Hexagonal prism (6)
10. Dihexagonal prism (12)
11. Rhombic pyramid (4)
12. Trigonal pyramid (3)
13. Ditrigonal pyramid (6)
14. Tetragonal pyramid (4)
15. Ditetragonal pyramid (8)
16. Hexagonal pyramid (6)
17. Dihexagonal pyramid (12)
18. Rhombic dipyramid (8)
19. Trigonal dipyramid (6)
20. Ditrigonal dipyramid (12)
21. Tetragonal dipyramid (8)
22. Ditetragonal dipyramid (16)
23. Hexagonal dipyramid (12)
24. Dihexagonal dipyramid (24)
25. Trigonal trapezohedron (6)
26. Tetragonal trapezohedron (8)
27. Hexagonal trapezohedron (12)
28. Rhombic scalenohedron (8)
29. Ditrigonal scalenohedron (12)
30. Rhombohedron (6)
31. Rhombic tetrahedron (or rhombic disphenoid) (4)
32. Tetragonal tetrahedron (or tetragonal disphenoid) (4)

Cubic forms

33. Hexahedron (or cube) (6)
34. Tetrahexahedron (24)
35. Rhomb-dodecahedron often simply called dodecahedron(12)
36. Trigon-trioctahedron (or trisoctahedron) (24)
37. Tetragon-trioctahedron (or trapezohedron) (24)
38. Pentagon-trioctahedron (or gyroid) (24)
39. Hexaoctahedron (or hexoctahedron) (48)
40. Tetrahedron (4)
41. Tetragon-tritetrahedron(or deltohedron) (12)
42. Trigon-tritetrahedron (or tristetrahedron) (12)
43. Pentagon-tritetrahedron (or tetartoid) (12)
44. Hexatetrahedron (or hextetrahedron) (24)
45. Dihexahedron (or pentagon-dodecahedron or pyritohedron) (12)
46. Didodecahedron (or diploid) (24)

I-4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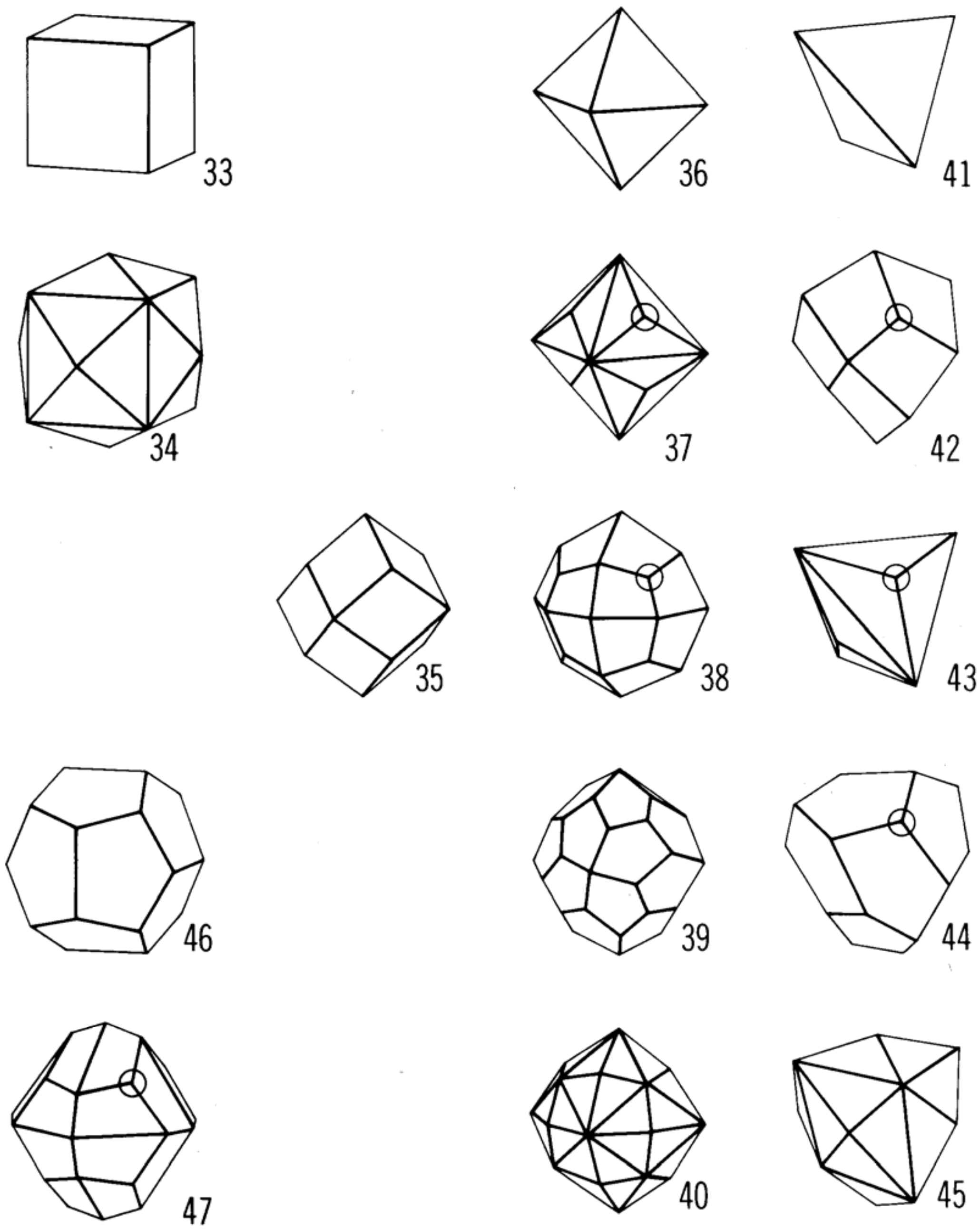
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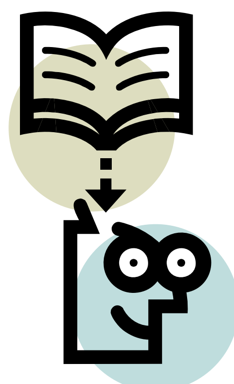
MID-TERM EXAMINATION

October 18th, 2007

GOOD LUCK!!!



Laboratory exercise No. 2

THIS WEEK'S MINERALS I, NATIVE ELEMENTS, SULPHIDES AND OXIDES

This week's exercise is aimed at familiarizing you with the minerals of the native element, sulphide or oxide classes. You will learn 21 different mineral species. In order to get the maximum out of this exercise it is absolutely essential to read the descriptions of these 21 minerals in your textbook. You will be given a short mineral identification quiz at the beginning of next week's lab period on the 21 minerals covered in this exercise. In addition, you must answer the short questions below.

