982 3-1
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Duration: 3hrs

max marks: 100

NB: Draw neat sketches wherever necessary.

1X10=10

1 A Fill in the blanks:

i) Minerals which look completely dark in PPL and XPL are know as **OPAQUE** minerals.

ii) According to Moh's relative hardness scale **5** is the hardness of Apatite.

iii) Transparent variety of calcite is known as **ICELAND SPAR.**

iv) Minerals belonging to isometric system are optically **ISOTROPIC.**

v) Hornblende mineral has **TWO** set of cleavage.

vi) Calcite is characterized by change in relief under Plane polarized light, this property is known as **TWINKLING**.

vii) **LEPIDOLITE** is a lithium bearing mica.

viii) Carlsbad twinning is shown by **ORTHOCLASE** feldspar.

ix) Chromium bearing garnet is **UVAROVITE**

x) Fuschite is a **CHROMIUM** bearing mica.

2X5=10

1 B Define the following:

i) Refractive index and relief
-the ratio of the speed of light in a vacuum to that in a second medium of greater density.
- the degree in which mineral grains stand out from the mounting medium

ii) Uniaxial positive and uniaxial negative
- are a class of anisotropic minerals that include all minerals that crystallize in the tetragonal and hexagonal crystal systems where refractive index of extraordinary ray is greater than that of ordinary ray.
- are a class of anisotropic minerals that include all minerals that crystallize in the tetragonal and hexagonal crystal systems where refractive index of ordinary ray is greater than that of extraordinary ray.

iii) Double refraction in minerals and isotropism .
-an optical property in which a single ray of unpolarized light entering an anisotropic medium is split into two rays, each traveling in a different direction.
- The ions or atoms in some minerals have an equivalent arrangement along all crystallographic axes.

iv) Polarised and non-polarized light:
-

Light that is reflected or transmitted through certain media so that all v ibrations are restricted to a single plane.

-

Light that is reflected or transmitted through certain media so that all v ibrations are in all directions and not restricted to a single direction.

v) Polarisation colours and anomalous polarization colours
-Various colours that visible under microscope after polarized light passes through the mineral.

- If a mineral has strong absorption of certain wavelengths of light, these same wavelengths will be absorbed by the crystal with the analyzer inserted, and thus the crystal may produce an abnormal or anomalous interference color, one that is not shown in the interference color chart

2 Answer any TWO of the following: 2X10=20

a) Define pleochroism. What causes pleochroism in minerals? Name any four minerals which are identified using pleochroism.
- Property of a mineral of colour change on rotation of a stage
-Description required: Oreintation and crystal system
-Biotite, Hornblende, Andalusite, Cordierite

b) Define birefringence. Explain the birefringence of quartz and calcite. How do we judge birefringence from interference colours?
Definition, Diagram, Explanation

c) Illustrate the optical indicatrix and centered optic axis figure of a uniaxial positive minerals.
Diagram and Description

:entered Uniaxial Interference Figure

ıg a grain with the optic axis oriented exactly perpendicular to the stage will sometin 'y difficult. It would be much more common to find one wherein the optic axis is at angle to being perpendicular to the microscope stage. Such a grain will exhibit the ving properties:

It is a grain that shows] refractive index and an Σ' refractive index that is close the]refractive index,

Thus, it will show only a small change in relief change upon rotation.

It would also show very low order (1° gray interference colors between extinction positions if the analyzer is inserted in orthoscope mode.

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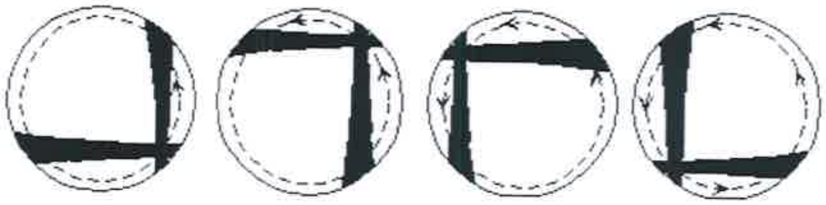
3

