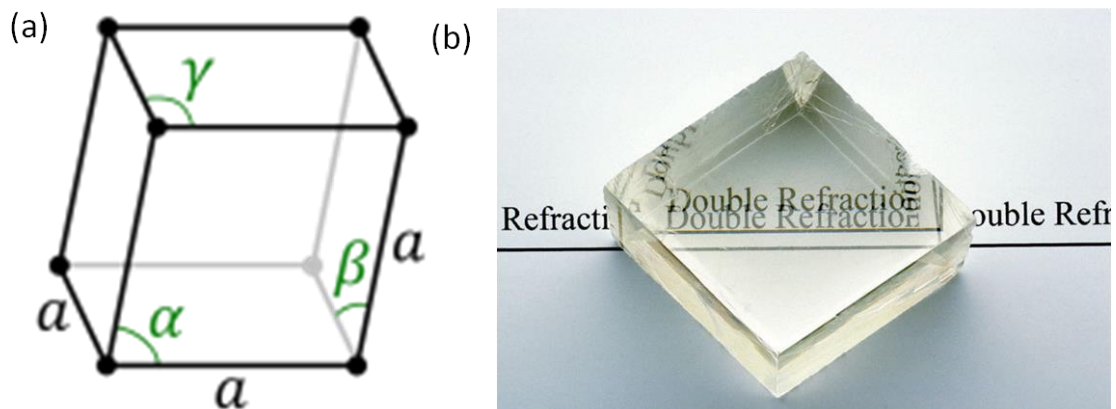


## Experiment 7 Birefringence in Calcite Crystals

The chemical name of the calcite crystal is calcium carbonate ( $\text{CaCO}_3$ ). Calcium carbonate, also known as optical calcite crystal, is rarely found in nature and forms Rhombohedron crystal structure. This crystal shows extraordinary optical properties. Studies showed that 1000 years back the North Atlantic Vikings used to determine the sun's orientation in a cloudy weather using calcite crystals. It is thought that by looking into the polarization of the scattered light of the clouds the sun's location was determined. Because of Viking's invention, calcite crystal also named as "sunstone". In this experiment calcite crystal's unusual optical properties will be studied.

The figure 1 illustrates the atomic structure of calcite crystal. Three nonorthogonal axes form the crystal structure. Due to Rhombohedron atomic structure the calcite crystals found in nature is distinct and has flat surfaces. The figure 1b shows the photograph of the calcite crystal. As can be seen from the photograph the text behind the crystal appear as double. This phenomenon is known in optics as double refraction. In this experiment we will study the double refraction.



(a) Atomic structure of the calcite crystal (b) Double refraction in calcite crystal.

1. The crystals have not undergone any changes and given to you as found in nature. Using caliper determine the  $\alpha$ ,  $\beta$ ,  $\gamma$  to the smallest significant value of the calcite crystal.

2. As shown in figure 1b, due to special optical properties of calcite crystals the objects behind the crystal are seen as double. Draw a small dot on a white paper and put the crystal on that paper as in figure 1b. You will see two dots. Slowly rotate the crystal on perpendicular axis, explain your observations.

3. Determine the polarization axis of the polarizer, and briefly explain your reasoning.

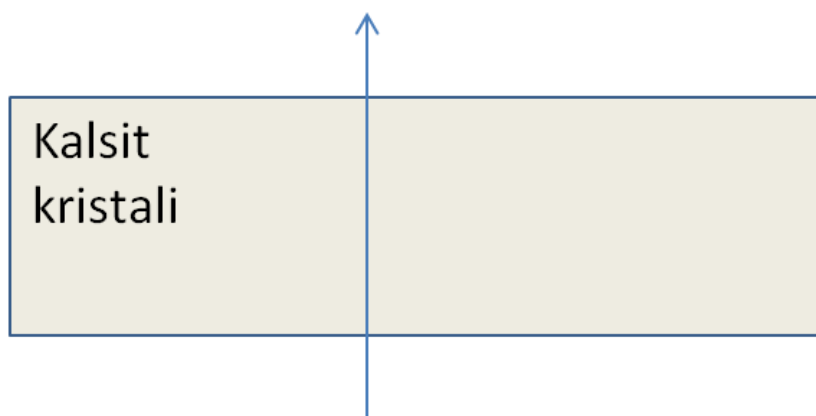
4. Using polarizing filter determine the axis of polarization of two dots, draw your results in the figure below specifying angles.