Native elements

Graphite (in metamorphic rock)	1242
Copper	1114
Sulphur	1231

Native elements are minerals that are composed of a single chemical element. In your collection, you will see graphite, native copper and sulphur. These three minerals are all easily distinguished by their physical properties. Graphite is a very soft mineral with a greasy touch that leaves a gray streak on the fingers or paper. Native copper is malleable and is an excellent electrical conductor. It is usually found as thin veins in volcanic rocks. When found in nature, native copper is covered with "vert-de-gris", a mixture of grayish-green oxidation compounds of copper. The small brilliant metallic copper nuggets that are usually sold in mineral shops have had this oxidation removed with an acid bath. Sulphur is a characteristic yellow colour with a distinctive odour. Sulphur is easily enflamed with a match (but please don't try this in the lab!).

Native gold and diamond are two other native element minerals that although not in your collection, you should be familiar with. Look up the properties of these two minerals in your textbook.

Sulphides

Pyrite (in slate)	2911a
Pyrite (massive)	2911b
Galena	2611a
Sphalerite (light brown)	2621a
Sphalerite (dark brown)	2621b
Chalcopyrite	2631
Pyrrhotite	2651
Bornite	243
Cinnabar	269
Realgar	26.10
Arsenopyrite	2951
Molybdenite (in calc-silicate rock and cleavage flakes)	2961a & b

Sulphides are minerals composed of a metallic element compounded to sulphur. They are extremely important economic minerals since they constitute the ores of most of the metals used in our society. We find many sulphide minerals associated with volcanic or plutonic rocks. Colour is an important property for sulphide minerals. Nearly all sulphides have metallic luster with characteristic colours. Pyrite is a brilliant metallic yellow, galena is lead-gray, chalcopyrite is greenish-yellow, pyrrhotite is brassy-yellow, arsenopyrite is silvery-gray, bornite is blue iridescent, molybdenite is bluish-gray, cinnabar is deep red and realgar is scarlet-orange. Of all the sulphide minerals, sphalerite is different because it can show many different colours; brown, brownish-yellow, gray, even pale yellow. Sphalerite has a resinous luster and releases a sulphurous smell when scratched or crushed.

Oxides

Hematite	4412a
Hematite (var. specularite)	4412b
Spinel (with forsterite and calcite)	7211
Magnetite	7216
Chromite	721.12
Ilmenite	4413a
Corundum (barrel-shaped crystals)	4411a
Corundum (cleaved fragment)	4411b
Rutile	4511a
Rutile (crystals in marble)	4511b
Uraninite (in pegmatite)	5.1.2.1a
Uraninite (pitchblende)	5.1.2.1b

Oxide minerals are composed of a metallic element combined to oxygen. They show a wide variety of colours and physical properties. They are therefore more easily distinguished amongst each other but conversely, lack properties that readily identify them as a class of minerals. Within the oxide class, four minerals are easily confused, they are specular hematite, magnetite, chromite and ilmenite. All of these minerals are dark gray or black and have high specific gravity. Hematite is distinguished by its bright red streak and its lack of magnetism. Magnetite is strongly magnetic whereas chromite and ilmenite are not. Chromite has a pale brown streak and ilmenite has a dark gray streak.

Questions

1) How can you distinguish graphite from molybdenite?
2) What are the principal ore minerals of copper that are exploited in Canada? Where are they extracted?
3) Pyrrhotite is an iron sulphide that is commonly associated with pentlandite. What is pentlandite and where in Canada is this association found? What is pentlandite used for?
4) Hematite (Fe_2O_3) and magnetite (Fe_3O_4) are both iron oxides. Given that both of these minerals are composed exclusively of iron and oxygen, how can you explain that hematite is non-magnetic and that magnetite is strongly magnetic?

N.B. Most of these answers you will find in your textbook, but not all! Don’t be afraid to go and explore at the library for answers.

Laboratory exercise No. 3

THIS WEEK'S MINERALS II, HYDROXIDES, HALIDES, CARBONATES SULPHATES AND PHOSPHATES

This week you will see the remaining non-silicate minerals. More specifically, you will see the hydroxides, halides, carbonates, sulphates and phosphates. Among these minerals, the carbonates are particularly abundant in the sedimentary rocks (e.g. limestones). For this exercise you must familiarize yourself with the 16 different minerals of this exercise. Once again, there will be a short quiz at the beginning of next week's exercise.

Hydroxides

Goethite	7122
Bauxite (a mixture of gibbsite, diaspore and boehmite)	623
Brucite (foliated, in marble)	6.1.1.1a
Brucite (nodules in marble, with characteristic weathering)	6.1.1.1b

Halides

Halite	9.1.1.1
Sylvite	9.1.1.2
Fluorite (green)	9.2.1a
Fluorite (purple, or grayish)	9.2.1b

Carbonates

Calcite (var. chalk)	14.1.1.1a
Calcite (var. dogtooth spar)	14.1.1.1b
Calcite (rhombohedral cleaved fragment)	14.1.1.1c
Dolomite (granular, in marble)	14.2.1.1a
Dolomite (crystals)	14.2.1.1b
Rhodocrosite	14.1.1.4
Siderite	14.1.1.3a
Magnesite (granular)	14.1.1.2
Malachite	16.1.6

Sulphates

Barite	28.3.1.1
Anhydrite (cleaved fragment)	28.3.2a
Gypsum (var. selenite)	29.6.3a
Gypsum (granular)	29.6.3b

Phosphates

Apatite (crystal section)	41.7.1.1a
Apatite (green, in calcite)	41.7.1.1b
Apatite (var. collophanite)	41.7.1.1c

Questions

1) Calcite constitutes one of the most exploited industrial minerals in Canada. What are the uses of calcite? Include in your answer as many uses as possible.
2) Calcite is on of two polymorphs of $CaCO_3$. What is the other? How are these two polymorphs distinguished? What about their respective stability fields?
3) Within the phosphate class are minerals which can crystallize directly from the action of living organisms. Can you name some examples?
4) Bauxite is the principal ore of aluminum. Canada does not have any deposits of bauxite but is amongst the world's principal producers of metallic aluminum. How can you explain this?