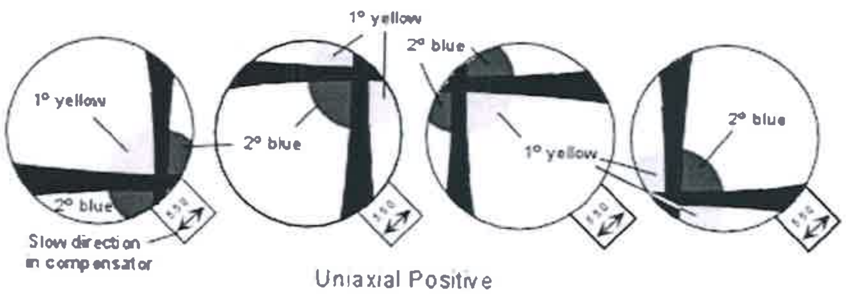
a grain would show an ntered optic axis figure ›wn here. On rotation of ıge, the melatope would in a circle around the eter of the field of view, ıe bars of the isogyres l remain oriented E-W -S



Sign from Off-Centered Interference Figure

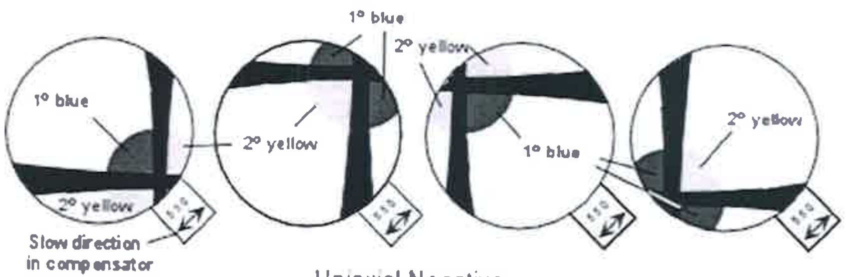
with an off centered interference figure, optic sign can still be determined because o ɜep track of the isogyres and still divide the figure into quadrants.

ı for an optically ve crystal, all NE and uadrants will turn blue ıe NW and SE ants will turn yellow, :olors replacing the / color present before ion of the ensator.



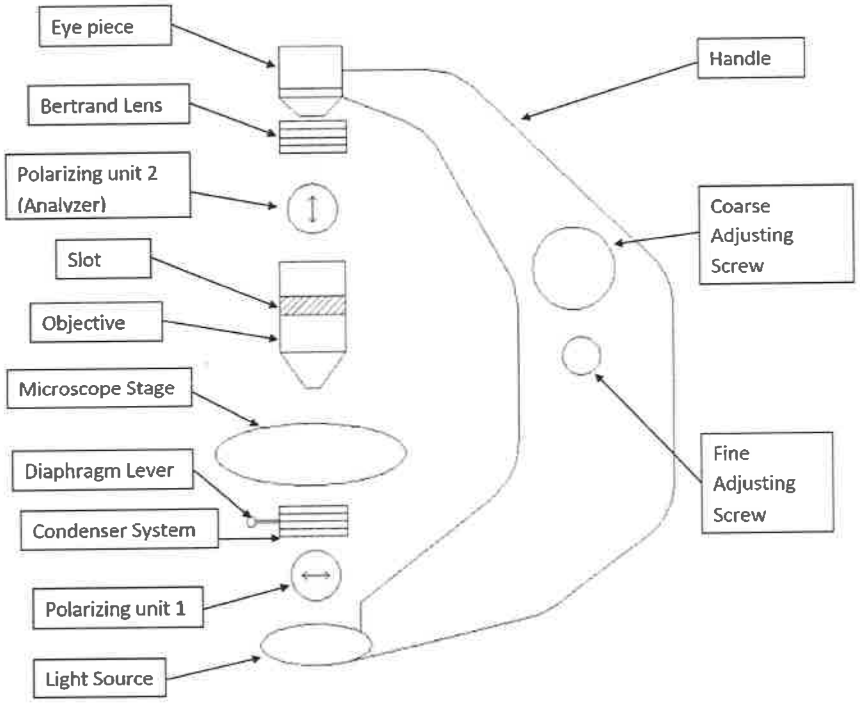
Uniaxial Positive

ırly for an optically ive crystal, all NE and uadrants will turn v and all NW and SE ants will turn blue, :olors replacing the / color present before ion of the ensator.