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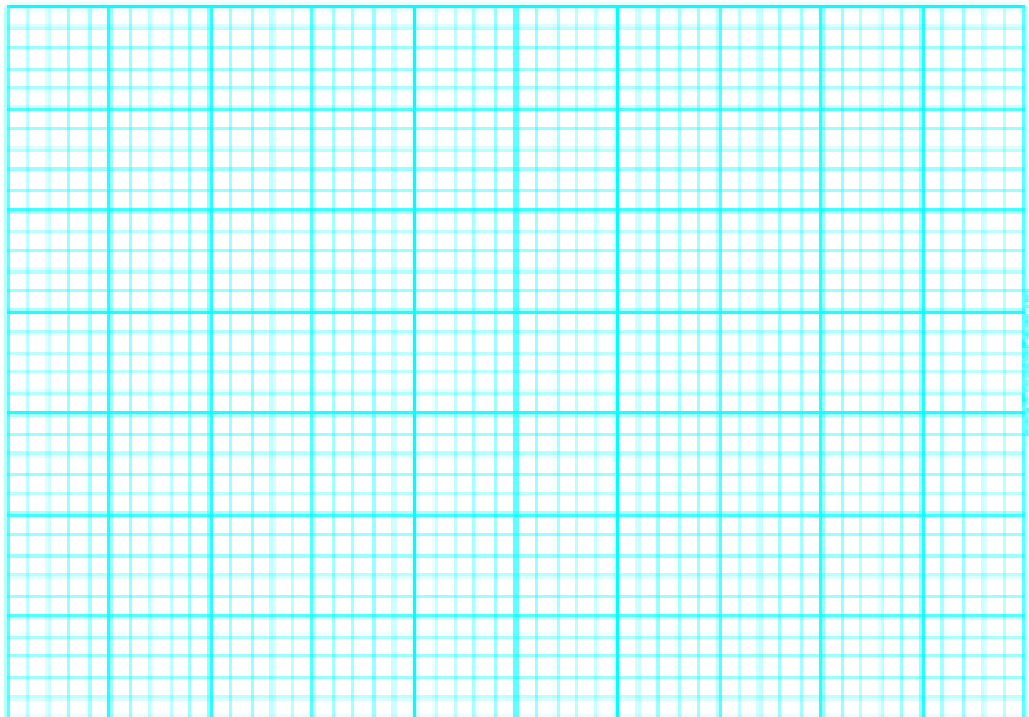


5. Look carefully and determine which one of two dots is seen closer and find which polarization has greater refractive index.

6. Determining double refraction under the Calcite crystal. You can think of the light coming from the two dots on paper makes normal incidence on the surface of the crystal. Depending on the polarization the light must travel in different directions for the two dots to appear. First light passes through the crystal at normal incidence without any refraction. The figure below demonstrate this behavior. On the other hand, the other light with different polarization follows extraordinary path in the crystal causing the second dot to appear. The light incident on the surface at right angle undergoes refraction hence following different path. Considering time-reversal symmetry, indicate the extraordinary path that the second light travels.