Laboratory exercise No. 4

THIS WEEK'S MINERALS III, TECTOSILICATES
Silica group, feldspars, feldspathoids, zeolites and other tectosilicates

Tectosilicates, or framework silicates, are distinguished from other silicate minerals by their complex three-dimensional network of interlocking SiO_4 tetrahedra. Among these minerals we find quartz, the other polymorphs of SiO_2, and also the minerals of the feldspar group. Although quartz is certainly the best-known mineral by the public at large, it is not the most abundant mineral. It is the feldspars that are the most important constituents of the Earth's crust. In addition to quartz and feldspars, the tectosilicates also include the feldspathoid minerals, the zeolites and a few other species. As part of this week's exercise you will study 23 specimens that represent 14 different mineral species. These minerals will be the focus of a quiz next week. In addition, make sure that you can answer the questions included at the end of the lab.

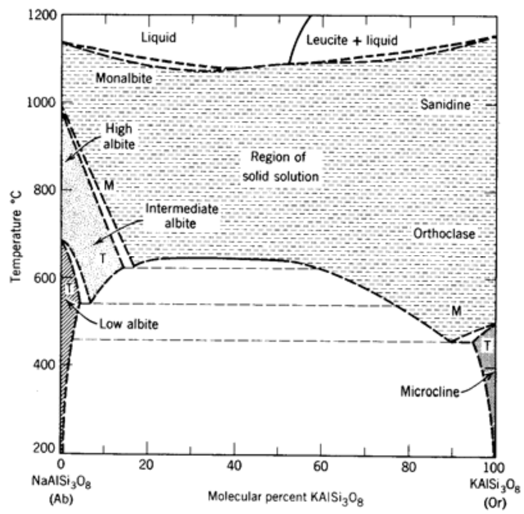
Silica group	
Quartz (α, crystal)	56.1a.1.1a
Quartz (var. amethyst)	56.1a.1.1b
Quartz (var. smoky)	56.1a.1.1c
Quartz (var. rose)	56.1a.1.1d
Quartz (var. jasper)	56.1a.1.1f
Quartz (var. flint)	56.1a.1.1g
Quartz (var. chert)	56.1a.1.1h
Opal	56.1a.3.3
Feldspar group	
Albite (cleaved fragment)	56.4a.1.1
Labradorite (cleaved fragment)	56.4a.1.4
Microcline (gray, perthitic)	56.4b.1.1a
Microcline (pink, perthitic)	56.4b.1.1b
Microcline (var. amazonite, perthitic)	56.4b.1.1c
Feldspathoid group	
Leucite (in volcanic rock)	56.3.1.2
Nepheline (in syenite)	56.2.1.1
Cancrinite (yellow, in rock)	56.6.1.1
Sodalite (blue)	56.7.1.1
Zeolite group	
Heulandite	56.13.2.1
Stilbite	56.13.2.2
Chabazite	56.13.5.1
Other tectosilicates	
Analcime	56.3.1.1
Scapolite (crystal)	56.9.1b
Scapolite (cleaved fragment)	56.9.1c

Questions

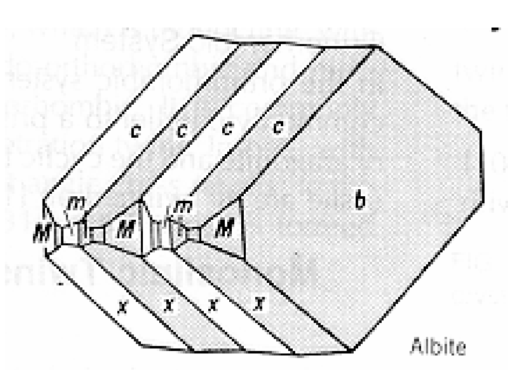
1) The most common polymorph of SiO_2 found in nature is certainly α-quartz. What are the other natural polymorphs of SiO_2? Give their physical properties and discuss in what geological environments they occur. Hint: check-out figure 9.4c in Klein and Hurlbut.

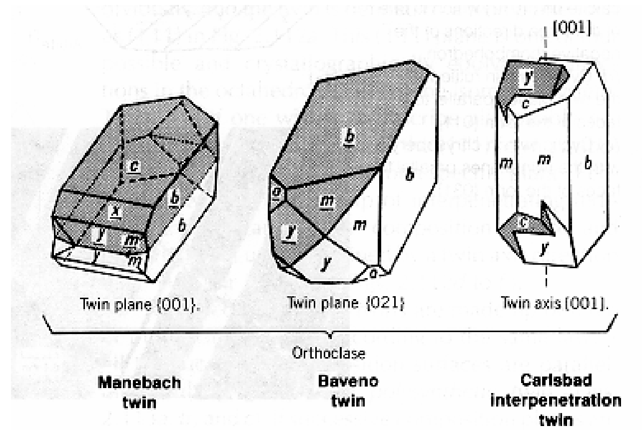
2) Explain why zeolites are important tectosilicates in industrial chemistry. Your answer must consider the structural basis for these properties.

3) What is perthite? Describe this texture commonly found in alkali feldspar and discuss its origin. You may wish to consider the following phase diagram in your answer.



4) Describe the principal twin laws found in the feldspars. What are the dominant twins in the potassium feldspars and the plagioclases.





Laboratory exercise No. 5

THIS WEEK'S MINERALS IV, PHYLLOSILICATES
Micas, chlorite, clays and other phyllosilicates

This week's exercise is on phyllosilicate minerals, or if you prefer, sheet silicates. Phyllosilicates are composed of long-range two-dimensional sheets of SiO_4 tetrahedra. In these sheets, each SiO_4 tetrahedron shares three of its four oxygens with another tetrahedron. The overall Si:O ratio is 2:5. Ideally, the tetrahedra are disposed in six-sided rings and the sheet has an overall hexagonal symmetry.

In the common phyllosilicates, the tetrahedral sheets are linked to sheets of octahedra to form layers. Please note the terminology here, <u>sheets</u> are combined to form <u>layers</u>. Two fundamental structures are possible. These are referred to as 1:1 layers or 2:1 layers. The 1:1 layers (also called t-o layers) are composed of a single tetrahedral sheet linked to a single octahedral sheet. In the case of 2:1 layers (also called t-o-t layers), the single octahedral sheet is sandwiched between two sheets of tetrahedron. In both of these fundamental structures, the number of structural combinations possible is further increased since the octahedral sheet may be dioctahedral or trioctahedral in nature.