Uniaxial Negative

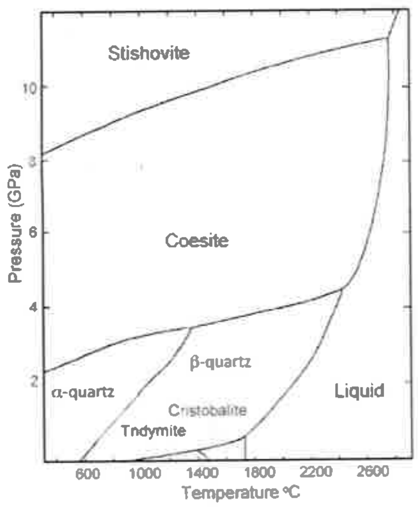
d) Explain the various parts of the petrological microscope.



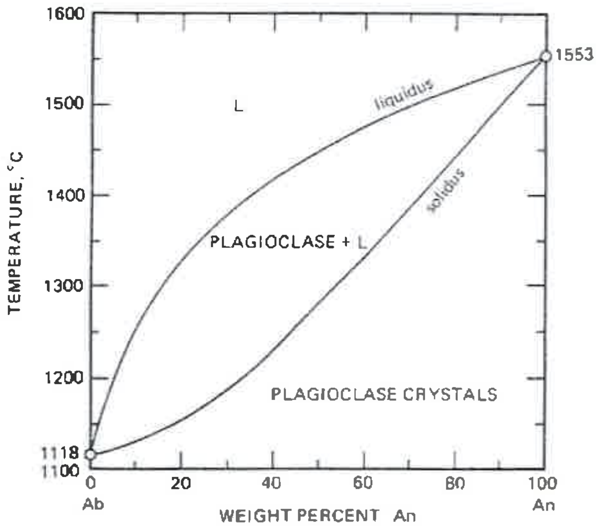
- Parts of a Petrological Microscope - drawn by Rukshan

3 Answer any TWO of the following: **2X10=20**

a) Illustrate the phase diagram of silica group of minerals. What is the difference between alpha-quartz and coesite?
Diagram and description



b) Give an account of plagioclase group of minerals. Explain the solid solution existing in plagioclase.
Albite-Ologoclase-Andesine-Labrodarite-Bytownite- Anorthite



c) Name the important mineral categorized under mica group, discuss its mode of occurrence, chemical composition and uses.
Muscovite, Biotite, Fuschite, Annite, Pyrphyllite, Illite, Smectite, Sericite
The micas can be divided into the dioctahedral micas and the trioctahedral micas, as discussed above. Muscovite, Paragonite, and Margarite are the white micas, and represent the dioctahedral group, and Biotite and Clintonite (Xanthophyllite) the black or brown mica, represents the trioctahedral group. Muscovite and Biotite are the most common micas, but the Lithium- rich, pink mica, Lepidolite, $K(Li,Al)_2AlSi_3O_{10}(OH)_2$ is also common, being found mostly in pegmatites.

Muscovite

Muscovite, $KAl_3Si_3O_{10}(OH)_2$, and Paragonite, $NaAl_3Si_3O_{10}(OH)_2$, are two potential end members of the solid solution series involving K and Na. But, there is a large miscibility gap between the two end members with Muscovite being between 65% and 100% of K-rich end member, and Paragonite showing compositions between about 80% and 100% of the Na-rich end member.

Occurrence - Muscovite is common constituent of Al-rich medium grade metamorphic rocks where is found in Al-rich schists and contributes to the schistose foliation found in these rocks. Muscovite is also found in siliceous, Al-rich plutonic igneous rocks (muscovite granites), but has not been found as a constituent of volcanic rocks. In these rocks it is commonly found in association with alkali feldspar, quartz, and sometimes biotite, garnet, andalusite, sillimanite, or kyanite.