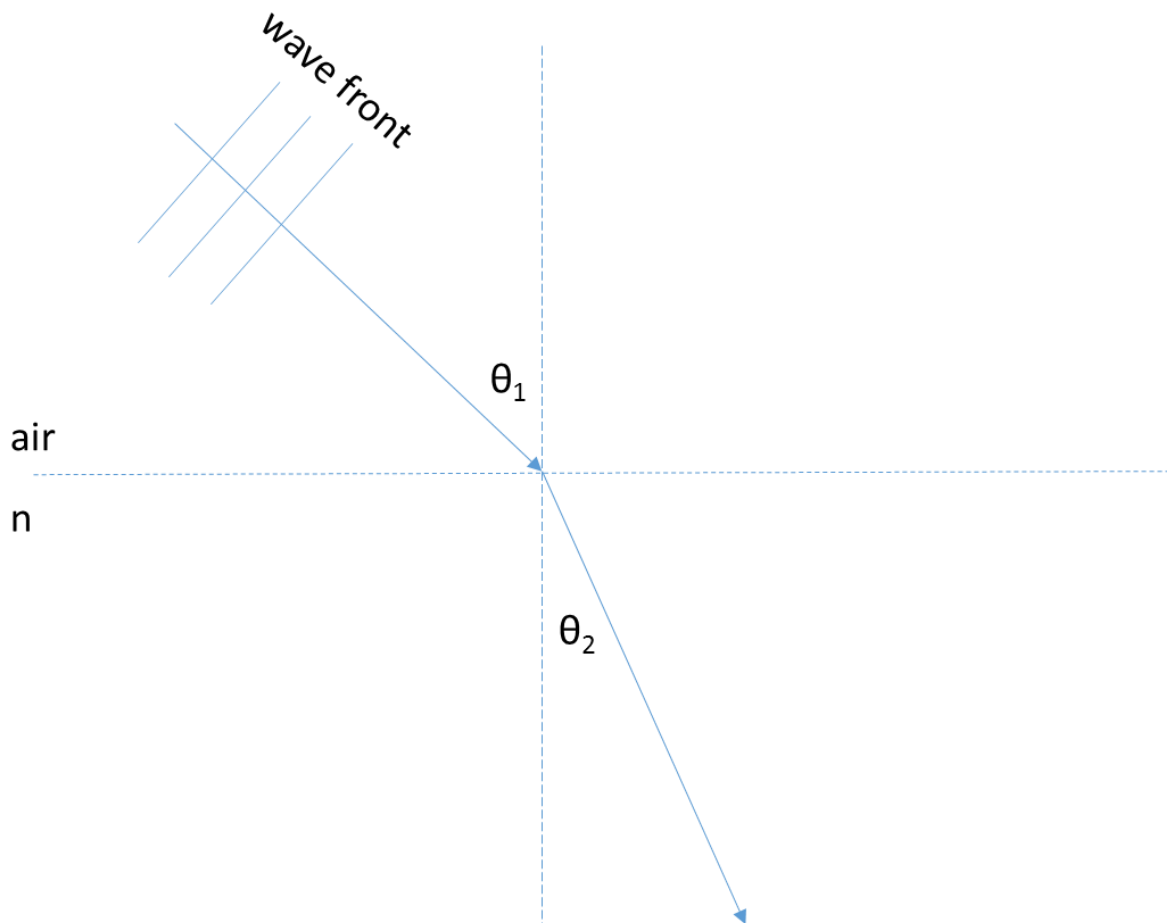


7. Measure the angle between the ordinary and extraordinary path when the light travels in the crystal to some significant value. Draw your sketch below.