Phyllosilicates as a sub-class are distinguished by an excellent to good cleavage which gives them a foliated, flaky, platy or tabular habit. This cleavage is caused by the weak bonds across the 1:1 or 2:1 layers. Cleaved sheets are usually flexible or elastic. The minerals have vitreous or pearly luster. Phyllosilicates minerals are stable under an extremely wide range of pressure-temperature conditions and thus occur in <u>all</u> families of rocks. In addition, they are the principal mineral constituents of soils.

Any discussion of the phyllosilicate minerals must include the clay minerals. Clay minerals are minerals with layered structures and an average grain-size of 1 or 2 micrometers (μm). They are the extremely fine-grained hydrous phyllosilicates that compose soils or certain types of sedimentary rocks. The most common clay minerals are kaolinite, montmorillonite, smectite, illite and mica. <u>Clay minerals</u> should be distinguished from <u>clay</u>, which is an unconsolidated earthy material that becomes plastic when wet and that is composed of mineral grains, phyllosilicates or not, that are less than 2 μm in diameter.

In this week's lab exercise you will see 13 different mineral species that are represented by 18 specimens. A short quiz at the beginning of next week's lab will include these species. The questions at the end of the exercise are included as a study guide. The material covered in these questions will be covered later in class.

Phyllosilicates

Kaolinite	55.5j.1.1
Montmorillonite (smectite gr.)	55.4e.1.1
Talc (foliated)	55.3.2.1a
Talc (fine-grained, in soapstone)	55.3.2.1b
Pyrophyllite (radiating crystals)	55.3.1.1.a
Muscovite (cleaved sheet)	55.4a.1.1a
Muscovite (in pegmatite)	55.4a.1.1b
Glauconite (in sandstone)	55.4a.3.1
Biotite (cleaved sheet)	55.4a.4.1a
Biotite (in syenite)	55.4a.4.1b
Phlogopite (cleaved sheet)	55.4a.4.3a
Phlogopite (with calcite)	55.4a.4.3b
Lepidolite (in pegmatite)	55.4a.4.4
Vermiculite (cleaved sheet)	55.4g.1.1
Chlorite (in schist)	55.5a.1
Chyrsotile, serpentine gr. (var. picrolite)	55.7b.1.1a
Chyrsotile, serpentine gr. (asbestiform)	55.7b.1.1b
Prehnite	52.8.5

Questions

1) The serpentine group of minerals includes three species that are polymorph of $Mg_3Si_2O_5(OH)_4$. What are they? How are they distinguished?
2) Present the complete classification of the mica group. Distinguish dioctahedral from trioctahedral micas, true micas from brittle micas. Explain the crystallochemical basis for this classification.
3) Phyllosilicates are extremely important industrial minerals. What are the common (and not so common) uses of chrysotile, vermiculite, talc, montmorillonite and kaolinite?
4) Explain how clay minerals can adsorb toxic contaminants in environmental engineering applications.

Laboratory exercise No. 6

DESCRIPTIVE MINERALOGY V, INOSILICATES
Amphiboles, pyroxenes and pyroxenoids

This week's exercise is on chain silicates or inosilicates. Inosilicates have structures composed of infinite chains of SiO_4 tetraedra. In the case of pyroxenes and pyroxenoids these are single chains. In the amphiboles, the degree of polymerization is higher and the chains are double. Pyroxenes and amphiboles certainly constitute the most abundant mafic silicate minerals of the Earth's crust. They are extremely common minerals that occur in most plutonic, volcanic and metamorphic rock types. They are only moderately resistant to weathering and therefore will not commonly be found in clastic sedimentary rocks. The pyroxenoids are uncommon minerals.

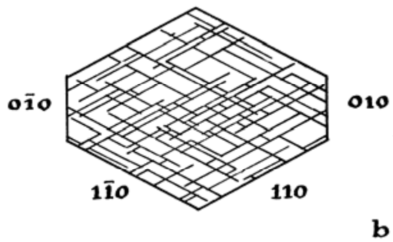
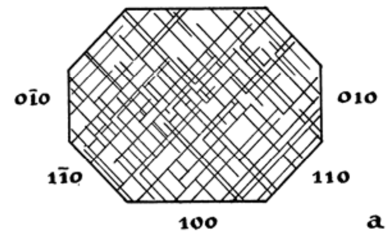
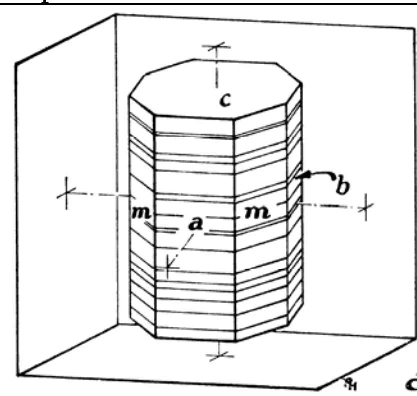
The main focus of the lab will be the pyroxene and amphibole group minerals. The two groups share, in addition to their chain silicate structures, many chemical and physical properties in common and this will often make the job of distinguishing them difficult. For example, pyroxenes and amphiboles both crystallize in the orthorhombic and monoclinic systems (point groups *2/m2/m2/m* and *2/m*, respectively) although in both groups the monoclinic species are more widespread, they have similar crystal forms, are often prismatic in habit, have similar hardness, specific gravity and colour.

Despite their strong similarities, telling amphibole from pyroxene is quite possible! The experienced student will develop several methods to make the job easy. Some of these distinctions are summarized in the table below. Be careful, the table is a generalization, there are many exceptions!

Considerable solid solution exists within both the amphibole and pyroxene group minerals. Consequently, naming minerals in both groups will require, to be well done, a chemical analysis. The naming of minerals species in both groups has been the object of studies by the International Mineralogical Association (IMA) and rules have been published by the IMA. Mineralogists publishing results of their work in scholarly journals are required to abide by these rules. References to official IMA classifications are given below.

The lab includes 20 specimens that represent 13 species. These include 5 amphiboles, 5 pyroxenes and 3 pyroxenoids. A short quiz at the beginning of next week's lab will include these species.

GENERAL PROPERTIES FOR DISTINGUISHING AMPHIBOLES AND PYROXENES

Property	AMPHIBOLES	PYROXENES
Coulour	In general dark colours, black, dark green. Some amphiboles are blue.	Green, possibly dark green, but in general not as dark as amphiboles.
Cleavage	 2 cleavages at 60°, looking down *c*-axis.	 2 cleavages at 90°, looking down *c*-axis.
Quality of cleavage	In general, very good.	In general, good. Cleaved surfaces are not as brilliant as in amphiboles.
Parting	No parting.	 Good basal parting along {001} resulting from twin planes. Parting is not as closely spaced as cleavage.
Habit	Prismatic; prisms can be quite elongated, acicular or even asbestiform.	Prismatic; shorter prisms than in amphiboles. Very rarely acicular.