Properties - Muscovite is easily identified in hand specimen by its white to sometimes light brownish color and its perfect {001} cleavage. In thin section, the {001} cleavage is easily seen and it's high birefringence is exhibited by the large change in relief on rotation of the stage and it's 2nd to 4th order interference colors. It is clear and shows no pleochroism (which distinguishes it from Biotite), and it is biaxial negative with a 2V between 28 and 50o. One of the most diagnostic properties of the micas, including muscovite, is the mottled or birds-eye extinction exhibited by these minerals.

Biotite

Biotite is a solid solution between the end members Phlogopite KMg3AlSi3O10(OH)2 and Annite KFe3AlSi3O10(OH)2, although pure Annite does not occur in nature. In addition, small amounts of Na, Rb, Cs, and Ba may substitute for K, and like in other minerals, F can substitute for OH and increase the stability of Biotite to higher temperatures and pressures.

Occurrence - Nearly pure phlogopite is found in hydrous ultrabasic rocks like kimberlite, and is also found in metamorphosed dolomites. Biotite, with more Fe-rich compositions is common in dacitic, rhyolitic, and trachytic volcanic rocks, granitic plutonic rocks, and a wide variety of metamorphic rocks. In metamorphic rocks, biotite usually shows a preferred orientation with its {001} forms parallel to the schistose foliation.

Properties - In hand specimen, Biotite is brown to black and shows the perfect {001} micaceous cleavage. In thin section, it shows the perfect cleavage and mottled extinction typical of all micas. It's most characteristic property is its pleochroism, showing yellow to brown to green colors. Hornblende shows similar pleochroic colors, but is distinguished from biotite by the differences in cleavage of the 2 minerals. Biotite is biaxial negative with a low 2V of 0o to 25o.

d) Explain the characteristic physical and optical identification properties of Nepheline and Leucite.
Feldspathoids
The feldspathoid group of minerals are SiO2 poor, alkali rich minerals that occur in low SiO2, high Na2O - K2O igneous rocks. In general, these minerals are not compatible with quartz, and therefore, are rarely, if ever, seen in rocks that contain quartz. They do, however, often occur with feldspars. Because of the alkalic nature of the rocks that contain feldspathoids, associated pyroxenes and amphiboles are of the sodic variety, i.e. aegerine or riebeckite.

The main feldspathoids are Nepheline (Na,K)AlSiO4, Kalsilite KAlSi2O6, and Leucite KAlSi2O6. At high temperature there is complete solid solution between Nepheline and Kalsilite, but at low temperature

Nepheline can contain only about 12 wt% K_2O.

Other similar members of the feldspathoid group are:

Sodalite $3NaAlSiO_4.NaCl$
Nosean $3NaAlSiO_4.NaSO_4$
Haüyne $3NaAlSiO_4.Ca(Cl,SO_4)$

Nepheline

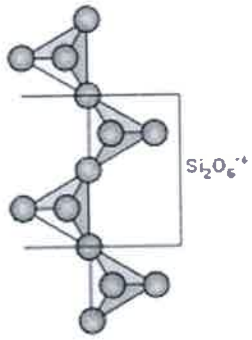
Nepheline occurs in both volcanic and plutonic alkaline igneous rocks. In hand specimen, Nepheline is difficult to distinguish from the feldspars, and thus must usually be identified by its association with other alkalic minerals. Nepheline has a yellowish colored alteration product, called cancrinite. Nepheline is hexagonal, and thus uniaxial, making it easy to distinguish from the feldspars. Furthermore, it is optically negative, making it distinguishable from quartz. It usually shows no cleavage, has low birefringence, and low relief (refractive indices are smaller than the feldspars). The only other common mineral with which nepheline could be confused is apatite, which is also uniaxial negative. Apatite, however, shows much higher relief than does nepheline.