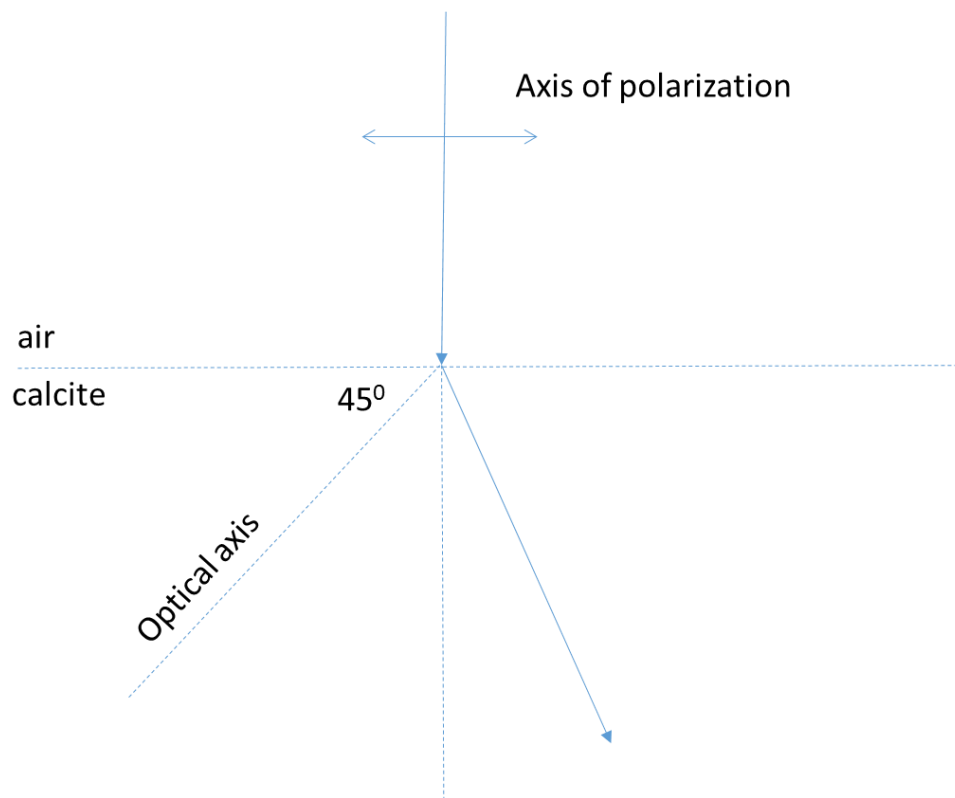


8. Discuss whether the Snells' law applies for normal and extraordinary light passage.

9. In 1669 Huygens explained the double refraction in Calcite crystals with his wave theory. We can summarize Huygens principles as follows: Every point on a wave-front may be considered a source of secondary spherical wavelets which spread out in the forward direction at the speed of light. The new wave-front is the tangential surface to all of these secondary wavelets. Before going into Calcite crystal, using Huygens principle calculate the refraction angle of the light passing from air into a medium of refraction index  $n$  at some angle, see figure below. Ignore the reflected light. Demonstrate the Snell's law using only geometry and Huygens principle.



10. Huygens principle is based on the assumption that the light undergoes uniform refraction at all parts in the crystal. However, for the light propagating in calcite crystal the refractive index can be different depending on the electric field orientation. The calcite crystal is the crystal formation of carbon, oxygen, and calcium atoms. Due to the variance in bonding strength between these atoms, the light-crystal interactions depend on the electric field orientation. The refractive index of the medium that the light sees is  $n=1.658$  if the electric field of the light is along the carbon-calcium orientation, and it is  $n=1.486$  if it's perpendicular. The line in which carbon-calcium atoms are oriented is called optical axis. The optical axis of the calcite crystal makes 45 degrees with its surface. The figure below shows the optical axis and the surface of the calcite crystal. As illustrated in the figure, when the beam of polarized light is incident on the surface of crystal, the refractive indices are different since the light has both parallel and perpendicular electric field component on the optical axis. Hence, every point on the wave-front propagates as elliptic wave form instead of circular form in the crystal. Using Huygens principle define the path the light follows in the calcite crystal as shown below and calculate the angle it makes with the normal axis.





11. Using Calcite crystal design a polarizing filter. Your filter must allow only one type of polarization to pass. You are free to use any optical axis of the crystal or, even combine two Calcite crystals.