Amphibole group

Grunerite (in schist)	54.2b.1.3
Tremolite (crystal)	54.2b.2.1
Actinolite (in radiating crystals)	54.2b.2.2b
Hornblende (cleavage fragment)	54.2b.3.2a
Hornblende (crystal)	54.2b.3.2b
Hornblende (phenocrysts in andesite rock)	54.2b.3.2c
Hornblende (in calc-silicate rock)	54.2b.3.2d
Riebeckite-glaucophane (in rock)	54.2b.4.1

Pyroxene group

Enstatite (in rock)	54.1a.1.1
Hypersthene (cleavage fragment)	54.1a.1.2a
Hypersthene (in granite rock)	54.1a.1.2b
Augite (cleavage fragment)	54.1b.4.1a
Augite (crystal)	54.1b.4.1b
Augite (in diabase rock, showing basal parting)	54.1b.4.1c
Augite (in calc-silicate rock)	54.1b.4.1d
Diopside (with calcite)	54.1b.3.1a
Spodumene (in pegmatite)	54.1c.1.1

Pyroxenoids

Rhodonite	54.3.2.1a
Wollastonite	54.3.3.1
Pectolite	54.4.1.1

Questions

1. Despite their widespread abundance, amphibole and pyroxene minerals have very little industrial or commercial applications. Can you find any applications for these minerals other than their occasional use as gemstones?
2. Pyroxenoids are, much like pyroxenes, single-chain silicates. What is the fundamental structural difference between these two groups of minerals?
3. Name and describe three plutonic and three volcanic igneous rocks that have pyroxene as an important mineral component.
4. Name and describe three plutonic rocks that have amphibole as an important mineral component.

References

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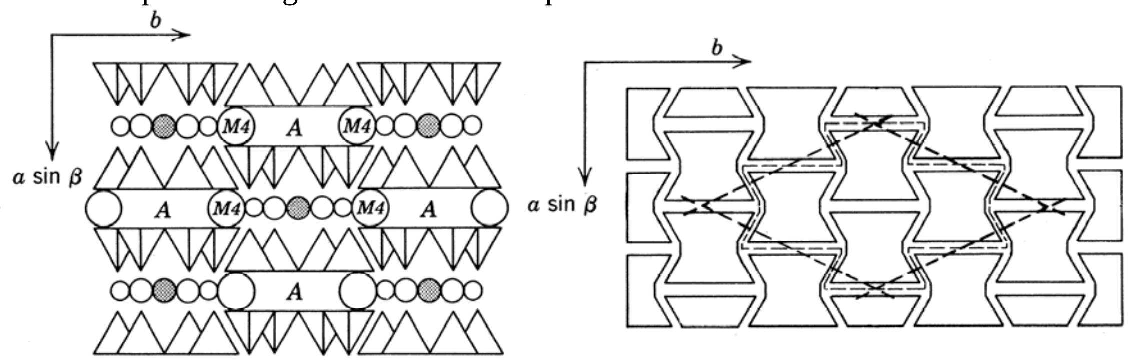
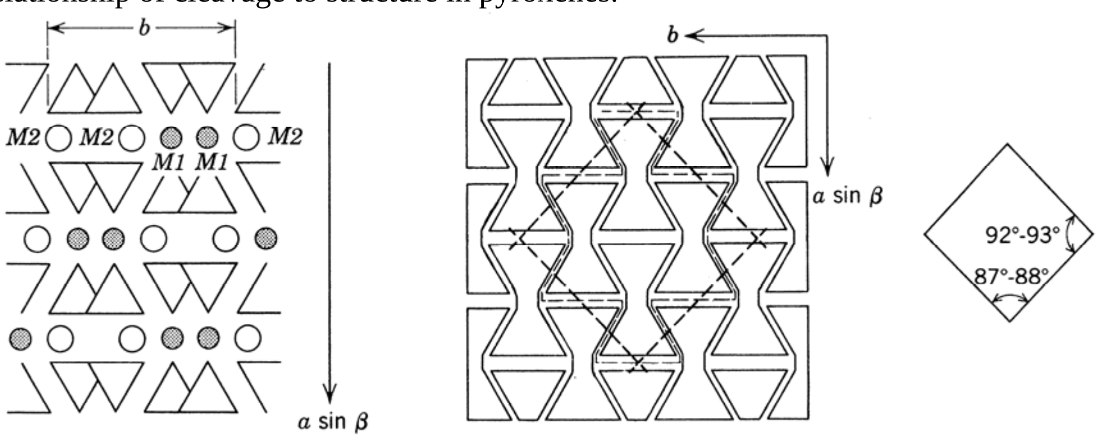
Morimoto N. (1989): Nomenclature of pyroxenes. *Canadian Mineralogist* 27, 143-156.

Relationship of cleavage to structure in amphiboles.



Relationship of cleavage to structure in pyroxenes.



Laboratory exercise No. 7

THIS WEEK'S MINERALS VI, CYCLO- , SORO- AND ORTHOSILICATES

Beryl, tourmaline, epidote, olivine, garnet and many others!

This is our last exercise in this most enjoyable series on "this week's minerals". To mark the occasion, I propose to place the cherry on top of the sunday by covering an impressive list of cyclo-, soro- and orthosilicate minerals, many of which are quite interesting for their beauty, gem qualities and occurrence. Although most of the minerals covered in this week's exercise are widespread accessory minerals in metamorphic and igneous rocks, few of them ever make up the bulk of common rocks like the feldspars, amphiboles, pyroxenes or micas do. This does not diminish in any way their importance in helping geologists understand the rocks of the Earth's crust. Many of this week's minerals are important thermodynamic indicators of pressure and temperature conditions during metamorphism, others are used for radiochronological dating.

The cyclosilicates are characterized by rings of SiO_4 tetrahedra. Three cyclic configurations are found: Si_3O_9 rings (three tetrahedra), Si_4O_{12} rings (four tetrahedra) and Si_6O_{18} rings (six tetrahedra). Of these, the Si_6O_{18} ring is the most common and is found in minerals such as beryl and tourmaline. In cordierite, two of the six Si^{4+} cations in the ring are replaced by Al^{3+}.