Sodalite
Sodalite occurs predominantly in alkali-rich plutonic igneous rocks, like syenites, but can also be found in volcanic rocks. It is essentially 3 nepheline molecules with an added NaCl molecule. It is a clear colored isometric mineral with low relief. Thus, the only thing sodalite might be confused with is a hole in the thin section. The blue color of sodalite in hand specimen and its association with other alkali-rich minerals is usually necessary to detect its presence in a rock.

Leucite
Leucite is found in alkalic volcanic rocks, and is rarely found in plutonic rocks. It is a tetragonal mineral, however, its refractive indices e and w are so close together that it almost always appears isometric. It usually occurs as small, slightly rounded, low relief grains that go extinct upon insertion of the analyzer. Commonly, leucite contains tiny inclusions within the mineral, and sometimes shows a slight twinning, barely visible with the analyzer inserted.

4 Answer any TWO of the following: **(2X10=20)**

a) Give an account of structure and classification of pyroxenes group of a minerls. Which is a common pyroxene seen in a basalts?
Occurrence and Distinction of the Pyroxenes



Augite - is commonly found in both plutonic and volcanic igneous rocks, as well as high grade meta-igneous rocks like gneisses and granulites. It is easily distinguished from amphiboles by the nearly 90ocleavage angles, and is distinguished from Opx by inclined extinction relative to the {110} cleavage, as discussed above. Augite also has higher maximum birefringence than Opx, and shows 2nd to 3rd order interference colors. Augite is optically positive with a 2V of about 60o. It shows high relief, relative to quartz and feldspars and is commonly colorless to brown or green in thin section, showing no pleochroism.

Hypersthene - is commonly found in both plutonic and volcanic igneous rocks and in meta-igneous rocks as well. It is distinguished from augite by its lower interference colors and lack of inclined extinction relative to {110}. Hypersthene is sometimes pleochroic, showing light pink to light green colors. The chemical composition of hypersthene can be estimated using 2V (see p. 163 of DHZ). Compositions close to Enstatite are optically positive with a 2V of 60 to 90o, whereas intermediate compositions are optically negative with a 2V of 50 to 90o.

Pigeonite - is generally only found in volcanic igneous rocks, although, as mentioned above, it can occur as exsolution lamellae in augites of more slowly cooled igneous rocks. Pigeonite is distinguished from augite by its lower 2V of 0 to 30o, and is distinguished from hypersthene by its lack of pleochroism, lower 2V and inclined extinction relative to the {110} cleavage.

Aegerine (acmite) - Aegerine Augite - are sodic pyroxenes and thus are found in alkalic igneous rocks associated with sodic amphiboles, alkali feldspars, and nepheline. The mineral is common in alkali granites, quartz syenites, and nepheline syenites (all alkalic plutonic rocks), and are also found in sodic volcanic rocks like peralkaline rhyolites.

Aegerine is distinguished from other clinopyroxenes by a low extinction angle relative to the {110} cleavage (0 -10o, with augite having an extinction angle of 35 - 48o), and by the green brown pleochroism present in aegerine. Aegerine is also optically negative with a 2V of 60 to 70o, whereas Aegerine-augite has a higher 2V and can be optically positive or negative. It is distinguished from the pleochroic sodic amphiboles by its nearly 90o pyroxene cleavage angle.

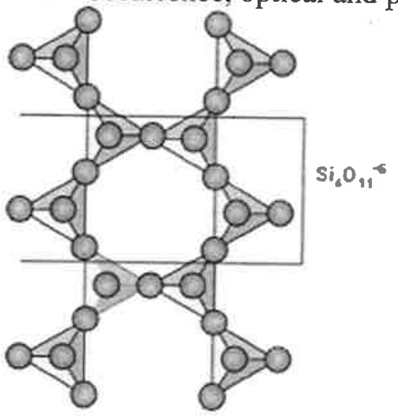
Jadeite - is a sodium aluminum pyroxene that is characterized by its presence in metamorphic rocks formed at relatively high pressure. It can form by a reaction of Albite to produce :

NaAlSi3O8	=	NaAlSi2O6 +	SiO2
Albite		Jadeite	Quartz

Jadeite has a lower refractive index than all other pyroxenes, and has low birefringence, showing low order 1st and 2nd order interference colors.