Sorosilicates have Si_2O_7 groups made up of two shared SiO_4 tetrahedra. Few common minerals are found in this subclass. The orthosilicates (or nesosilicates) are more common, they are characterized by structures that have independent SiO_4 tetrahedra, i.e. where no single tetrahedron is linked to another one in the structure. Common representatives of this subclass include the members of the olivine and garnet groups. Finally, in some minerals such as vesuvianite and the members of the epidote group, Si_2O_7 groups are found along with independent SiO_4 tetrahedra, resulting in a mixed (hybrid) soro- and orthosilicate subclass.

Unlike the amphibole or pyroxene groups, nomenclature for the cyclo- soro-, and orthosilicates is in general, straightforward. In this laboratory you will see 21 different mineral species, represented by 29 specimens.

Cyclo- and sorosilicates

Beryl	53c.1.1.1
Cordierite (in a high-grade gneiss)	53c.1.1.2
Schorl, tourmaline gr.	53c.2.1.1
Dravite, tourmalinte gr. (in marble)	53c.2.1.2
Elbaite, tourmaline gr. (with lepidolite)	***53c.2.1.3***
Epidote (granular)	52.7.1.2
Allanite (probably metamict)	52.7.2.1
Vesuvianite	52.7.4.3a

Vesuvianite (crystal)	52.7.4.3b
Chloritoid (in schist)	51.15.1
Orthosilicates	
Forsterite, olivine gr. (with calcite and phlogopite)	51.2.1.1
Forsterite, olivine gr. (in dunite)	51.2.1.2a
Olivine gr. (in basalt)	51.2.1.2b
Almandine, garnet gr. (in schist)	51.3.1.2
Grossular, garnet gr. (in calc-silicate rock)	51.3.2.1
Andradite, garnet gr., (from a pegmatite)	51.3.2.2
Zircon	51.4.1.1
Chondrodite, humite gr. (in marble)	51.5.1.3
Topaz (showing cleavage)	51.4.5.1a
Topaz (cleaved fragments)	51.4.5.1b
Sillimanite (in gneiss)	51.4.4.1
Andalusite (var. chiastolite)	51.4.4.3a
Andalusite (var. chiastolite, in schist)	51.4.4.3b
Kyanite (blue, bladed)	51.4.4.4a
Kyanite (in schist or gneiss)	51.4.4.4b
Staurolite (twinned crystal)	51.4.5.2a
Staurolite (in schist)	51.4.5.2b
Titanite (showing parting)	51.7.1.1a
Titanite (in calc-silicate rock)	51.7.1.1b

Questions

1) Of the approximately 3500 minerals species known to man, only a few are used as gemstones. Table 15.1 in Klein and Hurlbut lists all common (boldface) and less common minerals that are used as gems. Several of the common gemstones in this table are minerals covered in today's exercise. Most gemstones are identified by the name of their mineral species or variety. A few have neither species nor varieties names. Construct a table of all the gemstones that are covered by this week's minerals. In your table, indicate if the names used for these gems are legitimate species or varieties names or others.

2) Garnets are an important group of minerals. What are the principal garnet species and what is the extent of solid solution between them?

3) Many of this week's minerals are commonly found as porphyroblasts (e.g. garnet, cordierite, andalusite, staurolite). How is a porphyroblast different from a phenocryst? Can you name some minerals in your sets that are commonly found as phenocrysts? While we are on this topic, what is a porphyroclast, a oikocryst, a glomerocryst?

4) Andalusite, kyanite and sillimanite are the three polymorphs of $Al_2Si_2O_5$. The three minerals are common accessories in aluminous metasedimentary rocks such as schists and gneisses. Explain how these three polymorphs can be used to constrain the pressure-temperature conditions of the metamorphic rocks in which they occur

MINERALS PRESENTED IN GEO2163

NON-SILICATES

Native elements	
Graphite (in metamorphic rock)	1242
Native copper	1114
Sulphur	1231
Sulphides	
Pyrite (in slate)	2911a
Pyrite (massive)	2911b
Galena	2611a
Sphalerite (light brown)	2621a
Sphalerite (dark brown)	2621b
Chalcopyrite	2631
Pyrrhotite	2651
Bornite	243
Cinnabar	269
Realgar	26.10
Arsenopyrite	2951
Molybdenite (in calc-silicate rock and cleavage flakes)	2961a & b
Oxides	
Hematite	4412a
Hematite (var. specularite)	4412b
Spinel (with forsterite and calcite)	7211
Magnetite	7216
Chromite	721.12
Ilmenite	4413a
Corundum (barrel-shaped crystal)	4411a
Corundum (cleaved fragment)	4411b
Rutile	4511a
Rutile (crystals in marble)	4511b
Uraninite (in pegmatite)	5.1.2.1a
Uraninite (pitchblende)	5.1.2.1b
Hydroxides	
Goethite	7122
Bauxite (a mixture of gibbsite, diaspore and boehmite)	623
Brucite (foliated, in marble)	6.1.1.1a
Brucite (nodules in marble, with characteristic weathering)	6.1.1.1b
Halides	
Halite	9.1.1.1
Sylvite	9.1.1.2
Fluorite (green)	9.2.1a
Fluorite (purple or grayish)	9.2.1b
Carbonates	
Calcite (var. chalk)	14.1.1.1a
Calcite (var. dogtooth spar)	14.1.1.1b
Calcite (rhombohedral cleaved fragment)	14.1.1.1c

Dolomite (granular, in marble)	14.2.1.1a
Dolomite (crystals)	14.2.1.1b
Rhodocrosite	14.1.1.4
Siderite	14.1.1.3a
Magnesite (granular)	14.1.1.2
Malachite	16.1.6
Sulphates	
Barite	28.3.1.1
Anhydrite (cleaved fragment)	28.3.2a
Gypsum (var. selenite)	29.6.3a
Gypsum (granular)	29.6.3b
Phosphates	
Apatite (crystal)	41.7.1.1a
Apatite (green, in calcite)	41.7.1.1b
Apatite (var. collophane)	41.7.1.1c