It is monoclinic with an extinction angle of 33 to 40o, and can thus be easily distinguished form hypersthene. It is usually colorless in thin section, helping to distinguish it from augite and aegerine, and has lower birefringence than augite and aegerine.

b) Discuss the silicate structure of amphibole group of minerals. Explain the mode occurrence, optical and physical properties and of hornblende.



XYZ2O6

where X = Na+, Ca+2, Mn+2, Fe+2, or Mg+2 filling octahedral sites called M2

Y = Mn+2, Fe+2, Mg+2 , Al+3, Cr+3, or Ti+4 filling smaller octahedral sites called M1

Z = Si+4 or Al+3 in tetrahedral coordination.

The pyroxenes can be divided into several groups based on chemistry and crystallography:

Orthorhombic Pyroxenes (Orthopyroxenes - Opx)

These consist of a range of compositions between enstatite - MgSiO3 and ferrosilite - FeSiO3

Monoclinic Pyroxenes (Clinopyroxenes - Cpx)

The Diopside- Hedenbergite series - Diopside (CaMgSi2O6) - Ferrohedenbergite (CaFeSi2O6)

The Sodic Pyroxenes - Jadeite (NaAlSi2O6) and Aegerine (NaFe+3Si2O6)

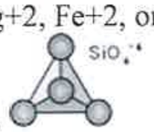
Augite is closely related to the diopside - Hedenbergite series with addition of Al and minor Na substitution - (Ca,Na)(Mg,Fe,Al)(Si,Al)2O6

Pigeonite is also a monoclinic pyroxene with a composition similar to the orthopyroxenes with more Ca substituting for Fe, and Mg.

c) Define nesosilicates group of minerals. Explain the characteristic properties, composition and mode of occurrence of olivine group of minerals.

Nesosilicates (Island Silicates)

If the corner oxygens are not shared with other SiO4-4 tetrahedrons, each tetrahedron will be isolated. Thus, this group is often referred to as the island silicate group. The basic structural unit is then SiO4-4. In this group the oxygens are shared with octahedral groups that contain other cations like Mg+2, Fe+2, or Ca+2. Olivine is a good example:

(Mg,Fe)2SiO4. 

d) Describe the crystallography, chemical composition and occurrence of garnet group of minerals.

Garnets

Garnets are isometric minerals and thus isotropic in thin section, although sometimes they are seen to be weakly birefringent (slightly anisotropic). They are also nesosilicates, and therefore based on the SiO4 structural unit. The general formula for garnets is:

A3B2(Si3O12)

where the A sites are cubic sites containing large divalent cations, usually Ca, Fe, Mg, or Mn, and the B sites are octahedral sites occupied by smaller trivalent cations, like Al and Fe+3.

Garnets with no Ca in the A site and Al in the B site are called the

(4)

pyralspite series. These consist of the end members:

Pyrope - $Mg_3Al_2Si_3O_{12}$

Almandine - $Fe_3Al_2Si_3O_{12}$

Spessartine - $Mn_3Al_2Si_3O_{12}$

Garnets with Ca in the A site are called the ugrandite series and consist of the end members:
Uvarovite - $Ca_3Cr_2Si_3O_{12}$

Grossularite - $Ca_3Al_2Si_3O_{12}$

Andradite - $Ca_3Fe^{+3}_2Si_3O_{12}$

Limited solid solution exists between end members of each series.

Occurrence

The garnets occur mostly in metamorphic rocks where they are often seen to form euhedral (well-formed) crystals.

The Mg-rich garnet, pyrope, is found in metamorphic rocks formed at high pressure and in eclogites (basalts metamorphosed at high pressure) and peridotites (ultrabasic rocks containing olivine, Opx, Cpx, and garnet).

The Fe-rich garnet, almandine, is the most common garnet and is found in metamorphic aluminous schists.

The Mn-rich variety, spessartine, is limited to Mn-rich metamorphic rocks like meta-cherts.