SILICATES

Silica group	
Quartz (α, crystal)	56.1a.1.1a
Quartz (var. amethyst)	56.1a.1.1b
Quartz (var. smoky)	56.1a.1.1c
Quartz (var. rose)	56.1a.1.1d
Quartz (var. jasper)	56.1a.1.1f
Quartz (var. flint)	56.1a.1.1g
Quartz (var. chert)	56.1a.1.1h
Opal	56.1a.3.3
Feldspar group	
Albite (cleaved fragment)	56.4a.1.1
Labradorite (cleaved fragment)	56.4a.1.4
Microcline (gray, perthitic)	56.4b.1.1a
Microcline (pink, perthitic)	56.4b.1.1b
Microcline (var. amazonite, perthitic)	56.4b.1.1c
Feldspathoid group	
Leucite (in volcanic rock)	56.3.1.2
Nepheline (in syenite)	56.2.1.1
Cancrinite (yellow, in rock)	56.6.1.1
Sodalite (blue)	56.7.1.1
Zeolite group	
Heulandite	56.13.2.1
Stilbite	56.13.2.2
Chabazite	56.13.5.1
Other tectosilicates	
Analcime	56.3.1.1
Scapolite (crystal)	56.9.1b
Scapolite (cleaved fragment)	56.9.1c
Phyllosilicates	

Kaolinite	55.5j.1.1
Montmorillonite (smectite gr.)	55.4e.1.1
Talc (foliated)	55.3.2.1a
Talc (fine-grained, in soapstone)	55.3.2.1b
Pyrophyllite (radiating crystals)	55.3.1.1.a
Muscovite (cleavage sheet)	55.4a.1.1a
Muscovite (in pegmatite)	55.4a.1.1b
Glauconite (in sandstone)	55.4a.3.1
Biotite (cleavage sheet)	55.4a.4.1a
Biotite (in syenite)	55.4a.4.1b
Phlogopite (cleavage sheet)	55.4a.4.3a
Phlogopite (with calcite)	55.4a.4.3b
Lepidolite (in pegmatite)	55.4a.4.4
Vermiculite (cleaved sheet)	55.4g.1.1
Chlorite (in schist)	55.5a.1
Chrysotile, serpentine gr.	55.7b.1.1a
Chrysotile, serpentine gr. (asbestiform)	55.7b.1.1b
Prehnite	52.8.5
Amphibole group	
Grunerite (in schist)	54.2b.1.3
Tremolite (crystal)	54.2b.2.1
Actinolite (in radiating crystals)	54.2b.2.2b
Hornblende (cleaved fragment)	54.2b.3.2a
Hornblende (crystal)	54.2b.3.2b
Hornblende (phenocrysts in andesite)	54.2b.3.2c
Hornblende (from a calc-silicate rock)	54.2b.3.2d
Riebeckite-glaucophane (in schist)	54.2b.4.1
Pyroxene group	
Enstatite-ferrosilite (in metamorphic rock)	54.1a.1.1
Enstatite-ferrosilite (cleaved fragment)	54.1a.1.2a
Enstatite-ferrosilite (in granulite)	54.1a.1.2b
Augite (cleaved fragment)	54.1b.4.1a
Augite (crystal)	54.1b.4.1b
Augite (in gabbro dyke)	54.1b.4.1c
Augite (in calc-silicate rock)	54.1b.4.1d
Diopside (crystal)	54.1b.3.1a
Spodumene (in pegmatite)	54.1c.1.1
Pyroxenoids	
Rhodonite	54.3.2.1a
Wollastonite	54.3.3.1
Pectolite	54.4.1.1
Cyclo- and sorosilicates	
Beryl	53c.1.1.1
Cordierite (in a high-grade gneiss)	53c.1.1.2
Schorl, tourmaline gr.	53c.2.1.1
Dravite, tourmalinte gr. (in marble)	53c.2.1.2
Elbaite, tourmaline gr. (with lepidolite)	53c.2.1.3
Epidote (granular)	52.7.1.2

Allanite (probably metamict)	52.7.2.1
Vesuvianite	52.7.4.3a
Vesuvianite (crystal)	52.7.4.3b
Chloritoid (in schist)	51.15.1
Orthosilicates	
Forsterite, olivine gr. (with calcite and phlogopite)	51.2.1.1
Forsterite, olivine gr. (in dunite)	51.2.1.2a
Olivine gr. (in basalt)	51.2.1.2b
Almandine, garnet gr. (in schist)	51.3.1.2
Grossular, garnet gr. (in calc-silicate rock)	51.3.2.1
Andradite, garnet gr., (from a pegmatite)	51.3.2.2
Zircon	51.4.1.1
Chondrodite, humite gr. (in marble)	51.5.1.3
Topaz (showing cleavage)	51.4.5.1a
Topaz (cleaved fragments)	51.4.5.1b
Sillimanite (in gneiss)	51.4.4.1
Andalusite (var. chiastolite)	51.4.4.3a
Andalusite (var. chiastolite, in schist)	51.4.4.3b
Kyanite (blue, bladed)	51.4.4.4a
Kyanite (in schist or gneiss)	51.4.4.4b
Staurolite (twinned crystal)	51.4.5.2a
Staurolite (in schist)	51.4.5.2b
Titanite (showing parting)	51.7.1.1a
Titanite (in calc-silicate rock)	51.7.1.1b

TEACHING COLLECTION
MINERALOGY I
GEO2161-2561
SET #1

1242 GRAPHITE In metamorphic rock	1114 NATIVE COPPER	1231 SULPHUR Strong odour, yellow colour	2911a PYRITE In slate	2911b PYRITE Massive	2611a GALENA
2621a SPHALERITE Light brown	2621b SPHALERITE Dark brown	2631 CHALCOPYRITE	2651 PYRRHOTITE	243 BORNITE	269 CINNABAR
26.10 REALGAR	2951 ARSENOPYRITE Silver-white	2961a and b MOLYBDENITE In rock and cleaved flakes	4412a HEMATITE Massive	4412b HEMATITE Var. specularite	7211 SPINEL With forsterite and calcite in marble
7216 MAGNETITE	721.12 CHROMITE	4413a ILMENITE	4411a CORUNDUM Barrel-shaped, tapered crystals	4411b CORUNDUM Coarse-grained, or cleaved fragment	4511a RUTILE
4511b RUTILE Prismatic crystals in marble	5.1.2.1a URANINITE Black, in pegmatite	5.1.2.1b URANINITE Var. pitchblende	7122 GOETHITE	623 BAUXITE A mixture of gibbsite, diaspore and boehmite	6.1.1.1a BRUCITE Foliated, in marble
6.1.1.1b BRUCITE Small white nodules in marble	9.1.1.1 HALITE	9.1.1.2 SYLVITE Reddish, often with some halite (clear)	9.2.1a FLUORITE Green	9.2.1b FLUORITE Purple or grayish	14.1.1.1a CALCITE Var. chalk

PLEASE REPLACE SPECIMENS IN DESIGNATED POSITIONS
AVOID EXCESSIVE SCRATCHING OR BREAKING
A SINGLE DROP OF ACID IS ALL THAT IS NEEDED

TEACHING COLLECTION
MINERALOGY I
GEO2161-2561
SET #2

14.1.1.1b CALCITE Var. dogtooth spar	14.1.1.1c CALCITE Rhombohedral cleaved fragment	14.2.1.1a DOLOMITE Granular, in marble	14.2.1.1b DOLOMITE Crystals	14.1.1.4 RHODOCROSITE	14.1.1.3a SIDERITE
14.1.1.2 MAGNESITE Granular	16.1.6 MALACHITE	28.3.1.1 BARITE	28.3.2a ANHYDRITE Cleaved fragment	29.6.3a GYPSUM Var. selenite	29.6.3b GYPSUM Granular
41.7.1.1a APATITE Crystal	41.7.1.1b APATITE Green, in calcite	41.7.1.1c APATITE Var. collophane	EMPTY	56.1a.1.1a QUARTZ α, crystal	EMPTY
56.1a.1.1b QUARTZ Var. amethyst	56.1a.1.1c QUARTZ Var. smoky	56.1a.1.1d QUARTZ Var. rose	56.1a.1.1f QUARTZ Var. jasper	56.1a.1.1g QUARTZ Var. flint	56.1a.1.1h QUARTZ Var. chert
56.1a.3.3 OPAL	56.4a.1.1 ALBITE Cleaved fragment	56.4a.1.4 LABRADORITE Granular, coarse-grained	56.4b.1.1a MICROCLINE Grey, perthitic	56.4b.1.1b MICROCLINE Pink,perthitic	56.4b.1.1c MICROCLINE Var. amazonite Perthitic
56.3.2.1 LEUCITE In volcanic rock	56.2.1.1 NEPHELINE Coarse-grained, in syenite	56.6.1.1 CANCRINITE Yellow, granular	56.7.1.1 SODALITE Blue characteristic colour	56.13.2.1 HEULANDITE	56.13.2.2 STILBITE

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TEACHING COLLECTION
MINERALOGY I
GEO2161-2561
SET #3

56.13.5.1 CHABAZITE	EMPTY	56.3.1.1 ANALCIME	56.9.1b SCAPOLITE Crystal	56.9.1c SCAPOLITE Cleaved fragment	55.5j.1.1 KAOLINITE
55.4e.1.1 MONTMORILLONITE SMECTITE Gr.	55.3.2.1a TALC Foliated	55.3.2.1b TALC Fine-grained, in soapstone	55.3.1.1a PYROPHYLLITE Radiating crystals	55.4a.1.1a MUSCOVITE Cleaved sheet	55.4a.1.1b MUSCOVITE In pegmatite
55.4a.3.1 GLAUCONITE In sandstone	55.4a.4.1a BIOTITE Cleaved sheet	55.4a.4.1b BIOTITE In syenite	55.4a.4.3a PHLOGOPITE Crystal	55.4a.4.3b PHLOGOPITE In marble	55.4a.4.4 LEPIDOLITE Granular, or in pegmatite
55.4g.1.1 VERMICULITE Cleaved sheet	55.5a.1 CHLORITE In schist	55.7b.1.1a SERPENTINE Gr.	55.7b.1.1b CHRYSOTILE SERPENTINE Gr. Asbestiform	52.8.5 PREHNITE	54.2b.1.3 GRUNERITE In schist
54.2b.2.1 TREMOLITE Crystal	54.2b.2.2b ACTINOLITE Crystals, often in radiating clusters	54.2b.3.2a HORNBLENDE Cleaved fragment	54.2b.3.2b HORNBLENDE Crystal	54.2b.3.2c HORNBLENDE Phenocrysts in andesite	54.2b.3.2d HORNBLENDE Coarse-grained, from a calc-silicate rock
54.2b.4.1 RIEBECKITE-GLAUCOPHANE In schist	54.1a.1.1a ENSTATITE-FERROSILITE In metamorphic rock	54.1a.1.1b ENSTATITE-FERROSILITE Var. bronzite Coarse-grained	54.1a.1.1c ENSTATITE-FERROSILITE In granulite	54.1b.4.1a AUGITE Cleaved fragment	54.1b.4.1b AUGITE Crystal

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TEACHING COLLECTION

MINERALOGY I
GEO2161-2561
SET #4

54.1b.4.1c AUGITE In gabbro dyke	54.1b.4.1d AUGITE Coarse-grained, in calc-silicate rock	54.1b.3.1a DIOPSIDE Crystal	54.1c.1.1 SPODUMENE In pegmatite	54.3.2.1a RHODONITE	54.3.3.1 WOLLASTONITE
54.4.1.1 PECTOLITE	53c.1.1.1 BERYL In pegmatite	53c.1.1.2 CORDIERITE In high-grade gneiss	53c.2.1.1 SCHORL TOURMALINE Gr.,	53c.2.1.2 DRAVITE TOURMALINE Gr., In marble	53c.2.1.3 ELBAITE TOURMALINE Gr., With lepidolite (purple mica)
52.7.1.2 EPIDOTE Granular	52.7.2.1 ALLANITE Coarse-grained, probably metamict	52.7.4.3a VESUVIANITE	52.7.4.3b VESUVIANITE Crystal	51.15.1 CHLORITOID In schist	51.2.1.1 FORSTERITE OLIVINE Gr. In marble with calcite and phlogopite
51.2.1.2a FORSTERITE OLIVINE Gr. In dunite	51.2.1.2b OLIVINE Gr. In basalt	51.3.1.2 ALMANDINE GARNET Gr. In schist	51.3.2.1 GROSSULAR GARNET Gr. In calc-silicate rock	51.3.2.2 ANDRADITE GARNET Gr. From a pegmatite	51.4.1.1 ZIRCON
51.5.1.3 CHONDRODITE HUMITE Gr. In marble	51.4.5.1a TOPAZ Showing cleavage	51.4.5.1b TOPAZ Clear cleaved fragments	51.4.4.1 SILLIMANITE In gneiss	51.4.4.3a ANDALUSITE Var. chiastolite	51.4.4.3b ANDALUSITE Var. chiastolite In schist
51.4.4.4a KYANITE Blue, bladed	51.4.4.4b KYANITE In schist or gneiss	51.4.5.2a STAUROLITE Twinned crystals	51.4.5.2b STAUROLITE In schist	51.7.1.1a TITANITE Showing parting	51.7.1.1b TITANITE In calc-silicate rock

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