Identifying Properties

Garnets are generally isotropic although some may be weakly birefringent. In hand specimen they exhibit a wide range of colors and these are sometimes seen in thin section. Color is controlled by the amounts of Fe^{+2}, Fe^{+3}, Mg^{+2}, and Cr^{+3} present.

Pyrope is usually pinkish red to purplish in hand specimen and is usually clear in thin section.

Almandine is usually deep red to brownish black in hand specimen and pink in thin section.

Spessartine ranges from black to red to brown and orange and is usually pink in thin section.

Grossularite has a color in hand specimen that reflects the amount of Fe and Mn present and thus ranges from brown to yellow to pink. If Cr is present, the color is usually green. In thin section grossularite varies in color from clear to brown or green in Cr-rich varieties.

Uvarovite, with high Cr concentration is usually deep green in hand specimen and green in thin section.

Andradite ranges from yellow to dark brown, but if appreciable amounts of Ti are present, the color could be black in hand specimen and brown in thin section.

The composition and identity of the garnets is best determined either by association with other minerals or by more sophisticated techniques such as electron microprobe or XRD.

Garnets are easily distinguished from other minerals by their high relief, isotropic character, and common euhedral habit.

5 Write short note on any four of the following: **(4X5=20)**

a) Nicol prism
William Nicol (1770-1851) of Edinburgh developed what is now called the Nicol prism in 1828. The problem with using calcite as a polarizer is the presence of two beams of polarized light. In principle, the E ray can be eliminated by using a narrow crystal, long enough so that the E ray can be sufficiently displaced from the O ray to allow it to be masked off. Nicol used the now classic technique of slicing the crystal diagonally at QS and fastening the two halves back together with a cement (such as canada balsam) of such in index of refraction that the E ray is totally reflected at the internal interface, leaving the O ray to emerge alone from the crystal.
The late 19th century nicol prism used for demonstration purposes at Kenyon College shows the typical angle of the front and rear faces of 68° with respect to the long axis of the crystal. The nicol prism is colorless, unlike tourmaline , but its basic long, narrow construction unfortunately gives it a small angular field of view. It was almost always used as an analyzer; only in the Saccharimeter was it used as a polarizer.

b) Quartz wedge
Description with diagram.

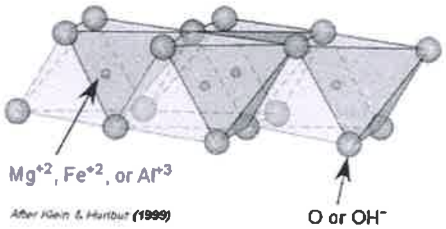
c) Optical identification properties and mode of occurrence of sodalite
Sodalite
Sodalite occurs predominantly in alkali-rich plutonic igneous rocks, like syenites, but can also be found in volcanic rocks. It is essentially 3 nepheline molecules with an added NaCl molecule. It is a clear colored isometric mineral with low relief. Thus, the only thing sodalite might be

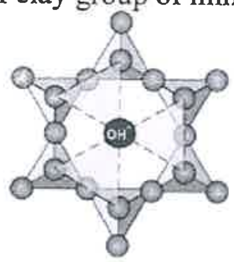
confused with is a hole in the thin section. The blue color of sodalite in hand specimen and its association with other alkali-rich minerals is usually necessary to detect its presence in a rock.

d) Alkali feldspar group of minerals
Description of chemical composition variation

e) Uses of zeolites
Diagram and description

f) Structure and mode of occurrence of clay group of minerals.





Another important sheet silicate structure is that of vermiculite. This is similar to the talc structure, discussed above, with layers of water molecules occurring between each T-O-T layer.
Similarly, insertion of layers of water molecules between the T-O-T sheets of pyrophyllite produces the structure of smectite clays. The vermiculite and smectite groups are therefore expanding type sheet silicates and as the water is incorporated into the structure the mineral increases its volume.

Although we have shown that the octahedral layers fit perfectly between the tetrahedral layers, this is an oversimplification. If the tetrahedral layers were stacked perfectly so that apical oxygens were to occur vertically aligned, then the structure would have hexagonal symmetry. But, because this is not the case, most of the phyllosilicates are monoclic.
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